COGNITIVE PROCESSES IN INDIVIDUAL AND COLLECTIVE CREATIVITY: A CROSS-CULTURAL PERSPECTIVE

EDITED BY: Chang Liu, Linden John Ball, Haiying Long and Wangbing Shen
PUBLISHED IN: Frontiers in Psychology

frontiers Research Topics

frontiers

ISSN 1664-8714
ISBN 978-2-88963-281-7
DOI 10.3389/978-2-88963-281-7

About Frontiers

Frontiers is more than just an open-access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers Journal Series

The Frontiers Journal Series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the Frontiers Journal Series operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to Quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews.
Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the Frontiers Journals Series: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area! Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers Editorial Office: researchtopics@frontiersin.org

COGNITIVE PROCESSES IN INDIVIDUAL AND COLLECTIVE CREATIVITY: A CROSS-CULTURAL PERSPECTIVE

Topic Editors:
Chang Liu, Nanjing Normal University, China
Linden John Ball, University of Central Lancashire, United Kingdom
Haiying Long, Florida International University, United States
Wangbing Shen, Hohai University, China

Creativity, the highest level of human wisdom, has become an increasingly important concept in different fields of psychological enquiry, particularly because it is portrayed as contributing to many aspects of society, including personal development, economic prosperity and technological advancement. However, although considerable research attention from a wide range of disciplinary backgrounds has focused on trying to understand creativity, the specific nature of creativity, its theoretical underpinnings and cognitive mechanisms, remain unclear, not least when it comes to the understanding of creativity at the individual level and creativity at the collective level. On the one hand, there are crucial distinctions between individual and collective creativity. On the other hand, the process of being creative involves not only independent or individual efforts but also interdependent or collective efforts. Understanding these differences and interrelationships is crucially important in studies of creativity. In this Research Topic, we bring together research from a wide variety of cognitive and psychological approaches and perspectives in order to provide a comprehensive and in-depth understanding of creativity at both the individual and collective levels.

Furthermore, cognitive mechanisms in the creativity process are unavoidably affected by sociocultural factors and these mechanisms look different across cultures, particularly between Eastern cultures and Western cultures, two worlds that often imply dramatically dissimilar values and perspectives. Despite the fact that many studies have compared and contrasted these two cultures in various respects, little research has focused on the specific topic of cultural variation in creative cognition. In addition, very few studies have examined the differences in the cognitive mechanisms underpinning the cultural variations that can be observed at a surface level. This Research Topic aims to fill this gap in the literature and examine the cognitive processes and mechanisms in the creativity process at both individual and collective levels across different cultures by using theoretical and empirical evidence.

Citation: Liu, C., Ball, L. J., Long, H., Shen, W., eds. (2019). Cognitive Processes in Individual and Collective Creativity: A Cross-Cultural Perspective. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-88963-281-7

Table of Contents

frontiers in Psychology

ORIGINAL RESEARCH
published: 15 June 2018
doi: 10.3389/fpsyg.2018.00925

Examining Brain Structures Associated With Emotional Intelligence and the Mediated Effect on Trait Creativity in Young Adults

Li He[1,2,3†], Yu Mao[2,3†], Jiangzhou Sun[2,3], Kaixiang Zhuang[2,3], Xingxing Zhu[2,3], Jiang Qiu[2,3] and Xiaoyi Chen[1,4]*

[1] School of Education, Chongqing Normal University, Chongqing, China, [2] Key Laboratory of Cognition and Personality, Ministry of Education, Southwest University, Chongqing, China, [3] Faculty of Psychology, Southwest University, Chongqing, China, [4] Student Mental Health Education and Consultation Center, Chongqing Normal University, Chongqing, China

Little is known about the association between emotional intelligence (EI) and trait creativity (TC), and the brain structural bases which involves. This study investigated the neuroanatomical basis of the association between EI and TC which measured by the Schutte self-report EI scale and the Williams creativity aptitude test. First, the voxel-based morphometry (VBM) analysis was used to explore the brain structures which is closely related to EI in a large young sample (n = 213). The results showed that EI was positively correlated with the regional gray matter volume (rGMV) in the right orbitofrontal cortex (OFC), which is regarded as a key region of emotional processing. More importantly, further mediation analysis revealed that rGMV in the right OFC partially mediated the association between EI and TC, which showed the OFC volume could account for the relationship between EI and TC. These findings confirmed the close relationship between EI and TC, and highlighted that the brain volumetric variation in the OFC associated with the top-down processing of emotion regulation, which may play a critical role in the promotion of TC. Together, these findings contributed to sharpening the understanding of the complex relationship between EI and TC from the perspective of brain structural basis.

Keywords: emotional intelligence, trait creativity, orbitofrontal cortex, gray matter volume, voxel-based morphometry

OPEN ACCESS

Edited by:
Chang Liu,
Nanjing Normal University, China

Reviewed by:
Qingbai Zhao,
Central China Normal University, China
Wei Liao,
University of Electronic Science and Technology of China, China

****Correspondence:***
Xiaoyi Chen
xyichen@163.com

† These authors have contributed equally to this work.

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *31 March 2018*
Accepted: *22 May 2018*
Published: *15 June 2018*

Citation:
He L, Mao Y, Sun J, Zhuang K, Zhu X, Qiu J and Chen X (2018) Examining Brain Structures Associated With Emotional Intelligence and the Mediated Effect on Trait Creativity in Young Adults. Front. Psychol. 9:925. doi: 10.3389/fpsyg.2018.00925

INTRODUCTION

Emotional intelligence (EI) refers to the ability to reason and analyze emotions accurately, as well as utilize emotions and emotional knowledge to enhance thought and action (Mayer et al., 2008), which also reflects individual's ability to perceive, regulate, and utilize emotion (Salovey and Mayer, 1990). Individuals with high EI are more likely to gain more beneficial outcomes (Parke et al., 2015), such as closer relationship (Brackett et al., 2006), better social problem solving (Barbey et al., 2014), higher well-being and life satisfaction (Kong and Zhao, 2013), better work performance and higher academic achievement (Rivers et al., 2012; Libbrecht et al., 2014). On the contrary, the deficiency of EI always pose a threat to mental and body health, which may cause psychological distress (Hertel et al., 2009), gaming and Internet abuse (Parker et al., 2013), anxiety and depression (Salguero et al., 2012; Zavala and Lopez, 2012).

Emerging neuroscience studies have revealed that several emotion-related regions may correlate with EI, such as the anterior insula (AI), amygdala, orbitofrontal cortex (OFC), anterior cingulate cortex (ACC), and ventromedial prefrontal cortex (vmPFC) (Frith and Frith, 2007; Blakemore, 2008; Krueger et al., 2009; Kreifelts et al., 2010; Koven et al., 2011; Takeuchi et al., 2011, 2013a,b; Pan et al., 2014; Tan et al., 2014; Hogeveen et al., 2016b). The AI and ACC have been regarded to play a critical in the generating of emotional awareness, an important ability to perceive feelings of oneself (Medford and Critchley, 2010; Hogeveen et al., 2016a). For the ability to understand other's emotions, some evidence showed that the amygdala and the vmPFC may aim to ensure the recognition of facial expressions (Vuilleumier et al., 2004; Wolf et al., 2014). The OFC has been regarded as a core region of emotional assessment and emotional regulation, especially which adjusts emotional expression by reasonably evaluating the emotional salient stimuli and regulating the subjective emotional experience (Kringelbach, 2005; Roelofs et al., 2009). Prior studies also found the OFC is associated with inhibitory control, which may help to regulate negative emotion effectively, reduce maladaptive behavior, and enhance behavior flexibility (Roberts and Wallis, 2000; Rudebeck et al., 2013). In addition, studies on human brain lesion further confirmed several brain regions related to individual's emotional ability. Patients with substantial lesion in the AI exhibited significantly higher levels of alexithymia (Hogeveen et al., 2016a). Alexithymia can be characterized by dysfunction in emotional awareness, social interaction, and interpersonal relationship (Bagby et al., 1994), which was negatively correlated with EI (Baughman et al., 2013; Onur et al., 2013). Other research showed that patients with damages in the OFC exhibit lower EI score and behaved handicaps in emotional regulation compared with the healthy group, which significantly impaired subjective emotional experience and adaptive behavior (Bar-On et al., 2003; Beer et al., 2003; Hornak et al., 2003; Krueger et al., 2009; Hogeveen et al., 2016b). At the extremes, the damage or dysfunction in the OFC may result in 'acquired sociopathic' behavior (Saver and Damasio, 1991).

Combining the above studies, it is obvious that EI plays an important role in emotional processing, interpersonal communication, academic achievement, work performance and so on, which reveals the ability to perceive, regulate, and utilize the emotions of oneself and others is vital for daily life. As an extremely important human activity, creative behavior would be affected by emotion as well (Higgins et al., 1992; Fong, 2006; Hoffmann and Russ, 2012; Kim et al., 2013; Ding et al., 2014; Hao et al., 2017), while previous studies also showed a significant positive correlation between EI and creativity (Guastello et al., 2004; Barczak et al., 2010; Carmeli et al., 2014; Parke et al., 2015; Sahin et al., 2016; Toyama and Mauno, 2017). For example, Barczak et al. (2010) investigated the influence of team EI on team creativity in a young sample. They found team EI enhanced team creativity by promoting team trust and developing a collaborative culture of the team. Researchers also investigated the impact of EI on creativity in workplace, Carmeli et al. (2014) found that employees with higher EI tend to exhibit a higher level of generosity, which fosters a sense of vigor, and further results in the enhancement of creativity. In addition, based on the affective information processing theory, a recent study showed that the emotional regulation of EI allows employees to keep more positive affect when facing a complex problem situation, and the emotional facilitation of EI enables employees to utilize positive affect to promote creativity (Parke et al., 2015). Guastello et al. (2004) investigated the relationships among EI, mood disorders, and creativity, results showed that EI and creativity were higher among people with mood disorders who completed treatment relative to people in treatment, which means EI may improve creativity by offsetting emotional disorders and maintaining positive affect (Guastello et al., 2004). The above findings revealed a positive effect of EI on creativity.

As we know, numerous outstanding creators like Albert Einstein always possess great creative potential that makes them unique and acquires more creative achievements. Creative potential can be regarded as a multidimensional composite consists of some aspects related to cognition and others related to personality (Gough, 1979; Piffer, 2012; Li et al., 2015; Silvia et al., 2016). Creative cognition refers to the cognitive processes that occur in the generation and evaluation of creative ideas and products, such as divergent thinking, whereas creative traits might be a series of aptitude or personality variables (e.g., curiosity, openness to experience, and imagination) that also could integrate other factors such as psychopathological traits and genetic impacts (Zeng et al., 2009; Piffer, 2012; Li et al., 2015; Zhuang et al., 2017). In line with precious studies (Li et al., 2015; Zhuang et al., 2017), we focused on personality or aptitude aspects of the creative trait that usually assessed using the Williams creativity aptitude test (WCAT). These aptitudes (trait creativity, TC) have a positive impact on creative thinking and creative problem solving (Sternberg, 1999). Prior study also suggested that TC acts as a valid predictor of creative achievement in real life (Feist and Barron, 2003). Most existing studies, however, have only focused on the association between EI and creative cognition, ignoring the association between EI and TC, as well as the brain structure bases which involves. Thus, the present study aimed to investigate the association between EI and TC, and elucidates the brain neural substrates between them in a large young sample.

A recent voxel-based morphometry (VBM) study revealed that TC (as measured by WCAT) was associated with emotion-related brain structures, such as the regional gray matter volume (rGMV) of the OFC, hippocampus, and amygdala (Zhuang et al., 2017), while these regions are closely related to emotional processing. Intriguingly, another brain structure study also found that EI displayed a close correlation with the rGMV in the insula, OFC, and the parahippocampal gyrus (Tan et al., 2014). These similar brain regions involved in EI and TC suggest that they may share a common brain structure basis. Moreover, individuals with higher EI who exhibit more excellent ability of emotional processing and tend to be critical thinkers (Yao et al., 2017), which may help to creative problem solving (Eggers et al., 2017). Taken together, the above findings may reveal a close relationship between EI and TC, and the underlying similar brain structures that they both involved. However, to our knowledge, there is no direct evidence have clarified the complex association

between them. In this study, we examined the association between EI and TC, as measured by the Schutte Self-Report Emotional Intelligence Scale and WCAT, respectively. Then, the VBM analysis was used to identify the rGMV related to EI at the whole-brain level. Considering EI refers to a set of emotional abilities (e.g., emotional regulation, utilization of emotions, appraisal of emotions and so on), we hypothesized that EI would be closely associated with the rGMV in emotion-related areas such as the OFC, ACC, and the amygdala. Furthermore, we conducted a mediation analysis to explore whether brain structures could account for the association between EI and TC, because EI and TC may share similar brain structure bases (Tan et al., 2014; Zhuang et al., 2017).

MATERIALS AND METHODS

Participants

A total of 225 right-handed, healthy subjects from the Southwest University in China participated in the study as part of our ongoing project to examine the associations between brain, creativity, and mental health. Seven subjects were excluded because of incomplete behavior data, and five participants were excluded due to extraordinary motion artifacts. Therefore, 213 participants were included in analyses (103 males and 110 females; mean age = 20.0 ± 1.3; ranged from 17 to 27). Based on a self-report questionnaire survey before the scan, none of them had a history of psychiatric or neurological illness, or substance abuse. This study was granted by the Institutional Review Board of Southwest University Imaging Center for Brain Research, and all participants signed the written informed consents.

Emotional Intelligence Scale

The Schutte Self-Report Emotional Intelligence Scale (SSREIS) is an effective self-report EI assessment that developed by Schutte et al. (1998). The SSREIS in Chinese version has been widely used in Chinese populations and includes four dimensions: regulation of emotions, utilization of emotions, self-emotion appraisal, and others' emotion appraisal (Wang, 2002). Each item was used a five-point scale ranging from "not true of me" to "very often true of me." The total score is calculated by adding the answers of all the items, which represents the level of EI. The Cronbach's α in the present study was 0.79.

Williams Creativity Aptitude Test

Trait creativity was measured by the WCAT, which is part of the creativity assessment packet (Williams, 1980). The Chinese version developed by Lin and Wang (1994), which consists of 50 items and contains four domains: challenge, imagination, curiosity, and risk-taking. Participants were instructed to rate the extent to which they agree or disagree with each item using a six-point Likert scale. The total score was calculated by adding the answers of all the items. The higher score individuals have, the greater aptitude for creativity they exhibit. This scale showed a good reliability and validity in prior studies (Lin and Wang, 1994; Hwang et al., 2007; Li et al., 2015). The Cronbach's α in the present study was 0.79.

General Intelligence

In order to dispel the impact of general intelligence on EI and creativity, the Chinese version of the Combined Raven's Test-Rural (CRT-RC3) was used to measure individuals' general intelligence. The CRT-RC3 contains the Raven's colored progressive matrix (A, B, and AB sets) and Raven's standard progressive matrix (C, D, and E sets), which consist of 72 non-verbal items and each item requires participants to select the best answer from six or eight alternatives to complete the missing matrix. This scale has been widely used in Chinese populations and previous researches have reported that this test exhibits a good degree of reliability and validity in measuring general intelligence (Wang, 2007).

Magnetic Resonance Image Data Acquisition

Imaging data were collected by using a 12-channel head coil on a Siemens 3 T Trio scanner (Siemens Medical Systems, Erlangen, Germany). High-resolution T1-weighted structural images were acquired with a magnetization-prepared rapid gradient echo (MPRAGE) sequence: TR = 1900 ms; TE = 2.52 ms; flip angle = 9°; FOV = 256 mm × 256 mm; slices = 176; thickness = 1.0 mm; voxel size = 1 mm × 1 mm × 1 mm.

Voxel-Based Morphometry Analysis

The MR images were processed with the VBM toolbox using SPM8[1] implemented in MATLAB R2010a (Math Works Inc., Natick, MA, United States). Firstly, all images from each subject were displayed in SPM8 to screen for artifacts or gross anatomical abnormalities. In the process of registration, the MR images were manually reoriented to the anterior commissure to enhance registration. Then, the MR images were segmented into gray matter, white matter, and cerebrospinal fluid by using the new segmentation toolbox in SPM8. Subsequently, we performed DARTEL for registration, normalization, and modulation (Ashburner, 2007). To ensure that regional differences in the total amount of gray matter were conserved, the image intensity of each voxel was modulated by Jacobian determinants derived from spatial normalization (Good et al., 2001). Additionally, the registered images were transformed to MNI space. Finally, in order to improve the signal-to-noise ratio, an 8-mm full-width at half-maximum (FWHM) Gaussian kernel was used to smooth the modulated images.

Statistical Analysis

Voxel-based morphometry analysis was performed in SPM8. We used multiple linear regression analysis at the whole-brain level to determine whether the rGMV was associated with individual differences in EI score. In order to eliminate the potential effects of possible confound variables, gender, age, general intelligence, and total GMV were controlled as no interest variables. An absolute threshold masking of 0.2 was used to minimize the boundary effects between gray matter and white matter, which means signal intensity values of voxels with gray matter lower

[1] www.fil.ion.ucl.ac.uk/spm

than 0.2 were removed from the analysis. The voxel-level family-wise error (FWE) method was used at the whole-brain level, and the significance threshold was set at $p < 0.05$, corrected for multiple comparisons.

Mediation Analysis

To examine whether the specific rGMV could explain the association between EI and TC, mediation analysis was performed by using SPSS macro with 0.95 confidence level and 5000 bootstrap sample (Preacher and Hayes, 2004, 2008). The total effect of EI on TC (path c) consists of two parts, namely, the direct effect of EI on TC after controlling for the rGMV of the right OFC (path c') and the indirect effect of EI on TC through the OFC volume (path a × b). The mediation analysis aims to evaluate whether the indirect effect is significant. If the confidence interval (CI) does not include zero, which means the rGMV of the OFC mediated the association between EI and TC. In addition, gender, age, general intelligence, and total GMV were controlled as covariates in the model.

RESULTS

Behavioral Results

The average, standard deviation, and Person correlation of all variables for this sample are presented in **Table 1**. The statistical software SPSS 22.0 was used to analyze all behavioral data, and the Pearson correlation coefficient of EI and TC was calculated by controlling for gender, age, and general intelligence. As indicated in **Table 1**, there were weakly but significantly positive correlations between the subscale scores of the SSREIS and the subscale scores of the WCAT. In addition, the results also showed that the total score of the SSREIS was strongly and significantly positively associated with the total score of the WCAT ($r = 0.42$, $p < 0.001$), which revealed a close relationship between EI and TC.

VBM Results

This study investigated the relationship between the rGMV and individual difference in EI (measured by SSREIS) at the whole-brain level. In order to eliminate the potential effects of possible confound variables, gender, age, general intelligence, and total GMV were controlled as no interest covariates and regressed out. At the whole-brain level, multiple regression analysis revealed a positive relationship between total score of the SSREIS and the rGMV in the right OFC (Brodmann area: 11; MNI coordinate: 30, 36, −12; cluster size = 95; $r = 0.33$; $t = 5.40$; $p = 0.001$, FWE corrected; see **Figure 1**). There was no significant negative correlation between total score of the SSREIS and any other brain regions ($p > 0.05$, FWE corrected), subscale scores of the SSREIS also showed an insignificant correlation with any other brain regions as well ($p > 0.05$, FWE corrected).

After identifying potential neural correlations of EI, we used the right OFC that is significantly correlated with EI from the VBM analysis to further examined the relationship between WCAT and OFC, the mean gray matter volume extracted by using the REX toolbox developed by the LKM

TABLE 1 | The means, standard deviations, and correlations of scores on SSREIS and WCAT ($n = 213$).

	Mean (*SD*)	Range	Gender	Age	Raven	ME	UE	SA	AEO	TEI	Risk-taking	Curiosity	Imagination	Challenge	TTC
Gender	1.52 (0.50)	1–2	–	−0.20**	0.04	0.01	−0.08	0.10	−0.05	−0.01	−0.09	−0.19**	−0.05	−0.13	−0.16*
Age	19.95 (1.28)	17–27		–	0.01	−0.06	−0.17*	−0.14*	−0.06	−0.15*	−0.17*	0.01	−0.03	−0.26**	−0.14*
Raven	66.25 (3.28)	50–72			–	0.08	−0.02	0.06	0.04	0.05	0.04	0.11	−0.02	−0.06	0.03
SSREIS															
ME	17.86 (2.32)	12–23				–	0.37***	0.40***	0.46***	0.79***	0.30***	0.29***	0.27***	0.24***	0.38***
UE	19.33 (2.24)	13–25					–	0.22**	0.33***	0.68***	0.19**	0.16*	0.20**	0.16*	0.24***
SA	20.69 (1.99)	16–25						–	0.31***	0.66***	0.25***	0.28***	0.10	0.21**	0.29***
AEO	14.85 (2.03)	10–20							–	0.72***	0.26***	0.24***	0.16*	0.25***	0.31***
TEI	72.73 (6.17)	59–92								–	0.35***	0.34***	0.26***	0.30***	0.42***
WCAT															
Risk-taking	24.49 (2.69)	18–31									–	0.34***	0.45***	0.51***	0.75***
Curiosity	32.27 (3.68)	23–41										–	0.28***	0.42***	0.72***
Imagination	26.57 (3.49)	18–35											–	0.36***	0.73***
Challenge	28.37 (2.86)	21–35												–	0.74***
TTC	111.69 (9.35)	89–134													–

*Gender: male = 1, female = 2; SD, standard deviation; ME, Monitor of Emotions; UE, Utilization of Emotions; SA, Social Ability; AEO, Appraisal of Emotions in Others; TEI, total score of emotional intelligence; TTC, total score of trait creativity; SSREIS, Schutte Self-Report Emotional Intelligence Scale; WCAT, Williams Creativity Aptitude Test. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.*

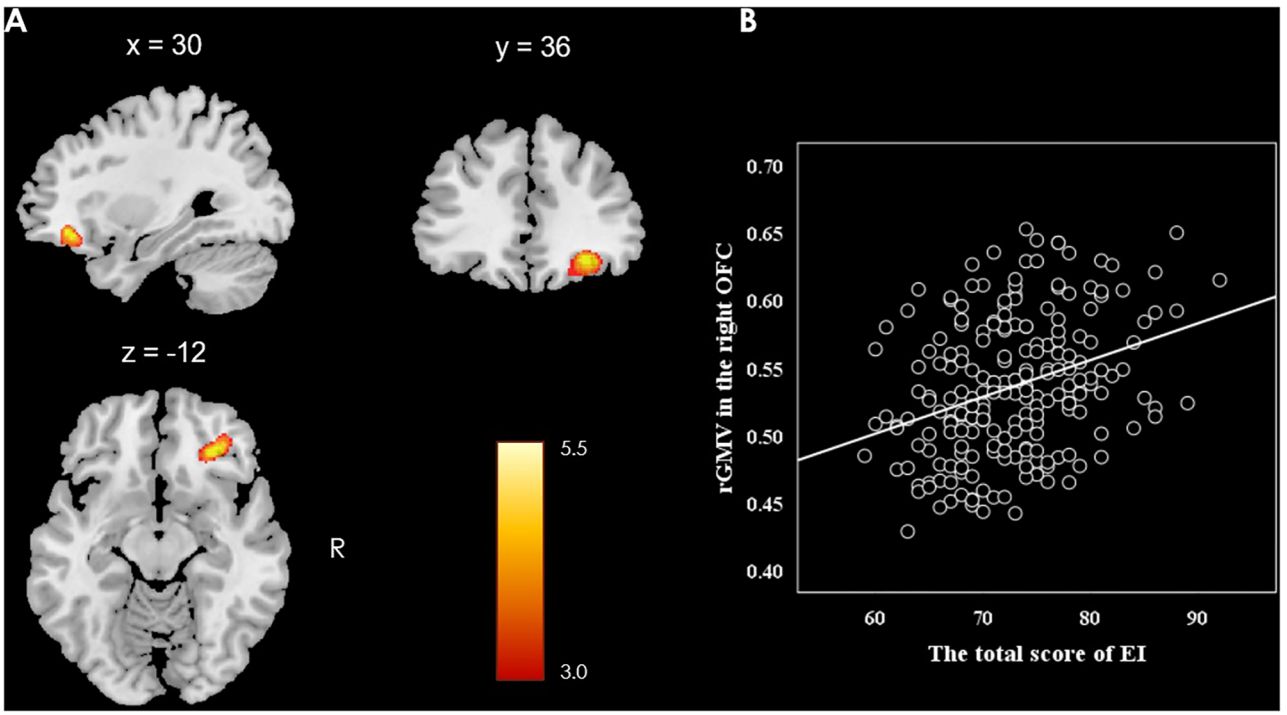

FIGURE 1 | Brain regions of positive correlation between GMV and EI. **(A)** The right OFC exhibited significant positive correlation with total score of EI as measured by the SSREIS (shown at $t > 3$ for visualization purposes), gender, age, general intelligence and total GMV were regressed out. **(B)** Scatter plots showed the correlation between EI and rGMV in the right OFC ($r = 0.33$, $p < 0.001$).

experts[2]. Correlation analysis showed that rGMV in the OFC was positively correlated with imagination ($r = 0.13$; $p = 0.05$), curiosity ($r = 0.24$; $p < 0.001$), challenge ($r = 0.28$; $p < 0.01$), risk-taking ($r = 0.30$; $p < 0.001$), and TC total score ($r = 0.32$; $p < 0.001$) as measured by WCAT. After controlling gender, age, and Raven's score, the correlation results stood robust (imagination, $r = 0.12$, $p > 0.05$; curiosity, $r = 0.20$, $p = 0.005$; challenge, $r = 0.22$, $p = 0.001$; risk-taking, $r = 0.26$, $p < 0.001$; TC total score, $r = 0.26$, $p < 0.001$).

Mediation Results

Based on behavior and VBM results, we performed a mediation analysis to further explore whether EI affects TC through rGMV in the right OFC. In the present study, we chose the EI total score measured by SSREIS as independent variable, TC (imagination, curiosity, challenge, risk-taking, and total score) measured by WCAT as dependent variables, and rGMV in the right OFC as the mediator. In addition, we also regarded gender, age, general intelligence, and total GMV as covariates for all mediation analyses.

As expected, mediation analysis revealed that (1) rGMV in the right OFC partially mediated the association between EI total score and TC total score (path a = 0.31, $p < 0.001$; path b = 0.18, $p = 0.02$; path a × b = 0.06, bootstrapped 95% CI = 0.01, 0.12; see **Figure 2**); (2) rGMV in the right OFC partially mediated the association between EI total score and curiosity (path a = 0.31, $p < 0.001$; path b = 0.16, $p = 0.04$; path a × b = 0.05, bootstrapped 95% CI = 0.002, 0.114); (3) rGMV in the right OFC partially mediated the association between EI total score and risk-taking (path a = 0.31, $p < 0.001$; path b = 0.16, $p = 0.04$; path a × b = 0.05, bootstrapped 95% CI = 0.006, 0.115).

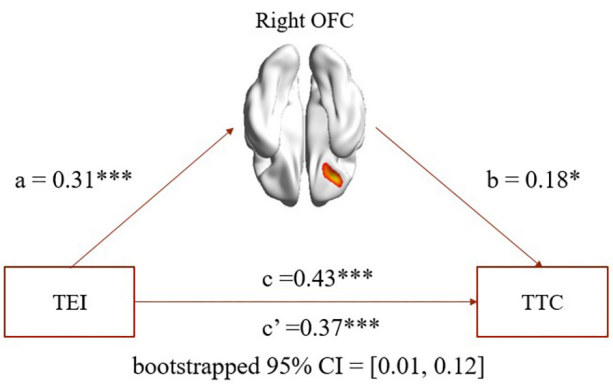

FIGURE 2 | Mediation analysis. Path a, path b, and path c are significant, and path c' is significantly smaller than path c (bootstrapped 95% CI: 0.01–0.12). The mediation results suggest that rGMV in the right OFC partially mediated the association between TEI and TTC. TEI, total score of emotional intelligence; TTC, total score of trait creativity. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$

[2]http://web.mit.edu/swg/software.htm

DISCUSSION

The present study investigated the neural basis of EI and the relationship among EI, brain structure, and individual TC as measured by WCAT in a large young sample. Behavioral results showed that EI was positively correlated with TC, and it's noteworthy that there was a strong and significant positive association between total score of the SSREIS and the total score of the WCAT. In addition, VBM results revealed that rGMV in the right OFC displayed a positive correlation with EI. More importantly, further mediation analysis showed that the right OFC volume partially mediated the association between EI and TC.

Behavioral results confirmed that different dimensions of EI was positively correlated with TC in varying degrees, especially there was a strong and significant positive relationship between the overall level of EI and TC, which is consistent with previous findings (Guastello et al., 2004). Several investigations have showed that the higher level of EI individuals have, the better ability to perceive, regulate, and utilize the emotions of oneself and others they exhibit (Brackett et al., 2006), which always lead to maintain a good mood in daily life (Hertel et al., 2009). Meanwhile, positive affect is also linked with the improvement of TC (Guastello et al., 2004), that is, individual's creativity is generally activated in a positive emotional state, which contributes to producing more creative behaviors and higher creative achievements (Ding et al., 2014; Libbrecht et al., 2014). Based on these findings, it is reasonably speculated that individuals with greater levels of EI tend to exhibit higher TC.

Voxel-based morphometry results exhibited that EI was significantly positively correlated with brain regions mainly located in the right OFC, which has been considered to play a crucial role in emotional processing, sensory integration, and reward-driven system (Kringelbach, 2005). Stalnaker et al. (2015) also suggested that the OFC is critical for signaling emotions as well. In addition, studies on human brain lesion provided evidence for the confirmation of emotional function related to the OFC. For example, patients with lesion in the OFC performed handicaps in identifying emotional face and voice (Hornak et al., 2003), as well as effective emotional regulation (Beer et al., 2003; Hogeveen et al., 2016b), which significantly impaired interpersonal communication and social behavior (Hornak et al., 2003). These findings contribute to the deeper understanding of the OFC guides adaptive behavior and emotional experience (Stalnaker et al., 2015). Furthermore, previous VBM studies have demonstrated that individuals with generalized anxiety disorder have significantly less rGMV in the OFC (Moon and Jeong, 2015), while higher EI can predict less anxiety and depression (Salguero et al., 2012; Zavala and Lopez, 2012), which revealed that the OFC volume may be closely related to EI, particularly the emotional regulation of EI (Tan et al., 2014). Spontaneous brain activity during resting state also found a close relationship between EI and OFC (Pan et al., 2014). Combined with these findings, individuals with higher EI generally exhibit better emotional processing ability, especially in the top–down aspects of emotional regulation, which is closely related to the volumetric variation in the OFC.

Interestingly, mediation results revealed that rGMV in the OFC partially mediated the association between EI and TC. Based on previous studies, individuals with high EI generally exhibited excellent emotional regulation ability and benign social cognitive functioning (Brackett et al., 2006; Hertel et al., 2009), that may play a major role in promoting the tendency to engage in creativity (Guastello et al., 2004; Ding et al., 2014; Parke et al., 2015). From the perspective of the brain structure variations, the OFC is closely related to emotional processing (Kringelbach, 2005), especially in the top-down aspects of emotional regulation (Petrovic et al., 2016; Silvers et al., 2016). Emotional regulation is essential for the maintenance of positive affect that further contribute to promoting creativity (Parke et al., 2015), our results also showed the OFC volume associated with TC, which was in line with a recent VBM study. Zhuang et al. (2017) found that TC was positively correlated with emotion-related brain region, especially in the OFC (Zhuang et al., 2017); another neuroimaging study also reported that the higher levels of self-report creativity individuals have, the larger cortical surface of the OFC they exhibit (Bashwiner et al., 2016). These findings provided evidence for the close association between the OFC and TC, and further showed the OFC volume could account for the relationship between EI and TC. Taken together, the above discussions suggested that the larger volume in the OFC associated with EI reflects enhancement of emotional processing ability, especially in the top–down aspects of emotional regulation, which contributes to the promotion of TC.

Several limitations of this study should be mentioned. First, although the sample size is relatively large compared with other studies (Koven et al., 2011; Killgore et al., 2012), all participants of the present study consisted of healthy, young undergraduates, which may restrain the generalizability of these findings. In addition, behavior data mainly relied on self-report questionnaires, in spite of previous researches have shown that these questionnaires used in our study have high reliability and validity, the results may also be vulnerable to social desirability. The use of multiple methods and repeated measurements may reduce the impact of subjectivity. Equally important, the cross-sectional design limits causal inference, and the implementation of longitudinal studies may be needed to further clarify causal directions.

CONCLUSION

The present study found that the gray matter volumetric variation in the right OFC positively correlated with EI. Moreover, further mediation analysis revealed that the OFC volume partially mediated the association between EI and TC, suggested that the

larger volume in the OFC associated with EI reflects enhancement of emotional processing ability, especially in the top-down aspects of emotional regulation, which contributes to the promotion of TC. These results help sharpen the understanding of the relationship between EI and TC from the perspective of neural substrates.

AUTHOR CONTRIBUTIONS

LH, JQ, and XC designed and conducted the study. LH, YM, JS, KZ, and XZ analyzed the data. LH, YM, and XC drafted the manuscript. JQ and XC provided critical revisions.

FUNDING

This research was supported by the National Natural Science Foundation of China (31470981, 31571137, 31500885, 31600878, and 31771231), Project of the National Defense Science and Technology Innovation Special Zone, Chang Jiang Scholars Program, National Outstanding Young People Plan, the Program for the Top Young Talents by Chongqing, the Fundamental Research Funds for the Central Universities (SWU1609177), Natural Science Foundation of Chongqing (cstc2015jcyjA10106), Fok Ying Tung Education Foundation (151023), and the Research Program Funds of the Collaborative Innovation Center of Assessment toward Basic Education Quality at Beijing Normal University.

REFERENCES

Ashburner, J. (2007). A fast diffeomorphic image registration algorithm. *Neuroimage* 38, 95–113. doi: 10.1016/j.neuroimage.2007.07.007

Bagby, R. M., Parker, J. D. A., and Taylor, G. J. (1994). The 20-item toronto alexithymia scale:1. Item selection and cross-validation of the factor structure. *J. Psychosom. Res.* 38, 23–32. doi: 10.1016/0022-3999(94)90005-1

Barbey, A. K., Colom, R., Paul, E. J., Chau, A., Solomon, J., and Grafman, J. H. (2014). Lesion mapping of social problem solving. *Brain* 137, 2823–2833. doi: 10.1093/brain/awu207

Barczak, G., Lassk, F., and Mulki, J. (2010). Antecedents of team creativity: an examination of team emotional intelligence, team trust and collaborative culture. *Creat. Innov. Manage.* 19, 332–345. doi: 10.1111/j.1467-8691.2010.00574.x

Bar-On, R., Tranel, D., Denburg, N. L., and Bechara, A. (2003). Exploring the neurological substrate of emotional and social intelligence. *Brain* 126, 1790–1800. doi: 10.1093/brain/awg177

Bashwiner, D. M., Wertz, C. J., Flores, R. A., and Jung, R. E. (2016). Musical creativity "revealed" in brain structure: interplay between motor, default mode, and limbic networks. *Sci. Rep.* 6:20482. doi: 10.1038/srep20482

Baughman, H. M., Schermer, J. A., Veselka, L., Harris, J., and Vernon, P. A. (2013). A behavior genetic analysis of trait emotional intelligence and alexithymia: a replication. *Twin Res. Hum. Genet.* 16, 554–559. doi: 10.1017/thg.2012.151

Beer, J. S., Heerey, E. A., Keltner, D., Scabini, D., and Knight, R. T. (2003). The regulatory function of self-conscious emotion: insights from patients with orbitofrontal damage. *J. Pers. Soc. Psychol.* 85, 594–604. doi: 10.1037/0022-3514.85.4.594

Blakemore, S. J. (2008). The social brain in adolescence. *Nat. Rev. Neurosci.* 9, 267–277. doi: 10.1038/nrn2353

Brackett, M. A., Rivers, S. E., Shiffman, S., Lerner, N., and Salovey, P. (2006). Relating emotional abilities to social functioning: a comparison of self-report and performance measures of emotional intelligence. *J. Pers. Soc. Psychol.* 91, 780–795. doi: 10.1037/0022-3514.91.4.780

Carmeli, A., McKay, A. S., and Kaufman, J. C. (2014). Emotional intelligence and creativity: the mediating role of generosity and vigor. *J. Creat. Behav.* 48, 290–309. doi: 10.1002/jocb.53

Ding, X. Q., Tang, Y. Y., Tang, R. X., and Posner, M. I. (2014). Improving creativity performance by short-term meditation. *Behav. Brain Funct.* 10:9. doi: 10.1186/1744-9081-10-9

Eggers, F., Lovelace, K. J., and Kraft, F. (2017). Fostering creativity through critical thinking: the case of business start-up simulations. *Creat. Innov. Manage.* 26, 266–276. doi: 10.1111/caim.12225

Feist, G. J., and Barron, F. X. (2003). Predicting creativity from early to late adulthood: intellect, potential, and personality. *J. Res. Pers.* 37, 62–88. doi: 10.1016/s0092-6566(02)00536-6

Fong, C. T. (2006). The effects of emotional ambivalence on creativity. *Acad. Manag. J.* 49, 1016–1030. doi: 10.1016/j.jad.2014.10.040

Frith, C. D., and Frith, U. (2007). Social cognition in humans. *Curr. Biol.* 17, 724–732. doi: 10.1016/j.cub.2007.05.068

Good, C., Johnsrude, I., Ashburner, J., Henson, R., Friston, K., and Frackowiak, R. (2001). A voxel-based morphometric study of ageing in 465 normal adult human brains. *Neuroimage* 1, 21–36. doi: 10.1006/nimg.2001.0786

Gough, H. G. (1979). Creative personality scale for the adjective check list. *J. Pers. Soc. Psychol.* 37, 1398–1405. doi: 10.1037/0022-3514.37.8.1398

Guastello, S. J., Guastello, D. D., and Hanson, C. A. (2004). Creativity, mood disorders, and emotional intelligence. *J. Creat. Behav.* 38, 260–281. doi: 10.1002/j.2162-6057.2004.tb01244.x

Hao, N., Xue, H., Yuan, H., Wang, Q., and Runco, M. A. (2017). Enhancing creativity: proper body posture meets proper emotion. *Acta Psychol.* 173, 32–40. doi: 10.1016/j.actpsy.2016.12.005

Hertel, J., Schutz, A., and Lammers, C. H. (2009). Emotional intelligence and mental disorder. *J. Clin. Psychol.* 65, 942–954. doi: 10.1002/jclp.20597

Higgins, L. F., Qualls, S. H., and Couger, J. D. (1992). The role of emotions in employee creativity. *J. Creat. Behav.* 26, 119–129. doi: 10.1002/j.2162-6057.1992.tb01167.x

Hoffmann, J., and Russ, S. (2012). Pretend play, creativity, and emotion regulation in children. *Psychol. Aesthet. Creat. Arts* 6, 175–184. doi: 10.1037/a0026299

Hogeveen, J., Bird, G., Chau, A., Krueger, E., and Grafman, J. (2016a). Acquired alexithymia following damage to the anterior insula. *Neuropsychologia* 82, 142–148. doi: 10.1016/j.neuropsychologia.2016.01.021

Hogeveen, J., Salvi, C., and Grafman, J. (2016b). 'Emotional intelligence': lessons from lesions. *Trends Neurosci.* 39, 694–705. doi: 10.1016/j.tins.2016.08.007

Hornak, J., Bramham, J., Rolls, E. T., Morris, R. G., O'Doherty, J., Bullock, P. R., et al. (2003). Changes in emotion after circumscribed surgical lesions of the orbitofrontal and cingulate cortices. *Brain* 126, 1691–1712. doi: 10.1093/brain/awg168

Hwang, W. Y., Chen, N. S., Dung, J. J., and Yang, Y. L. (2007). Multiple representation skills and creativity effects on mathematical problem solving using a multimedia whiteboard system. *Educ. Technol. Soc.* 10, 191–212.

Killgore, W. D. S., Weber, M., Schwab, Z. J., DelDonno, S. R., Kipman, M., Weiner, M. R., et al. (2012). Gray matter correlates of Trait and Ability models of emotional intelligence. *Neuroreport* 23, 551–555. doi: 10.1097/WNR.0b013e32835446f7

Kim, E., Zeppenfeld, V., and Cohen, D. (2013). Sublimation, culture, and creativity. *J. Pers. Soc. Psychol.* 105, 639–666. doi: 10.1037/a0033487

Kong, F., and Zhao, J. J. (2013). Affective mediators of the relationship between trait emotional intelligence and life satisfaction in young adults. *Pers. Individ. Dif.* 54, 197–201. doi: 10.1016/j.paid.2012.08.028

Koven, N. S., Roth, R. M., Garlinghouse, M. A., Flashman, L. A., and Saykin, A. J. (2011). Regional gray matter correlates of perceived emotional intelligence. *Soc. Cogn. Affect. Neurosci.* 6, 582–590. doi: 10.1093/scan/nsq084

Kreifelts, B., Ethofer, T., Huberle, E., Grodd, W., and Wildgruber, D. (2010). Association of trait emotional intelligence and individual fMRI-activation

patterns during the perception of social signals from voice and face. *Hum. Brain Mapp.* 31, 979–991. doi: 10.1002/hbm.20913

Kringelbach, M. L. (2005). The human orbitofrontal cortex: linking reward to hedonic experience. *Nat. Rev. Neurosci.* 6, 691–702. doi: 10.1038/nrn1747

Krueger, F., Barbey, A. K., McCabe, K., Strenziok, M., Zamboni, G., Solomon, J., et al. (2009). The neural bases of key competencies of emotional intelligence. *Proc. Natl. Acad. Sci. U.S.A.* 106, 22486–22491. doi: 10.1073/pnas.0912568106

Li, W. F., Li, X. T., Huang, L. J., Kong, X. Z., Yang, W. J., Wei, D. T., et al. (2015). Brain structure links trait creativity to openness to experience. *Soc. Cogn. Affect. Neurosci.* 10, 191–198. doi: 10.1093/scan/nsu041

Libbrecht, N., Lievens, F., Carette, B., and Cote, S. (2014). Emotional intelligence predicts success in medical school. *Emotion* 14, 64–73. doi: 10.1037/a0034392

Lin, C., and Wang, M. (1994). *The Creativity Assessment Packet*. Taipei: Psychological Publishing.

Mayer, J. D., Roberts, R. D., and Barsade, S. G. (2008). Human abilities: emotional intelligence. *Annu. Rev. Psychol.* 59, 507–536. doi: 10.1146/annurev.psych.59.103006.093646

Medford, N., and Critchley, H. D. (2010). Conjoint activity of anterior insular and anterior cingulate cortex: awareness and response. *Brain Struct. Funct.* 214, 535–549. doi: 10.1007/s00429-010-0265-x

Moon, C. M., and Jeong, G. W. (2015). Alterations in white matter volume and its correlation with clinical characteristics in patients with generalized anxiety disorder. *Neuroradiology* 57, 1127–1134. doi: 10.1007/s00234-015-1572-y

Onur, E., Alkin, T., Sheridan, M. J., and Wise, T. N. (2013). Alexithymia and emotional intelligence in patients with panic disorder, generalized anxiety disorder and major depressive disorder. *Psychiatr. Q.* 84, 303–311. doi: 10.1007/s11126-012-9246-y

Pan, W. G., Wang, T., Wang, X. P., Hitchman, G., Wang, L. J., and Chen, A. T. (2014). Identifying the core components of emotional intelligence: evidence from amplitude of low-frequency fluctuations during resting state. *PLoS One* 9:e111435. doi: 10.1371/journal.pone.0111435

Parke, M. R., Seo, M. G., and Sherf, E. N. (2015). Regulating and facilitating: the role of emotional intelligence in maintaining and using positive affect for creativity. *J. Appl. Psychol.* 100, 917–934. doi: 10.1037/a0038452

Parker, J. D. A., Summerfeldt, L. J., Taylor, R. N., Kloosterman, P. H., and Keefer, K. V. (2013). Problem gambling, gaming and Internet use in adolescents: relationships with emotional intelligence in clinical and special needs samples. *Pers. Individ. Dif.* 55, 288–293. doi: 10.1016/j.paid.2013.02.025

Petrovic, P., Ekman, C. J., Klahr, J., Tigerstrom, L., Ryden, G., Johansson, A. G. M., et al. (2016). Significant grey matter changes in a region of the orbitofrontal cortex in healthy participants predicts emotional dysregulation. *Soc. Cogn. Affect. Neurosci.* 11, 1041–1049. doi: 10.1093/scan/nsv072

Piffer, D. (2012). Can creativity be measured? An attempt to clarify the notion of creativity and general directions for future research. *Think. Skills Creat.* 7, 258–264. doi: 10.1016/j.tsc.2012.04.009

Preacher, K. J., and Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behav. Res. Methods Instr. Comput.* 36, 717–731. doi: 10.3758/BF03206553

Preacher, K. J., and Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behav. Res. Methods* 40, 879–891. doi: 10.3758/BRM.40.3.879

Rivers, S. E., Brackett, M. A., Reyes, M. R., Mayer, J. D., Caruso, D. R., and Salovey, P. (2012). Measuring emotional intelligence in early adolescence with the MSCEIT-YV: psychometric properties and relationship with academic performance and psychosocial functioning. *J. Psychoeduc. Assess.* 30, 344–366. doi: 10.1177/0734282912449443

Roberts, A. C., and Wallis, J. D. (2000). Inhibitory control and affective processing in the prefrontal cortex: neuropsychological studies in the common marmoset. *Cereb. Cortex* 10, 252–262. doi: 10.1093/cercor/10.3.252

Roelofs, K., Minelli, A., Mars, R. B., van Peer, J., and Toni, I. (2009). On the neural control of social emotional behavior. *Soc. Cogn. Affect. Neurosci.* 4, 50–58. doi: 10.1093/scan/nsn036

Rudebeck, P. H., Saunders, R. C., Prescott, A. T., Chau, L. S., and Murray, E. A. (2013). Prefrontal mechanisms of behavioral flexibility, emotion regulation and value updating. *Nat. Neurosci.* 16, 1140–1145. doi: 10.1038/nn.3440

Sahin, F., Ozer, E., and Deniz, M. E. (2016). The predictive level of emotional intelligence for the domain-specific creativity: a study on gifted students. *Egitim Ve Bilim* 41, 181–197.

Salguero, J. M., Palomera, R., and Fernandez-Berrocal, P. (2012). Perceived emotional intelligence as predictor of psychological adjustment in adolescents: a 1-year prospective study. *Eur. J. Psychol. Educ.* 27, 21–34. doi: 10.1007/s10212-011-0063-8

Salovey, P., and Mayer, J. D. (1990). Emotional intelligence. *Imagin. Cogn. Pers.* 9, 185–211. doi: 10.2190/DUGG-P24E-52WK-6CDG

Saver, J. L., and Damasio, A. R. (1991). Preserved access and processing of social knowledge in a patient with acquired sociopathy due to ventromedial frontal damage. *Neuropsychologia* 29, 1241–1249. doi: 10.1016/0028-3932(91)90037-9

Schutte, N. S., Malouff, J. M., Hall, L. E., Haggerty, D. J., Cooper, J. T., Golden, C. J., et al. (1998). Development and validation of a measure of emotional intelligence. *Pers. Individ. Dif.* 25, 167–177. doi: 10.1016/s0191-8869(98)00001-4

Silvers, J. A., Hubbard, A. D., Chaudhury, S., Biggs, E., Shu, J., Grunebaum, M. F., et al. (2016). Suicide attempters with Borderline Personality Disorder show differential orbitofrontal and parietal recruitment when reflecting on aversive memories. *J. Psychiatr. Res.* 81, 71–78. doi: 10.1016/j.jpsychires.2016.06.020

Silvia, P. J., Christensen, A. P., and Cotter, K. N. (2016). "Commentary: the development of creativity-ability, motivation, and potential," in *Perspectives on Creativity Development*, Vol. 151, ed. B. Barbot (Hoboken, NJ: John Wiley & Sons), 111–119. doi: 10.1002/cad.20147

Stalnaker, T. A., Cooch, N. K., and Schoenbaum, G. (2015). What the orbitofrontal cortex does not do. *Nat. Neurosci.* 18, 620–627. doi: 10.1038/nn.3982

Sternberg, R. J. (1999). *Handbook of Creativity*. New York, NY: Cambridge University Press.

Takeuchi, H., Taki, Y., Nouchi, R., Sekiguchi, A., Hashizume, H., Sassa, Y., et al. (2013a). Resting state functional connectivity associated with trait emotional intelligence. *Neuroimage* 83, 318–328. doi: 10.1016/j.neuroimage.2013.06.044

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., et al. (2011). Regional gray matter density associated with emotional intelligence: evidence from voxel-based morphometry. *Hum. Brain Mapp.* 32, 1497–1510. doi: 10.1002/hbm.21122

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Nagase, T., et al. (2013b). White matter structures associated with emotional intelligence: evidence from diffusion tensor imaging. *Hum. Brain Mapp.* 34, 1025–1034. doi: 10.1002/hbm.21492

Tan, Y. F., Zhang, Q. L., Li, W. F., Wei, D. T., Qiao, L., Qiu, J., et al. (2014). The correlation between Emotional Intelligence and gray matter volume in university students. *Brain Cogn.* 91, 100–107. doi: 10.1016/j.bandc.2014.08.007

Toyama, H., and Mauno, S. (2017). Associations of trait emotional intelligence with social support, work engagement, and creativity in Japanese eldercare nurses. *Jpn. Psychol. Res.* 59, 14–25. doi: 10.1111/jpr.12139

Vuilleumier, P., Richardson, M. P., Armony, J. L., Driver, J., and Dolan, R. J. (2004). Distant influences of amygdala lesion on visual cortical activation during emotional face processing. *Nat. Neurosci.* 7, 1271–1278. doi: 10.1038/nn1341

Wang, C. K. (2002). The relationship between emotional intelligence and anxiety, depression and mood in a sample of college students. *Chin. J. Clin. Psychol.* 10, 298–299.

Wang, D. (2007). A report on the third revision of Combined Raven's Test (CRT-C3) for children in China. *Chin. J. Clin. Psychol.* 15, 559–568.

Williams, F. E. (1980). *Creativity Assessment Packet (CAP): Manual*. Buffalo, NY: DOK.

Wolf, R. C., Philippi, C. L., Motzkin, J. C., Baskaya, M. K., and Koenigs, M. (2014). Ventromedial prefrontal cortex mediates visual attention during facial emotion recognition. *Brain* 137, 1772–1780. doi: 10.1093/brain/awu063

Yao, X. N., Yuan, S. G., Yang, W. J., Chen, Q. L., Wei, D. T., Hou, Y. L., et al. (2017). Emotional intelligence moderates the relationship between regional gray matter volume in the bilateral temporal pole and critical thinking

disposition. *Brain Imaging Behav.* 12, 488–498. doi: 10.1007/s11682-017-9701-3

Zavala, M. A., and Lopez, I. (2012). Adolescents at risks: what is the role of emotional intelligence? *Behav. Psychol.* 20, 59–75.

Zeng, L., Salvendy, G., and Zhang, M. (2009). Factor structure of web site creativity. *Comput. Hum. Behav.* 25, 568–577. doi: 10.1016/j.chb.2008.12.023

Zhuang, K. X., Xia, Y. M., Sun, J. Z., Chen, Q. L., Wei, D. T., Yang, W. J., et al. (2017). Emotion-related brain structures associated with trait creativity in middle children. *Neurosci. Lett.* 658, 182–188. doi: 10.1016/j.neulet.2017.08.008

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 24 September 2018
doi: 10.3389/fpsyg.2018.01810

Beliefs About Creativity Influence Creative Performance: The Mediation Effects of Flexibility and Positive Affect

*Nujaree Intasao and Ning Hao**

School of Psychology and Cognitive Science, East China Normal University, Shanghai, China

This research explores potential factors that may influence the relationship between beliefs about creativity and creative performance. In Study 1, participants (N = 248) recruited from upper secondary schools in Thailand were asked to solve the Alternative Uses Task (a typical divergent thinking task) and complete a series of questionnaires concerning individual beliefs about creativity and potential factors of interest. The results of structural equation modeling reveal a mediation effect of flexibility on the relationship between self-efficacy and originality. The path from self-efficacy to flexibility was also partially mediated by positive affect. Self-efficacy was also positively correlated with task enjoyment and effort. Additionally, the growth mindset was positively associated with positive affect, while the fixed mindset was positively related to negative affect. In Study 2, participants (N = 214) were asked to solve the Insight Problems Task (a typical convergent thinking task). The results indicate that the growth mindset was positively related to task enjoyment, effort, and positive affect. The fixed mindset was negatively related to task enjoyment, effort, and creative performance. A positive relationship between the fixed mindset and negative affect was also observed. Taken together, these findings unveil some potential factors that mediate the relationships between beliefs about creativity and creative performance, which may be specific to divergent thinking tasks.

Keywords: fixed mindset, growth mindset, self-efficacy, beliefs about creativity, creativity

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Maciej Karwowski,
University of Wrocław, Poland
Baoguo Shi,
Capital Normal University, China

***Correspondence:**
Ning Hao
nhao@psy.ecnu.edu.cn

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *02 July 2018*
Accepted: *06 September 2018*
Published: *24 September 2018*

Citation:
Intasao N and Hao N (2018) Beliefs About Creativity Influence Creative Performance: The Mediation Effects of Flexibility and Positive Affect. Front. Psychol. 9:1810. doi: 10.3389/fpsyg.2018.01810

INTRODUCTION

Creativity and Beliefs About Creativity

Psychologists agree upon the definition of creativity as the ability to produce work that is novel (original and unique) and useful (Stein, 1953; Sternberg and Lubart, 1993; Runco and Jaeger, 2012). From a cognitive perspective, creativity is concerned with two types of thinking, namely divergent thinking and convergent thinking, both of which lead to creative production (Cropley, 2006). Divergent thinking involves searching through various directions, and multiple solutions to a problem are generated; in convergent thinking, thought is directed to one correct or best solution (Guilford, 1956, 1959).

Despite the growing number of studies done on creativity, there is still much to be learned (Runco and Albert, 2010). Throughout the years, researchers have studied creativity from various

perspectives, including how individuals' beliefs influence creativity. The topic of beliefs about creativity has been approached from different angles such as how people view themselves (i.e., creative self-beliefs) and how people perceive the nature of creativity. In this paper, we focuses on creative self-efficacy which is one of the key self-beliefs, and beliefs about the malleable nature of creativity (i.e., creative mindsets) which have attracted more researchers recently.

Creative self-efficacy is the belief that one can produce creative outcomes (Tierney and Farmer, 2002). As in most fields, research on creative self-efficacy has been grounded in Bandura's (1977) work on self-efficacy beliefs. Within this framework, self-efficacy beliefs determine how efficient people function through cognitive, motivational, affective, and decisional processes (Bandura, 1993, 2011). Self-beliefs of efficacy influence how much effort people put into a task, how persistent they are, and what task choices they prefer (Bandura, 1977; Zimmerman, 2000b; Schunk and DiBenedetto, 2016). When facing a challenge, people gauge their capacity to keep themselves motivated, focus on the task at hand, and manage negative thoughts and feelings (Bandura and Locke, 2003). Self-efficacy and performance mutually influence each other (Bandura, 1989; Williams and Williams, 2010). Past experiences shape people's current beliefs and their current beliefs drive their future actions.

Previous research has revealed evidence of the association between creative self-efficacy and creativity as assessed by various measures. For instance, in organizational settings, Michael et al. (2011) found that employees' creative self-efficacy was positively related to their self-reported innovative behaviors. Studies by Tierney and Farmer (2002, 2011) also demonstrated that employees with high levels of creative self-efficacy tended to be rated with high levels of creativity by their supervisors as well. In school contexts, Beghetto et al. (2011) investigated elementary school students' self-efficacy in creativity and found more self-efficacious students were given higher ratings of creative expression by their teachers. Karwowski (2011) studied high school and gymnasia students' creative self-efficacy. Using an unfinished, framed drawing task as a measure of divergent thinking, Karwowski also found a positive link between students' self-efficacy and their performance of the task. Based on prior research, the connection between creative self-efficacy and creativity is quite promising.

Unlike creative self-efficacy, creative mindsets are not self-beliefs but rather implicit theories concerning the source and nature of creativity (Karwowski and Brzeski, 2017). The work of Dweck and her colleagues on malleability beliefs has guided research on creative mindsets (e.g., Dweck and Leggett, 1988; Mueller and Dweck, 1998; Hong et al., 1999). According to their research, it makes a difference whether people believe that a certain attribute is fixed or unchangeable (fixed beliefs) or that a certain attribute is developable through hard work (incremental beliefs). When engaging in a task, people with fixed beliefs attribute their success or failure to the presence or lack of ability; conversely, people with incremental beliefs ascribe the task outcome to effort (Hong et al., 1999; Haimovitz and Dweck, 2017). As such, holding incremental beliefs is linked to desirable behaviors such as persistence, adoption of adaptive goals, and resilience in the face of setbacks (Mueller and Dweck, 1998; Yeager and Dweck, 2012). Holding fixed beliefs, on the other hand, is related to maladaptive behaviors such as learned helplessness (Hong et al., 1999). Compared to fixed beliefs, therefore, incremental beliefs lead to achievement in the long term (Blackwell et al., 2007). Dweck (2006) has introduced the terms "growth mindsets" and "fixed mindsets." People with incremental beliefs endorse a growth mindset, while people with fixed beliefs endorse a fixed mindset. In this paper, the term "creative mindsets" is used to refer to beliefs concerning the malleable nature of creativity.

The concept of creative mindsets is relatively new. As a result, the connections between creative mindsets and creativity have been explored less than creative self-efficacy has. O'Connor et al. (2013) conducted a series of studies to examine creative mindsets and creativity. Using their self-developed scale, they found that the creative growth mindset positively predicted interest in creative thinking, creative performance as assessed by the Unusual Uses Task (also known as the Alternative Uses Task), self-reported creativity (Study 1), and prior creative achievements across various domains (Study 2). Manipulation of creative mindsets (Study 3) also demonstrated that participants in the growth-mindset-induced group performed better in the Unusual Uses Task. This study provided evidence that creative mindsets affect creative performance. Karwowski (2014) developed a scale to measure creative mindsets and examined their relations to creative problem-solving as measured by insight problems. He found that the fixed mindset was related to inefficient problem-solving performance.

Besides using different instruments to measure creativity and creative mindsets, O'Connor et al. (2013) and Karwowski (2014) viewed two types of mindsets differently in terms of their constructs. The research done by O'Connor et al. (2013) was based on the premise that people endorse either fixed beliefs or incremental beliefs. That is, growth and fixed mindsets together form one construct. This view is in accordance with the research done by Dweck and her colleagues (e.g., Hong et al., 1999; Blackwell et al., 2007). However, Karwowski (2014) argued that people can hold two kinds of mindsets simultaneously, which means that the fixed mindset and the growth mindset should be conceived of as two correlated yet separate constructs. This view has been supported by correlational results of factor analyses conducted by Hass et al. (2016), who found a negative correlation between fixed mindsets and growth mindsets, but the correlation was too small for the two to be considered as one construct. Furthermore, they found a positive correlation between the creative growth mindset and self-efficacy, but not between the fixed mindset and self-efficacy. As such, they concluded that while the two mindsets are related, they are indeed two distinct constructs. Additionally, applying a bifactor modeling approach and a latent profile analysis, Karwowski et al. (2018b) demonstrated that people can hold both fixed and growth mindsets. In fact, their results showed that people could be classified as people as those with high growth and low fixed mindsets, those with low growth and high fixed mindsets, those with high growth and high fixed mindsets, and those with low fixed and malleable mindsets.

Overall, evidence from past research has established the associations between these two types of beliefs about creativity and creativity. Specifically, high creative self-efficacy and growth mindset, rather than fixed mindset, appear to be linked to desirable creative outcomes. However, some inconsistencies regarding how researchers have hypothesized the direction of the associations should be addressed, especially if studies have involved creativity tasks. For instance, Karwowski (2011) used a creativity task, specifically a divergent thinking task, to study the association between creative self-efficacy and creativity. In his study, the performance in the task was treated as a predictor of self-efficacy. The direction of the divergent thinking performance and self-efficacy found in this study is in alignment with Karwowski and Beghetto's (2018) Creative Behavior as Agentic Action model, which proposes that the link between creative potentials and creative achievement is mediated and moderated by creative confidence and valuing creativity. According to this model, divergent and convergent thinking abilities are viewed as creative potentials and essentially these abilities influence self-efficacy. Creative mindsets were later included in the Elaborated Creative Behavior as Agentic Action model (Karwowski et al., 2016). According to this model, creative mindsets influence the relationships between creative potential, creative self-beliefs, and creative behavior. In this later model, divergent and convergent thinking are also perceived as creative potentials which are neither predictors of self-efficacy nor creative mindsets. Conversely, some studies on creativity's relationship with creative mindsets examined performance in a divergent thinking task, such as the Alternative Uses Task (O'Connor et al., 2013) or a convergent thinking task (e.g., insight problems; Karwowski, 2014), as an outcome of creative mindsets. This indicates that performance in divergent or convergent thinking tasks can be used as both a predictor and an outcome of beliefs. This difference may simply depend on how researchers view the performance of the tasks. As a predictor, performance may serve as a reference for people to evaluate their abilities and form their beliefs. As an outcome, performance represents some form of creative behavior which is a result of how beliefs influence actions. The present research is based on the premise that beliefs influence creative performance and it aims to explore some psychological factors that could potentially explain this mechanism.

Potential Mediators Between Beliefs and Creativity

Cognitive Processing Channels

The dual pathway to creativity model asserts that creativity can be achieved through two cognitive pathways, namely the flexibility pathway and the persistence pathway (De Dreu et al., 2008; Nijstad et al., 2010). In the flexibility pathway, creativity is obtained through cognitive flexibility: that is, flexibly switching from one perspective to another (Nijstad et al., 2010). In the persistence pathway, creativity is accessed through cognitive persistence: in other words, through sustained and focused task-directed cognitive effort (Nijstad et al., 2010). The use of cognitive flexibility manifests itself in divergent thinking when individuals engage in broad cognitive categories and frequently switch among categories during the thinking process. On the other hand, the use of the persistence pathway is apparent when individuals draw many ideas from a few categories. In divergent thinking tasks in which participants have to produce ideas to solve a problem, the number of categories used by participants functions as an indicator of cognitive flexibility, while within-category fluency or the number of ideas within a category is used to measure persistence (De Dreu et al., 2008; Roskes et al., 2012). According to this model, some states or traits facilitate cognitive flexibility, while others enhance cognitive persistence. For instance, when using a brainstorming task, De Dreu et al. (2008) found that cognitive flexibility (the number of categories used) mediated the effect of positive affective states on originality; while cognitive persistence (within-category fluency) mediated the effect of negative mood states on creative fluency. Although both cognitive pathways can lead to creativity, the persistence pathway is believed to be less effective compared to the flexibility pathway because it requires more cognitive resources (Roskes et al., 2012).

Self-efficacy beliefs (Schunk and Zimmerman, 1997; Bandura, 2011) and incremental beliefs (Dweck, 2000; Dweck and Master, 2008) promote self-regulation. This paper hypothesizes that these beliefs are associated with greater flexibility, and that these associations may be due to their links to self-regulation. On the one hand, self-regulation, which involves cyclically making adjustments as needed based on prior knowledge (Zimmerman, 2000a), is driven by task-switching ability, since this ability allows people to flexibly switch between means and goals when appropriate (Hofmann et al., 2012). If self-efficacy and incremental beliefs are linked to the effective self-regulatory process, and this process relies on cognitive flexibility, then these beliefs could be related to cognitive flexibility. On the other hand, self-efficacy and incremental beliefs influence adaptive reactions to a situation, such as sustaining positive affect in the face of setbacks, adopting approach-based orientations, and maintaining motivation (as discussed in the "*Self-Regulatory Responses*" section). Because these reactions are believed to be facilitators of flexible processing, the beliefs should be connected with cognitive flexibility in one way or another.

Self-Regulatory Responses

As previously mentioned, self-efficacy beliefs and malleability beliefs predict how people react to a situation. In this way, the beliefs predict achievement through the use of self-regulatory strategies. This paper hypothesizes that the same principle would apply to beliefs concerning creativity and creative achievement. More specifically, this paper hypothesizes that creative self-efficacy and creative mindsets affect creativity by triggering self-regulatory reactions that promote or demote creativity.

Affective states

The beneficial effects of beliefs on emotional regulation seem to be most apparent when individuals encounter challenging situations. Perceived self-efficacy has an impact on individuals emotionally (Linnenbrink and Pintrich, 2003). Past research has shown that people with a weak sense of self-efficacy are more vulnerable to negative emotional experiences such as childhood

depression (Bandura et al., 1999), test anxiety (Komarraju and Nadler, 2013; Roick and Ringeisen, 2017), and job stress (Klassen and Chiu, 2010). With respect to creative self-efficacy, Rego et al. (2012) found that employees' self-efficacy beliefs were positively correlated with positive affect, and that positive affect partially mediated the relationship between self-efficacy and creativity as rated by their supervisors.

With respect to malleability beliefs, research devoted to intelligence among students revealed that students who think intelligence is undevelopable are likely to experience negative feelings such as anxiety, anger, shame, hopelessness, and boredom (King et al., 2012). In the sports domain, Gardner et al. (2015) found that people with a stronger fixed mindset were more vulnerable to competition anxiety, whereas a stronger growth mindset was related to less anxiety. The unfavorable impacts of fixed beliefs could be explained by their association with less effective emotion regulation (Schroder et al., 2015). Given that creative mindsets have been built on the same foundation as other areas, their connections with affect should appear indifferent. That is a fixed mindset would be associated with negative affect and a growth mindset would be related to positive affect.

As previously mentioned, creativity can be achieved via flexibility and persistence pathways, with flexibility being the preferable pathway. Both positive affect and negative affect can lead to creativity as long as they are activating (De Dreu et al., 2008; Nijstad et al., 2010). Positive activating affect facilitates cognitive flexibility; on the other hand, negative activating affect increasing the use of cognitive persistence. Based on past research, it seems that when performing a creativity task, people with high creative self-efficacy and a growth mindset would experience lower negative affect and higher positive affect, which would lead to flexible thinking and creativity, while a fixed mindset would result in the opposite outcomes.

Approach/avoidance orientation

When engaging in a task, people with a strong sense of self-efficacy anticipate success, while those who perceive low self-efficacy visualize failure (Bandura, 1993). Inefficacious people are therefore apt to see task demands as threats to be avoided rather than challenges to be learned from (Chemers et al., 2001). Past research on achievement goals has provided some evidence on the impact of self-efficacy beliefs on approach/avoidance orientations. For instance, studies in educational settings have shown that students with high self-efficacy tend to adopt approach-based goals such as mastering a given task or demonstrating their competence (Pajares et al., 2000; Cury et al., 2006; Van Yperen, 2006; Komarraju and Nadler, 2013). Conversely, students with low self-efficacy are prone to engage in avoidance-based goals such as avoiding showing their incompetence (Pajares et al., 2000; Cury et al., 2006; Van Yperen, 2006). With respect to creative self-efficacy, research done by Beghetto (2006) and Puente-Díaz and Cavazos-Arroyo (2017) has revealed a similar trend in which people with high creative self-efficacy tend to engage in approach orientations.

Malleability beliefs influence what types of goals people adopt, but unlike self-efficacy, they seem to be unable to predict the engagement of approach/avoidance orientations. Research has indicated that people who hold a fixed mindset are likely to adopt both approach-based goals such as demonstrating their competence (Robins and Pals, 2002; Cury et al., 2006) and avoidance-based goals such as avoiding showing their incompetence (Cury et al., 2006). On the other hand, those that hold a growth mindset have a tendency to adopt approach-based goals such as learning or mastering a subject (Robins and Pals, 2002; Cury et al., 2006; Lou and Noels, 2016) and avoidance-based goals such as avoiding learning less than they could (Cury et al., 2006). In the case of creative mindsets, a recent study by Puente-Díaz and Cavazos-Arroyo (2017) revealed that the growth mindset and the fixed mindset were both positively related to approach-based goals. Evidently, mindsets predict what types of goals people prefer, but not the approach/avoidance orientation of the goals.

Because approach orientations are linked to higher cognitive flexibility, (Nijstad et al., 2010; Roskes et al., 2012), this paper hypothesizes that people with high creative self-efficacy will adopt an approach orientation, which will then enhance cognitive flexibility and subsequently creativity.

Task enjoyment

Task enjoyment/interest is an indicator of intrinsic motivation (Ryan, 1982; Davis et al., 1992; Ryan and Deci, 2000). In fact, the use of self-reported interest and enjoyment of the activity is a common approach to assessing intrinsic motivation (Ryan and Deci, 2000). Intrinsic motivation is when people are driven to engage in an activity because they find it interesting or enjoyable (Amabile and Pillemer, 2012). This type of motivation is involved in cognitive flexibility (Deci and Ryan, 2000), and is believed to be conducive to creativity (Amabile and Pillemer, 2012).

Perception of ability has been positively linked to motivation (Bandura, 1993, 2011). For example, early work by Bandura and Schunk (1981) found that students with higher mathematical self-efficacy were more intrinsically interested in arithmetic tasks. Zimmerman and Kitsantas (1997) also found that perceived self-efficacy in dart skills was positively correlated with interest in the game. Similar results have been found in sports literature. Hu et al. (2007) provided participants with fake feedback on their exercise tests to manipulate their self-efficacy in exercise. The results showed that people in the high-self-efficacy group enjoyed their physical activity more than their counterparts in the low-self-efficacy group.

As for studies concerning malleability beliefs, the same trend has been found in people with a growth mindset. For instance, in a study by Aronson et al. (2002), participants who were convinced that intelligence was improvable through hard work reported that they experienced greater enjoyment during academic processes. The impact of incremental beliefs on enjoyment even persists after setbacks. Mueller and Dweck (1998) demonstrated that praising students for their hard work (promoting growth mindsets) rather than their intelligence (promoting fixed mindsets) helped to sustain their task enjoyment even after facing failure. With respect to creativity research, O'Connor et al. (2013) also found a positive correlation between the creative growth mindset and self-reported interest in creative thinking.

Taking this all into consideration, this paper hypothesizes that self-perceived efficacy and creative mindsets will impact creativity via enjoyment of the task and the use of flexible processing.

Effort

Effort reflects how much people engage in an activity. Research literature emphasizes that exerting more effort is an adaptive behavioral outcome of self-efficacy beliefs (Bandura, 1977; Zimmerman, 2000b) and malleability beliefs (Dweck, 2000). Effort is a more controllable factor in comparison with ability. The extent of effort put forth depends on people's own will, so if they are convinced that their accomplishments rely on their hard work, they tend to be more motivated to work harder (Schunk, 1983).

Research has suggested that people with high self-efficacy are likely to have a positive attitude toward effort. In the presence of challenges, self-efficacy predicts how long people persevere and how much energy they invest in a task (Zimmerman, 2000b; Pajares and Schunk, 2002; Bandura, 2011). After applying both questionnaire and diary methods to assess academic effort, Trautwein et al. (2009) reported a positive association between effort and self-competence beliefs. Similarly, Komarraju and Nadler (2013) found positive correlations among undergraduate students' grade point average, self-efficacy, and effort regulation (working hard and persisting when necessary). Their mediation analysis also demonstrated that effort regulation partially mediated the link between self-efficacy and academic achievement.

With respect to malleability beliefs, research suggests that by valuing hard work, people with a growth mindset expend more effort on tasks. For instance, Mueller and Dweck (1998) demonstrated that when students were praised for their ability, they tended to view their performance as the outcome of their ability instead of their effort, and so when given a choice, they were less willing to spend more time on the activity. Hong et al. (1999) provided participants with a false negative result of a task that allegedly tested their intelligence. Manipulating participants' fixed and growth mindsets, they found that those in the growth-mindset group were prone to ascribe the outcome to effort, and they were apt to express willingness to take remedial action.

To a certain extent, creativity requires conscious effort (Cropley, 2006). Conscious effort is involved with creative production in the preparation process (Busse and Mansfield, 1980; Cropley, 2006) in the way that it enables and provides direction to unconscious creative processing (Busse and Mansfield, 1980). As such, effort may mediate the links between the beliefs and creative performance.

The Present Research

The two present studies were intended to explore factors that could explain how creative self-efficacy and creative mindsets impact creativity. Creative self-efficacy and mindsets, more specifically the growth mindset, have been found to be correlated with each other (Karwowski, 2014; Hass et al., 2016), yet the causal aspect of the relationship is not clear. For instance, highly self-efficacious people might experience more success, thus believing that their ability can be improved. Holding a growth mindset might motivate people to work harder, help them gain more achievements, and consequently boost their self-efficacy. Given that the direction of self-efficacy and creative mindsets was not our focus, we therefore treated both of them equally as predictors of creative performance. Furthermore, the relationships between beliefs and creative performance was not our main interest; instead, our main concern was to explore factors that could link them.

As previously mentioned, creativity can be achieved by adopting flexible cognitive processing and persistent processing. Because these two processing styles manifest themselves in divergent thinking, we applied a divergent thinking task in Study 1. To test if creative beliefs may impact creativity through either or both cognitive flexibility and persistence, we treated these two traits as mediators. Additionally, self-efficacy and ability mindsets determine how people regulate themselves when facing a challenge (through self-regulatory responses). Previously, we proposed some self-regulatory responses that affect creativity in a positive way. There is also some evidence suggesting that adopting certain self-regulatory responses may lead to different types of cognitive processing. Accordingly, we treated these self-regulatory reactions as another set of mediators, and tested whether they could connect beliefs with creative performance directly and/or connect them with creative performance indirectly, through different types of cognitive channels. In Study 2, we adopted a convergent thinking task instead, to examine if beliefs would impact this task in the same way. However, due to the task type, cognitive flexibility and persistence scores could not be computed, and are thus not included in the examination.

STUDY 1

Participants

The participants were upper secondary school students recruited from schools in Thailand. Originally, 276 students participated in this study. Nine cases were excluded due to missing data. Fourteen cases were excluded due to unengaged responses. Five cases were excluded due to misunderstanding the instruction of the creativity task. The final sample thus consisted of 248 students with a mean age of 16.97 (SD = 1.07). Of this sample, 157 were female, and all were native Thai speakers. The research is approved by the University Committee on Human Research Protection (UCHRP) of East China Normal University. In addition, permission from the schools' principals and consent forms from participants and their parents/guardians were obtained prior to data collection.

Measures

The questionnaires employed in this study were originally written in English. In order to administer the questionnaires to this particular sample, the back-translation technique recommended by Brislin (1986) was applied. First, one of the authors translated the questionnaire items from English to Thai, and a professional English–Thai translator blindly to the original content translated them back to English. The back-translated and original versions

were later compared to determine whether or not the concepts were different. Problematic items were adjusted via discussion between the two translators. To ensure that the translated questionnaires were comprehensible to the target sample, four upper secondary school students were asked to complete them and provide feedback. Again, problematic items were adjusted via discussion between the two translators.

Beliefs Concerning Creativity

Creative self-efficacy

Creative self-efficacy was measured using six items of creative self-efficacy subscale from the Short Scale of Creative Self Scale (Karwowski et al., 2018a). Participants responded on a 5-point Likert scale with 1 being "strongly disagree" and 5 being "strongly agree." One sample item is, "I am good at proposing original solutions to problems."

Creative mindsets

Creative mindsets were measured using a 5-point Likert (1 being "strongly disagree" and 5 being "strongly agree") developed by Karwowski (2014). The scale consists of a 5-item fixed mindset subscale ("You either are creative, or you are not—even trying very hard you cannot change much") and a 5-item growth mindset subscale ("Everyone can create something great at some point if he or she is given appropriate conditions").

Creativity

The Alternative Uses Task was used to assess creativity associated with divergent thinking. In this task, participants were given 10 min to come up with creative uses for a brick. Three scores (originality, flexibility, and persistence) were computed from this task. *The originality score* was the number of responses that were provided by less than 5% of all participants. A high score indicated high creativity. *The flexibility score* was the number of categories used. A high score reflected high cognitive flexibility (e.g., De Dreu et al., 2008; Roskes et al., 2012). *The persistence score* was the number of responses divided by the flexibility score. A high score represented high cognitive persistence (e.g., De Dreu et al., 2008). As such, only the originality score was used to represent creative performance, while the flexibility score and the persistence score were used to indicate cognitive processing tendencies.

Self-Regulatory Responses

Affective states

Affective states during the task were assessed using the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988). The scale consists of 10 items of mood descriptors evaluating positive affect (PA) and 10 items of mood descriptors evaluating negative affect (NA). These two dimensions were later renamed positive activation and negative activation due to the activating nature of the mood descriptors used in the scale (Watson et al., 1999). Participants had to indicate on a scale of 1 to 7 (1 being "not at all" and 7 being "extremely") to what extent they felt a specific mood during the creativity task. These scales were to be completed after the creativity task.

Approach/avoidance orientation

A force-choice approach was employed to assess approach orientation versus avoidance orientation. This approach was used successfully in prior studies to measure approach/avoidance achievement goals (e.g., Mueller and Dweck, 1998; Van Yperen and Renkema, 2008). Participants in this study were forced to choose one of the two statements that was the most accurate for them. The two statements were "During the task, I focused on performing well," representing the approach orientation, and "During the task, I focused on not performing poorly," representing the avoidance orientation. For analysis purposes, the avoidance orientation and the approach orientation were coded as 0 and 1, respectively.

Task enjoyment

Seven items from the Interest/Enjoyment Subscale from the Intrinsic Motivation Inventory (Ryan, 1982) were used as a measure of task enjoyment. A sample item of this subscale is "I enjoyed doing the task very much." Participants had to respond on a scale of 1 to 7 with 1 being "not true at all" and 7 being "extremely true."

Effort

Effort exerted during the creativity task was measured using the Effort/Importance Subscale from the Intrinsic Motivation Inventory (Ryan, 1982). Out of 5 items, 1 item of this subscale measures importance. For this study, this item was excluded and the remaining four items were used to measure effort. A sample item is "I put a lot of effort into the task." Participants had to respond on a scale of 1–7 with 1 being "not true at all" and 7 being "extremely true."

Other Variables

Valence and arousal

The valence and arousal scales from Lang's (1980) Self-Assessment-Manikin were used to measure valence and arousal dimensions of affective states. Participants were asked to complete these scales before engaging in the creativity task to measure their pre-existing affective states.

Age

The participants' ages were asked as one of the demographic questions.

Procedure

The questionnaires and the creativity task were paper-based and administered in a classroom to groups of 20 to 30 participants at a time. Participants were asked to complete the demographic questions first, followed by the scales measuring pre-task affective states, creative mindsets, and creative self-efficacy. Participants then worked on the creativity task. Lastly, approach/avoidance orientations, affective states, task enjoyment, and effort were measured.

Results and Discussion

This study employed the structural equation modeling (SEM) technique for statistical analyses using Mplus version 7.4. SEM is a multivariate method that allows researchers to test a series

of dependence relationships at the same time (Hair et al., 2010). Given that this study dealt with multiple variables, this method was suitable for the present data.

In this study's SEM models, all three creativity scores (originality, flexibility, and persistence), age, and valence and arousal were treated as continuous variables. Of all these variables, kurtosis values of the originality score and the persistence score were outside the acceptable range of ±2 (Lomax and Hahs-Vaughn, 2012). Log-transformation was therefore performed for the persistence score, and because the originality score contained zero values, square-root transformation was performed instead. Kurtosis values of these two variables fell within the acceptable range after the transformation. Approach/avoidance orientation was a binary variable. While indicators that are Likert-scale responses with five categories or more are generally treated as continuous variables, the histograms of our scale responses revealed some floor and ceiling effects. Treating indicators with asymmetrical distribution as continuous is not appropriate (Kline, 2016); therefore, responses in the scales of creative self-efficacy, creative mindsets, task enjoyment, and effort were defined as ordered-categorical variables. Analyses were employed using mean-and-variance-adjusted weighted least squares estimation (WLSMV) to account for non-continuous variables. With this estimation method, the regression coefficients produced are linear regression coefficients when dependent variables are continuous or continuous latent; the regression coefficients are probit regression coefficients when dependent variables are binary or ordered categorical (Muthén and Muthén, 1998–2012). Fit indices and criteria used were χ^2/df for the parsimonious fit with value < 3 (Marsh and Hocevar, 1985; Hair et al., 2010), comparative fit index (*CFI*) for the incremental fit with values > 0.90 (Bentler, 1990; Hair et al., 2010), and root mean square error of approximation (*RMSEA*) for the absolute fit with value < 0.08 (Browne and Cudeck, 1993).

Test of the Measurement Model

Before proceeding with SEM, a confirmatory factor analysis (CFA) was performed to validate the measurement model of seven latent constructs: creative self-efficacy, fixed mindset, growth mindset, negative affect, positive affect, task enjoyment, and effort. Items loaded on their perspective factors smaller than 0.35 were dropped to improve unidimensionality. Accordingly, 1 item from the fixed mindset scale, 4 items from the positive affect scale, and 1 item from the effort scale were removed. The final model yielded an acceptable fit [$\chi^2(758) = 1490.29$, $p < 0.001$, $\chi^2/df = 1.97$, *CFI* = 0.92, and *RMSEA* = 0.06]. The reliability coefficients of these scales, along with descriptive statistics and correlations among the latent and observed variables, are presented in **Table 1**.

Next, the relationships among the variables were tested using a series of SEM models. To control the effects of age and affective states prior to engaging in the creativity task on dependent variables, age and valence and arousal were entered into all SEM models as covariates (i.e., all endogenous variables were regressed on these variables).

Effects of Beliefs on Creativity

The effects of creative self-efficacy and the two kinds of creative mindsets on creativity were first investigated. Model 1, comprising of creative self-efficacy and the two types of creative mindsets as predictor variables, and the originality score as the only outcome variable, demonstrated an adequate fit [$\chi^2(135) = 242.54$, $p < 0.001$, $\chi^2/df = 1.80$, *CFI* = 0.90, and *RMSEA* = 0.06]. No trimming was performed. To account for possible multicollinearity among independent variables, variance inflation factors (VIFs) were computed. A variable may constitute a problem, if the VIF is greater than 10 (Kline, 2016). The results suggested that multicollinearity was not an issue among the predictors (VIFs range: 1.15–1.58). Based on this model, creative self-efficacy was found to positively predict originality ($\beta = 0.24$, $p = 0.001$), indicating that the more people believe they have capacities to be creative, the more likely they are to produce creative ideas. A study by Karwowski (2011) also found this positive relationship between creative self-efficacy and divergent thinking. Effects of creative growth and fixed mindsets on originality were not observed ($\beta = -0.06$, $p = 0.502$ and $\beta = -0.17$, $p = 0.055$, respectively). Research literature emphasizes the role of mindsets when facing setbacks (Dweck, 2006). As such, their role may be limited when it comes to relatively easy tasks (Karwowski et al., 2016). Given that the Alternative Uses Task is not a very challenging task, it might not allow the effects of mindsets to manifest themselves.

Effects of Beliefs on Creativity via Cognitive Processing Channels

Creativity can be achieved by being cognitively flexible or/and being cognitively persistent (Nijstad et al., 2010). The flexibility score and the persistence score were therefore inserted into the model as mediators (Model 2). In this model, the scores of originality, flexibility, and persistence were regressed on creative self-efficacy and the two creative mindsets. The originality score was also regressed on the flexibility and persistence scores. Following Preacher and Hayes's (2008) recommendation, residuals of the mediators were covaried. The model yielded an acceptable fit [$\chi^2(159) = 265.89$, $p < 0.001$, $\chi^2/df = 1.67$, *CFI* = 0.91, and *RMSEA* = 0.05], and no trimming was performed. Examination of VIFs suggested multicollinearity among the predictors and mediators was not a concern (VIFs range: 1.17–1.58). Indirect effects were tested using the *model indirect* command in Mplus. With this command, indirect effects are defined as products of regression coefficients (Muthén and Muthén, 1998–2012).

Results showed that persistence and flexibility positively predicted originality ($\beta = 0.40$, $p < 0.001$ and $\beta = 0.74$, $p < 0.001$, respectively). Results also showed that creative self-efficacy positively predicted flexibility ($\beta = 0.29$, $p < 0.001$), but unlike Model 1 no longer had a significant effect on originality ($\beta = 0.04$, $p = 0.435$). A significant indirect effect of creative self-efficacy on originality via flexibility was detected ($\beta = 0.21$, $p = 0.001$). These results demonstrate that the effect of self-efficacy on originality was fully mediated through flexibility, indicating that people produce creative ideas by engaging in flexible processing when they are self-efficacious in their creativity.

TABLE 1 | Descriptive statistics, reliability coefficients, and correlations for Study 1.

	CSE[a]	CGM[a]	CFM[a]	PA[a]	NA[a]	TE[a]	Ef[a]	Ap/Av	Or	Pe	Fl
CGM	0.32***										
CFM	−0.04	−0.52***									
PA	0.42***	0.37***	−0.24**								
NA	−0.06	−0.18*	0.27***	−0.05							
TE	0.29***	0.19**	−0.09	0.61***	−0.2***						
Ef	0.37***	0.29***	−0.16*	0.48***	−0.21***	0.56***					
Ap/Av	0.17	0.17	0.05	0.08	−0.02	0.10	0.12				
Or	0.24**	0.11	−0.14*	0.25***	−0.02	0.17**	0.16*	−0.02			
Pe	0.00	−0.02	0.08	0.05	0.00	0.07	−0.04	0.01	0.14*		
Fl	0.28***	0.16*	−0.2**	0.34***	−0.08	0.22**	0.21**	0.04	0.62***	−0.34***	
CR	0.80	0.76	0.68	0.81	0.92	0.93	0.86				
α	0.75	0.67	0.63	0.78	0.87	0.90	0.80				
M	3.23	4.35	2.41	4.60	2.07	4.81	5.31		3.37	2.87	4.56
SD	0.49	0.48	0.65	0.89	0.90	0.97	1.12		2.85	1.39	1.72
Frequency (%)							Ap:167(67.34)				

*Correlation coefficients were estimated based on Model 3. *p < 0.05, **p < 0.01, ***p < 0.001; CSE, creative self-efficacy; CGM, creative growth mindset; CFM, creative fixed mindset; PA, positive affect; NA, negative affect; TE, task enjoyment; Ef, effort; Ap, approach orientation; Av, avoidance orientation; Or, originality score; Pe, persistence score; Fl, flexibility score; CR, composite reliability; α, Cronbach's alpha; M, means; SD, standard deviations. [a]The means of these scales were calculated as though their indicators were continuous variables. However, these indicators were actually treated as ordered-categorical variables in the SEM models.*

Additionally, flexibility was also predicted by the fixed mindset, but in a negative direction (β = −0.19, p = 0.026). An indirect effect of fixed mindset on originality via flexibility also appeared significant (β = −0.14, p = 0.03), indicating that people who hold a low level of fixed mindset tend to be more cognitively flexible, and this in turn leads to more original ideas. Results from the growth mindset failed to emerge. **Figure 1** illustrates Model 2 with path coefficients.

Effects of Beliefs on Creativity via Self-Regulatory Responses

To test whether or not any proposed self-regulatory responses (i.e., positive affect, negative affect, approach/avoidance orientation, task enjoyment, and effort) could explain the connections between the beliefs and creativity, these variables were added into the model (Model 3, as illustrated in **Figure 2**). For this model, all self-regulatory responses and the creativity scores (i.e., originality, flexibility, and persistence) were regressed on creative self-efficacy and the two mindsets. The creativity scores were regressed on all self-regulatory responses. The originality score was also regressed on the flexibility score and the persistence score. Again, residuals of parallel but not serial mediators were covaried. The model fit indices were satisfactory [$\chi^2(996) = 1763.69$, $p < 0.001$, $\chi^2/df = 1.77$, $CFI = 0.91$, and $RMSEA = 0.06$]. No trimming was performed and multicollinearity among the predictors and mediators was not a concern (VIFs range: 1.09–2.20).

After examining path coefficients, the results demonstrated that creative self-efficacy positively predicted positive affect (β = 0.34, $p < 0.001$), task enjoyment (β = 0.24, $p < 0.001$), and effort (β = 0.32, $p < 0.001$). As in Model 2, the direct effect of creative self-efficacy on flexibility remained significant (β = 0.20, p = 0.03). With regard to creative mindsets, the fixed mindset appeared to be a positive predictor of negative affect (β = 0.24, p = 0.015). Inconsistent with Model 2, the direct effect of the fixed mindset on flexibility became insignificant (β = −0.15, p = 0.101). In addition, the growth mindset appeared to positively predict positive affect (β = 0.16, p = 0.04). The results were in line with prior studies demonstrating the beneficial effects of high self-efficacy on affect (e.g., Rego et al., 2012), task enjoyment (e.g., Hu et al., 2007), and effort (e.g., Trautwein et al., 2009), as well as the favorable effect of growth mindset and the adverse effect of fixed mindset on affect (e.g., King et al., 2012). With respect to the direct relationships of the proposed self-regulation related responses and creativity, only the positive relationship between positive affect and flexibility was observed (β = 0.25, p = 0.016). Additionally, persistence and flexibility remained positively related to originality (β = 0.41, $p < 0.001$ and β = 0.76, $p < 0.001$, respectively). All path coefficients of this model are displayed in **Table 2**.

Again, the *model indirect* command in Mplus was employed to test indirect effects. As in Model 2, creative self-efficacy predicted originality via flexibility (β = 0.15, p = 0.034). The results also revealed that creative self-efficacy positively predicted flexibility via positive affect (β = 0.09, p = 0.023), and positive affect positively predicted originality via flexibility (β = 0.19, p = 0.02). The indirect path from creative self-efficacy to originality via positive affect and flexibility also appeared to be statistically significant (β = 0.07, p = 0.028). No other indirect effects were observed.

In summary, the relationship between creative self-efficacy and creativity as indicated by the originality score can be explained by flexibility and positive affect. More precisely, creative self-efficacy facilitates flexible thinking, which in turn enhances creativity. Additionally, creative self-efficacy also promotes positive affect, which partially increases cognitive flexibility. This is in alignment with the notion of the dual pathway to creativity model in which creativity can be

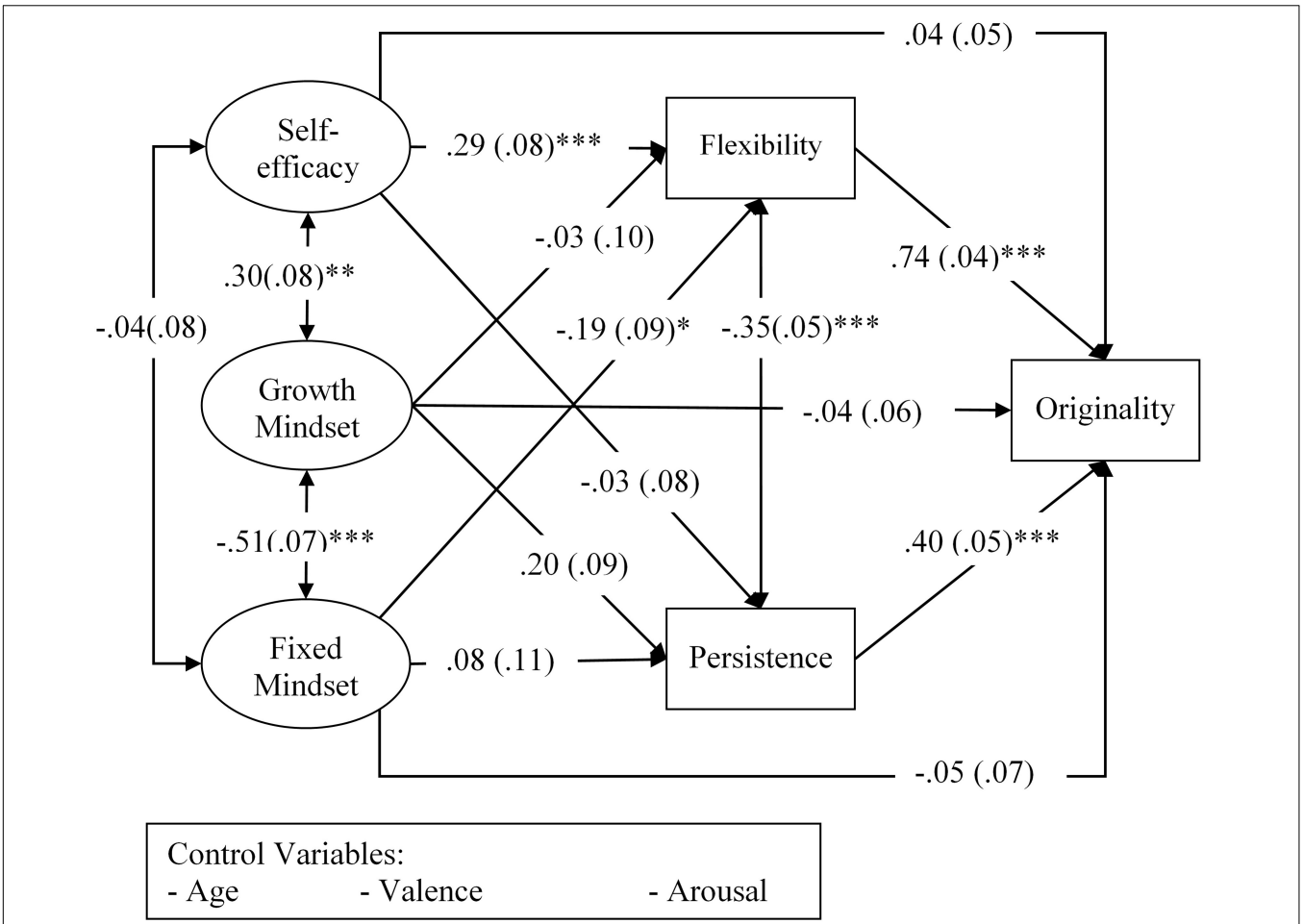

FIGURE 1 | The relationships between creativity as indicated by the originality score and, creative self-efficacy and creative mindsets via cognitive processing channels while controlling the effects of age, valence and arousal (Model 2). The values represent standardized path coefficients with standard errors in parentheses. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

achieved effectively through flexibility, and flexibility can be driven by positive affect (Nijstad et al., 2010). However, the effect of negative affect on creativity via persistence was not detected. This could be explained by the work of Roskes et al. (2012) suggesting that the persistence pathway costs more cognitive resources and people tend to exert these resources only when necessary. It is possible that participants in this study did not see the necessity of performing the task well. Therefore, their negative affect did not lead to creativity.

STUDY 2

Participants

Participants were upper secondary school students recruited from schools in Thailand. Initially, 239 students participated in this study. Of this number, 12 cases were excluded due to missing data and 13 cases were excluded due to unengaged responses. The final sample consisted of 214 students with a mean age of 17.05 ($SD = 0.91$). Among this sample, 116 students were female, and all were native Thai speakers. The research is approved by the University Committee on Human Research Protection (UCHRP) of East China Normal University. In addition, permission from the schools' principals and consent forms from participants and their parents/guardians were obtained prior to data collection.

Measures

All measures used in this study were the same as those used in Study 1, except for the creativity task. In this study, the Insight Problems Task was used to measure creativity associated with convergent thinking. Participants were presented with 10 insight problems. They were given 10 min to solve as many problems as possible. The number of correct answers was used as the indicator of creative problem-solving. Insight problems used in this study were adapted from Dow and Mayer (2004). A sample problem is "A woman's earring fell into a cup that was filled with coffee, but her earring did not get wet. How could this be?"

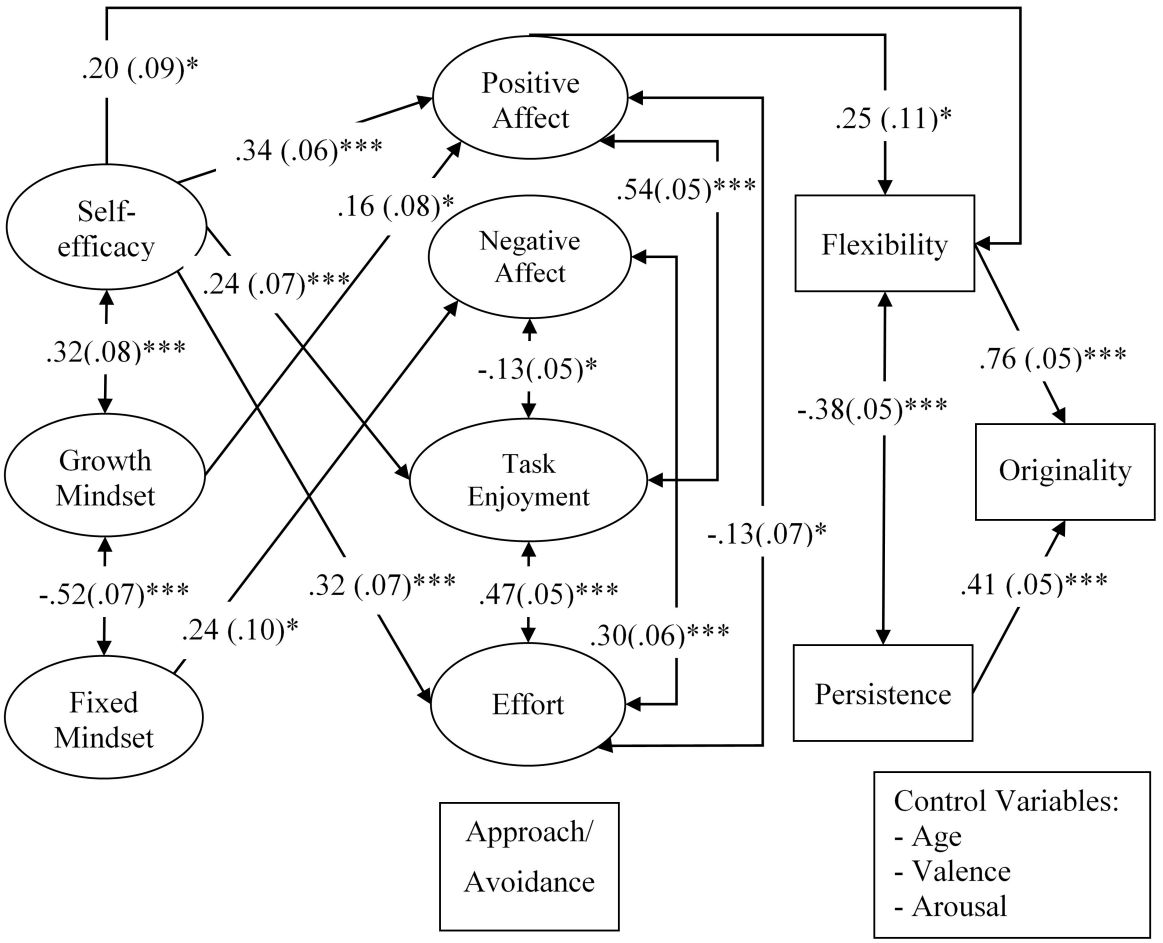

FIGURE 2 | The relationships between creativity as indicated by the originality score and, creative self-efficacy and creative mindsets via cognitive processing channels and self-regulatory responses while controlling the effects of age, valence and arousal (Model 3). For the sake of clarity, only significant direct paths are displayed. The values represent standardized path coefficients with standard errors in parentheses. *$p < 0.05$, ***$p < 0.001$.

Procedure

The procedure was the same as that followed in Study 1.

Results and Discussion

As in Study 1, an SEM analysis using Mplus version 7.4 was employed. Mean-and-variance-adjusted weighted least squares estimation was once again used to handle categorical and continuous data. The problem-solving score, age, and valence and arousal were treated as continuous variables. Approach/avoidance orientation was treated as a binary categorical variable, and responses of the other Likert scales were treated as ordered-categorical variables. Model fit indices and criteria were the same as those used in Study 1.

Test of the Measurement Model

Before proceeding with SEM, a CFA was conducted to validate the measurement model of seven latent constructs: creative self-efficacy, fixed mindset, growth mindset, positive affect, negative affect, task enjoyment, and effort. As in Study 1, items with factor loadings smaller than 0.35 were excluded to improve unidimensionality. As a result, 1 item from the fixed mindset scale, 1 item from the effort scale, 1 item from the negative affect scale, and 5 items from the positive affect scale were omitted. The final model showed an acceptable fit [$\chi^2(681) = 1236.22$, $p < 0.001$, $\chi^2/df = 1.82$, $CFI = 0.95$, and $RMSEA = 0.06$]. The scale reliability coefficients are presented in **Table 3** along with descriptive statistics and correlations among the latent and observed variables.

Again, in SEM age, and valence and arousal were included in all models as covariates.

Effects of Beliefs on Creativity

To examine the associations between the beliefs and creativity, creative self-efficacy, fixed mindset, and growth mindset were added into the model as predictors, and the problem-solving score was entered into the model as the outcome variable (Model 4). The model demonstrated an acceptable fit [$\chi^2(135) = 196.31$, $p < 0.001$, $\chi^2/df = 1.45$, $CFI = 0.95$, and $RMSEA = 0.05$]. No trimming was performed. The VIF of each predictor was between 1.22 and 2.01, suggesting multicollinearity was not a problem.

TABLE 2 | Direct effects of Model 3.

	Effects of CSE		Effects of CGM		Effects of CFM	
	β *(SE)*	*p*-value	β *(SE)*	*p*-value	β *(SE)*	*p*-value
On PA	0.34 (0.06)	<0.001	0.16 (0.08)	0.040	−0.16 (0.09)	0.069
On NA	−0.02 (0.07)	0.735	−0.05 (0.11)	0.649	0.24 (0.10)	0.015
On TE	0.24 (0.07)	<0.001	0.08 (0.09)	0.385	−0.05 (0.09)	0.560
On Ef	0.32 (0.07)	<0.001	0.12 (0.10)	0.221	−0.09 (0.09)	0.312
On Ap/Av	0.09 (0.10)	0.370	0.22 (0.13)	0.097	0.16 (0.13)	0.212
On Or	0.05 (0.06)	0.362	−0.02 (0.07)	0.757	−0.06 (0.07)	0.355
On Pe	−0.02 (0.09)	0.795	0.03 (0.11)	0.807	0.08 (0.11)	0.452
On Fl	0.20 (0.09)	0.030	−0.08 (0.10)	0.432	−0.15 (0.09)	0.101
	Effects of PA		**Effects of NA**		**Effects of TE**	
	β (SE)	*p*-value	β *(SE)*	*p*-value	β *(SE)*	*p*-value
On Or	−0.06 (0.10)	0.510	0.07 (0.05)	0.156	−0.03 (0.08)	0.688
On Pe	0.04 (0.12)	0.760	−0.02 (0.07)	0.782	0.10 (0.12)	0.402
On Fl	0.25 (0.11)	0.016	−0.02 (0.06)	0.699	0.01 (0.10)	0.933
	Effects of Ef		**Effects of Ap/Av**			
	β *(SE)*	*p*-value	β *(SE)*	*p*-value		
On Or	0.05 (0.06)	0.430	−0.06 (0.06)	0.286		
On Pe	−0.12 (0.09)	0.192	−0.01 (0.09)	0.915		
On Fl	0.01 (0.09)	0.930	0.02 (0.09)	0.827		
	Effects of Pe		**Effects of Fl**			
	β *(SE)*	*p*-value	β *(SE)*	*p*-value		
On Or	0.41 (0.05)	<0.001	0.76 (0.05)	<0.001		

CSE, creative self-efficacy; CGM, creative growth mindset; CFM, creative fixed mindset; PA, positive affect; NA, negative affect; TE, task enjoyment; Ef, effort; Ap, approach orientation; Av, avoidance orientation; Or, originality score; Pe, persistence score; Fl, flexibility score.

The results demonstrated that the growth mindset positively predicted problem-solving performance (β = 0.26, p = 0.01). Conversely, the fixed mindset negatively predicted problem-solving (β = −0.31, p < 0.001). This result is in line with Karwowski's (2014) finding, demonstrating a negative association between the fixed mindset and problem-solving. A significant link between creative self-efficacy and problem-solving did not emerge (β = 0.00, p = 0.98).

Effects of Beliefs on Creativity via Self-Regulatory Responses

All proposed self-regulatory responses (negative affect, positive affect, approach/avoidance orientation, task enjoyment, and effort) were introduced into the model (Model 5, as illustrated in **Figure 3**) to test whether or not they could explain how the beliefs are connected to creative problem-solving. For this model, all self-regulatory responses and the problem-solving score were regressed on creative self-efficacy and the two mindsets. The problem-solving score was also regressed on self-regulatory responses. All self-regulatory responses were entered into the model as parallel mediators and covaried. The model fit indices were acceptable [$\chi^2(841) = 1403.54$, $p < 0.001$, $\chi^2/df = 1.67$, $CFI = 0.94$, and $RMSEA = 0.06$]. No trimming was performed. Multicollinearity was not an issue among the predictors and mediators (VIFs range: 1.20–3.55).

Examining direct paths revealed that the fixed mindset negatively predicted task enjoyment (β = −0.23, p = 0.005) and effort (β = −0.22, p = 0.021), but positively predicted negative affect (β = 0.20, p = 0.013). Consistent with Model 4, the fixed mindset negatively predicted problem-solving (β = −0.31, p < 0.001). The growth mindset positively predicted task enjoyment (β = 0.55, p < 0.001), effort (β = 0.55, p < 0.001), and positive affect (β = 0.54, p < 0.001). Inconsistent with Model 4, the positive association between the growth mindset and the problem-solving score became insignificant (β = 0.17, p = 0.23). No significant effects from creative self-efficacy emerged. Path coefficients are presented in **Table 4**. These results were similar to those in Study 1 in terms of the adaptive effect of growth mindset and the maladaptive effect of fixed mindset on affect.

Additionally, when testing for indirect effects using the *model indirect* command in Mplus, no significant results were detected indicating that the proposed self-regulatory responses cannot explain the connection between the beliefs and creative problem-solving.

Taken together, results suggest that creative growth and fixed mindsets may trigger some self-regulatory responses (i.e., affect,

TABLE 3 | Descriptive statistics, reliability coefficients, and correlations for Study 2.

	CSE[a]	CGM[a]	CFM[a]	PA[a]	NA[a]	TE[a]	Ef[a]	Ap/Av	PS
CGM	0.55***								
CFM	−0.12	−0.34***							
PA	0.29***	0.59***	−0.25***						
NA	−0.24***	−0.28***	0.24**	−0.33***					
TE	0.25***	0.60***	−0.38***	0.79***	−0.42***				
Ef	0.45***	0.68***	−0.40***	0.74***	−0.25***	0.69***			
Ap/Av	0.25**	0.21*	−0.12	0.17	−0.06	0.25**	0.20*		
PS	0.18*	0.33***	−0.40***	0.25***	−0.16**	0.32***	0.31***	0.13	
CR	0.84	0.77	0.65	0.87	0.92	0.93	0.82		
α	0.80	0.66	0.62	0.84	0.88	0.90	0.75		
M	3.33	4.27	2.50	4.85	2.31	5.03	5.25	0.73	2.76
SD	0.52	0.50	0.66	0.99	1.00	1.08	1.12	0.44	1.87
Frequency (%)							Ap:157(73.36)		

*Correlation coefficients were estimated based on Model 5. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; CSE, creative self-efficacy; CGM, creative growth mindset; CFM, creative fixed mindset; PA, positive affect; NA, negative affect; TE, task enjoyment; Ef, effort; Ap, approach orientation; Av, avoidance orientation; PS, problem-solving score; CR, composite reliability; α, Cronbach's alpha; M, means; SD, standard deviations. [a]The means of these scales were calculated as though their indicators were continuous variables. However, these indicators were actually treated as ordered-categorical variables in the SEM models.*

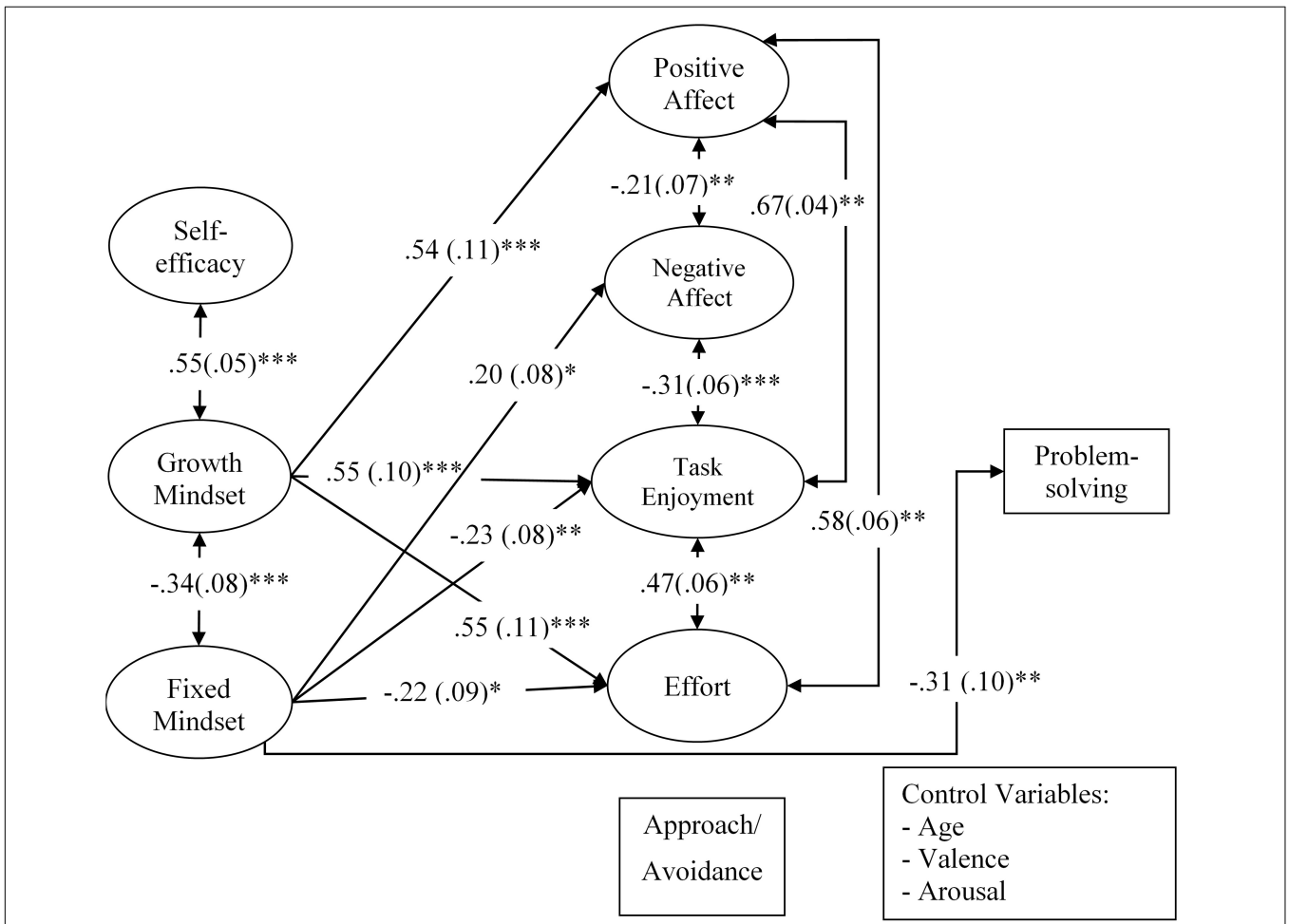

FIGURE 3 | The relationships between creativity as indicated by the problem-solving score and, creative self-efficacy and creative mindsets via self-regulatory responses while controlling the effects of age, valence and arousal (Model 5). For the sake of clarity, only significant direct paths are displayed. The values represent standardized path coefficients with standard errors in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 4 | Direct effects of Model 5.

	Effects of CSE		Effects of CGM		Effects of CFM	
	β *(SE)*	*p*-value	β *(SE)*	*p*-value	β *(SE)*	*p*-value
On PA	−0.03 (0.09)	0.728	0.54 (0.11)	<0.001	−0.10 (0.08)	0.207
On NA	−0.14 (0.09)	0.101	−0.11 (0.13)	0.373	0.20 (0.08)	0.013
On TE	−0.08 (0.07)	0.237	0.55 (0.10)	<0.001	−0.23 (0.08)	0.005
On Ef	0.13 (0.08)	0.131	0.55 (0.11)	<0.001	−0.22 (0.09)	0.021
On Ap/Av	0.20 (0.14)	0.145	0.04 (0.18)	0.824	−0.08 (0.13)	0.522
On PS	0.03 (0.11)	0.773	0.17 (0.14)	0.230	−0.31 (0.10)	0.001
	Effects of PA		**Effects of NA**		**Effects of TE**	
	β *(SE)*	*p*-value	β *(SE)*	*p*-value	β *(SE)*	*p*-value
On PS	−0.02 (0.15)	0.876	0.01 (0.06)	0.876	0.11 (0.14)	0.414
	Effects of Ef		**Effects of Ap/Av**			
	β *(SE)*	*p*-value	β *(SE)*	*p*-value		
On PS	0.01 (0.18)	0.972	0.02 (0.11)	0.849		

CSE, creative self-efficacy; CGM, creative growth mindset; CFM, creative fixed mindset; PA, positive affect; NA, negative affect; TE, task enjoyment; Ef, effort; Ap, approach orientation; Av, avoidance orientation; PS, problem-solving score.

task enjoyment, and effort), albeit in the opposite direction. These responses, however, cannot account for the effectiveness of problem-solving.

GENERAL DISCUSSION

This research was intended to explore potential factors that could explain the associations between beliefs about creativity (i.e., creative self-efficacy and creative mindsets) and creative performance. Based on prior studies concerning self-efficacy and malleability beliefs, several related factors were proposed and tested for their mediating roles in the relationships between creative beliefs and creative production.

Study 1 investigated creativity associated with divergent thinking using the Alternative Uses Task as a measure. Results from SEM models demonstrated that creative self-efficacy positively predicted positive affect, task enjoyment, and effort. The growth mindset positively predicted positive affect. Conversely, the fixed mindset positively predicted negative affect. These results suggest that when engaging in a creativity task, people who feel more self-efficacious are likely to experience positive affect, enjoy the task more, and expend more effort. When people believe creativity can be improved, they, too, experience positive affect; however, when people see creativity as a fixed, unchangeable ability, they experience more negative affect. Overall, these results converge with past work outside of the topic of creativity that suggests that self-efficacy beliefs (Bandura, 1977; Pajares, 2008) and growth mindsets rather than fixed mindsets (Dweck, 2000; Molden and Dweck, 2006; Dweck and Master, 2008) are linked to beneficial self-regulatory outcomes.

Assessing the indirect effects of the beliefs on creativity revealed the mediation effect of flexibility on the relationship between creative self-efficacy and creativity, suggesting that participants with higher self-efficacy were more capable of producing creative ideas by being more cognitively flexible as reflected by the number of categories used during the task. This could be because self-efficacy is closely related to self-regulation. When people have a strong sense of self-efficacy, they self-monitor and adapt strategies as needed (Schunk and Zimmerman, 1997; Zimmerman, 2000a). As such, it is possible that, during the task, participants who were more self-efficacious were more successful in shifting from the old means that did not work to alternative ones or, in this case, to new categories of responses. This finding indicates that self-efficacy is involved with cognitive flexibility, which subsequently engenders creativity.

Furthermore, positive affect partially mediated the relationship between creative self-efficacy and flexibility. This result suggests that people who are more confident in their creative ability experience more positive affect, and this positive affect is partially responsible for greater flexible thinking. High self-efficacy promotes positive affect (Linnenbrink and Pintrich, 2003), which in turn facilitates cognitive flexibility. Activating positive affect encourages people to explore new possibilities freely and flexibly by making them feel safe and free of problems; positive affect is also involved in the release of dopamine in certain brain areas that are related to cognitive flexibility (Nijstad et al., 2010). This cognitive flexibility subsequently enhances creativity.

Study 2 investigated creative convergent thinking measured by insight problems. Results from this study revealed that the creative growth mindset was positively related to task

enjoyment, effort, and positive affect, whereas the fixed mindset was negatively related to task enjoyment and effort but positively related to negative affect. These results indicate that when performing a creativity task, people who firmly believe creativity is developable are likely to experience more positive affect, enjoy the task more, and exert more effort. On the other hand, the more people see creativity as an unchangeable ability, the more they experience negative affect, the less they find the task enjoyable, and the less they expend effort on it. In addition, a negative association was discovered between the fixed mindset and the number of solved insight problems. This result is in alignment with Karwowski's (2014) finding and indicates that viewing creativity as undevelopable suppresses the effectiveness of problem-solving. The direct effects of creative self-efficacy and indirect effects of the beliefs on creativity failed to emerge.

The negative predictive effect of the fixed mindset on problem-solving may be explained by the inability of those who hold a stronger fixed belief to adapt when necessary. When solving a problem, the solver tends to explore the solution based on his or her experience first, and when that experience is insufficient to solve the problem, the solver steps into a state where he or she does not know what to do next (Knoblich et al., 1999). The solver must overcome the familiar way of thinking and come up with a new approach in order to find the solution (Dow and Mayer, 2004). Schroder et al. (2014) examined how induced mindsets influence cognitive control brain activity. They found that attention allocation to responses was enhanced immediately after exposure to a fixed mindset, but this attention was not related to behavioral change following errors, indicating that enhanced attention to responses does not lead to adaptive performance adjustments in people with a fixed mindset. As such, the limited ability to adjust observed among people who endorse the creative fixed mindset may lead to ineffectiveness in changing their way of thinking, resulting in unsuccessful problem-solving.

When comparing the results of the two studies, some discrepancies were observed. In Study 1, the predictive effects on the self-regulatory responses (i.e., affect, task enjoyment, and effort) and creativity (i.e., flexibility and originality scores) mostly emerged from creative self-efficacy, whereas the fixed and growth mindsets only affected affect. In Study 2, the predictive effects of self-efficacy were not detected at all, but more effects of creative mindsets were detected. Specifically, both mindsets predicted affect, task enjoyment, and effort, albeit in opposite directions. Additionally, the fixed mind set also predicted creative problem-solving. The differences could be due to the distinct nature of the tasks used to test creativity; that is, Study 1 employed the Alternative Uses Task as a measure of divergent thinking, while Study 2 used insight problems to assess convergent thinking. The associations between the beliefs and creativity may vary depending on tasks. Because the relationship between self-efficacy and performance is reciprocal (Bandura, 1989; Williams and Williams, 2010), it is possible that engaging in a difficult task lowers people's confidence in their ability, thus weakening the effect of self-efficacy that was tested prior the creativity tasks. The insight problem-solving task used in Study 2 is more difficult than the Alternative Uses Task used in Study 1, hence the discrepancies in the results.

The general results of these two studies reveal similar trends in which creative self-efficacy and the creative growth mindset are linked to desirable outcomes. The fixed mindset, on the other hand, is associated with adverse results.

Several limitations of this research must be addressed. First, this research was cross-sectional and correlational in design. As a result, no claim can be made with respect to the causality of the relationships among variables. Second, the questionnaires employed in this research were translated from English to Thai. Although the scale reliabilities appeared to be adequate after the removal of some items, further studies are necessary to assess the validation of the scales used in this particular sample. Lastly, although the sample size for each study met the common minimum requirement of 200 cases for SEM studies (Kline, 2016), the models were quite complex, and thus larger sample sizes are recommended for future research.

Many questions concerning the effects of beliefs about creativity on creativity remain unanswered. First of all, there were some discrepancies between the results gathered using a divergent thinking task in Study 1 and those acquired using a convergent thinking task in Study 2. These discrepancies could exist because the associations between the beliefs and creativity vary depending on the task. Future research could explore the effects of the beliefs on various task types. Additionally, researchers could examine the impact of task difficulty. Given that the self-regulatory benefits of self-efficacy (Bandura, 1977) and incremental beliefs (Dweck, 2000) seem to be most apparent when people encounter obstacles, more effects of the beliefs on psychological outcomes and creativity might emerge or disappear when taking into account the level of task difficulty. Secondly, the present research only provided correlational results. In the future, longitudinal and experimental research should be conducted in order to confirm the directionality of the relationships among the beliefs, self-regulatory responses, and creativity. Finally, these findings only demonstrated the mediation effects of positive affect and flexibility on the relationship between creative self-efficacy and creative performance. Future research could replicate these results by testing the same variables used in this research and expanding the investigation to include further relevant factors.

CONCLUSION

This research explores factors that could explain the relationship between beliefs about creativity (i.e., creative self-efficacy and mindsets) and creative performance. This research contributes additional knowledge regarding how beliefs concerning creativity, particularly creative self-efficacy beliefs, might influence creativity. The present findings suggest that creative self-efficacy could positively affect creativity by promoting positive affect and enhancing cognitive flexibility. This research also reveals some connections between beliefs concerning

creativity and adaptive self-regulatory outcomes (i.e., affect, task enjoyment, and effort).

AUTHOR CONTRIBUTIONS

NH and NI designed this study. NI collected and analyzed the data. NI and NH wrote the article.

FUNDING

This work was sponsored by the "Shuguang Program" supported by Shanghai Education Development Foundation and Shanghai Municipal Education Commission (16SG25), the Philosophy and Social Science Foundation of Shanghai (2017BSH008), and the Humanity and Social Science foundation of Ministry of Education of China (17YJA190007) to NH.

REFERENCES

Amabile, T. M., and Pillemer, J. (2012). Perspectives on the social psychology of creativity. *J. Creat. Behav.* 46, 3–15. doi: 10.1002/jocb.001

Aronson, J., Fried, C. B., and Good, C. (2002). Reducing the effects of stereotype threat on African American college students by shaping theories of intelligence. *J. Exp. Soc. Psychol.* 38, 113–125. doi: 10.1006/jesp.2001.1491

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychol. Rev.* 84, 191–215. doi: 10.1037//0033-295x.84.2.191

Bandura, A. (1989). Regulation of cognitive processes through perceived self-efficacy. *Develop. Psychol.* 25, 729–735. doi: 10.1037//0012-1649.25.5.729

Bandura, A. (1993). Perceived self-efficacy in cognitive development and functioning. *Educ. Psychol.* 28, 117–148. doi: 10.1207/s15326985ep2802_3

Bandura, A. (2011). On the functional properties of perceived self-efficacy revisited. *J. Manage.* 38, 9–44. doi: 10.1177/0149206311410606

Bandura, A., and Locke, E. A. (2003). Negative self-efficacy and goal effects revisited. *J. Appl. Psychol.* 88, 87–99. doi: 10.1037/0021-9010.88.1.87

Bandura, A., Pastorelli, C., Barbaranelli, C., and Caprara, G. V. (1999). Self-efficacy pathways to childhood depression. *J. Pers. Soc. Psychol.* 76, 258–269. doi: 10.1037//0022-3514.76.2.258

Bandura, A., and Schunk, D. H. (1981). Cultivating competence, self-efficacy, and intrinsic interest through proximal self-motivation. *J. Pers. Soc. Psychol.* 41, 586–598. doi: 10.1037//0022-3514.41.3.586

Beghetto, R. (2006). Creative self-efficacy: correlates in middle and secondary students. *Creat. Res. J.* 18, 447–457. doi: 10.1207/s15326934crj1804_4

Beghetto, R. A., Kaufman, J. C., and Baxter, J. (2011). Answering the unexpected questions: exploring the relationship between students' creative self-efficacy and teacher ratings of creativity. *Psychol. Aesthet. Creat. Arts* 5, 342–349. doi: 10.1037/a0022834

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychol. Bull.* 107, 238–246. doi: 10.1037//0033-2909.107.2.238

Blackwell, L. S., Trzesniewski, K. H., and Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: a longitudinal study and an intervention. *Child Dev.* 78, 246–263. doi: 10.1111/j.1467-8624.2007.00995.x

Brislin, R. W. (1986). "The wording and translation of research instruments," in *Field Methods in Cross-Cultural Research*, eds W. L. Lonner and J. W. Berry (Newbury Park, CA: Sage), 137–164.

Browne, M. W., and Cudeck, R. (1993). "Alternative ways of assessing model fit," in *Testing Structural Equation Models*, eds K. A. Bollen and J. S. Long (Newbury Park, CA: Sage), 136–162.

Busse, T. V., and Mansfield, R. S. (1980). Theories of the creative process: a review and a perspective. *J. Creat. Behav.* 14, 91–132. doi: 10.1002/j.2162-6057.1980.tb00232.x

Chemers, M. M., Hu, L.-T., and Garcia, B. F. (2001). Academic self-efficacy and first year college student performance and adjustment. *J. Educ. Psychol.* 93, 55–64. doi: 10.1037//0022-0663.93.1.55

Cropley, A. (2006). In praise of convergent thinking. *Creat. Res. J.* 18, 391–404. doi: 10.1207/s15326934crj1803_13

Cury, F., Elliot, A. J., Fonseca, D. D., and Moller, A. C. (2006). The social-cognitive model of achievement motivation and the 2 × 2 achievement goal framework. *J. Pers. Soc. Psychol.* 90, 666–679. doi: 10.1037/0022-3514.90.4.666

Davis, F. D., Bagozzi, R. P., and Warshaw, P. R. (1992). Extrinsic and intrinsic motivation to use computers in the workplace. *J. Appl. Soc. Psychol.* 22, 1111–1132. doi: 10.1111/j.1559-1816.1992.tb00945.x

De Dreu, C. K., Baas, M., and Nijstad, B. A. (2008). Hedonic tone and activation level in the mood-creativity link: toward a dual pathway to creativity model. *J. Pers. Soc. Psychol.* 94, 739–756. doi: 10.1037/0022-3514.94.5.739

Deci, E. L., and Ryan, R. M. (2000). The "what" and "why" of goal pursuits: human needs and the self-determination of behavior. *Psychol. Inq.* 11, 227–268. doi: 10.1207/s15327965pli1104_01

Dow, G. T., and Mayer, R. E. (2004). Teaching students to solve insight problems: evidence for domain specificity in creativity training. *Creat. Res. J.* 16, 389–398. doi: 10.1080/10400410409534550

Dweck, C. S. (2000). *Self-Theories: Their Role in, Motivation, Personality, and Development*. Philadelphia, PA: Psychology Press.

Dweck, C. S. (2006). *Mindset: The New Psychology of Success*. New York, NY: Random House.

Dweck, C. S., and Leggett, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychol. Rev.* 95, 256–273. doi: 10.1037//0033-295x.95.2.256

Dweck, C. S., and Master, A. (2008). "Self-theories motivate self-regulated learning," in *Motivation and Self-Regulated Learning: Theory, Research, and Applications*, eds D. H. Schunk and B. J. Zimmerman (New York, NY: Lawrence Erlbaum Associates), 31–51.

Gardner, L. A., Vella, S. A., and Magee, C. A. (2015). The relationship between implicit beliefs, anxiety, and attributional style in high-level soccer players. *J. Appl. Sport Psychol.* 27, 398–411. doi: 10.1080/10413200.2015.1019681

Guilford, J. P. (1956). The structure of intellect. *Psychol. Bull.* 53, 267–293. doi: 10.1037/h0040755

Guilford, J. P. (1959). Three faces of intellect. *Am. Psychol.* 14, 469–479. doi: 10.1037/h0046827

Haimovitz, K., and Dweck, C. S. (2017). The origins of children's growth and fixed mindsets: new research and a new proposal. *Child Dev.* 88, 1849–1859. doi: 10.1111/cdev.12955

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. E. (2010). *Multivariate Data Analysis*. Upper Saddle River, NJ: Pearson Prentice Hall.

Hass, R. W., Katz-Buonincontro, J., and Reiter-Palmon, R. (2016). Disentangling creative mindsets from creative self-efficacy and creative identity: Do people hold fixed and growth theories of creativity? *Psychol. Aesthet. Creat. Arts* 10, 436–446. doi: 10.1037/aca0000081

Hofmann, W., Schmeichel, B. J., and Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends Cogn. Sci.* 16, 174–180. doi: 10.1016/j.tics.2012.01.006

Hong, Y. Y., Chiu, C. Y., Dweck, C. S., Lin, D. M. S., and Wan, W. (1999). Implicit theories, attributions, and coping: a meaning system approach. *J. Pers. Soc. Psychol.* 77, 588–599. doi: 10.1037/0022-3514.77.3.588

Hu, L., Motl, R. W., McAuley, E., and Konopack, J. F. (2007). Effects of self-efficacy on physical activity enjoyment in college-aged women. *Int. J. Behav. Med.* 14, 92–96. doi: 10.1007/bf03004174

Karwowski, M. (2011). It doesn't hurt to ask. But sometimes it hurts to believe: polish students creative self-efficacy and its predictors. *Psychol. Aesthet. Creat. Arts* 5, 154–164. doi: 10.1037/a0021427

Karwowski, M. (2014). Creative mindsets: measurement, correlates, consequences. *Psychol. Aesthet. Creat. Arts* 8, 62–70. doi: 10.1037/a0034898

Karwowski, M., and Beghetto, R. A. (2018). Creative behavior as agentic action. *Psychol. Aesthet. Creat. Arts*. doi: 10.1037/aca0000190

Karwowski, M., and Brzeski, A. (2017). "Creative mindsets: prospects and challenges," in *The Creative Self*, eds M. Karwowski and J. C. Kaufman (San Diego, CA: Academic Press), 367–383. doi: 10.1037/aca0000190

Karwowski, M., Lebuda, I., and Beghetto, R. A. (2016). "Creative self-beliefs," in *Cambridge Handbook of Creativity*, eds J. C. Kaufman and R. J. Sternberg (New York, NY: Cambridge University Press), 302–326.

Karwowski, M., Lebuda, I., and Wiśniewska, E. (2018a). Measuring creative self-efficacy and creative personal identity. *Int. J. Creat. Prob. Solv.* 28, 45–57.

Karwowski, M., Royston, R. P., and Reiter-Palmon, R. (2018b). Exploring creative mindsets: variable and person-centered approaches. *Psychol. Aesthet. Creat. Arts*. doi: 10.1037/aca0000170

King, R. B., McInerney, D. M., and Watkins, D. A. (2012). How you think about your intelligence determines how you feel in school: the role of theories of intelligence on academic emotions. *Learn. Individ. Differ.* 22, 814–819. doi: 10.1016/j.lindif.2012.04.005

Klassen, R. M., and Chiu, M. M. (2010). Effects on teachers' self-efficacy and job satisfaction: teacher gender, years of experience, and job stress. *J. Educ. Psychol.* 102, 741–756. doi: 10.1037/a0019237

Kline, R. B. (2016). *Principles and Practice of Structural Equation Modeling*, 4th Edn. New York, NY: Guilford Press.doi: 10.1037/a0019237

Knoblich, G., Ohlsson, S., Haider, H., and Rhenius, D. (1999). Constraint relaxation and chunk decomposition in insight problem solving. *J. Exp. Psychol. Learn. Mem. Cogn.* 25, 1534–1555. doi: 10.1037//0278-7393.25.6.1534

Komarraju, M., and Nadler, D. (2013). Self-efficacy and academic achievement: Why do implicit beliefs, goals, and effort regulation matter? *Learn. Individ. Differ.* 25, 67–72. doi: 10.1016/j.lindif.2013.01.005

Lang, P. J. (1980). "Behavioral treatment and bio-behavioral assessment: computer applications," in *Technology in Mental Health Care Delivery Systems*, eds J. B. Sidowski, J. H. Johnson, and T. A. Williams (Norwood, NJ: Ablex), 119–l37. doi: 10.1016/j.lindif.2013.01.005

Linnenbrink, E. A., and Pintrich, P. R. (2003). The role of self-efficacy beliefs in student engagement and learning in the classroom. *Read. Writ. Q.* 19, 119–137. doi: 10.1080/10573560308223

Lomax, R. G., and Hahs-Vaughn, D. L. (2012). *An Introduction to Statistical Concepts for Education and Behavioral Sciences*, 3rd Edn. New York, NY: Routledge. doi: 10.1080/10573560308223

Lou, N. M., and Noels, K. A. (2016). Changing language mindsets: Implications for goal orientations and responses to failure in and outside the second language classroom. *Contemp. Educ. Psychol.* 46, 22–33. doi: 10.1016/j.cedpsych.2016.03.004

Marsh, H. W., and Hocevar, D. (1985). Application of confirmatory factor analysis to the study of self-concept: first and higher order factor models and their invariance across groups. *Psychol. Bull.* 97, 562–582. doi: 10.1037//0033-2909.97.3.562

Michael, L. A. H., Hou, S. T., and Fan, H. L. (2011). Creative self-efficacy and innovative behavior in a service setting: optimism as a moderator. *J. Creat. Behav.* 45, 258–272. doi: 10.1002/j.2162-6057.2011.tb01430.x

Molden, D. C., and Dweck, C. S. (2006). Finding "meaning" in psychology: a lay theories approach to self-regulation, social perception, and social development. *Am. Psychol.* 61, 192–203. doi: 10.1037/0003-066x.61.3.192

Mueller, C. M., and Dweck, C. S. (1998). Praise for intelligence can undermine children's motivation and performance. *J. Pers. Soc. Psychol.* 75, 33–52. doi: 10.1037/0022-3514.75.1.33

Muthén, L. K., and Muthén, B. O. (1998–2012). *Mplus User's Guide*, 7th Edn. Los Angeles, CA: Muthén & Muthén.

Nijstad, B. A., Dreu, C. K. W. D., Rietzschel, E. F., and Baas, M. (2010). The dual pathway to creativity model: creative ideation as a function of flexibility and persistence. *Eur. Rev. Soc. Psychol.* 21, 34–77. doi: 10.1080/10463281003765323

O'Connor, A. J., Nemeth, C. J., and Akutsu, S. (2013). Consequences of beliefs about the malleability of creativity. *Creat. Res. J.* 25, 155–162. doi: 10.1080/10400419.2013.783739

Pajares, F. (2008). "Motivational role of self-efficacy beliefs in self-regulated learning," in *Motivation and Self-Regulated Learning: Theory, Research and Applications*, eds D. H. Schunk and B. J. Zimmerman (New York, NY: Lawrence Erlbaum Associates), 111–139.

Pajares, F., Britner, S. L., and Valiante, G. (2000). Relation between achievement goals and self-beliefs of middle school students in writing and science. *Contemp. Educ. Psychol.* 25, 406–422. doi: 10.1006/ceps.1999.1027

Pajares, F., and Schunk, D. (2002). "The development of academic self-efficacy," in *Development of Achievement Motivation*, eds A. Wigfield and J. S. Eccles (San Diego, CA: Academic Press), 15–31.

Preacher, K. J., and Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behav. Res. Methods* 40, 879–891. doi: 10.3758/BRM.40.3.879

Puente-Díaz, R., and Cavazos-Arroyo, J. (2017). The influence of creative mindsets on achievement goals, enjoyment, creative self-efficacy and performance among business students. *Think. Skills Creat.* 24, 1–11. doi: 10.1016/j.tsc.2017.02.007

Rego, A., Sousa, F., Marques, C., and Cunha, M. P. E. (2012). Retail employees' self-efficacy and hope predicting their positive affect and creativity. *Eur. J. Work Organ. Psychol.* 21, 923–945. doi: 10.1080/1359432x.2011.610891

Robins, R. W., and Pals, J. L. (2002). Implicit self-theories in the academic domain: implications for goal orientation, attributions, affect, and self-esteem change. *Self Identity* 1, 313–336. doi: 10.1080/1529886029010 6805

Roick, J., and Ringeisen, T. (2017). Self-efficacy, test anxiety, and academic success: a longitudinal validation. *Int. J. Educ. Res.* 83, 84–93. doi: 10.1016/j.ijer.2016.12.006

Roskes, M., De Dreu, C. K., and Nijstad, B. A. (2012). Necessity is the mother of invention: avoidance motivation stimulates creativity through cognitive effort. *J. Pers. Soc. Psychol.* 103, 242–256. doi: 10.1037/a0028442

Runco, M. A., and Albert, R. S. (2010). "Creativity research: a historical view," in *The Cambridge Handbook of Creativity*, eds J. S. Kaufman and R. J. Sternberg (Cambridge: Cambridge University Press), 16–31. doi: 10.1017/CBO9780511763205.003

Runco, M. A., and Jaeger, G. J. (2012). The standard definition of creativity. *Creat. Res. J.* 24, 92–96. doi: 10.1080/10400419.2012.650092

Ryan, R. M. (1982). Control and information in the intrapersonal sphere: an extension of cognitive evaluation theory. *J. Pers. Soc. Psychol.* 43, 450–461. doi: 10.1037//0022-3514.43.3.450

Ryan, R. M., and Deci, E. L. (2000). Intrinsic and extrinsic motivations: classic definitions and new directions. *Contemp. Educ. Psychol.* 25, 54–67. doi: 10.1006/ceps.1999.1020

Schroder, H. S., Dawood, S., Yalch, M. M., Donnellan, M. B., and Moser, J. S. (2015). The role of implicit theories in mental health symptoms, emotion regulation, and hypothetical treatment choices in college students. *Cognit. Ther. Res.* 39, 120–139. doi: 10.1007/s10608-014-9652-6

Schroder, H. S., Moran, T. P., Donnellan, M. B., and Moser, J. S. (2014). Mindset induction effects on cognitive control: a neurobehavioral investigation. *Biol. Psychol.* 103, 27–37. doi: 10.1016/j.biopsycho.2014.08.004

Schunk, D. H. (1983). Ability versus effort attributional feedback: differential effects on self-efficacy and achievement. *J. Educ. Psychol.* 75, 848–856. doi: 10.1037//0022-0663.75.6.848

Schunk, D. H., and DiBenedetto, M. K. (2016). "Self-efficacy theory in education," in *Handbook of Motivation at School*, eds K. R. Wentzel and D. B. Miele (New York, NY: Taylor & Francis), 34–54.

Schunk, D. H., and Zimmerman, B. J. (1997). Social origins of self-regulatory competence. *Educ. Psychol.* 32, 195–208. doi: 10.1207/s15326985ep3204_1

Stein, M. I. (1953). Creativity and culture. *J. Psychol.* 36, 311–322. doi: 10.1080/00223980.1953.9712897

Sternberg, R. J., and Lubart, T. I. (1993). Investing in creativity. *Psychol. Inq.* 4, 229–232. doi: 10.1037/0003-066X.51.7.677

Tierney, P., and Farmer, S. M. (2002). Creative self-efficacy: its potential antecedents and relationship to creative performance. *Acad. Manage. J.* 45, 1137–1148. doi: 10.2307/3069429

Tierney, P., and Farmer, S. M. (2011). Creative self-efficacy development and creative performance over time. *J. Appl. Psychol.* 96, 277–293. doi: 10.1037/a0020952

Trautwein, U., Lüdtke, O., Roberts, B. W., Schnyder, I., and Niggli, A. (2009). Different forces, same consequence: conscientiousness and competence beliefs are independent predictors of academic effort and achievement. *J. Pers. Soc. Psychol.* 97, 1115–1128. doi: 10.1037/a0017048

Van Yperen, N. W. (2006). A novel approach to assessing achievement goals in the context of the 2 × 2 framework: identifying distinct profiles of individuals with different dominant achievement goals. *Pers. Soc. Psychol. Bull.* 32, 1432–1445. doi: 10.1177/0146167206292093

Van Yperen, N. W., and Renkema, L. J. (2008). Performing great and the purpose of performing better than others: on the recursiveness of the achievement goal adoption process. *Eur. J. Soc. Psychol.* 38, 260–271. doi: 10.1002/ejsp.425

Watson, D., Clark, L. A., and Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *J. Pers. Soc. Psychol.* 54, 1063–1070. doi: 10.1037//0022-3514.54.6.1063

Watson, D., Wiese, D., Vaidya, J., and Tellegen, A. (1999). The two general activation systems of affect: structural findings, evolutionary considerations, and psychobiological evidence. *J. Pers. Soc. Psychol.* 76, 820–838. doi: 10.1037//0022-3514.76.5.820

Williams, T., and Williams, K. (2010). Self-efficacy and performance in mathematics: reciprocal determinism in 33 nations. *J. Educ. Psychol.* 102, 453–466. doi: 10.1037/a0017271

Yeager, D. S., and Dweck, C. S. (2012). Mindsets that promote resilience: when students believe that personal characteristics can be developed. *Educ. Psychol.* 47, 302–314. doi: 10.1080/00461520.2012.722805

Zimmerman, B. J. (2000a). "Attaining self-regulation: a social cognitive perspective," in *Handbook of Self-regulation*, eds M. Boekaerts, P. R. Pintrich, and M. Ziedner (San Diego, CA: Academic Press), 13–39. doi: 10.1016/B978-012109890-2/50031-7

Zimmerman, B. J. (2000b). Self-efficacy: an essential motive to learn. *Contemp. Educ. Psychol.* 25, 82–91. doi: 10.1006/ceps.1999.1016

Zimmerman, B. J., and Kitsantas, A. (1997). Developmental phases in self-regulation: shifting from process goals to outcome goals. *J. Educ. Psychol.* 89, 29–36. doi: 10.1037//0022-0663.89.1.29

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 08 October 2018
doi: 10.3389/fpsyg.2018.01912

Does Religion Hinder Creativity? A National Level Study on the Roles of Religiosity and Different Denominations

Zhen Liu[1†], Qingke Guo[1†], Peng Sun[1], Zhao Wang[2*] and Rui Wu[1*]*

[1] School of Psychology, Shandong Normal University, Jinan, China, [2] College of Humanities and Social Science, Dalian Medical University, Dalian, China

Creativity plays an irreplaceable role in economic and technological development. It seems that religion has a negative association with creativity. If it is true, how can we interpret the rapid development of human society with religious believers comprising 81% of global population? Based on the datasets of the World Values Survey and the Global Creativity Index, this study examined the effects of different religions/denominations on national creativity, and the moderation effect of gross domestic product per capita (GDPpc) in 87 countries. The results showed that: (1) religiosity was negatively associated with creativity at national level; (2) Proportions of Protestant and Catholic adherents in a country were both positively associated with national creativity, while proportion of Islam adherents was negatively associated with national creativity; (3) GDPpc moderated the relationships of creativity with overall religiosity, proportion of Protestant adherents, and proportion of Catholic adherents. In countries with high GDPpc, national religiosity and proportion of Islam could negatively predict national creativity, and proportion of Protestants could positively predict national creativity; in countries with low GDPpc, these relationships became insignificant. These findings suggest that national religiosity hinders creativity to a certain extent. However, some denominations (i.e., Protestant and Catholic) may exert positive influences on creativity due to their religious traditions and values. The religion–creativity relationship at national level only emerges in affluent countries.

Keywords: national creativity, religion, denominational differences, GDP per capital, national level

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Hansika Kapoor,
Monk Prayogshala, India
Zhonglu Zhang,
Guangzhou University, China

***Correspondence:**
Peng Sun
psycho_sun@163.com
Zhao Wang
wangzhao_81425@163.com
Rui Wu
RuiWu1229@126.com

†Share first authorship

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *08 June 2018*
Accepted: *18 September 2018*
Published: *08 October 2018*

Citation:
Liu Z, Guo Q, Sun P, Wang Z and Wu R (2018) Does Religion Hinder Creativity? A National Level Study on the Roles of Religiosity and Different Denominations. Front. Psychol. 9:1912. doi: 10.3389/fpsyg.2018.01912

INTRODUCTION

Creativity, one of the unique human abilities, has been playing an irreplaceable role in human society. Technological advancement and economic growth both can benefit from creativity. For countries, creativity has been considered as a key indicator of national competitiveness (Florida, 2002). Recently, increasing literature on creativity has been conducted from a cultural perspective (Glăveanu, 2010), mostly at national level (e.g., Rinne et al., 2013; Efrat, 2014; Kaasa, 2016). Religion has strong power in shaping societal and individual outcomes (Herbig and Dunphy, 1998; Chan-Serafin et al., 2013; Okulicz-Kozaryn, 2015), but few studies have examined the effect of religion on national creativity.

Some researchers posit that religion hinders creativity, because rules and traditions are over stressed by religion while creativity requires people to challenge traditions and rules to seek a breakthrough (Gino and Wiltermuth, 2014; Okulicz-Kozaryn, 2015). But some other researchers argue that religion may be beneficial for creativity because religion cultivates personal virtues (e.g., hard-working) and cognitive schema that are positively associated with creativity (Day, 2005; Assouad and Parboteeah, 2018). In fact, empirical studies tend to support a negative association between religion and creativity (e.g., Dollinger, 2007; Bénabou et al., 2013, 2015; Okulicz-Kozaryn, 2015). However, if religion hinders creativity, it seems paradoxical that rapid economic and technological development can occur in this world where more than 81% of the population is religious (according to the 6th waves of World Value Survey, WVS).

Previous literature suggests that different religions/denominations have dissimilar effects on prosocial behaviors (Prouteau and Sardinha, 2015), trust (Dingemans and Ingen, 2015), and entrepreneurship (Dana, 2009). National economic situation has been found to have a moderating effect on the relationship between religion and outcomes, such as values (Saroglou et al., 2004) and prosociality (Guo et al., 2018). We speculated that the different findings on religion–creativity relationship and the paradox between rapid development and numerous religious populations can be accounted for by the dissimilar effects of religious denominations, as well as the moderation effect of economy. Thus, using datasets of WVS and the Global Creativity Index (GCI), we conducted this national-level study to explore the influences of different denominations on creativity, and the moderating role of economic factor in the religion–creativity relationship.

Creativity at National Level

Glăveanu (2010) classified the research on creativity into three paradigms, namely, He-paradigm, I-paradigm, and We-paradigms. He-paradigm is the earliest strategy for the exploration of creativity, which focuses on outstanding ability and fertility of the genius. This paradigm always considers creativity exclusive to the genius group. With the increase of creativity studies, I-paradigm emerges, which starts to investigate creativity of ordinary individuals rather than genius. In this stage, the relationship between creativity and personal attributes (such as personality and cognition) attracts the interest of many researchers. In the last few decades, We-paradigm, which focuses on social psychology of creativity, has become prevalent. Researchers adopting this paradigm, have gradually realized the great influence of sociocultural factors on creativity (Glăveanu, 2010), and tend to understand creativity in particular contexts (e.g., Rinne et al., 2013; Kaasa, 2016).

A growing body of literature has examined the relationship between culture variables, especially the Hofstede's (1980) cultural values, and national creativity. Using data of 33 countries, Shane (1993) explored the relationship between Hofstede's cultural values and per capita numbers of trademarks which was used as indicator of national creativity. He found that national rate of innovation was negatively associated with power distance and uncertainty avoidance, but was positively connected with individualism. These findings were completely replicated by Efrat (2014) who used more comprehensive indicators of national creativity, including patents, scientific and technical journal articles, and high-technology exports. However, using a dataset for 43 countries, Rinne et al. (2013) found that only individualism was positively related to indicators of national creativity, the GCI and the Design and Creativity Index. The negative effects of power distance and uncertainty avoidance on national creativity had not been replicated.

Religion and Creativity

There have always been controversies over the religion–creativity relationship. Existing literature supports two opposite standpoints: religion hinders creativity and religion facilitates creativity, which were, respectively, called "hinder hypothesis" and "facilitate hypothesis" in this study.

Okulicz-Kozaryn (2015) argued that religion requires people to follow traditions and discourages people to embrace diversity. Thus most of religious followers tend to be conservative individuals who are more likely to be less creative (Dollinger, 2007). Moreover, creativity is associated with challenging traditions and rules, and tolerance of diversity, which are discouraged by most religious traditions. Brenkert (2009) pointed that rule breaking was a feature of creativity and innovation. Gino and Wiltermuth (2014) found that dishonest individuals tend to be more creative. They further proposed that dishonesty and creativity both involved rule-breaking. These findings may indirectly support the "hinder hypothesis" because religious people are usually more honest and are more likely to follow the rules than their secular counterparts (Saroglou, 2010; Okulicz-Kozaryn, 2015). Meanwhile, religiosity has been found to be positively related with conformity that is disruptive to creativity, but negatively with self-direction that is conductive to creativity (Schwartz and Huismans, 1995). Given the above, it seems reasonable to assume that religion hinders creativity.

However, Assouad and Parboteeah (2018) held that the believers' particular traits (e.g., self-control, honest, spirit of cooperation, and hard-working) fostered by religions can contribute to creativity. By cultivating these virtues in the adherents, religion can build a positive environment and network for creativity and entrepreneurship (Dana, 2009; Assouad and Parboteeah, 2018). Day (2005) further proposed that religion can facilitate creativity through different mechanisms. First, people in religious activities can learn to view their experiences in a new way. Second, religious faith can enrich followers' schemas which provide more ways for organizing information. Third, religious activities can facilitate internal loci of control, which is associated with more effective problem solving (Day, 2005). Recently Shen et al. (2017) have found a positive relationship between morality and creativity, providing indirect evidence for the "facilitate hypothesis." That is, religion cultivates morality, and morality is positively associated with creativity.

To date there have been only a few researches studying the religion–creativity association at aggregate level. Okulicz-Kozaryn (2015) investigated the relationship between religiosity and creativity at local level (i.e., across United States counties).

They found that local religiosity (indicated by adherence per population and church density) correlated significantly and negatively with local creativity (indicated by creative class and patent number), supporting the "hinder hypothesis." Bénabou et al. (2013) also found negative relationships between religion and creativity both across US states and across the world. Using dataset for 30 countries, Assouad and Parboteeah (2018) found that the normative aspect of religion had a positive relation with firm-level innovation, which supports the "facilitate hypothesis." But they also found that the regulatory aspect of religion was negatively related to firm-level innovation, while the normative aspect of religion showed no relationship with creativity.

Contrary to the scarcity of direct research, there are a greater number of indirect studies on the religion–creativity association, mostly supporting the "hinder hypothesis." Scientists are considered to be the most creative people both by the public and by the academia. Scientists tend to have lower level of religiosity and smaller proportion of adherents than the general population (Larson and Witham, 1998; Ecklund and Scheitle, 2007). Furthermore, the proportion of believers among scientists has been observed to be on a downward trend (Larson and Witham, 1998). Besides, the I-paradigm also provides indirect evidence for the "hinder hypothesis." For example, Dollinger (2007) found that highly conservative individuals, who had poor performances on creativity, tended to use religiosity as the common theme in a photo essay task. Using the data of WVS, Bénabou et al. (2015) found that individual religiosity negatively predicted pro-innovation attitudes and positively predicted anti-innovation attitudes even when numerous socio-demographic variables were controlled.

The Present Study

Culture is the set of customs, traditions, and values shared by people in a society or a community (Kaasa, 2016). Herbig and Dunphy (1998, p. 18) defined religion as "a socially shared set of beliefs, ideas, and actions which. . . . . .is believed to affect the course of natural and human events." From these definitions it is easy to find that religion and culture are similar constructs. Religion and culture shape each other, and are part of each other (Ronen and Shenkar, 2013). Culture's influence on creativity has been revealed by numerous studies (e.g., Shane, 1993; Efrat, 2014), while the relationship between religion and creativity/innovation has not been soundly addressed. This is the reason why this study was designed and conducted.

Using datasets of GCI and WVS, we explored the relationship between religion and national creativity. GCI covers three aspects of national creativity, namely technology, talent, and tolerance (Florida, 2002, 2014). Thus it is an indicator of national creativity more comprehensive than that used by Bénabou et al. (2013), as well as that used by Assouad and Parboteeah (2018). Considering the results of direct and indirect research on religion and creativity, we propose that religiosity is negatively related with creativity at national level (*Hypothesis 1*).

Religion plays an essential role in influencing individual even social/national outcomes. And creativity is a vital factor in shaping social development and economic growth of each country, whether it is religious or not (Raghupathi and Raghupathi, 2017). However, existing literature seemingly shows that religion is not beneficial for creativity, despite there are still different voices. Religious population comprises more than 81% of the world's population. And the overwhelming majority of countries in the world are religious. If the conclusion is in accordance with reality, the technological development and economic growth in our world should have not been so rapid. What causes this paradoxical phenomenon? We propose that different effects of religions/denominations and moderation effect of economy may be solutions to this perplexing question.

Berry (1999) investigated the general relationship between religious backgrounds and creativity, using about 1,400 outstanding achievers in art- or science-related areas. He found that the achievers in science areas were mostly from Protestant background, while the achievers in art-related areas were mostly from Catholic background. Dana (2009) also found that religion may have both positive and negative impact on entrepreneurship, which may differ across religious denominations. Various religions value entrepreneurship differently, and contribute to different networks (including credit, employment, information, and supply networks of co-religionists) that affect entrepreneurship (Dana, 2009). These findings show that the effects of religions on national creativity may depend on teachings and values of different religions/denominations. Previous literature suggests that the proportion of adherents in a population can be considered as an indicator of the religious culture (e.g., Okulicz-Kozaryn, 2015; Einolf, 2017). And the tradition and values maintained and promoted by a religion/denomination could pervade religious boundaries and exert influences on the whole society (Lam, 2006). According to samples and variables in the dataset of WVS, this study used five religious denominations (i.e., Protestant, Orthodoxy, Catholic, Islam, and Buddhist). We propose that various religions/denominations have different relationships with national creativity.

According to the Protestant work ethic (Weber, 1930) valuing hard work, discipline, and frugality (Inglehart and Oyserman, 2004), and the finding that a greater number of achievers in science-related areas come from Protestant background (Berry, 1999), we hypothesize that Protestant culture is positively related with national creativity (*Hypothesis 2a*). Due to the fact that Catholic also has a tradition encouraging hard work and thrift which can translate into economic success (Andersen et al., 2017), and the finding that achievers from Catholic background have more creativity in arts than counterparts from Protestant background (Berry, 1999), we hypothesize that Catholic culture may also have a positive relation with national creativity (*Hypothesis 2b*). What effect Orthodoxy has on creativity is not hypothesized in this study because the Orthodoxy–creativity relationship has seldom been studied by existing literature. With respect to Muslim, we hypothesize its relationship with national creativity is negative (*Hypothesis 2c*), because determinism is deeply embedded in Islam culture (Herbig and Dunphy, 1998; Westwood and Low, 2003). Furthermore, traditional interpretations of Islam are not compatible with the development of science, which also

hinders creativity. It is a little difficult to deduce the Buddhism–creativity relationship. On one hand, Buddhism may "de-emphasize materialism and encourage acceptance and quietude" (Westwood and Low, 2003, p. 242), suggesting that Buddhism does not encourage change and innovation. On the other hand, Buddhism emphasizes impermanence and recommends its adherents to engage in mindfulness and meditation practice, which can improve creativity (Colzato et al., 2012; Ding et al., 2014; Berkovich-Ohana et al., 2017). These effects of Buddhism may operate in the opposite directions, leading us to hypothesize that there is no relationship between Buddhism culture and national creativity (*Hypothesis 2d*).

Creativity and economy influence one another (Rinne et al., 2013; Raghupathi and Raghupathi, 2017). It seems that economic factors should be taken into consideration when the religion–creativity relation is examined. Previous literature has indicated a moderating effect of economy in the religiosity–prosociality relationship at national level (Guo et al., 2018). This suggests that roles religion plays may vary according to different levels of economic development across countries (Saroglou et al., 2004). Therefore gross domestic product per capita (GDPpc) was introduced as a moderator in this study to explore the detailed relationship between religion and creativity.

The relationship between economy and creativity/innovation is bidirectional (Rinne et al., 2013; Raghupathi and Raghupathi, 2017). However, in the initial phase of economic development in a country, economy can be developed prior to or even be independent with innovation. In developing countries, the patents of foreigners take up a considerable proportion (Raghupathi and Raghupathi, 2017), and technology mostly relies on "spillovers" of developed countries (Fagerberg et al., 2010). In this case, the religion–creativity relationship may be too weak to be observed. But with full development of economy, the impact of religion on creativity/innovation should become evident. This is because that in developed countries creativity/innovation is an essential factor for economic development (Fagerberg et al., 2010). In this case, intrinsic relationship of religion with national creativity will rise to the surface. Thus, we proposed another hypothesis that the association of religions/denominations and national creativity may be moderated by GDPpc. Specifically, the religion–creativity relationship would be weaker in low (even disappear) relative to high GDPpc countries (*Hypothesis* 3).

MATERIALS AND METHODS

A nation-level design was applied in this study, regarding a country as a unit of analysis (e.g., Rinne et al., 2013; Kaasa, 2016; Guo et al., 2018). Finally there were 87 countries in our analyses with data available for all research variables.

Independent Variables

Religious variables were provided by the WVS[1] (Inglehart et al., 2014), a major cross cultural survey on beliefs and values. Since 1981, WVS has been conducted for six waves, generating a dataset including about 100 countries. Datasets for six waves were all involved in this study.

According to previous research (Bénabou et al., 2013; Guo et al., 2018), overall religiosity of a country/region was measured with four items of WVS: church attendance, importance of deity, importance of religion, and religious faith for children. The item, "Apart from weddings and funerals, how often do you attend religious services these days?" with an 8-point scale ranging from "several times a day" to "never," was used to capture the church attendance. The importance of deity was measured by the question "How important is deity in your life" using a 10-point scale (1 = "not at all important," 10 = "very important"), where the particular deity depends on the participants' religion. The importance of religion was measured by the item, "How important is religion in your life" with a 4-point scale ranging from "very important" to "not at all important." After reverse-scoring the negatively worded items, each score of these items was averaged according to country/region (individual-level Cronbach's $\alpha = 0.70$). The religious faith for children was measured by the proportion of participants in each country who chose religious faith as one of the important qualities (up to five) for children. Then the four scores were standardized at country level and combined into the indicator of overall religiosity of each country (national-level Cronbach's $\alpha = 0.82$). It should be noted that both religious and irreligious respondents answered these four items. We computed the overall religiosity indicator for all valid respondents rather than for only adherents of the five denominations.

Religious denominations in WVS have been classified in great detail. Following previous literature (Berger, 2006), we identified five religions/denominations (Protestant, Orthodoxy, Catholicism, Muslim, and Buddhism) and merged their sub-denominations (see **Table 1**). The number of believers of each denomination was calculated according to answers to the item "Do you belong to a religion or religious denomination? If yes, which one." Then the numbers for believers of the five denominations were divided by the valid sample sizes, respectively, to indicate the percentages of five denominations in each country.

Dependent Variable

National creativity was taken from the research of Florida et al. (2015). In their study on GCI, an indicator of nation-level creativity, of 139 countries across the world, was measured on a 3Ts (Technology, Talent, and Tolerance) model of creativity (Florida, 2002, 2014). GCI is a broad-based measure of national creativity that includes research and development investment, patent applications, creative class, educational attainment, and attitudes toward minorities. Thus, compared to indicators used in previous research, such as patents per capita (e.g., Bénabou et al., 2013) and proportion of individuals in creative occupations (e.g., Okulicz-Kozaryn, 2015), GCI can be considered as a more comprehensive measure of national creativity.

Moderator Variable

GDPpc, which is usually used as an economic variable in national-level studies, was taken from the World Bank Open

[1] www.worldvaluessurvey.org

TABLE 1 | Religious denominations and sub-denominations.

Denomination	Sub-denomination
Protestant	Anglican; Baptist; Christian Reform; Evangelical; Methodists; Pentecostal; Presbyterian; Protestant; Seven Day Adventist; The Church of Sweden; Dutch Reformed; Reformed Churches in the Netherlands; Evangelical/Apostolic Faith Mission
Catholicism	Catholic: Does not follow rules; Greek Catholic; Roman Catholic
Orthodoxy	Orthodox
Muslim	Al-Hadis; Muslim; Shia; Sunni
Buddhism	Buddhism

Data[2]. The last WVS wave was conducted from 2010 to 2014, so the indicator of GDPpc was calculated by averaging the data collected during 2010–2014. A logarithm transformation was applied to GDPpc in order to yield normally distributed data.

Control Variables

Intelligence is significantly associated with creativity (for a review, see Sternberg and O'Hara, 1999). Cinnirella and Streb (2017) argued that religious tolerance, measured by the religious pluralism index (RPI), had a positive effect on creativity and innovation. Therefore, national IQ and RPI were used as controls in this study. National IQ was obtained from a research focusing on intelligence and human capital (Meisenberg and Lynn, 2011). In this research, the missing data of human capital were extrapolated by national IQ, as a high correlation between them (r = 0.981). Thus, the missing data of IQ were substituted by the Human Capital reported by Meisenberg and Lynn (2011) in this study. Scores for national RPI were calculated using the formula 1-$\Sigma^{N}{}_{i} = {}_{1}\pi_{i}^{2}$ (Cinnirella and Streb, 2017), where π_i refers to the percentage of individuals who believe Protestant, Orthodoxy, Catholicism, Muslim, Buddhism, or other religions in each country, respectively.

RESULTS

Descriptive statistics for 87 countries/regions, including the numbers of valid participants and believers of different denominations, scores for overall religiosity, national IQ, GDPpc, and RPI were presented in **Table 2**.

National-level correlations among variables in the present study were shown in **Table 3**. The overall religiosity was negatively related to GDPpc, GCI, IQ, and PRI. Proportion of Catholics had a positive correlation with GCI. Proportion of Protestants was positively correlated with GCI and PRI. In addition, proportion of Muslims was negatively connected with GCI, GDPpc, IQ, and RPI.

Then a hierarchical regression was conducted to further explore the religion–creativity relationship, controlling IQ and RPI. IQ and RPI as the controls were entered in Step 1, and overall religiosity or denominational cultures (indicated by proportions of different religious denominations) were entered in Step 2 (see **Tables 4**, **5**). **Table 4** showed that RPI and IQ could significantly predict GCI. But religiosity no longer had a significant effect on GCI when RPI and IQ were controlled. As **Table 5** shown, only Protestant proportion and Catholic proportion could positively predict GCI, which is consist with the correlation analysis, but the negative Muslim–GCI relationship disappeared in the regression model.

To test the moderating effect of GDPpc on the relationships between religion and GCI, Hayes's (2013) PROCESS macro for SPSS was employed. Six moderation analyses were conducted in Model 1 with 5,000 bootstrap samples. The detailed results were presented in **Table 6**.

GDPpc moderated the relationship between overall religiosity and GCI (see **Table 4**). As **Figure 1** shown, in countries with high GDPpc, the overall religiosity could negatively predict GCI (b = −0.016, $t(81)$ = −2.023, p = 0.046, 95% confidence interval, CI = [−0.033, −0.000]), but in countries with low GDPpc, the predictive effect of overall religiosity on GCI was not significant (b = −0.004, $t(81)$ = 0.522, p = 0.603, 95% CI = [−0.011, 0.018]).

The interaction between GDPpc and proportion of Protestants in a country positively predicted GCI (see **Table 4**). As shown in **Figure 2**, in countries with high GDPpc, proportion of Protestants could positively predict GCI (b = 0.214, $t(81)$ = 2.302, p = 0.024, 95% CI = [0.029, 0.400]), while in countries with low GDPpc, the predictive effect was not significant (b = −0.178, $t(81)$ = −1.143, p = 0.257, 95% CI = [−0.488, 0.132]).

In contrary, the interaction between GDPpc and proportion of Muslims in a country negatively predicted GCI (see **Table 4**). As shown in **Figure 3**, in countries with high GDPpc, proportion of Muslims could negatively predict GCI (b = −0.448, $t(81)$ = −5.071, $p < 0.001$, 95% CI = [−0.624, −0.272), while in countries with low GDPpc, proportion of Muslims failed to predict GCI (b = −0.009, $t(81)$ = −0.193, p = 0.847, 95% CI = [−0.104, 0.085]).

DISCUSSION

Creativity exerts strong influences on society, economy, science, and technology. The effect of culture on national creativity and innovation has been found by numerous studies (e.g., Efrat, 2014; Kaasa, 2016). Religion has a complex interaction with culture (Ronen and Shenkar, 2013), and is essential for human society. This study explored the effects of different religions/denominations on national creativity, and revealed some intriguing and innovative findings.

[2]http://data.worldbank.org

TABLE 2 | Descriptive statistics at national level (N = 87).

country	*N*	Catholicism	Protestant	Orthodoxy	Muslim	Buddhism	Religiosity	GCI	IQ	RPI
Albania	1994	650	184	204	706	6	−1.02	0.20	82.90	0.75
Algeria	2482	0	0	0	2476	0	3.77	0.28	82.80	0.00
Argentina	6371	4872	131	29	4	76	−0.39	0.68	96.00	0.41
Armenia	3056	14	6	11	1	2	−1.20	0.27	92.00	0.23
Australia	4858	1209	1727	83	32	63	−4.17	0.97	98.00	0.81
Azerbaijan	2991	2	5	53	2794	0	−0.81	0.24	84.80	0.13
Bangladesh	3021	17	2	1	2684	10	5.06	0.32	81.00	0.20
Belarus	3552	322	32	2264	6	0	−3.24	0.60	95.10	0.59
Bosnia	1185	154	1	248	485	0	−0.45	0.25	94.00	0.77
Brazil	4582	2916	775	117	3	11	2.31	0.67	87.00	0.56
Bulgaria	2048	14	9	1285	238	2	−3.85	0.51	92.50	0.59
Burkina Faso	1517	473	120	3	818	0	4.54	0.38	71.00	0.60
Canada	4030	1530	729	39	59	24	−1.49	0.92	100.00	0.81
Chile	5647	3624	531	142	0	1	0.39	0.61	91.00	0.58
China	6138	30	151	0	117	300	−8.33	0.46	105.50	1.00
Colombia	10545	8224	535	127	2	2	2.36	0.41	83.50	0.39
Croatia	1174	989	4	14	14	0	−2.11	0.48	99.00	0.29
Cyprus	2042	11	3	1415	498	0	0.93	0.45	91.50	0.46
Czechia	1993	797	75	0	0	0	−6.58	0.61	98.00	0.84
Dominican Republic	409	245	48	0	0	0	2.58	0.92	82.00	0.63
Ecuador	1201	753	142	0	0	0	2.70	0.53	88.00	0.59
Egypt	6050	0	0	0	5687	0	4.87	0.20	81.00	0.11
El Salvador	1254	738	288	0	0	28	4.17	0.25	78.90	0.60
Estonia	2509	34	215	516	6	6	−5.86	0.63	99.00	0.95
Ethiopia	1482	23	291	971	158	1	3.59	0.30	68.50	0.52
Finland	2991	325	2097	30	63	0	−4.09	0.92	97.00	0.49
France	994	417	22	2	47	5	−5.59	0.82	98.00	0.82
Georgia	4698	42	4	4225	166	2	1.65	0.45	86.50	0.19
Germany	6034	1375	1941	47	148	8	−5.12	0.84	99.00	0.84
Ghana	3047	528	1748	193	404	1	5.35	0.07	70.00	0.62
Great Britain	1012	113	293	3	43	4	−3.98	0.88	100.00	0.90
Guatemala	995	559	310	0	2	1	4.60	0.45	79.00	0.59
Hong Kong	2243	67	102	0	2	273	−5.79	0.72	108.00	0.97
Hungary	3023	1827	679	17	6	0	−4.24	0.67	96.50	0.58
India	9976	167	86	40	983	119	1.00	0.29	82.00	0.30
Indonesia	3007	65	136	0	2785	0	5.79	0.20	87.00	0.14
Iran	5187	0	0	0	5081	0	3.71	0.48	83.50	0.04
Iraq	6207	16	2	9	6159	0	3.98	0.03	87.00	0.02
Italy	1011	885	0	0	0	2	0.34	0.72	97.00	0.23
Japan	7367	45	55	106	0	2924	−5.14	0.71	105.00	0.84
Jordan	3622	33	8	23	3499	0	4.52	0.38	84.00	0.07
Kazakhstan	1502	15	10	400	756	2	−2.88	0.36	84.70	0.68
Kyrgyzstan	2534	9	17	170	2111	3	−0.60	0.24	74.40	0.30
Latvia	1127	222	233	217	4	1	−4.36	0.56	96.10	0.88
Lebanon	1129	261	13	133	622	0	1.30	0.32	82.00	0.62
Lithuania	977	778	20	42	1	2	−2.21	0.49	92.00	0.36
Macedonia	2032	10	5	1084	505	0	−0.89	0.39	90.50	0.65
Malaysia	2498	84	55	0	1509	461	3.79	0.46	88.50	0.58
Mali	1503	27	8	1	1426	1	4.34	0.35	69.50	0.10
Mexico	10729	7957	779	39	5	8	1.78	0.41	88.00	0.44
Moldova	2950	40	49	2660	2	0	−0.37	0.26	92.50	0.19
Montenegro	317	25	0	208	68	0	−3.53	0.52	85.80	0.51

(Continued)

TABLE 2 | Continued

country	*N*	Catholicism	Protestant	Orthodoxy	Muslim	Buddhism	Religiosity	GCI	IQ	RPI
Morocco	3650	2	1	1	3635	0	5.11	0.18	84.00	0.01
Netherlands	2810	591	316	57	53	6	−5.74	0.89	100.00	0.94
New Zealand	2897	410	1470	3	12	15	−4.62	0.95	99.00	0.71
Norway	2142	25	1590	10	17	6	−5.46	0.88	100.00	0.45
Pakistan	3932	0	0	0	3320	0	5.23	0.24	84.00	0.29
Peru	5360	4178	567	0	1	3	2.11	0.42	85.00	0.38
Philippines	3593	2707	140	0	123	0	4.33	0.49	90.00	0.42
Poland	3086	2914	28	28	0	1	1.89	0.52	95.00	0.11
Romania	4462	258	243	3908	9	3	1.96	0.43	91.00	0.23
Russia	8374	18	55	4193	366	21	−4.76	0.58	96.50	0.75
Rwanda	3034	1639	753	32	305	5	2.49	0.14	76.00	0.64
Saudi Arabia	1499	0	0	0	1457	0	3.64	0.36	79.00	0.05
Singapore	3480	197	376	0	557	1055	−0.66	0.90	108.50	0.83
Slovakia	1557	1155	149	3	0	0	−1.83	0.48	98.00	0.44
Slovenia	3067	2085	49	58	41	3	−3.73	0.82	96.00	0.54
South Africa	15970	2054	7450	109	625	25	2.70	0.56	72.00	0.72
South Korea	6999	1050	1430	25	7	1710	−2.92	0.66	106.00	0.88
Spain	6256	5036	37	9	7	10	−3.56	0.81	97.00	0.35
Sweden	3192	52	2224	13	36	1	−6.55	0.92	99.00	0.51
Switzerland	3708	1612	1594	7	25	1	−2.84	0.82	101.00	0.62
Tanzania	1162	330	219	58	469	0	5.30	0.13	72.50	0.72
Thailand	2729	7	2	0	65	2639	0.56	0.37	88.00	0.06
Trinidad and Tobago	1977	400	847	6	125	5	3.72	0.43	86.70	0.72
Tunisia	1205	0	0	0	1205	0	3.82	0.26	84.00	0.00
Turkey	8259	24	13	3	7826	0	2.02	0.35	88.50	0.10
Uganda	1002	356	453	8	169	0	4.62	0.20	72.00	0.64
Ukraine	5108	358	44	3273	17	8	−2.66	0.52	95.00	0.58
United States	6018	1364	1800	25	19	31	0.84	0.95	98.00	0.82
Uruguay	2972	972	211	0	0	2	−3.78	0.69	96.00	0.89
Uzbekistan	1490	1	4	45	1426	1	−1.87	0.29	79.60	0.08
Venezuela	2366	1777	155	2	0	2	1.87	0.47	84.00	0.43
Viet Nam	2491	151	26	1	1	383	−5.22	0.38	94.00	0.76
Yemen	1000	0	0	0	1000	0	4.47	0.11	83.00	0.00
Zambia	1500	513	694	2	20	2	3.90	0.10	75.00	0.65
Zimbabwe	2498	491	1449	10	15	2	4.50	0.11	71.50	0.61

GCI, Global Creativity Index; IQ, intelligence quotient; RPI, religious pluralism index.

TABLE 3 | Correlations among key variables at national level (*N* = 87).

	M	*SD*	1	2	3	4	5	6	7	8	9	10
1. Religiosity	0	3.78	1									
2. Catholicism	0.25	0.29	0.04	1								
3. Protestant	0.13	0.19	−0.08	0.02	1							
4. Orthodoxy	0.11	0.23	−0.11	−0.30**	−0.22*	1						
5. Islam	0.25	0.37	0.50***	−0.48***	−0.37***	−0.16	1					
6. Buddhism	0.03	0.12	−0.09	−0.17	−0.11	−0.11	−0.11	1				
7. GCI	0.49	0.25	−0.65***	0.22*	0.28**	−0.09	−0.53***	0.06	1			
8. GDPpc	8.97	1.32	−0.63***	0.17	0.20	−0.12	−0.39***	0.09	0.82***	1		
9. IQ	89.10	9.70	−0.77***	0.08	−0.04	0.01	−0.44***	0.19	0.72***	0.80***	1	
10. RPI	0.50	0.28	−0.55***	0.09	0.35***	−0.02	−0.64***	0.02	0.49***	0.35***	0.40***	1

*GCI, Global Creativity Index; GDPpc, gross domestic product per capita; IQ, intelligence quotient; RPI, religious pluralism index. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

TABLE 4 | Regression analysis of the relationship between overall religiosity and GCI (N = 87).

	Model 1		Model 2	
	b	*t*	*b*	*t*
RPI .	0.21**	3.04	0.18*	2.40
IQ	0.02***	7.91	0.01***	4.88
Religiosity			−0.01	−0.86
ΔR^2	0.56***		0.00	

*IQ, intelligence quotient; RPI, religious pluralism index. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

Overall Religiosity and National Creativity

Consistent with previous findings (Bénabou et al., 2013; Okulicz-Kozaryn, 2015), correlation analysis in this study showed that overall religiosity had a negative association with GCI. Moderation analysis further indicated that this relationship was significant only in countries with high GDPpc, but disappeared in countries with low GDPpc. However, hierarchical regression analysis illustrated that religiosity failed to predict GCI when national level IQ and RPI were controlled. Therefore hypothesis 1, namely "hinder hypothesis," was partly supported.

Religion and creativity in some sense are opposite in nature. Religion is about obedience and conformity to traditions (Schwartz and Huismans, 1995), while creativity is about challenge and change (Brenkert, 2009; Gino and Wiltermuth, 2014; Okulicz-Kozaryn, 2015). Religion is associated with conservatism (Dollinger, 2007), prescribing inheritance and protection of religious traditions. Common beliefs, values, and religious practices yield particular patterns shared by believers in a religious community (Dana, 2009). Moreover, religion emphasizes rules and traditions. Compared to secular people, it is more difficult for religious people to accept creative and innovative ideas that challenge rules and traditions. On the contrary, creativity requires a critical and doubtful spirit that traditions and existing relationships in the world are challengeable (Brenkert, 2009). Strong endorsement of obedience and conformity to traditions among religious adherents can create a conservative atmosphere in the whole society and exert a negative influence of creativity. Creativity is a social or situational phenomenon (Okulicz-Kozaryn, 2015). On one hand, creative ideas usually come from social interaction, allowing different ideas to collide and interact; on the other hand, whether one idea/activity is creative depends on perspectives of the society or the public. These features suggest that creativity is less likely to occur in societies with strong religiosity (Glăveanu, 2010).

Correlation analyses also showed that the overall religiosity was negatively related to RPI, and RPI was positively related to GCI. These results echo Cinnirella and Streb's (2017) argument that religious tolerance has a positive relation with innovation and creativity. In addition, previous research finds that religiosity has a negative relationship with diffusion rate of innovation (Azam et al., 2011) and total factor productivity (Herzer and Strulik, 2016), providing indirect evidence for the "hinder hypothesis." Here the "hinder hypothesis" should be given more consideration. In this study, we found that the negative effect of religiosity on creativity became insignificant when IQ and RPI were controlled, and the religiosity–creativity relationship is significant only in affluent countries. This suggests whether the "hinder hypothesis" holds depends on other factors (e.g., economy).

The Effects of Different Denominations on National Creativity

Correlation and regression analysis in this study illustrated that both proportion of Catholics and proportion of Protestants had a positively correlation with GCI, while only the correlation analysis showed that proportion of Muslims had a negative correlation with GCI. Proportions of adherents of Orthodox and Buddhism had no significant relation with GCI. Thus Hypothesis 2 was supported. These results can account for the controversies over the religion–creativity association. That is, the effects of different denominational cultures on national creativity were dissimilar.

Religions can build social networks based on different religious traditions, doctrines, and values (Dana, 2009). This suggests that religions can influence creativity and innovation

TABLE 5 | Regression analysis of the relationships between denominations and GCI (N = 87).

	Model 1		Model 2		Model 3	
	b	*t*	*b*	*t*	*b*	*t*
RPI	0.21**	3.04	0.11	1.57	0.10	1.50
IQ	0.02***	7.91	0.02***	8.96	0.02***	9.08
Catholicism				0.13*	2.33	
Protestant			0.34***	3.50	0.35***	3.61
Orthodoxy						
Islam						
Buddhism						
ΔR^2	0.562***		0.06***		0.02***	

*IQ, intelligence quotient; RPI, religious pluralism index. Denominational cultures were put in Step 2 using a stepwise method, with the regression coefficients of excluded variables not being presented. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

TABLE 6 | Moderating effects of GDPpc on relationships between religion and creativity (N = 87).

	Independent variable → GCI			GDPpc → GCI			interaction → GCI			R^2
	b	*SE*	CI	*b*	*SE*	CI	*b*	*SE*	CI	
Religiosity	−0.01	0.01	[−0.34, 0.83]	0.12***	0.02	[0.09, 0.16]	−0.01*	0.00	[−0.01, −0.00]	0.74***
Catholicism	0.06	0.05	[−0.05, 0.16]	0.13***	0.02	[0.09, 0.16]	0.08	0.06	[−0.04, 0.19]	0.73***
Protestant	0.02	0.10	[−0.19, 0.23]	0.11***	0.02	[0.07, 0.15]	0.15*	0.06	[0.04, 0.26]	0.75***
Orthodoxy	−0.07	0.05	[−0.16, 0.03]	0.12***	0.02	[0.08, 0.16]	−0.14	0.04	[−0.22, −0.06]	0.74***
Muslim	−0.23***	0.05	[−0.33, −0.12]	0.12***	0.02	[0.09, 0.15]	−0.17***	0.04	[−0.24, −0.10]	0.80***
Buddhism	−0.05	0.30	[−0.066, 0.55]	0.12***	0.02	[0.09, 0.16]	−0.08	0.19	[−0.45, 0.30]	0.72***

*CI, 95% confidence interval; GCI, Global Creativity Index; GDPpc, Gross Domestic Product per capita. *p < 0.05, **p < 0.01, ***p < 0.001.*

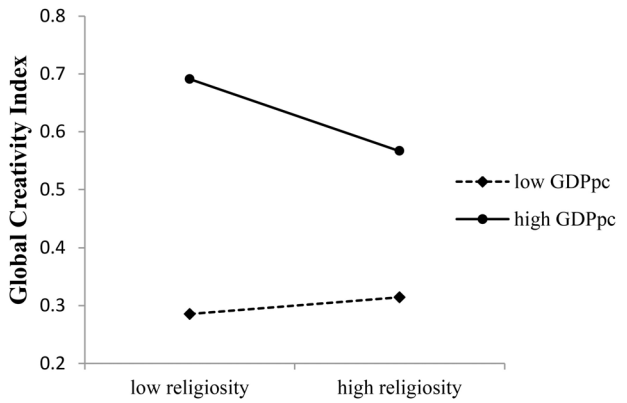

FIGURE 1 | Moderating effects of GDPpc on the religiosity–creativity association.

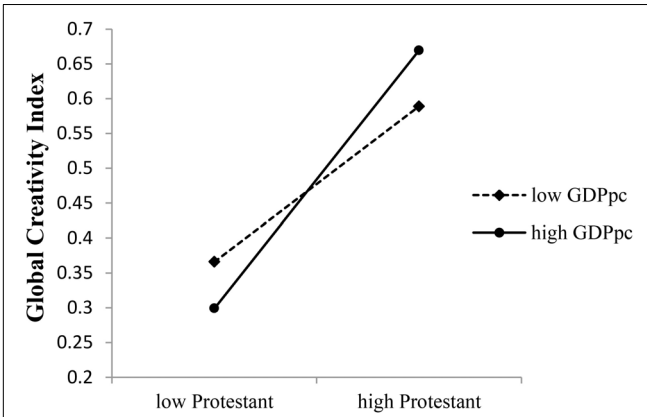

FIGURE 2 | Moderating effects of GDPpc on the Protestant–creativity association.

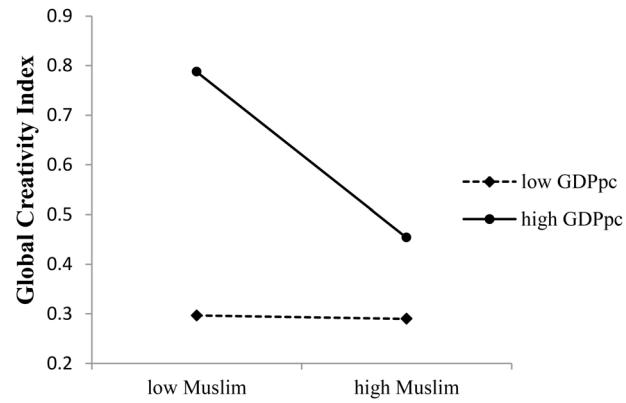

FIGURE 3 | Moderating effects of GDPpc on the Muslim–creativity association.

through norms, customs, and beliefs that are to some extend pervading (Herbig and Dunphy, 1998). Berry (1999) argued that different religious traditions had dissimilar value systems encouraging the adherents to attain achievements in different domains.

This study showed that two denominational cultures, namely Protestant and Catholic, had positive effects on creativity, supporting Hypothesis 2a and 2b. The positive effect of Protestant culture on creativity can be partly attributed to the Protestant work ethic. Weber (1930) pointed that Protestant work ethic that emphases hard work, discipline, and frugality was conducive to rapid development of economics and science. Individuals are religiously compelled to work hard to thrive in a secular career, facilitating the accumulation of capital. Berry (1999) further proposed that the emphasis laid on utilitarianism and disinterested inquiry into "Nature" were responsible for Protestant fruitfulness in science-related areas. Protestant culture also values individual choice, personal freedom, and self-actualization (Inglehart and Oyserman, 2004), which are contributive to innovation and creativity. Existing research finds that intrinsic motivations are usually associated with increased creativity, while extrinsic motivations are usually associated with decreased creative performance (Hennessey, 2003). Professional development, achievement, and wealth accumulation advocated by Protestant work ethic can stimulate more intrinsic motivations in Protestants to achieve maximized personal value. Westwood and Low (2003) argued that achievement orientation and individualism in Protestant culture are beneficial for creativity and innovation. Consistently, this positive connection between individualism and creativity or innovation has been supported by much national level research (e.g., Shane, 1993; Efrat, 2014).

Recently, some researchers hold that the work ethics such as hard working and thrifty have spread in Catholic world before Protestant Reformation (Parboteeah et al., 2009; Andersen et al., 2017). These ethics, which have translated into economic success and productivity growth, can partly account for the positive relationship between Catholic and creativity. Herbig and Dunphy (1998) proposed that the values conductive to creativity and innovation, such as achievement-orientation, materialism, and individualism, are not exclusive to Protestant. These propositions are supported empirically by Berry (1999) who found that Catholic may be as creative as Protestants.

Contrary to Protestant and Catholic, Islam has a negative relationship with national creativity, supporting Hypothesis 2c. This suggests that countries with a greater proportion of Islam adherents tend to have a lower level of creativity. In Koran, supreme power regulates everything, the duty of adherents is only to obey and follow faith and rules. The faith that Allah determined all and creates the entire world is deeply rooted in Islam culture, leading the believers to accept all givens and refuse to spontaneously seek to alter things (Westwood and Low, 2003). These traditions, in some sense, are disruptive to innovation and creativity. Herbig and Dunphy (1998) proposed that fatalism, non-secularism, and belief in absolute truth in the Islamic world impeded science and innovation. However, there are also studies showing that Islamic tradition has a positive impact on creativity in art-related areas (Lubart, 2010). Furthermore, in our regression model the negative effect of Islam on GCI was partialed out by IQ and RPI, indicating that the association between Islam and creativity need further investigation.

In line with the Hypothesis 2d, Buddhism had no relation with creativity. Asceticism advocated by Buddhism devalues materialism and productivity growth (Westwood and Low, 2003). This may counteract the positive effects of Buddhist practice such as mindfulness (Berkovich-Ohana et al., 2017) and meditation (Colzato et al., 2012; Ding et al., 2014) on creativity. However, the effects of Buddhism on creativity need deep investigations in future studies. Because Buddhism encourages the impartial investigation of nature, which is consistent with modern Western scientific and philosophic thought (Yong, 2005).

Effect of GDPpc on the Relationship Between Religion and Creativity

This study found that GDPpc had a moderation effect on the religion–creativity relationship. Specifically, the overall religiosity–creativity association, the Protestant–creativity association, and the Islam–creativity association were all moderated by GDPpc. Further analysis showed that only in countries with high GDPpc the national creativity can be predicted by overall religiosity or denominational cultures (Protestant and Islam). Thus Hypothesis 3 was also supported.

It is surprising and interesting that no matter whether the religion–creativity relationship is positive or negative, the originally significant relationship lose its significance in low GDPpc countries. This can be account for by the fact that a considerable amount of patents belong to foreigners in low GDP countries (Raghupathi and Raghupathi, 2017). Fagerberg et al. (2010) also indicated that technologic advancement in developing countries mostly relies on "spillovers" of that of developed countries. In other words, the GCI scores of low GDP countries are not indicative of the creativity of the residents of these countries. A heavy reliance on the innovation and technology in foreign countries may have weakened the influences of religions/denominations on national creativity in low GDP countries.

The economies of less affluent countries are mostly in factor-driven or investment-driven stage, with innovation/creativity being less important in economic development, while the almost all of developed countries are in innovation-driven stage (Ozawa, 1992; Acs et al., 2008). In less affluent countries, foreign direct investment is an important impetus to GDP growth (Seyoum et al., 2015). Ozawa (1992) proposed that the foreign direct investment provided not only finance but also technology for developing countries. That is, domestic creativity of a developing country is largely invisible and occupies a small portion. But for affluent countries, creativity/innovation became the core impetus to economic growth, causing the fact that the relationship between creativity and its restraining or promoting factor starts to emerge, and that creativity/innovation mostly relies on domestic resources. These may partly account for the moderation effects of GDP in this study.

Limitations and Future Directions

To our knowledge, there was only one research exploring the religion–creativity relationship at national level (Bénabou et al., 2013). We have made a significant progress in using more comprehensive indicators of religiosity and national creativity. In addition, we investigated the effects of different denominations on national creativity, as well as the moderation effect of economy in a larger sample of countries. But there are still some limitations.

First, although GCI used in this study is a more comprehensive indicator of creativity than that used in previous research, it still lacks creativity measures of other domains, such as music, literature, and painting. Various cultures encourage creativity in different areas (Westwood and Low, 2003). Findings in this study thus cannot be generalized to creativity in other areas. Future researchers are expected to explore whether religions/denominations are associated with creativity in these domains.

Second, this study has only explored the effects of limited numbers of denominations/religions in creativity. There are many denominations that are not included, such as Judaism. Judaism may be more strongly contributive to innovations in both science-related and art-related areas than other religious traditions (Berry, 1999). However, in the WVS dataset that comprises 340,297 responders, there are only 2,172 Judaists. Judaists contribute to a proportion that is too small to be used as an indicator of Judaism religious culture that may exert influence of national creativity. Maybe individual level study is more appropriate for investigating the Judaism–creativity association.

Third, this study was conducted at national level, with no individual level data to validate the research findings. We hope that this limitation can be overcome by future research. In the investigation of the effects

of religion on social outcomes, individual level findings may collide with national level findings (Myers, 2012).

CONCLUSION

The present study found that the overall religiosity has a negative relationship with national creativity, which is consistent with previous research. However, different denominations show dissimilar effects on creativity. Protestant and Catholic are positively related with national creativity, while Islam is negatively related with national creativity. This study also finds that the religion–creativity relationship at national level was moderated by GDPpc. Specifically, the influences of religions/denominations on creativity only exist in affluent countries. These results provide explanations for why there are paradoxical findings on the roles of religions in influencing creativity.

AUTHOR CONTRIBUTIONS

ZL collected and analyzed the data under the supervision of QG. QG and ZL designed the study. QG, RW, and ZW contributed reagents, materials, and analysis tools. ZL, QG, PS, and RW contributed to the writing of the manuscript. ZL, QG, and ZW contributed to the revision.

REFERENCES

Acs, Z. J., Desai, S., and Hessels, J. (2008). Entrepreneurship, economic development and institutions. *Small Bus. Econ.* 31, 219–234. doi: 10.1007/s11187-008-9135-9

Andersen, T. B., Bentzen, J., Dalgaard, C. J., and Sharp, P. (2017). Pre-reformation roots of the protestant ethic. *Econ. J.* 127, 1756–1793. doi: 10.1111/ecoj.12367

Assouad, A., and Parboteeah, K. P. (2018). Religion and innovation. A country institutional approach. *J. Manag. Spiritual. Relig.* 15, 20–37. doi: 10.1080/14766086.2017.1378589

Azam, A., Qiang, F., Abdullah, M. I., and Abbas, S. A. (2011). Impact of 5-D of religiosity on diffusion rate of innovation. *Int. J. Bus. Soc. Sci.* 2, 177–185.

Bénabou, R., Ticchi, D., and Vindigni, A. (2013). Forbidden fruits: the political economy of science, religion, and growth. *SSRN Electron. J.* doi: 10.2139/ssrn.2460787

Bénabou, R., Ticchi, D., and Vindigni, A. (2015). Religion and innovation. *Am. Econ. Rev.* 105, 346–351. doi: 10.2139/ssrn.2460787

Berger, I. E. (2006). The influence of religion on philanthropy in Canada. *Voluntas* 17, 110–127. doi: 10.1257/aer.p20151032

Berkovich-Ohana, A., Glicksohn, J., Ben-Soussan, T. D., and Goldstein, A. (2017). Creativity is enhanced by long-term mindfulness training and is negatively correlated with trait default-mode-related low-gamma inter-hemispheric connectivity. *Mindfulness* 8, 717–727. doi: 10.1007/s11266-006-9007-3

Berry, C. (1999). Religious traditions as contexts of historical creativity: patterns of scientific and artistic achievement and their stability. *Pers. Individ. Dif.* 26, 1125–1135. doi: 10.1007/s12671-016-0649-y

Brenkert, G. G. (2009). Innovation, rule breaking and the ethics of entrepreneurship. *J. Bus. Venturing* 24, 448–464. doi: 10.1016/S0191-8869(98)00221-9

Chan-Serafin, S., Brief, A. P., and George, J. M. (2013). Perspective—how does religion matter and why? Religion and the organizational sciences. *Organ. Sci.* 24, 1585–1600. doi: 10.1016/j.jbusvent.2008.04.004

Cinnirella, F., and Streb, J. (2017). *Religious Tolerance as Engine of Innovation. CESifo Working Paper No. 6797*, Munich. doi: 10.1287/orsc.1120.0797

Colzato, L. S., Szapora, A., and Hommel, B. (2012). Meditate to create: the impact of focused-attention and open-monitoring training on convergent and divergent thinking. *Front. Psychol.* 3:116. doi: 10.3389/fpsyg.2012.00116

Dana, L. P. (2009). Religion as an explanatory variable for entrepreneurship. *Int. J. Entrep. Innov.* 10, 87–99.

Day, N. E. (2005). Religion in the workplace: correlates and consequences of individual behavior. *J. Manag. Spiritual. Relig.* 2, 104–135. doi: 10.1080/14766080509518568

Ding, X., Tang, Y. Y., Tang, R., and Posner, M. I. (2014). Improving creativity performance by short-term meditation. *Behav. Brain Funct.* 10:9. doi: 10.1186/1744-9081-10-9

Dingemans, E., and Ingen, E. (2015). Does religion breed trust? A cross-national study of the effects of religious involvement, religious faith, and religious context on social trust. *J. Sci. Study Relig.* 54, 739–755. doi: 10.1111/jssr.12217

Dollinger, S. J. (2007). Creativity and conservatism. *Pers. Individ. Dif.* 43, 1025–1035. doi: 10.1016/j.paid.2007.02.023

Ecklund, E. H., and Scheitle, C. P. (2007). Religion among academic scientists: distinctions, disciplines, and demographics. *Soc. Probl.* 54, 289–307. doi: 10.1525/sp.2007.54.2.289

Efrat, K. (2014). The direct and indirect impact of culture on innovation. *Technovation* 34, 12–20. doi: 10.1016/j.technovation.2013.08.003

Einolf, C. J. (2017). Cross-national differences in charitable giving in the west and the world. *Voluntas* 28, 472–491. doi: 10.1007/s11266-016-9758-4

Fagerberg, J., Srholec, M., and Verspagen, B. (2010). "Innovation and economic," in *Handbook of the Economics of Innovation,* Vol. 2, eds B. Hall and N. Rosenberg (Amsterdam: North-Holland), 833–872.

Florida, R. (2014). *The Rise of the Creative Class–Revisited: Revised and Expanded*. New York, NY: Basic Books.

Florida, R., Mellander, C., and King, K. (2015). *The Global Creativity Index 2015*. Available at: http://martinprosperity.org/content/the-global-creativity-index-2015

Florida, R. L. (2002). *The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday Life*. New York, NY: Basic Books.

Gino, F., and Wiltermuth, S. S. (2014). Evil genius? How dishonesty can lead to greater creativity. *Psychol. Sci.* 25, 973–981. doi: 10.1177/0956797614520714

Glăveanu, V. P. (2010). Paradigms in the study of creativity: introducing the perspective of cultural psychology. *New Ideas Psychol.* 28, 79–93. doi: 10.1016/j.newideapsych.2009.07.007

Guo, Q., Liu, Z., and Tian, Q. (2018). Religiosity and prosocial behavior at national level. *Psychol. Relig. Spiritual.* doi: 10.1037/rel0000171

Hayes, A. F. (2013). *An Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. New York, NY: Guilford Press.

Hennessey, B. (2003). "Is the social psychology of creativity really social? Moving beyond a focus on the individual," in *Group Creativity: Innovation Through Collaboration*, eds P. Paulus and B. Nijstad (New York, NY: Oxford University Press), 181–201.

Herbig, P., and Dunphy, S. (1998). Culture and innovation. *Cross Cult. Manag. Int. J.* 5, 13–21. doi: 10.1108/13527609810796844

Herzer, D., and Strulik, H. (2016). Religiosity and long-run productivity growth. *SSRN Electron. J.* doi: 10.2139/ssrn.2800094

Hofstede, G. (1980). Culture's consequences, international differences in work-related values. Beverly Hills, CA: Sage Publications, Inc.

Inglehart, R., Haerpfer, C., Moreno, A., Welzel, C., Kizilova, K., Diez-Medrano, J., et al. (eds). (2014). *World Values Survey: All Rounds - Country-Pooled Datafile Version*. Madrid: JD Systems Institute.

Inglehart, R., and Oyserman, D. (2004). "Individualism, autonomy, and self-expression: the human development syndrome," in *Comparing Cultures: Dimensions of Culture in a Comparative Perspective,* eds H. Vinken, J. Soeters, and P. Ester (Leiden: Brill), 74–96.

Kaasa, A. (2016). "Culture as a possible factor of innovation: evidence from the European Union and neighboring countries," in *Re-thinking Diversity. Management – Culture – Interpretation*, eds C. Braedel-Kühner and A. Müller (Wiesbaden: Springer VS), 83–107.

Lam, P. Y. (2006). Religion and civic culture: a cross-national study of voluntary association membership. *J. Sci. Study Relig.* 45, 177–193. doi: 10.1111/j.1468-5906.2006.00300.x

Larson, E. J., and Witham, L. (1998). Leading scientists still reject God. *Nature* 394:313. doi: 10.1038/28478

Lubart, T. (2010). "Cross-cultural perspectives on creativity," in *The Cambridge handbook of creativity,* eds J. C. Kaufman and R. J. Sternberg (New York, NY: Cambridge University Press), 265–278.

Meisenberg, G., and Lynn, R. (2011). Intelligence: a measure of human capital in nations. *J. Soc. Polit. Econ. Stud.* 36, 421–454.

Myers, D. G. (2012). Reflections on religious belief and prosociality: comment on galen (2012). *Psychol. Bull.* 138, 913–917. doi: 10.1037/a0029009

Okulicz-Kozaryn, A. (2015). The more religiosity, the less creativity across US counties. *Bus. Creat. Creat. Econ.* 1, 81–87. doi: 10.18536/bcce.2015.07.1.1.09

Ozawa, T. (1992). Foreign direct investment and economic development. *Transnatl. Corp.* 1, 27–54.

Parboteeah, K. P., Hoegl, M., and Cullen, J. (2009). Religious dimensions and work obligation: a country institutional profile model. *Hum. Relat.* 62, 119–148. doi: 10.1177/0018726708099515

Prouteau, L., and Sardinha, B. (2015). Volunteering and country-level religiosity: evidence from the European Union. *Voluntas* 26, 242–266. doi: 10.1007/s11266-013-9431-0

Raghupathi, V., and Raghupathi, W. (2017). Innovation at country-level: association between economic development and patents. *J. Innov. Entrep.* 6:4. doi: 10.1186/s13731-017-0065-0

Rinne, T., Steel, G. D., and Fairweather, J. (2013). The role of Hofstede's individualism in national-level creativity. *Creat. Res. J.* 25, 129–136. doi: 10.1080/10400419.2013.752293

Ronen, S., and Shenkar, O. (2013). Mapping world cultures: cluster formation, sources and implications. *J. Int. Bus. Stud.* 44, 867–897. doi: 10.1057/jibs.2013.42

Saroglou, V. (2010). Religiousness as a cultural adaptation of basic traits: a five-factor model perspective. *Pers. Soc. Psychol. Rev.* 14, 108–125. doi: 10.1177/1088868309352322

Saroglou, V., Delpierre, V., and Dernelle, R. (2004). Values and religiosity: a meta-analysis of studies using Schwartz's model. *Pers. Individ. Dif.* 37, 721–734. doi: 10.1016/j.paid.2003.10.005

Schwartz, S. H., and Huismans, S. (1995). Value priorities and religiosity in four Western religions. *Soc. Psychol. Q.* 58, 88–107. doi: 10.2307/2787148

Seyoum, M., Wu, R., and Lin, J. (2015). Foreign direct investment and economic growth: the case of developing African economies. *Soc. Indic. Res.* 122, 45–64. doi: 10.1007/s11205-014-0679-6

Shane, S. (1993). Cultural influences on national rates of innovation. *J. Bus. Venturing* 8, 59–73. doi: 10.1016/0883-9026(93)90011-S

Shen, W., Yuan, Y., Yi, B., Liu, C., and Zhan, H. (2017). A theoretical and critical examination on the relationship between creativity and morality. *Curr. Psychol.* 1–17. doi: 10.1007/s12144-017-9613-9

Sternberg, R. J., and O'Hara, L. A. (1999). "Creativity and intelligence," in *Handbook of Creativity,* ed. R. J. Sternberg (Cambridge, MA: Cambridge University Press), 251–272.

Weber, M. (1930). *The Protestant Ethic and the Spirit of Capitalism*. London: Allen and Unwin.

Westwood, R., and Low, D. R. (2003). The multicultural muse: culture, creativity and innovation. *Int. J. Cross Cult. Manag.* 3, 235–259. doi: 10.1177/14705958030032006

Yong, A. (2005). Buddhism and science: breaking new ground (review). *Buddhist Christ. Stud.* 25, 176–180. doi: 10.1353/bcs.2005.0071

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 10 October 2018
doi: 10.3389/fpsyg.2018.01929

Linking Self-Construal to Creativity: The Role of Approach Motivation and Cognitive Flexibility

Yan Shao, Bernard A. Nijstad and Susanne Täuber*

Department of Human Resource Management and Organizational Behavior, Faculty of Economics and Business, University of Groningen, Groningen, Netherlands

While some evidence has linked the way individuals define themselves in relation to others (independent versus interdependent self-construal) to creativity, little is known about the underlying mechanism in explaining why and how self-construal influences creativity. Integrating approach-avoidance motivation theory and the dual pathway to creativity model, this research focuses on the motivational and cognitive mechanisms that transfer the effects of self-construal on creativity. Specifically, we expect that independent self-construal is a driver of creativity because it facilitates individuals' approach motivation, which in turn increases flexible information processing. To test the three-stage mediation model, one experiment and one survey study were conducted. In Study 1, in a sample of 231 Dutch students, self-construal was manipulated by a story-writing task; approach-avoidance motivation, cognitive flexibility, and creativity were measured. In Study 2, self-construal, approach (and avoidance) motivation, cognitive flexibility, and creativity were all measured in a second sample of Dutch students (N = 146). The results of two studies supported the three-stage mediation model, showing that approach motivation and cognitive flexibility together mediated the effects of self-construal on creativity. Limitations and implications for future research are discussed.

Keywords: self-construal, creativity, approach motivation, avoidance motivation, cognitive flexibility, cognitive persistence

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Xinwen Bai,
Institute of Psychology (CAS), China
Imran Ali,
King Abdulaziz University, Saudi Arabia

****Correspondence:***
Yan Shao
y.shao@rug.nl

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *21 June 2018*
Accepted: *19 September 2018*
Published: *10 October 2018*

Citation:
Shao Y, Nijstad BA and Täuber S (2018) Linking Self-Construal to Creativity: The Role of Approach Motivation and Cognitive Flexibility. Front. Psychol. 9:1929. doi: 10.3389/fpsyg.2018.01929

INTRODUCTION

Since the intriguing publication of Markus and Kitayama (1991) on self-construal, research concerning the implications of individuals' self-construal on cognition, emotion, and motivation has grown rapidly (see Cross et al., 2011). Self-construal refers to how individuals see themselves in relation to others. Individuals differ in the extent to which they see themselves as autonomous, distinct and unique (independent self-construal) versus as dependent and integral part of larger social groups (interdependent self-construal; Markus and Kitayama, 1991; Kitayama et al., 1997; Gardner et al., 1999).

One important consequence of self-construal is that individuals with different self-construals vary in creativity, defined as generating novel and potentially useful ideas (Amabile, 1983). Some studies have provided preliminary evidence showing that individuals high in independent self-construal relative to those low in independent self-construal or high in interdependent self-construal are more divergent and creative in their thinking (Ng, 2003; Goncalo and Staw, 2006; Wiekens and Stapel, 2008; Jin et al., 2016; Wang and Wang, 2016). However, little is known about

the mechanisms underlying the linkage between self-construal and creativity. As suggested by motivated information processing theory that to be creative in generating ideas, individuals need to have a desire to do so (Kunda, 1990; see also Caruso et al., 2006), in the present research, we propose a motivational and cognitive mechanism in explaining the influence of self-construal on creativity by integrating approach-avoidance motivation theory (Elliot and Thrash, 2002; Carver, 2006; Elliot, 2006) and the dual pathway to creativity model (De Dreu et al., 2008; Nijstad et al., 2010).

As a fundamental psychological concept, approach-avoidance motivation has received considerable attention in the study of human behavior (Elliot and Thrash, 2002; Carver, 2006; Elliot, 2006). Approach motivation is conceptualized as the invigoration by or the direction of behaviors toward positive stimuli, whereas avoidance motivation refers to the instigation by or the direction of behaviors away from negative stimuli (Roskes et al., 2013). We suggest that because individuals with high independent self-construal have a tendency to distinguish themselves from others, they are more likely to pursue and obtain positive outcomes that may establish their uniqueness. In contrast, because individuals with high interdependent self-construal emphasize fitting in and harmony, they are motivated to avoid negative outcomes that may disconfirm their relationship with others. Thus, independent self-construal can be linked to approach motivation whereas interdependent self-construal is related to avoidance motivation.

According to the dual pathway to creativity model (De Dreu et al., 2008; Nijstad et al., 2010), creativity can be achieved through either enhanced cognitive flexibility (the use of many and broad cognitive categories or perspectives; Amabile, 1983) or cognitive persistence (the generation of ideas in a few cognitive categories or perspectives; Dietrich, 2004). Personal traits or contextual variables may affect creativity either through the flexibility pathway, the persistence pathway, or both (Nijstad et al., 2010). Research has suggested and shown that when approach motivation is activated, creativity can be achieved through the flexibility pathway, while when avoidance motivation is activated, creativity is achieved though systematic, persistent processing, but only under certain conditions (see Nijstad et al., 2010; Baas et al., 2013).

Integrating the above insights leads us to propose that independent self-construal is linked to creativity because it is associated with approach motivation, which further promotes cognitive flexibility. Although there are indications that interdependent self-construal is associated with avoidance motivation, the link between avoidance motivation and cognitive persistence is often weak or even negative and depends on additional moderators (e.g., fulfillment of goals; Friedman and Förster, 2002; Baas et al., 2011). Thus, we do not formulate explicit hypothesis about the effects of interdependent self-construal on creativity through avoidance motivation and persistence. The conceptual model is shown in **Figure 1**.

To test the three-stage mediation model, two studies were conducted. First, a laboratory experiment was conducted, in which we manipulated self-construal using a story-writing task and measured approach motivation, cognitive flexibility, and creativity. The experiment enabled us to establish the causal effect of self-construal on approach motivation, cognitive flexibility, and creativity. Second, a survey study was conducted to replicate the lab findings of Study 1 in a Dutch sample of students. With the two complimentary studies, we are able to examine the role of motivation and cognitive flexibility in explaining the effects of self-construal on creativity.

THEORY AND CONCEPTUAL MODEL

Self-Construal and Creativity

Self-construal theory is built on the basic assumption that individuals differ in the way they define and make meaning of themselves in relation to others. Two distinguishable self-construals were first suggested by Markus and Kitayama (1991). Independent self-construal (InSC) refers to the conception of the self as an autonomous, independent unity while interdependent self-construal (InterSC) is defined as the extent to which an individual sees the self as part of an encompassing social relationship (Markus and Kitayama, 1991; Kitayama et al., 1997; Gardner et al., 1999). Although the concept of self-construal was initially used to explain cross-cultural differences in individuals' representation of self, accumulated research has suggested that individuals within each culture vary in chronic self-construal, and are able to see themselves as more or less independent (or interdependent) according to certain situational cues (Gardner et al., 1999; Lee et al., 2000).

The link between self-construal and creativity has received some preliminary support. At the individual level, based on a sample of 158 white undergraduates from Australia and 186 Chinese undergraduates from Singapore, Ng's (2003) study found that independent self-construal had a positive relationship with creative behavior as measured by the Torrance Test of Creative Thinking (TTCT; Torrance, 1972), while interdependent self-construal was negatively related to creativity. Besides, Wiekens and Stapel (2008) demonstrated that the activation of an independent self-construal led to a higher motivation to be independent/different and higher idea generation performance, while the activation of an interdependent self-construal led to a higher motivation to be accepted/to conform and lower idea generation performance.

More recently, Bechtoldt et al. (2010) found that individuals with a Korean background had the default tendency to focus on appropriateness, whereas those with a Dutch background had the default tendency to focus on originality. Given that Korean and Dutch backgrounds are associated with high interdependent self-construal and high independent self-construal, respectively, this research provides indirect support for the relationship between self-construal and creativity. Moreover, based on a sample of junior school students in China, Wang and Wang (2016) found that independent self-construal is more positively associated with self-reported creativity than interdependent self-construal.

At the group level, Goncalo and Staw (2006) found that groups holding individualistic values were more creative than groups holding collectivistic values, especially when originality of responses was emphasized. Although individualism-collectivism is theoretically different from self-construal, research has argued

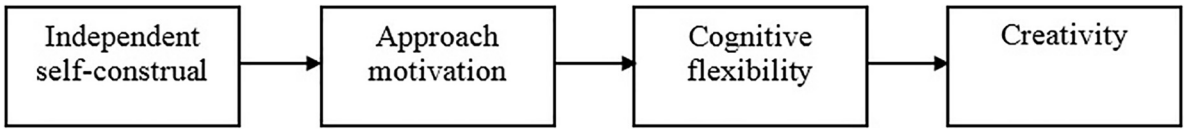

FIGURE 1 | Linking self-construal to creativity: A three-stage mediation model.

that cultural contexts with different values typically promote the development of one or the other self-construal more strongly (Markus and Kitayama, 1991; Cross et al., 2011). Taken together, these studies provide converging evidence that self-construal is an important antecedent of creativity, and that independent (rather than interdependent) self-construal is a diver of the production of novel, original ideas.

Self-Construal, Approach-Avoidance Motivation, and Creativity

Motivated information processing theory suggests that to be creative in generating ideas, individuals need to have a desire to do so (Kunda, 1990). We propose that self-construal can influence creativity because it affects motivations that facilitate creativity. Approach-avoidance motivation theory distinguishes between motivation systems that focus on approach and avoidance goals and goal pursuit strategies (Elliot and Thrash, 2002; Carver, 2006; Elliot, 2006). Approach and avoidance motivation can be viewed either as stable personal differences, or as situational variables that can be temporarily activated (Elliot, 2006; Gable and Harmon-Jones, 2008). Approach motivation is conceptualized as the invigoration by or the direction of behaviors toward positive stimuli or possibilities, whereas avoidance motivation refers to the instigation by or the direction of behaviors away from negative stimuli or threats (Roskes et al., 2013).

Self-Construal and Approach-Avoidance Motivation

The differences in self-construal have consequences for individuals' goal pursuits. Individuals high in independent self-construal primarily aim to enhance self-esteem and to be distinct in a positive way. Individuals high in interdependent self-construal generally attempt to defer, to be similar to others and to maintain harmony in social settings (Markus and Kitayama, 1991). Because individuals with discrete self-construals pursue different goals, we predict a relation between self-construal and motivational orientation (approach vs. avoidance).

There are at least two reasons why self-construal is related to approach-avoidance motivation. First, approach motivation guides people's attention and behavior toward pursuing positive events such as achievement, success, and accomplishment (Elliot and Thrash, 2002), which helps to satisfy individuals' goal to positively distinguish themselves from others. In contrast, avoidance motivation focuses individuals' attention and effort on staying away from negative events such as failures, conflicts and mistakes (Elliot and Thrash, 2002), which helps to satisfy individuals' goal to keep harmony and better fit in in social relationships. Following this reasoning, we propose higher independent self-construal is associated with higher approach motivation, whereas higher interdependent self-construal is linked to higher avoidance motivation. Empirical research has provided some evidence for this argument. For instance, Lee et al. (2000) have demonstrated that individuals high in independent self-construal, primed with independent situations, or with a Western cultural background emphasized approach-related information (achieving success) and showed more affective responses (happiness) associated with approach motivation. In contrast, individuals high in interdependent self-construal, primed with interdependent situations, or with an Eastern cultural background emphasized avoidance-related information (avoiding failure) and showed more affective responses (anxiety) associated with avoidance motivation.

Second, some cross-cultural studies have provided insights into the relationship between self-construal and approach-avoidance motivation. For instance, Elliot et al. (2001) showed that compared with non-Asian Americans, Asian Americans had more avoidance goals and compared with respondents from United States, those from South Korea adopted more avoidance goals (Elliot et al., 2001). In a similar vein, Lockwood et al. (2005) found that individuals with a collectivistic cultural background were more likely to be motivated by negative role models than individuals with an individualistic cultural background. In contrast, positive role models were more motivating for individuals from individualistic cultures rather than for those from collectivistic cultures. Given that individualistic cultures foster a dominant independent self-construal while collectivistic cultures nurture a dominant interdependent self-construal (Markus and Kitayama, 1991), we propose that independent self-construal is linked to approach motivation and interdependent self-construal is associated with avoidance motivation.

Approach-Avoidance Motivation and Creativity

Approach-avoidance motivation is associated with creativity because different motivations affect cognitive processing. According to cognitive tuning theory (Schwarz and Bless, 1991), when approach motivation is activated, individuals tend to evaluate the environment as benign. As a consequence, they are more likely to take risks and adopt a relatively heuristic processing style, which in turn enhances creativity. In contrast, when avoidance motivation is activated, individuals tend to judge the environment as problematic and they are more likely to adopt a relatively risk-averse, systematic, and perseverant processing style, which in turn undermines creativity.

A number of studies have supported the link between approach-avoidance motivation and creativity. For instance, Friedman and Förster (2002) demonstrated that bodily cues like

arm flexor (associated with approach motivation) relative to arm extensor contraction (associated with avoidance motivation) led to a "riskier," more heuristic processing style, which in turn boosted creativity in both a problem solving task and idea generation task. Relatedly, Friedman and Forster (2001) showed that cues associated with motivation of pursing idealized goals relative to cues associated with preventing negative outcomes resulted in higher creativity, because the motivation for achieving idealized goals triggered a riskier, explorative processing style than the motivation for preventing negative outcomes. This pattern also held when motivations were measured with individual differences. A more recent study by Roskes et al. (2012) showed that approach motivation generally led to higher creativity compared with avoidance motivation. Avoidance motivated individuals were as creative as approach motivated individuals only when participants were provided with extra motivations that could compensate their effortful processing style (Roskes et al., 2012). In general, we expect that approach motivation has a positive effect on creativity while avoidance motivation might have a negative effect on creativity.

Approach-Avoidance Motivation, Cognitive Flexibility, and Creativity

The dual pathway to creativity model (De Dreu et al., 2008; Nijstad et al., 2010) suggests that creativity can be achieved through either enhanced cognitive flexibility (the use of many broad cognitive categories or perspectives: Amabile, 1983) or cognitive persistence (the generation of ideas in a few cognitive categories or perspectives: Dietrich, 2004) and that personal traits or contextual variables may affect creativity either through the flexibility pathway, the persistence pathway, or both. Approach-avoidance motivation has been shown to influence creativity through affecting the pathway individuals adopt. For instance, De Dreu et al. (2011) found that when situations facilitated global, flexible processing, approach motivation potentiated creativity. However, when situations facilitated local, bottom-to-up processing, approach motivation led to lower creativity. This research demonstrated that flexible processing plays an important role in the relationship between approach motivation and creativity. What is more, it has been argued and shown that approach motivation generally boosts creativity because it associates with enhanced activation and cognitive flexibility (Baas et al., 2011).

Research evidence is less consistent about the relationship between avoidance motivation and creativity. Some findings suggested that avoidance motivation promotes creativity and other findings showed no or even negative effects (Friedman and Forster, 2001, Friedman and Förster, 2002; De Dreu et al., 2008). Although avoidance motivation has the potential to boost creativity through persistent processing, research has suggested that avoidance motivation leads to enhanced persistence only when the goals or moods associated with avoidance motivation are activated (Baas et al., 2011) or extra motivation is provided (Roskes et al., 2012). Furthermore, a meta-analysis revealed that creativity is facilitated most by positive activating mood states that are associated with approach motivation (e.g., happiness), rather than moods associated with avoidance motivation (e.g., relaxed, anxious; Baas et al., 2008).

Based on the above arguments and evidence, we expect that approach motivation boosts creativity because it associates with enhanced cognitive flexibility. Given the inconsistent evidence about the link between avoidance motivation, persistence and creativity, we do not have clear expectations about their relationships.

Self-Construal, Approach-Avoidance Motivation, Cognitive Flexibility, and Creativity

We thus propose that approach motivation plays an important role in transferring the effects of independent self-construal on creativity because it increases cognitive flexibility. Specifically, we propose that individuals high in independent self-construal are more creative as they generally hold higher approach motivation, and this motivation facilitates creativity through enhanced cognitive flexibility, compared with individuals low in independent self-construal. Although we expect that interdependent self-construal is associated with avoidance motivation, according to past research, the relationship between avoidance motivation, persistence, and creativity is difficult to predict without specifying contextual conditions. We thus do not formulate specific hypothesis about the interdependent self-construal-avoidance motivation-persistence-creativity link. Our hypothesis is the following:

> *Hypothesis 1. Independent self-construal impacts creativity through approach motivation and cognitive flexibility.*

STUDY 1

Method

Study 1 was designed to examine whether independent self-construal has a causal effect on creativity through approach motivation and cognitive flexibility. We expected that priming independent self-construal (relative to interdependent self-construal) will temporarily increase individuals' state approach motivation, which in turn promotes creative performance through enhanced cognitive flexibility. To achieve this goal, we manipulated self-construal using a story-writing task, and measured cognitive flexibility and creative performance with an idea generation task. State approach (and avoidance) motivation were measured with a five-item scale.

Sample and Participants

A total of 266 Dutch students (age M = 20.65, SD = 2.67; 94 women, 168 men, and 4 missing) participated the study for 4 euros or course credits. We randomly assigned all participants to either an interdependent self-construal or independent self-construal condition. In both conditions, participants completed some scales and performed an idea generation task. The study immediately followed another (unrelated) study, and the total session lasted for about 1 h and 15 min.

Manipulation and Procedure

Upon arrival in the laboratory, each participant was seated in front of a computer with keyboard. All instructions and measures were given on the computer. Participants were told that the session consisted of several separate parts. Firstly, all participants were asked to finish some personality questionnaires. After that, participants were instructed to perform a story-writing task for 5 min. This was the manipulation of self-construal, which was adopted from Trafimow et al. (1991). In the independent self-construal condition, participants were instructed to think about and write down what makes them different from their family and friends and what they expect themselves to do. In the interdependent self-construal condition, participants were asked to think about and write down what they have in common with their family and friends and what their family and friends expect them to do. Following that, the idea generation task was administered. Participants were instructed to think about and write down as many different and creative uses of a newspaper as possible for 6 min, and the ideas generated had to be neither typical nor virtually impossible. After that, we measured participants' state approach and avoidance motivation. Subsequently, we collected demographical information, thanked and debriefed all participants.

Measures: State Approach/Avoidance Motivation

We measured state motivation using five items on a seven-point Likert scale (1 = not at all, 7 = very much). Items of state approach motivation were "In the problem solving task, I enthusiastically embraced all opportunities to generate solutions" and "In the problem solving task, I was eager to use all possible ways to find solutions or ideas" (r = 0.68, M = 4.49, SD = 1.26). Sample items of state avoidance motivation included "In the problem solving task, I was concerned with making mistakes" and "In the problem solving task, I was cautious about going down the wrong way" (Cronbach's α = 0.75, M = 3.10, SD = 1.24). As previous research has shown that avoidance motivation can affect creative performance (e.g., Roskes et al., 2012), we controlled state avoidance motivation in our analysis.

Cognitive Flexibility and Creativity

The responses in the newspaper idea generation task were coded for fluency, flexibility, and originality. *Fluency* is the number of non-redundant ideas generated by each participant. *Flexibility* refers to the number of categories that the ideas can be grouped in. Two independent raters coded a subset of responses (30 ideas) for flexibility. The inter-rater agreement (Cohen's Kappa) was 0.86. Given the good inter-rater agreement, one rater continued to code all ideas. *Originality* was operationalized as the statistical rarity of a given response in a particular sample of subjects, which serves as the indicator of creativity in the present study. Specifically, following Baas et al. (2011), for each idea an originality score was computed: 1-(percentage participants who generated the same idea/100). The scale thus ranged from 0 (low originality) to 1 (high originality). For each participant, the final originality score was the average originality score across all non-redundant ideas.

Results

Data Screening

Two participants did not complete the experiment, thus having missing values on key variables, and three participants wrote down ideas that were not understandable. We excluded these five participants, resulting in 261 participants in our sample.

Manipulation Check

We carefully checked the content of participants' stories to see whether the manipulation was successful. This examination showed that there were 30 participants who did not follow the manipulation instruction correctly. They either wrote down similarities when instructed to write down differences or wrote down differences when instructed to write down similarities. We excluded these 30 participants, resulting in 231 participants in the final sample.

Descriptive Statistics

As we can see from **Table 1**, state approach motivation was significantly higher in the independent self-construal condition (M = 4.68) than in the interdependent self-construal condition (M = 4.30), $t(229) = -2.36$, $p < 0.05$. However, we did not find direct effects of the manipulation of self-construal on other variables (except a marginal significant effect on fluency). The correlation matrix showed that self-construal was significantly correlated with state approach motivation, and state approach motivation was significantly and positively correlated with fluency, flexibility, and originality. State avoidance motivation was significantly and negatively correlated with flexibility and

TABLE 1 | Study 1 descriptive statistics and correlations.

	Interdependent self-construal	Independent self-construal	*t*-Test		Correlations				
	M(SD)	*M(SD)*	*t(df)*	*p*	2	3	4	5	6
(1) Self-construal[a]					0.15*	0.10	−0.07	−0.11	−0.03
(2) Approach motivation	4.30(1.20)	4.69(1.29)	−2.36(229)	$p < 0.05$		−0.00	0.18**	0.19**	0.18**
(3) Avoidance motivation	2.98(1.24)	3.24(1.23)	−1.58(229)	ns			−0.25**	−0.20**	−0.12†
(4) Flexibility	5.91(2.27)	5.57(2.46)	1.11(229)	ns				0.86**	0.63**
(5) Fluency	8.59(3.90)	7.68(4.20)	1.58(229)	$p < 0.10$					0.59**
(6) Originality	0.63(0.09)	0.62(0.12)	0.51(229)	ns					

N = 231. [a]*Interdependent self-construal = 0, Independent self-construal = 1.* †$p < 0.10$; *$p < 0.05$; **$p < 0.01$.

TABLE 2 | Study 1 regression results of the three-stage mediation model.

Predictors	Dependent variables			
	Approach motivation		Flexibility	Originality
Constant	−0.16		0.08	0.63
Avoidance motivation	−0.02		−0.24**	0.00
Self-construal[a]	0.31*		−0.15	−0.00
Approach motivation			0.19**	0.01
Flexibility				0.08**
R^2	0.02†		0.10**	0.40**
	Effect	**BootSE**	**BootLLCI**	**BootULCI**
Indirect relation[b]	0.004	0.003	0.001	0.01

N = 231. [a]*0 = interdependent self-construal, 1 = independent self-construal.* [b]*Indirect relation = Self-construal-State approach motivation-Cognitive flexibility-Originality.* †$p < 0.10$; *$p < 0.05$; **$p < 0.01$.

fluency but not originality. Fluency, flexibility, and originality were significantly correlated ($r > 0.50$).

Self-Construal, State Approach Motivation, Cognitive Flexibility, and Originality

To test the three-stage mediation model, we used Model 6 of the PROCESS procedure described by Hayes (2013), which allowed us to test the indirect effect of self-construal on creativity through state approach motivation and cognitive flexibility while controlling for avoidance motivation. We generated 95% bootstrap bias-corrected confidence intervals for the indirect effect on the basis of 5000 bootstrap samples. The indirect effect is significant when the confidence intervals does not include zero. The results are shown in **Table 2**. The results demonstrated that the indirect effect of self-construal on originality through state approach motivation and cognitive flexibility was significant (β = 0.004, BootSE = 0.003, BootLLCI = 0.001, and BootULCI = 0.01). The three-stage mediation model was thus confirmed.

In sum, the results of Study 1 showed that there is a causal relationship between independent self-construal and creativity through state approach motivation and cognitive flexibility while controlling for avoidance motivation, which further confirmed the importance of self-construal in extending the dual pathway to creativity model. However, direct effects of our self-construal manipulation on creativity measures were not observed.

STUDY 2

In Study 1, we found some preliminary evidence to support our conceptual model by priming self-construal in the lab. In the second study, we aimed to replicate the lab findings of Study 1 in a different setting where we measured self-construal as a chronic individual difference.

Method

Participants

146 Dutch students (80 men and 66 women) were recruited to participate in this study. Their average age was 21.14. Results did not change when we included gender and age in the analysis, and we excluded these control variables in the report of the results. We invited the participants to the research lab to finish our survey programmed on a computer. The survey consisted of three parts. In the first part, each participant responded to various psychological scales. Following that, they were asked to perform an idea generation task to measure their cognitive flexibility and creativity. Finally, they answered several demographical questions.

Measures: Self-Construal

The self-construal scale (SCS; Singelis, 1994) involved a 12-item independent self-construal and a 12-item interdependent self-construal subscale. Sample items of the independent self-construal subscale were "I prefer to be direct and forthright when dealing with people I've just met" and "I enjoy being unique and different from others in many respects." Sample items of the interdependent self-construal subscale included "I have respect for the authority figures with whom I interact" and "It is important for me to maintain harmony within my group." Participants were instructed to rate the degree to which they agree or disagree with the statements on a seven-point scale, ranging from 1 (strongly disagree) to 7 (strongly agree). The Cronbach's alpha was 0.68 for independent self-construal and 0.62 for interdependent self-construal.

Behavioral Inhibition System/Behavioral Activation System

The Behavioral Inhibition System/Behavioral Activation System (BIS/BAS) scale (Carver and White, 1994), including a 7-item BIS and a 13-item BAS subscale, was used to measure approach-avoidance motivation. Participants were asked to indicate the extent to which the statements reflect themselves on a seven-point scale, ranging from 1 (not true at all of me) to 7 (very much true of me). Sample items of the BAS subscale included "I go out of my way to get things I want" and "I crave excitement and new sensations." The Cronbach's alpha was 0.78 for BAS. Sample items of the BIS subscale included "I worry about making mistakes" and "I have very few fears compared to my friends" (reverse scored). The Cronbach's alpha was 0.81 for BIS.

Cognitive Flexibility and Creativity

The measure of creativity was the Tin Can idea generation task (Baas et al., 2011). In this task, participants were asked to generate as many different creative ways to use a tin can as possible and the ideas generated had to be neither typical nor virtually impossible. The responses were coded for fluency, flexibility and originality. The operationalization of fluency and flexibility was the same as Study 1. Two independent raters coded a subset of responses (30 ideas) for flexibility. The inter-rater agreement (Cohen's Kappa) was 0.96. Given the good inter-rater agreement, one rater subsequently coded all ideas. *Originality* was operationalized with the same way as Study 1.

Control Variables

Because interdependent self-construal and avoidance motivation have been suggested to affect individual creative performance

(e.g., Friedman and Forster, 2001; Baas et al., 2011), we included them as covariates when testing the multiple-stage mediation model.

Results

Descriptive statistics, correlations, and scale reliabilities are presented in **Table 3**.

Confirmatory Factorial Analysis (CFA)

We performed confirmatory factorial analysis (CFA) (Lavaan 0.5-23 R package) to examine the discriminant validity of self-construal and BIS/BAS motivation (see **Table 4**). We compared fit statistics of five alternative models to the baseline model by means of χ^2-differences, root-mean-square error of approximation (RMSEA), the comparative fit index (CFI), the Tucher-Lewis index (TLI), and the standardized root-mean-square residual (SRMR). To enhance model parsimony, following Ng (2003), we randomly packaged measurement items to a small number of groups. Specifically, we randomly assigned the 12 items to 3 parcels for independent self-construal and interdependent self-construal, respectively. Similarly, we randomly packaged the 13 items to form 3 indicators for BAS and the 7 items to form 3 indicators for BIS. Item parceling has been suggested to enhance model parsimony by reducing the number of indicators and better meet the assumption of maximum likelihood estimation procedure used in the structural equation modeling (Finch and West, 1997).

Results from CFA analysis showed that the hypothesized baseline model (independent self-construal, interdependent self-construal, BIS and BAS) fitted the data well [$\chi^2(48) = 69.03$, $p < 0.05$; CFI = 0.95, TLI = 0.94, RMSEA = 0.06, RSMR = 0.06]. The four-factor model was significantly better than the one factor model where all indicators loaded on a single factor [$\Delta\chi^2(6) = 243.37$, $p < 0.001$], and showed a better fit than all other alternative models. This confirms the discriminant validity of the four constructs.

Common Method Bias

Because both self-construal and BIS/BAS motivation were measured using self-reports on a Likert scale, we examined the degree to which common method bias was present in the current study with common latent factor analysis (e.g., Williams et al., 1989; Podsakoff et al., 2003). Compared with the single-factor test (Harman, 1960), the common latent factor approach allows for the consideration of measurement error and does not

TABLE 3 | Study 2 descriptive statistics and correlations.

Variables	*M*	*SD*	1	2	3	4	5	6	7	8	9
(1) Age	21.13	2.21									
(2) Gender	0.54	0.50	−0.15								
(3) Fluency	8.66	3.92	0.23**	−0.10							
(4) Flexibility	5.77	2.63	0.18*	−0.11	0.90**						
(5) Originality	0.62	0.12	0.09	0.02	0.66**	0.67**					
(6) InSC	4.76	0.69	0.10	0.20*	0.23**	0.25**	0.27**	0.68			
(7) InterSC	4.45	0.60	−0.30**	−0.11	−0.10	−0.10	−0.14	−0.13	0.62		
(8) BAS	5.20	0.61	0.02	−0.02	0.26**	0.27**	0.20*	0.43**	0.08	0.81	
(9) BIS	4.63	0.99	0.03	−0.25**	0.08	0.06	0.12	−0.26**	0.16*	0.00	0.78

*N = 146. InSC = independent self-construal; InterSC = interdependent self-construal. Gender: 0 = women; 1 = men. In the correlation matrix, numbers at the diagonal are Cronbach's α values for measurement scales used in the current study. *$p < 0.05$; **$p < 0.01$.*

TABLE 4 | Study 2 confirmatory factor analysis.

Factor structure	χ^2	df	RMSEA	CFI	TLI	SRMR	$\Delta\chi^2(\Delta df)$
Baseline model: four factors	69.03	48	0.06	0.95	0.94	0.06	
Model1: one factor	312.40	54	0.18	0.43	0.30	0.15	243.37(6)***
Model2: two factors	167.28	53	0.12	0.75	0.69	0.11	98.26(5)***
Model3: two factors	266.61	53	0.17	0.53	0.41	0.16	197.58(5)***
Model4: three factors	100.92	51	0.08	0.90	0.86	0.08	31.89(3)***
Model5: three factors	137.58	51	0.11	0.81	0.75	0.10	68.55(3)***
Model6: three factors	225.04	51	0.15	0.62	0.50	0.15	156.02(3)***
Model7: three factors	102.57	51	0.08	0.89	0.85	0.09	33.54(3)***
Model8: common latent factor	61.40	44	0.05	0.96	0.94	0.06	7.63(4)

*N = 146. $\Delta\chi^2$ and Δdf refer to the differences with the baseline model. Model 1: All variables on one factor; Model 2: Independent self-construal and BAS on one factor while interdependent self-construal and BIS on another factor; Model 3: Independent and interdependent self-construal on one factor while BIS and BAS on another factor; Model 4: Interdependent self-construal and BIS on one factor; Model 5: Independent self-construal and BAS on one factor; Model6: BIS and BAS on one factor; Model7: Interdependent and independent self-construal on one factor. Model8: Adding a latent factor with all of the items as indicators to the baseline model. ***$p < 0.001$.*

require the researcher to identify the specific factor responsible for common method effects. This analysis was conducted by adding a latent factor with all of the items as indicators to our four-factor model (see **Table 4**). The paths from the indicators to the common factor were constrained to be equal and the variance of the common factor was constrained to be 1 to make sure the model can be identified (Eichhorn, 2014). The results showed that adding a common method factor did not improve the mode fit significantly [$\Delta\chi^2(2) = 7.63$, $p > 0.10$], which suggests that common method bias is not a serious concern in the current study.

The Three-Stage Mediation Model

We predicted that independent self-construal has an indirect effect on creativity through approach motivation and cognitive flexibility. The three-stage mediation model was tested using Model 6 of the PROCESS tool described by Hayes (2013). As shown in **Table 5**, after controlling for interdependent self-construal and avoidance motivation, independent self-construal had a significant indirect effect of on creativity through BAS and cognitive flexibility (β = 0.007, BootSE = 0.003, BootLLCI = 0.002, and BootULCI = 0.016), replicating Study 1. The results confirmed that independent self-construal affected creativity through enhanced approach motivation and cognitive flexibility

GENERAL DISCUSSION

Earlier research has highlighted the role of self-construal as an important source of creativity, but the existing literature is fragmented in terms of how and why self-construal is linked to creativity. Our research proposed that approach-avoidance motivation may serve as a motivational mechanism in explaining the effects of self-construal on creativity. Drawing on the dual pathway to creativity model, we further proposed that self-construal affects creativity because it enhances individuals' approach motivation, which in turn facilitates flexible information processing in ideation.

TABLE 5 | Study 2 regression results of the three-stage mediation model.

Predictors	**Dependent variables**			
	BAS	**Flexibility**		**Originality**
Constant	−0.13	0.01		0.61**
InterSC	0.11	−0.14		−0.01
BIS	0.09	0.15		0.01†
InSC	0.46**	0.18†		0.02†
BAS		0.23*		−0.00
Flexibility				0.07**
R^2	0.19**	0.11**		0.46**
Indirect relation	**Indirect effect**	**BootSE**	**BootLLCI**	**BootULCI**
	0.007	0.003	0.002	0.016

*N = 146. InSC = independent self-construal; InterSC = interdependent self-construal. Indirect Relation, Independent self-construal-BAS-Cognitive flexibility-Originality. †p < 0.10; *p < 0.05; **p < 0.01.*

Our conceptual model was supported in two complementary studies. In Study 1, we found that individuals primed with independent self-construal, relative to those primed with interdependent self-construal, were higher in state approach motivation, and state approach motivation was significantly and positively linked to cognitive flexibility and originality. The mediation analysis showed a significant three-stage indirect effect after controlling for avoidance motivation. In other words, findings of Study 1 supported our hypothesis that self-construal influences creativity through state approach motivation and cognitive flexibility. However, although we found that priming self-construal temporarily enhanced individuals' approach motivation, we did not find a significant direct effect of self-construal on creativity. One possible reason is that the manipulation was not strong enough to produce a direct effect, because self-construal and creativity are more distally related than self-construal and motivation. In Study 2, we conducted a survey among a Dutch student sample. We found that after controlling for avoidance motivation and interdependent self-construal, approach motivation, and cognitive flexibility together mediated the effects of independent self-construal on creativity, replicating the findings of Study 1.

Theoretical Implications

The present research takes a step toward uncovering the mechanism underlying the link between self-construal and creativity. Previous studies have begun to identify that independent self-construal is linked to motivation to be independent/different whereas interdependent self-construal induces motivation to be accepted/to conform (Wiekens and Stapel, 2008). However, little research has addressed the possibility that the motivation resulting from self-construal can mediate the effects of self-construal on creativity. Besides, despite that some studies have found a positive link between approach motivation and creativity because of flexibility (e.g., Roskes et al., 2012), little attention has been paid to reveal the sources of approach motivation. Our three-stage mediation model integrated previous fragmented literatures by demonstrating that approach motivation and cognitive flexibility sequentially mediate the relationship between independent self-construal and creativity.

Second, the mediators being tested in the present research have strong implications for uncovering future moderators of the relationship between self-construal and creativity. The present study shows that self-construal influences creativity because of approach motivation and cognitive flexibility. Therefore, we can expect that under some circumstances, the positive relationship between independent self-construal and creativity may not hold because the conditions do not afford approach motivation and/or flexible information processing. For example, past research suggested that approach motivation has a positive link with creativity only if the situation affords flexible and global processing (De Dreu et al., 2011). In a similar vein, we may expect that independent self-construal leads to creativity only if the situation makes approach motivation and/or cognitive flexibility feasible. This study thus

encourages future research to investigate contextual factors which moderate the relationship between independent self-construal and creativity.

In addition, this research examined the indirect effect of independent self-construal on creativity with mixed methods. Some past research has either used surveys or laboratory experiments. Our two complementary studies provide consistent support for the three-stage mediation model, which increases confidence about the indirect effect of independent self-construal on creativity. Specifically, we contributed knowledge that both situationally primed self-construal and chronic self-construal are associated with creative performance through approach motivation and cognitive flexibility.

Practical Implications

The central implication for management practices from this study is the challenge to realize the potential of independent self-construal for creative production. This research provides insights into manageable interventions that can be used to promote individual creativity. For instance, because self-construal is often stable and difficult to change, for employees low in independent self-construal, it might be more effective for managers to provide and emphasize rewards, achievements and train the employees with approach orientated strategies (e.g., the use of intuition) to achieve creativity than to change employee's self-definition. In addition, creating conditions that facilitate cognitive flexibility is critical to increase employees' creativity. For instance, research has shown that individuals with activated positive mood (e.g., happy) are more creative than those with deactivated positive mood (e.g., relaxed) because of differences in cognitive flexibility (De Dreu et al., 2008). Therefore, creating a work environment that helps employees be happy is beneficial for cognitive flexibility, which in turn boosts creativity.

Limitations and Avenues for Future Research

The contributions of the current study should be seen in light of several limitations. First, we only adopted one cognitive manipulation of self-construal. We are not certain whether the effects we observed in our experiment can be generalized to different manipulations such as the word search task (Brewer and Gardner, 1996), Sumerian warrior task (Trafimow et al., 1991) and a different version of story-writing task (Utz, 2004). Second, we used a single measure of creativity in the present research. Although idea generation tasks are widely used to assess creativity, the effect we observed for the idea generation task (divergent thinking task) may not hold for other convergent thinking tasks. For example, Shen et al. (2018) have found that although risk-taking orientation is not significantly related to divergent thinking performance, it has a significant, negative association with convergent thinking performance. Future research is thus encouraged to employ the Remote Associates Test (RAT: Mednick and Mednick, 1967) or other convergent thinking tasks to investigate the effects of self-construal on creativity. Third, our model was tested only in Dutch samples. Future research can address this limitation by testing our model in other cultures.

Also, in the current study we chose to only focus on the link between independent self-construal and originality of ideas. However, we believe that it is equally important to study how interdependent self-construal influences appropriateness or usefulness of ideas. Some evidence has suggested that individuals with different self-construals tend to have different biases toward creativity (e.g., Bechtoldt et al., 2010). Specifically, it seems that people with independent self-construal are motivated to stand out and be original in idea generation, while people with interdependent self-construal are motivated to be similar and generate mainly appropriate and useful ideas. Future study could directly examine this possibility by measuring both originality and appropriateness of ideas. Moreover, if people with different self-construals tend to focus on either originality or appropriateness of creativity, one intriguing question is how individuals can be ambidextrous in creativity by achieving appropriateness and originality simultaneously given that both aspects are important for creativity. Indeed, a few studies have started to investigate the conditions that can foster both appropriateness and originality simultaneously and have shown it is possible for individuals to be ambidextrous in creativity (e.g., Miron-Spektor and Beenen, 2015). In addition, Zhang et al. (2015) have shown that leaders can demonstrate paradoxical behaviors, creating a work environment that fosters employees' productivity and adaptivity simultaneously. In sum, the current study takes the first step to examine individuals' bias toward creativity because of their self-construal, and future studies may investigate the question how and why such a bias can be managed to achieve high creativity.

Finally, our second study used a self-report method to measure both independent self-construal and approach motivation. Although the common latent factor analysis showed that the common method bias is unlikely to threaten the validity of our results, future study is encouraged to reduce common method bias by, for example, measuring the two constructs with different methods or from different sources.

CONCLUSION

Scholars tend to argue that for individuals to be creative, they need to have the motivation to do so (Kunda, 1990). Although research has demonstrated that self-construal is a predictor of creativity, the mechanism underlying the self-construal and creativity link is unclear. The present study provides empirical evidence for the motivational mechanism, in that it showed that approach motivation plays a role in explaining the influences of independent self-construal on creativity. More importantly, this research showed that approach motivation mediates the self-construal-creativity link because it gives rise to cognitive flexibility. The motivational and cognitive mechanism clearly explains how and why independent self-construal impacts creativity.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of recommendations of the research ethics guidelines of the Research Ethics Committee of the Faculty of Economics and Business of the University of Groningen with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Research Ethics Committee of the Faculty of Economics and Business of the University of Groningen.

AUTHOR CONTRIBUTIONS

YS and BN developed the research idea together. Under the supervision of BN, YS collected and analyzed the data for Studies 1 and 2. YS took the lead in drafting the manuscript. BN and ST commented on the draft.

FUNDING

This research was financially supported by grant 453-15-002 of the Netherlands Organization for Scientific Research (NWO) awarded to BN.

ACKNOWLEDGMENTS

The abstract of this work has been previously published on Academy of Management Proceedings, Vol. 2016, No. 1. Published Online: 30 November, 2017 https://doi.org/10.5465/ambpp.2016.13896abstract.

REFERENCES

Amabile, T. M. (1983). The social psychology of creativity: a componential conceptualization. *J. Pers. Soc. Psychol.* 45, 357–376. doi: 10.1037/0022-3514.45.2.357

Baas, M., De Dreu, C. K. W., and Nijstad, A. B. (2008). A meta-analysis of 25 years of research on mood and creativity: hedonic tone, activation or regulatory focus? *Psychol. Bull.* 134, 779–806. doi: 10.1037/a0012815

Baas, M., De Dreu, C. K. W., and Nijstad, B. A. (2011). When prevention promotes creativity: the role of mood, regulatory focus, and regulatory closure. *J. Pers. Soc. Psychol.* 100, 794–809. doi: 10.1037/a0022981

Baas, M., Roskes, M., Sligte, D., Nijstad, B. A., and De Dreu, C. K. W. (2013). Personality and creativity: the dual pathway to creativity model and a research agenda. *Soc. Pers. Psychol. Compass* 7, 732–748. doi: 10.1111/spc3.12062

Bechtoldt, M. N., De Dreu, C. K. W., Nijstad, B. A., and Choi, H. S. (2010). Motivated information processing, social tuning, and group creativity. *J. Pers. Soc. Psychol.* 99, 622–637. doi: 10.1037/a0019386

Brewer, M., and Gardner, W. (1996). Who is this "We"? *J. Pers. Soc. Psychol.* 71, 83–93. doi: 10.1037/0022-3514.71.1.83

Caruso, E., Epley, N., and Bazerman, M. H. (2006). The costs and benefits of undoing egocentric responsibility assessments in groups. *J. Pers. Soc. Psychol.* 91, 857–871. doi: 10.1037/0022-3514.91.5.857

Carver, C. S. (2006). Approach, avoidance, and the self-regulation of affect and action. *Motiv. Emot.* 30, 105–110. doi: 10.1007/s11031-006-9044-7

Carver, C. S., and White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales. *J. Pers. Soc. Psychol.* 67, 319–333. doi: 10.1037/0022-3514.67.2.319

Cross, S. E., Hardin, E. E., and Gercek-Swing, B. (2011). The what, how, why, and where of self-construal. *Pers. Soc. Psychol. Rev.* 15, 142–179. doi: 10.1177/1088868310373752

De Dreu, C. K. W., Nijstad, B. A., and Baas, M. (2011). Behavioral activation links to creativity because of increased cognitive flexibility. *Soc. Psychol. Pers. Sci.* 2, 72–80. doi: 10.1177/1948550610381789

De Dreu, K., Baas, M., and Nijstad, B. A. (2008). Hedonic tone and activation level in the mood-creativity link: toward a dual pathway to creativity model. *J. Pers. Soc. Psychol.* 94, 739–756. doi: 10.1037/0022-3514.94.5.739

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychon. Bull. Rev.* 11, 1011–1026. doi: 10.3758/BF03196731

Eichhorn, B. R. (2014). *Common Method Variance Techniques. Cleveland State University, Department of Operations & Supply Chain Management*. Cleveland, OH: SAS Institute Inc.

Elliot, A. J. (2006). The hierarchical model of approach-avoidance motivation. *Motiv. Emot.* 30, 111–116. doi: 10.1007/s11031-006-9028-7

Elliot, A. J., Chirkov, V. I., Kim, Y., and Sheldon, K. M. (2001). A cross-cultural analysis of avoidance (relative to approach) personal goals. *Psychol. Sci.* 12, 505–510. doi: 10.1111/1467-9280.00393

Elliot, A. J., and Thrash, T. M. (2002). Approach-avoidance motivation in personality: approach and avoidance temperaments and goals. *J. Pers. Soc. Psychol.* 82, 804–818. doi: 10.1037/0022-3514.82.5.804

Finch, J. F., and West, S. G. (1997). The investigation of personality structure: statistical models. *J. Res. Pers.* 485, 439–485. doi: 10.1006/jrpe.1997.2194

Friedman, R. S., and Forster, J. (2001). The effects of promotion and prevention cues on creativity. *J. Pers. Soc. Psychol.* 81, 1001–1013. doi: 10.1037/0022-3514.81.6.1001

Friedman, R. S., and Förster, J. (2002). The influence of approach and avoidance motor actions on creative cognition. *J. Exp. Soc. Psychol.* 38, 41–55. doi: 10.1006/jesp.2001.1488

Gable, P. A., and Harmon-Jones, E. (2008). Approach-motivated positive affect reduces breadth of attention: research article. *Psychol. Sci.* 19, 476–482. doi: 10.1111/j.1467-9280.2008.02112.x

Gardner, W. L., Gabriel, S., and Lee, A. Y. (1999). "I" value freedom, but "we" value relationships: self-construal priming mirrors cultural differences in judgment. *Psychol. Sci.* 10, 321–326. doi: 10.1111/1467-9280.00162

Goncalo, J. A., and Staw, B. M. (2006). Individualism-collectivism and group creativity. *Organ. Behav. Hum. Decis. Process.* 100, 96–109. doi: 10.1016/j.obhdp.2005.11.003

Harman, H. H. (1960). *Modern Factor Analysis*. Chicago, IL: The University of Chicago Press.

Hayes, A. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. New York, NY: The Guilford Press.

Jin, X., Wang, L., and Dong, H. (2016). The relationship between self-construal and creativity—Regulatory focus as moderator. *Pers. Individ. Dif.* 97, 282–288. doi: 10.1016/j.paid.2016.03.044

Kitayama, S., Matsumoto, H., Markus, H. R., and Norasakkunkit, V. (1997). Individual and collective processes in the construction of the self: self-enhancement in the united states and self-criticism in Japan. *J. Pers. Soc. Psychol.* 72, 1245–1267. doi: 10.1037/0022-3514.72.6.1245

Kunda, Z. (1990). The case for motivated reasoning. *Psychol. Bull.* 108, 480–498. doi: 10.1037/0033-2909.108.3.480

Lee, A. Y., Aaker, J. L., and Gardner, W. L. (2000). The pleasures and pains of distinct self-contruals:The role of interdependance in regulatory focus. *J. Pers. Soc. Psychol.* 78, 1122–1134. doi: 10.1037//0022-3514.78.6.1I22

Lockwood, P., Marshall, T. C., and Sadler, P. (2005). Promoting success or preventing failure: cultural differences in motivation by positive and negative role models. *Pers. Soc. Psychol. Bull.* 31, 379–392. doi: 10.1177/0146167204271598

Markus, H. R., and Kitayama, S. (1991). Culture and the self: implications for cognition, emotion, and motivation. *Psychol. Rev.* 98, 224–253. doi: 10.1037/0033-295X.98.2.224

Mednick, S. A., and Mednick, M. T. (1967). *Examiners' Manual Remote Associations Test*. Boston, MA: Houghton Mifflin.

Miron-Spektor, E., and Beenen, G. (2015). Motivating creativity: the effects of sequential and simultaneous learning and performance achievement goals on product novelty and usefulness. *Organ. Behav. Hum. Decis. Process.* 127, 53–65. doi: 10.1016/j.obhdp.2015.01.001

Ng, A. K. (2003). A cultural model of creative and conforming behavior. *Creat. Res. J.* 15, 223–233. doi: 10.1080/10400419.2003.9651414

Nijstad, B. A., De Dreu, C. K. W., Rietzschel, E. F., and Baas, M. (2010). The dual pathway to creativity model: creative ideation as a function of flexibility and persistence. *Eur. Rev. Soc. Psychol.* 21, 34–77. doi: 10.1080/10463281003765323

Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., and Podsakoff, N. P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. *J. Appl. Psychol.* 88, 879–903. doi: 10.1037/0021-9010.88.5.879

Roskes, M., De Dreu, C. K. W., and Nijstad, B. A. (2012). Necessity is the mother of invention: avoidance motivation stimulates creativity through cognitive effort. *J. Pers. Soc. Psychol.* 103, 242–256. doi: 10.1037/a0028442

Roskes, M., Elliot, A. J., Nijstad, B. A., and De Dreu, C. K. W. (2013). Time pressure undermines performance more under avoidance than approach motivation. *Pers. Soc. Psychol. Bull.* 39, 803–813. doi: 10.1177/0146167213482984

Schwarz, N., and Bless, H. (1991). "Happy and mindless, but sad and smart? The impact of affective states on analytic reasoning," in *Emotion and Social Judgments*, ed. J. P. Forgas (Elmsford, NY: Pergamon Press, Inc.), 55–71.

Shen, W., Hommel, B., Yuan, Y., Chang, L., and Zhang, W. (2018). Risk-taking and creativity: convergent, but not divergent thinking is better in low-risk takers. *Creat. Res. J.* 30, 224–231. doi: 10.1080/10400419.2018.1446852

Singelis, T. M. (1994). The measurement of independent and interdependent self-construals. *Pers. Soc. Psychol. Bull.* 20, 580–591. doi: 10.1177/0146167294205014

Torrance, E. (1972). Predictive validity of the torrance tests of creative thinking. *J. Creat. Behav.* 6, 236–262. doi: 10.1002/j.2162-6057.1972.tb00936.x

Trafimow, D., Triandis, H. C., and Goto, S. G. (1991). Some tests of the distinction between the private self and the collective self. *J. Pers. Soc. Psychol.* 60, 649–655. doi: 10.1037/0022-3514.60.5.649

Utz, S. (2004). Self-construal and cooperation: is the interdependent self more cooperative than the independent self? *Self Identity* 3, 177–190. doi: 10.1080/13576500444000001

Wang, Y., and Wang, L. (2016). Self-construal and creativity: the moderator effect of self-esteem. *Pers. Individ. Dif.* 99, 184–189. doi: 10.1016/j.paid.2016.04.086

Wiekens, C. J., and Stapel, D. A. (2008). I versus we: the effects of self-construal level on diversity. *Soc. Cogn.* 26, 368–377. doi: 10.1521/soco.2008.26.3.368

Williams, L. J., Cote, J. A., and Buckley, M. R. (1989). Lack of method variance in self reported affect and perceptions at work. *J. Appl. Psychol.* 74, 462–468. doi: 10.1037/0021-9010.74.3.462

Zhang, Y., Waldman, D. A., Han, Y. L., and Li, X. B. (2015). Paradoxical leader behaviors in people management: antecedents and consequences. *Acad. Manag. J.* 58, 538–566. doi: 10.5465/amj.2012.0995

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

REVIEW
published: 31 October 2018
doi: 10.3389/fpsyg.2018.01924

The Neural Mechanism Underlying Cognitive and Emotional Processes in Creativity

Simeng Gu[1,2], Mengdan Gao[2], Yaoyao Yan[2], Fushun Wang[2,3,4], Yi-yuan Tang[5,6] and Jason H. Huang[3,4]**

[1] Department of Psychology, School of Medicine, Jiangsu University, Zhenjiang, China, [2] Institute of Emotion, School of Psychology, Nanjing University of Chinese Medicine, Nanjing, China, [3] Department of Neurosurgery, Baylor Scott & White Health, Temple, TX, United States, [4] College of Medicine, Texas A&M HSC, Temple, TX, United States, [5] Department of Psychological Sciences, Texas Tech University, Lubbock, TX, United States, [6] Center for Advanced Study in the Behavioral Sciences, Stanford University, Stanford, CA, United States

Creativity is related to both cognition and emotion, which are the two major mental processes, interacting with each other to form psychological processes. Emotion is the major driving force of almost all creativities, sometimes in an unconscious way. Even though there are many studies concerning the relationship between creativity and cognition, there are few studies about the neural mechanisms of the emotional effects on creativity. Here, we introduce a novel model to explain the relationship between emotions and creativities: *Three Primary Color model*, which proposes that there are four major basic emotions; these basic emotions are subsided by three monoamines, just like the three primary colors: dopamine-joy, norepinephrine-stress (fear and anger), and serotonin-punishment. Interestingly, these three neuromodulators play similar roles in creativity, whose core features are value and novelty (surprise), like the characteristics of the core features of basic emotions (hedonic value and arousal value). Dysfunctions of these neuromodulators may be the reasons for both psychopathology and creativity, in that they can change the thinking styles such as novelty seeking behavior, hyper-connectivity of brain areas, and/or cognitive disinhibition to induce both creativity and psychopathology. This new model will not only help researchers understand the dynamics of basic emotion elements, it can also bring an entirely new perspective into the relationship between psychopathology and creativity.

Keywords: creativity, cognition, basic emotions, monoamine, core affect

OPEN ACCESS

Edited by:
Chang Liu,
Nanjing Normal University, China

Reviewed by:
Weiwen Wang,
Institute of Psychology (CAS), China
Jianhui Song,
University of Alberta, Canada

***Correspondence:**
Fushun Wang
fushun.wang@bswhealth.org;
13814541138@163.com
Jason H. Huang
jason.huang@bswhealth.org

Specialty section:
This article was submitted to Cognitive Science, a section of the journal Frontiers in Psychology

Received: *22 July 2018*
Accepted: *19 September 2018*
Published: *31 October 2018*

Citation:
Gu S, Gao M, Yan Y, Wang F, Tang Y-y and Huang JH (2018) The Neural Mechanism Underlying Cognitive and Emotional Processes in Creativity. Front. Psychol. 9:1924. doi: 10.3389/fpsyg.2018.01924

INTRODUCTION

Creativity is regarded as a multidimensional entity, which is related to both cognition and emotion: the two major mental processes, which interact with each other to form psychological phenomena (Sahin et al., 2016; He et al., 2018). The relationship between creativity and cognition (or intelligence) has been of great interest to researchers since the late 1900s, and the major theoretical and practical findings are that creativity and intelligence are overlapping constructs; intelligence is a necessity but not a sufficient condition for creativity. In addition, some psychologists found that the correlation between creativity and intelligence is very low; some researchers believe that extremely high intelligence negatively affects creativity. Therefore, emotion may play an even more important

role in the process. The pervasive idea that creativity is intricately linked to emotion is due to the fact that individuals with affective disorders often exhibit extraordinary levels of creativity in various spheres of life (Holm-Hadulla, 2013; Leung et al., 2014; MacCabe et al., 2018), especially in some famous artists, for example Goethe, the poet (Holm-Hadulla et al., 2010; Holm-Hadulla, 2013). The reason may be that emotion is the major driving force for almost all creativities (Damasio and Carvalho, 2013). According to insights from Freud and Weber, it was found that people could produce more creative artwork such as sculptures or poems when they were forced to suppress their anger, possibly due to sublimation (Kim et al., 2013). Emotion can also affect creativity through obsessive thinking, which is often associated with childhood adversity (Arnsten, 2007; Thomson and Jaque, 2018). Although people with early exposure to childhood adversity experience greater negative effects, they are also endorsed with positive creative performance experiences (Thomson and Jaque, 2018). Creativity, in turn, may be used to modulate negative emotions. Results showed that flexibility, creativity, risk-taking, and complexity are negatively correlated with anxiety and that insight reappraisal can induce insight experience, enhance cognitive changes, and reduce negative emotional responses (Chiu et al., 2018). It is not surprising that creativity plays an important role in reappraisal, which is a well-recognized and widely adopted emotional regulation strategy (Wu et al., 2017). However, even though creativity is thought to be closely related to emotion, there are few studies about its dependence on emotion because of the complexity of emotional studies.

Emotion may be involved in the process of creativity through other "names," such as unconscious thought (Friis-Olivarius et al., 2017), motivation (Oriol et al., 2016), or personality (Feist, 1998; Chiu et al., 2018). For example, Wallas (1926) studied the cognitive process of creativity (Wiggins et al., 2015) and identified four parts in sequence: (1) preparation, in which the creative goal is identified and considered; (2) incubation, during which conscious attempts at creativity are not made; (3) illumination, the moment of enlightenment when an idea appears in conscious awareness, sometimes called the "Aha!" moment; and (4) verification, in which the new idea is applied (Wiggins et al., 2015). Ward (2003) described incubation as a time when unconscious behavior takes over, which allows for unique connections to be made without consciously trying to make logical order out of the problem. Furthermore, Helie and Sun (2010) proposed a unified framework of explicit-implicit interaction theory for understanding creativity. This theory analyzed five basic principles between explicit thinking and implicit thinking and concluded that creativity encompasses both conscious and unconscious incubation and insight. Emotion can affect creativity through personality too. For example, some researchers took the social-personality approach to measure creativity, like self-confidence, aesthetic orientation, risk-taking, or independent thinking. The most important parts of personality associated to creativity are related to emotion, such as openness, self-acceptance, hostility, and impulsivity.

In reality, emotion is never absent in all the four processes, but how emotion is involved is still a complicated issue. One of the reasons is explained by what Damasio said, emotion is one of the least-studied biological phenomena (Damasio and Carvalho, 2013). Wallas considered creativity to be a legacy of the evolutionary process, which allowed humans to rapidly adapt to rapidly changing environment. Simonton (1999) provided an updated perspective on this view in his book, *Origins of genius: Darwinian perspectives on creativity*. Similarly, basic emotions are genetically hardwired and highly conserved throughout evolution, and these emotions exhibit certain functional and adaptive properties that are shared across a wide phylogenetic range. Here, we explore the relationship between emotions and creativity by studying basic emotions. According to our previous studies, there are four basic emotions: joy, sadness, fear, and anger (Gu et al., 2016). These four basic emotions are the primary emotions, which we coined as the **Three Primary Color model**. In this model, we put the three monoamine neuromodulators in a plane: dopamine-joy, norepinephrine-surprise, and serotonin-dislike. This model is very simple, and it can be used as a tool to investigate the dynamics of basic emotions, the etiology of affective disorders such as depression, and their relations with creativity.

THE BASIC EMOTIONS

The main reason for the lack of studies about emotion in creativities may be that emotion is a rather complicated subject. To make complicated things simple, the easiest way to study emotion is possibly by studying the basic emotions. The central idea of basic emotion theory is that human nature constitutes a group of qualitatively distinct emotions (Russell, 2006). Basic emotions are thought be innate and universal and have evolved through their adaptive value with fundamental life tasks (Ekman, 1992); similarly, most creative art forms can find their evolutionary origins (Wiggins et al., 2015). Ekman (1992) proposed that basic emotions have a number of characteristics, which distinguish one emotion from another, such as universal signals, distinctive physiology, and automatic appraisal influenced by both ontogenetic and phylogenetic past. A summary of the studies about basic emotions were shown in a paper by Clore and Ortony (2013), which shows that most studies recognize six **classic** basic elements of emotion: happy, surprise, afraid, disgust, angry, and sad. Interestingly, a recent paper studied people's facial expressions, and the research found that disgust and anger shared a wrinkled nose and fear and surprise share raised eyebrows (Jack et al., 2014). Therefore, it is concluded that we humans have four **basic** elements of emotion: happy, sad, fear/surprise, and angry/disgust, and these four emotions are the basic building blocks from which we develop our modern, complex, and emotional stews (Jack et al., 2014). Consistently, several other papers also proposed four basic elements for emotion: fear, anger, happiness, and sadness (Gu et al., 2015, 2016; Wang and Pereira, 2016; Zheng et al., 2016).

CORE AFFECTS

The best way of studying basic emotions is to place them in dimensions. Russell and Barrett referred to several theoretical emotional studies and concluded that all basic emotions can be arranged in a circumplex (Weierich et al., 2010). The circumplex is defined as a circular arrangement of basic emotions around two independent, bipolar dimensions: hedonic (pleasure–displeasure) value and arousal (rest-activated) value. These two dimensional features are taken to be essential features of all emotions (Gu et al., 2016) and can be named as "core affects" (Russell, 2003; Salzman and Fusi, 2010). The horizontal dimension of the circumplex is the core affect *hedonic value* and the vertical dimension is *arousal value* (**Figure 1**; Posner et al., 2005). The different location of each emotion means that different emotions have different "amounts" of *hedonic* (including *pleasure–displeasure*) *value* and *arousal* (*rest-activated*) *value*, which are characteristic parameters to define basic emotions.

Many different names have been given to the horizontal dimension, such as liking, valence, hedonic tone, and many other identical items, since Wundt first introduced the dimension (Gu et al., 2015). The arousal dimension has been given to the vertical dimension, for it is related to the arousal states of the body. It depends on whether something happens in unexpected ways or not (Zheng et al., 2016). Similar to what Barrett (2006) proposed, "Arousal is associated with the uncertainty regarding whether a stimulus will predict threat of reward, the need to pay more attention to a stimulus of importance, or urgency to engage in active coping".

These core affects (valence and arousal) of emotions are due to features of stimuli (the *hedonic value and safety value*) (Zheng et al., 2016; **Figure 1**). According to appraisal theory of emotion, emotions result from people's interpretations and explanations of their circumstances. Arnold wanted to "introduce the idea of emotion differentiation by postulating that basic emotions such as fear, anger, and joy could be distinguished by different excitatory phenomena." In her pioneering studies about "cognitive theory" in the 1960s, Arnold specified that the first step in emotion is an appraisal of the situation. The individual has evolved an evolutionary safety check for the stimulus when it first arrives. If the individual senses danger, he will be scared and will fight or flee for survival. Later, if the individual feels it is safe, he will have a secondary check to see if it fits the individual's need, then the organism will be happy or sad. In the circumplex, the locations of the four basic emotions (happy, sad, fear, and angry) are very typical: fear and anger are on top of the vertical dimension, whereas happiness and sadness are on the two opposite sides of the horizontal dimension (**Figure 1**). These typical locations of the four basic emotions suggest that the four basic emotions have different parameters: happiness and sadness are due to the hedonic value of a stimulus (needs), whereas fear and anger depend on the safety value of a stimulus (safety needs) (Gu et al., 2016). These typical features may be the reasons for them to be basic emotions. Complex emotions are mixed with basic emotions, with different amounts of hedonic value and safety value of a stimulus; for example, surprise (fear or anger) + happiness can induce enthusiasm (Arnott and Elwood, 2009) or surprise (fear or anger) + sadness may induce disappointment (**Figure 2**).

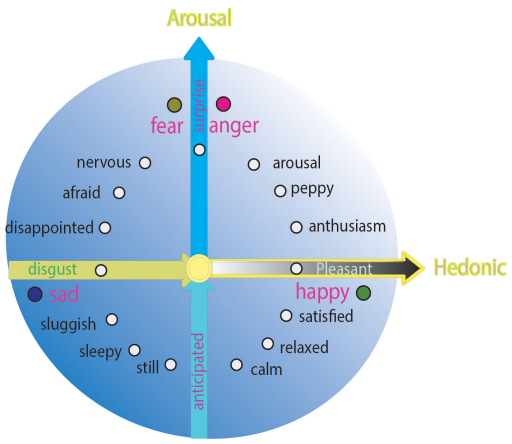

FIGURE 1 | Circumplex model of emotions. One example of self-report datum about circumplex model. All emotions, including the basic emotions can find their locations in the circle of the circumplex.

NEUROMODULATORS FOR BASIC EMOTIONS

With the development of drugs for affective disorders, catecholamine and serotonin have been regarded as the neural substrates for emotion, ever since the 50–60s of the last century (Schildkraut and Kety, 1967). Later on, dysfunctions of the monoamine system proved to be the substrates of many mental disorders such as depression, post-traumatic disorders, and attention-deficit hyperactivity disorder (Dougherty et al., 1999). Most of the first-line antidepressant and anti-psychotic

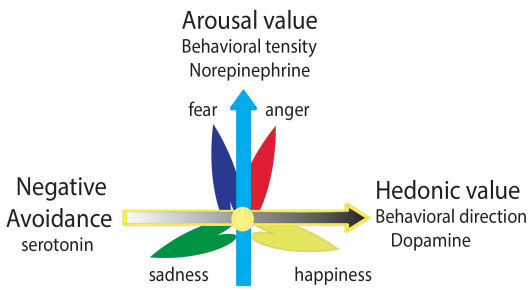

FIGURE 2 | Two dimensional model of basic emotions. Emotions can be induced by two affective qualities of a stimulus: the valence of the stimulus and the way the stimulus occurs. Horizontal dimension shows the valence of the stimulus, which means the hedonic quality of a stimulus or situations when they fit into personal needs (pleasant–unpleasant). Vertical dimension shows how the way a stimulus or situations occur, which means unexpected or uncertainty.

drugs target the monoamine system. Monoamine neuromodulators have a big advantage to work as substrates for the basic emotions: they affect both the peripheral nervous system and the central nervous system. The brain areas that release the monoamine are the ventral tegmental area, locus coeruleus (LC), and raphe nuclei. These monoamine producing systems project their axons and release these neuromodulators diffusely and widely throughout the cerebral cortex (Lovheim, 2012).

Monoamine neuromodulators are proposed to be substrates for the basic emotions: dopamine-pleasant, serotonin-displeasant, and norepinephrine-arousal (Lovheim, 2012; Gu et al., 2016; Wang and Pereira, 2016), like the three primary colors (**Figure 3**). However, even though numerous studies from different fields support the notion that all three monoamines are involved in affective diseases, their effects are still mixed. For example, antidepressant drugs affect almost all the monoamine neuromodulators and are also used for almost all affective diseases such as anxiety, phobia, depression, etc. There is a need to improve the conceptualization and classification of the emotional states and the neuromodulators. Here, we try to differentiate their functions in controlling emotion and behavior, and a new hypothesis about monoamines and emotions is introduced: three monoamine neuromodulators underlie the three core affects (dopamine-reward, serotonin-punishment, and norepinephrine-surprise); they work together to make different basic emotions, like the three primary colors. The dopamine (DA) system has been proved to be involved in reward (Bressan and Crippa, 2005; Haber and Knutson, 2010; Diana, 2011), the noradrenaline system has been related to the "fight or flight" responses at stressful events (Herrmann et al., 2004; Benarroch, 2009), and the serotonin system seems to be related to punishment (Tops et al., 2009). Their roles in creativities are also important.

Dopamine-Reward

Brain mesolimbic DA has long been linked to the rewarding processes in the brain ever since Wise (1980) first proposed the hedonic hypothesis of DA and proposed that DA is a signal of stimulus salience, providing the feeling of enjoyment (Bergamini et al., 2016). From then on, numerous studies have supported DA's role in the rewarding signals for food, sex, and other needs, which are often stimulated by reward seeking behaviors (Frank et al., 2016). Many pharmacological and behavioral studies on intracranial self-stimulation have established the important role of the medial prefrontal DA system in reward behavior. As a result, the term DA has been widely used synonymously with reward or happiness.

FIGURE 3 | Three primary color models of basic emotions. The four basic emotions: fear-anger, joy, sad, or three core affects are subsided by the release of three monoamine neuromodulators (norepinephrine-stress, dopamine-reward, and serotonin-punishment).

Norepinephrine – Surprise

Novelty, either real or perceived, to the organism, can induce robust norepinephrine release, and the brain norepinephrine system is well known to be activated by surprise or novelty (Morilak et al., 2005; Gu et al., 2015, 2016). Following exposure to novel signals, norepinephrine is released from the LC to the brain cortex and to almost all other limbic areas, such as the hypothalamus (Birnbaum et al., 1999; Leonard, 2001; Morilak et al., 2005; Barbieri et al., 2015). Even though the LC is very small, the axons of these neurons project to essentially the whole brain and potentially influence the entire nervous system. Both electrophysiological and neurochemical studies have shown that the brain LC is robustly activated by unexpected events (Ma and Morilak, 2005; Bott-Flügel et al., 2011), and norepinephrine release is determined by the salience of the stimulus. Novelty is a key feature of creativity (Wiggins et al., 2015), and it is proposed that the attribution of creativity entails the attribution of novelty; also, human creative drive is the search for novelty (Wiggins et al., 2015).

Serotonin – Punishment

Serotonin plays a critical role in a wealth of psychiatric conditions, such as depression, manic anxiety, and obsessive compulsions. However, despite the importance of serotonergic pharmacotherapies, particularly selective serotonin reuptake inhibitors, their roles in normal emotion are still mysterious (Dayan and Huys, 2008). More than 20 years ago, Deakin and Graeff hypothesized that different serotonin pathways act in response to aversive stimuli, such as through opposition of DA (Dayan and Huys, 2008), and the dysfunction of these pathways contributes to the pathophysiology of anxiety and affective disorders (Deakin and Graeff, 1991). Later, many studies have related serotonin to punishment, for example, Robinson showed that "serotonin is critical for punishment-induced inhibition" (Crockett et al., 2009, 2012; Robinson et al., 2012). Dayan concluded that "At a global level, serotonin is richly involved in the behavioral neuroscience of punishment and threat" (Dayan and Huys, 2009). As for creativity, the aesthetic is sometimes comfortable to the author, but sometimes it is utterly incomprehensible and even offensive to some observer, which might be a punishment aspect of the art.

RELATIONSHIP WITH CREATIVITY

Pleasure and arousal are the core affects of emotion. Izard (2009) suggested, "core affect" is not, in and of itself, a mental state of

emotion; instead, it is just a feature of emotion. By his report, arousal is associated with the uncertainty regarding whether a stimulus will predict threat of reward, the need to pay more attention to a stimulus of importance, or an urgency to engage in active coping. Emotions are both tendencies of actions as well as consequences of actions; therefore, actions, including creativity, have many elements, which are similar to the features of emotion. For example, the core features of emotions (arousal and reward and/or punishment) are similar to the core features of creativity (novelty and value).

Value and Novelty Are Two Basic Quantities of Creativity

By combining these emotional studies, we set out to explore the relationship between basic emotions and creativity. Konrad Lorenz and Nikolaas Tinbergen, the founders of modern neuroethology, revealed that **animal behaviors are expressions of some innate drives or instincts** (Asahina, 2017). It is proposed that animal behaviors, from egg-rolling in geese to the honeybee waggle dance, are executed by genetically programmed neural circuits that are triggered by specific sensory stimuli (Perry et al., 2016). Creativity is a type of human behavior, which is an expression of human innate states. In Western societies, "creativity" is most commonly used to refer to the embodied cognitive process that gives rise to pieces of music, sculptures, paintings, poems, and other accomplishments that are taken or presented as art. Value and novelty are the two basic simple quantities of art (Wiggins et al., 2015; **Figure 4**), and they are two major characteristics of creativity. Also, it is certainly true that creative people tend to seek novel stimuli over familiar or simple stimuli (Reuter et al., 2005). This is similar to the core affects of emotions (hedonic value and arousal value).

Value

The core affects of pleasure and arousal are due to stimulation effects on the subjects. Consistently, value and novelty of creativity are not two discrete kinds of creativity; instead, they are relations between observers and the created artifact (Wiggins et al., 2015). Value is dependent not only on the observer but also on the context in which the observation is made (Wiggins et al., 2015). Value is not only a characteristic of creativity, it is also present in many more pursuits apart from the artistic ones mentioned above (Wiggins et al., 2015). A prime example is mathematics, where the creation of the proof of a theorem is more highly valued if it is "elegant," according to the principles of the particular branch of mathematics to which it applies. Evolutionarily, **value** is anything that is elegantly coping with the situation. This is consistent with Lazarus's appraisal theory of emotions (Wang et al., 2018).

Richard Lazarus followed closely with Magda Arnold in the research of emotions through cognitive appraisal. Lazarus specified two major types of appraisals: (1) primary appraisal, directed at the establishment of the significance or meaning of the event to the organism and (2) secondary appraisal, directed at the assessment of the ability of the organism to cope with the consequences of the event. These two types of appraisals go hand in hand as one establishes the importance of the event. The first appraisal is related to harm and threat and induces fearful emotion to motivate avoidance and withdrawal. The second appraisal is conscious and concerned with coping (Lazarus, 1999; Zheng et al., 2016). Both fear and anger are due to unexpected stressful events (also see **Figure 5**; Zheng et al., 2016); fear is associated with feelings of uncertainty, whereas anger is associated with coping with stressful situations (Moons et al., 2010). After coping with stressful situations, Lazarus proposed a certain type of cognitive reappraisal processes, which included positive reappraisal (happy or rewarding emotions will be induced) and negative reappraisal (sad or punishing emotions will be induced and negative reappraisal (sad or punishing emotions will be induced) (Aldwin, 1994; Lazarus, 1999). If the organism can cope successfully with the stressful situation, the organism will then show positive emotions and be happy. Otherwise, the organism will experience negative emotions and be sad (Wang et al., 2017). Therefore, we propose that the emotion **joy is due to positive reappraisal: coping successfully**. This can also be reflexed on the value of creativity, in that creativity is the smartest way to

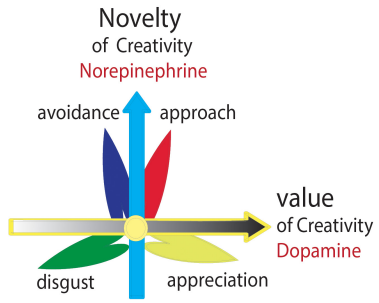

FIGURE 4 | Two features of creativity. Value and novelty are two basic quantities of arts, similar to hedonic value and arousal value of core affects, which are subsided by the release of two catecholamine neuromodulators (norepinephrine-stress, dopamine-reward).

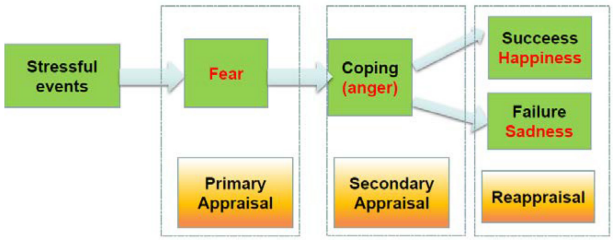

FIGURE 5 | Stress induced emotion flow. Like Lazarus suggested, there are two kinds of appraisals, the primary appraisal is to find the fearful situation, and the secondary appraisal to find the ability to cope with the situation. Fear is due to the first appraisal, and anger is due to the secondary appraisal. And afterwards, there will be reappraisal, which includes emotion based rethinking positively/negatively about the situation. Stress–Fear–Response (anger)–Consequences (happiness or sadness) constitute the emotional flow in our everyday lives. Similarly, creativity value is due to successfully coping with the situation.

deal with difficult situations in life. Altogether, *the happy emotion and creativity value are both due to the successful coping with the situation*.

Novelty

Novelty is another key feature of creativity. In Western culture, as we have articulated above, the attribution of creativity entails the attribution of novelty–various authors have argued that the human creative drive is the search for novelty (Justin and Sloboda, 2010). Huron proposed that it is appropriate for an animal to be alert and prepared for fight or flight in the face of novel circumstances, because the outcome of a novel experience is sometimes dangerous (Huron, 2006). Research based on physiological and behavioral measures in human responses to live music also found that the unexpectedness value of pitch can induce a significant part of the variance in physiological measures (heart rate, skin conductivity, etc.) that correspond with arousal (Salzman and Fusi, 2010). This constitutes evidence that unexpectedness in music correlates with arousal in listeners (Wiggins et al., 2015). Huron suggested that tension, thus, stimulated by expectation is in large part responsible for affects stimulated by Western music, whose emotive content is frequently in theory conceived as an ebb and flow of tension of various types. This affective experience is highly valued and, altogether, more subtle and dynamic than the common labeling of emotional analysis of music as "tender," "sad," etc. (Justin and Sloboda, 2010). Weiss et al. found that when nightingales heard a playback consisting of song types with branch transition patterns, they responded with song types that had bottleneck transition patterns. Conversely, when they heard song types with bottleneck transition patterns, they responded with song types that tended to be branching transitions in their population; that is, they responded with the unexpected (Justin and Sloboda, 2010).

NEUROMODULATORS FOR CREATIVITY

Monoamine neuromodulators are substrates of basic emotions. So, what are their potential roles in creativity?

Value-Dopamine

The hedonic hypothesis of DA postulates that DA in the brain plays a critical role in the subjective pleasure associated with positive reward. However, several complications in recent DA studies have opened this theory to debate and reexamination (Berridge and Kringelbach, 2015). The incentive salience hypothesis was recently introduced, which suggested that the major function of DA is not only to mediate the unconditioned pleasures from food, sex, and drugs but is also linked to the anticipatory, preparatory approach or the coping phases of reward behavior (Sandoval and Seeley, 2017) and in the relations of DA neuron to the reward outcome (Schultz et al., 1997). This hypothesis is highly consistent with Lazarus's (1999) reappraisal theory about happiness or sadness: *the happy and sad emotions are related to the success or failure to cope with stressful situations* (Wang et al., 2018).

This is really the case for DA neurons. Schultz screened the controlling process in great detail and found that DA release is the highest during the learning process. He suggested the name *predication error* for the learning process (Schultz et al., 1997; Eshel et al., 2016). It appears that learning is driven by deviations or "errors" between the predicted time and amount of rewards. Schultz et al. (1997) proposed that DA encodes expectations about external stimuli or reward, especially when it is uncertain or there is a deviation or error (predication error). *Therefore, DA release is not determined by rewarding stimuli or aversive stimuli. Instead, it is determined by the outcome of whether the coping process is successful or not*. Altogether, the DA system is a reward process, which is determined by the coping process (Cabib and Puglisi-Allegra, 1994; Spreux-Varoquaux et al., 2001).

The value of an art is the interaction between production and (probably, at least initially, introspective) evaluation by an artist, and then by a social community, that identifies relative value and relative novelty, of both the artifact and the way it was made. Margaret Boden makes another, perhaps more tractable, distinction between psychological creativity–the act of generating an artifact that is novel and of value to an individual–and historical creativity–the act of generating an artifact that is novel and valued in historical terms. Consistently, reward will in turn affect creativity. It is found that creativity-contingent rewards tend to increase creative performance, and these rewards are more positively related to creative performance when individuals are given more positive, contingent, and task-focused performance feedbacks and are provided more choice. In contrast, performance-contingent or completion-contingent rewards tend to have a slight negative effect on creative performance (Byron and Khazanchi, 2012).

Novelty-Norepinephrine

Stress results from real or perceived threat to the homeostasis or well-being of the human being (Zheng et al., 2016), and it is due to the uncertainty about the situation. Stress can activate the norepinephrine/locus coeruleus (NE/LC) system, which induces fight or flight behaviors and fear and anger emotions. Darwin descried two primary mechanisms of selection as the driving forces of biological evolution, natural selection, and sex selection. The critical elements for natural selection are variations in traits, while sexual selection can be viewed as a special case of natural selection, which acts on an individual's ability to mate, such as fighting. Biologists have investigated a variety of modes of sexual selection for mate choice. The simplest selection will be for a character that provides a direct benefit, such as if a female bird chooses a male whose genes produced a tail of the optimal size for fighting (Justin and Sloboda, 2010). Creative behavior can also result in sexual selection, for example, learning to weave a beautiful nest by the male weave-birds can give them a better chance to mate. Altogether, emotion can drive creativity through an attentional style driven by novelty salience (Carson, 2011). Internal rewards for seeking novelty may provide creative people with intrinsic motivation and intellectual curiosity (Schweizer, 2006). In addition, creative people tend to seek novelty; therefore, the character of novelty-seeking may be an incentive for creative work (Carson, 2011).

Serotonin-Inhibition

When an individual fails to cope with a stressful situation, serotonin will be released (Chaouloff et al., 1999). Serotonin is correlated positively with aversion and negatively with reward. This effect can also be demonstrated by serotonin's analgesic properties, and in fact, selective serotonin reuptake inhibitors taken chronically have an important role in the clinical management of chronic and neuropathic pain (Dayan and Huys, 2008). Numerous studies have found that serotonin is linked to aversive conditioning, reward suppression, and behavioral inhibition (Dayan and Huys, 2009). Therefore, serotonin has a major behavioral effect on suppression, inhibition, or freezing. Decreased inhibition is associated with increased creative achievement (Carson et al., 2003). Decreased inhibition increasing creativity may work through the disinhibition of hyperconnectivity, which is an abnormal neural linking of brain areas that are not in general functionally connected (Carson, 2011). Hyper-connectivity has been reported in the brains of highly creative subjects during creativity tasks, which may provide the neurological mechanism for remote associations between stimuli that are the basis for creative thought.

CREATIVITY AND PSYCHOPATHOLOGY

Despite the fact that creativity is a highly valued trait and viewed as an aspect of self-actualization, the possibility of creative people to suffer from psychosis has been noted ever since the ancient times. Many biographies and empirical studies have found that creativity has been associated with psychopathology. For example, it was found that more than 80% of the writers had suffered from mood disorder, which is four times higher than that of the control (Carson, 2011). The major reason is that *shifts of mental states associated with mood dysfunction can facilitate creativity*. Genetic vulnerability factors related to the functioning of DA and serotonin in the prefrontal brain and subcortical brain are the major reasons that predispose certain people to experience altered mental states (Carson, 2011). These altered emotional states may manifest in these people as severe psychopathology or as creative ability (Carson, 2011). Molecular genetic studies have begun to hone in on a set of genes, most of them are related to NE, DA, and serotonin transmission that are associated with both creativity and mood disorders (Carson, 2011). For example, several genes that are related to DA, including *DRD4*, *SLC6A3*, and *Taq1A*, have been linked to both risks of schizophrenia and bipolar disorder as well as novelty seeking in creativity. Catechol-O-methyltransferase (COMT), an enzyme responsible for degrading catecholamine, including DA and NE, has been implicated in schizophrenia and many mental disorders, and it has also been associated with creativity.

CONCLUSION

Creativity is considered a positive personal trait; however, highly creative people often demonstrate elevated risks for certain forms of psychopathology, such as mood disorders. How emotion affects creativity is still not entirely clear. Here, we offered a model to explain the relationship between creativity and emotion. This model, supported by recent findings from neuroscience and molecular genetics, suggested that the hyper-functions of neuromodulators (or hypo-function) confer the emotional pathology and also enhance creative ideation. These dysfunctions of neuromodulators might induce both mood disorders and creativity, via cognitive disinhibition, attentional style driven by novelty salience, and neural hyper-connectivity that might increase associations among disparate stimuli.

The mechanism of this model lies in that neuromodulators, including NE and DA, are the neural basis for both creativity and basic emotions, and their dysfunction can offer motivation and novelty seeking as well as hyper-connectivity for the brain. Structurally, values and novelty, determined by NE and DA, are key features for both creativity and basic emotions. Functionally, emotion flow follows a pathway: fear–anger–joy–sadness at stressful situations, which is similar to the process of creativity (which follows a procedure of preparation, incubation, illumination, sometimes called the "Aha!" moment, and verification). Altogether, this model will not only be helpful in better understanding the dynamics of basic emotions, it can also bring a brand new perspective in creativity.

AUTHOR CONTRIBUTIONS

SG, FW, and JH designed the work. SG, FW, JH, and Y-yT did the writing. MG and YY helped with drafting the figure and did some revisions for the work.

FUNDING

This work was supported by the Scott & White Plummer Foundation Grant (JH), National Science Foundation in China 816280007 (JH and FW), Jiangsu Nature Foundation BK20151565 (FW), Jiangsu Traditional Chinese Medicine Foundation ZD201501 (FW), Jiangsu Six Talent Peak project 2015YY006 (FW), and the University Science Research Project of Jiangsu Province 17KJD310001 (SG).

REFERENCES

Aldwin, C. M. (1994). *Stress, Coping, and Development*. New York, NY: The Guilford Press.

Arnott, G., and Elwood, R. (2009). Probing aggressive motivation in a cichlid fish. *Biol. Lett.* 5, 762–764. doi: 10.1098/rsbl.2009.0526

Arnsten, A. F. (2007). Catecholamine and second messenger influences on prefrontal cortical networks of "representational knowledge": a rational

bridge between genetics and the symptoms of mental illness. *Cereb. Cortex* 17(Suppl. 1), i6–i15. doi: 10.1093/cercor/bhm033

Asahina, K. (2017). Neuromodulation and strategic action choice in drosophila aggression. *Annu. Rev. Neurosci.* 40, 51–75. doi: 10.1146/annurev-neuro-072116-031240

Barbieri, A., Bimonte, S., Palma, G., Luciano, A., Rea, D., Giudice, A., et al. (2015). The stress hormone norepinephrine increases migration of prostate cancer cells in vitro and in vivo. *Int. J. Oncol.* 47, 527–534. doi: 10.3892/ijo.2015.3038

Barrett, L. F. (2006). Solving the emotion paradox: categorization and the experience of emotion. *Pers. Soc. Psychol. Rev.* 10, 20–46. doi: 10.1207/s15327957pspr1001_2

Benarroch, E. E. (2009). The locus ceruleus norepinephrine system: functional organization and potential clinical significance. *Neurology* 73, 1699–1704. doi: 10.1212/WNL.0b013e3181c2937c

Bergamini, G., Sigrist, H., Ferger, B., Singewald, N., Seifritz, E., and Pryce, C. R. (2016). Depletion of nucleus accumbens dopamine leads to impaired reward and aversion processing in mice: relevance to motivation pathologies. *Neuropharmacology* 109, 306–319. doi: 10.1016/j.neuropharm.2016.03.048

Berridge, K. C., and Kringelbach, M. L. (2015). Pleasure systems in the brain. *Neuron* 86, 646–664. doi: 10.1016/j.neuron.2015.02.018

Birnbaum, S., Gobeske, K. T., Auerbach, J., Taylor, J. R., and Arnsten, A. F. (1999). A role for norepinephrine in stress-induced cognitive deficits: alpha-1-adrenoceptor mediation in the prefrontal cortex. *Biol. Psychiatry* 46, 1266–1274. doi: 10.1016/S0006-3223(99)00138-9

Bott-Flügel, L., Bernshausen, A., Schneider, H., Luppa, P., Zimmermann, K., Albrecht-Küpper, B., et al. (2011). Selective attenuation of norepinephrine release and stress-induced heart rate increase by partial adenosine A1 agonism. *PLoS One* 6:e18048. doi: 10.1371/journal.pone.0018048

Bressan, R. A., and Crippa, J. A. (2005). The role of dopamine in reward and pleasure behaviour–review of data from preclinical research. *Acta Psychiatr. Scand.* 111, 14–21. doi: 10.1111/j.1600-0447.2005.00540.x

Byron, K., and Khazanchi, S. (2012). Rewards and creative performance: a meta-analytic test of theoretically derived hypotheses. *Psychol. Bull.* 138, 809–830. doi: 10.1037/a0027652

Cabib, S., and Puglisi-Allegra, S. (1994). Opposite responses of mesolimbic dopamine system to controllable and uncontrollable aversive experiences. *J. Neurosci.* 14, 3333–3340. doi: 10.1523/JNEUROSCI.14-05-03333.1994

Carson, S. H. (2011). Creativity and psychopathology: a shared vulnerability model. *Can. J. Psychiatry* 56, 144–153. doi: 10.1177/070674371105600304

Carson, S. H., Peterson, J. B., and Higgins, D. M. (2003). Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *J. Pers. Soc. Psychol.* 85, 499–506. doi: 10.1037/0022-3514.85.3.499

Chaouloff, F., Berton, O., and Mormede, P. (1999). Serotonin and stress. *Neuropsychopharmacology* 21(2 Suppl.), 28S–32S. doi: 10.1016/S0893-133X(99)00008-1

Chiu, F. C., Hsu, C. C., Lin, Y. N., Liu, C. H., Chen, H. C., and Lin, C. H. (2018). Effects of creative thinking and its personality determinants on negative emotion regulation. *Psychol. Rep.* doi: 10.1177/0033294118775973 [Epub ahead of print].

Clore, G. L., and Ortony, A. (2013). Psychological Construction in the OCC Model of Emotion. *Emot. Rev.* 5, 335–343. doi: 10.1177/1754073913489751

Crockett, M. J., Clark, L., and Robbins, T. W. (2009). Reconciling the role of serotonin in behavioral inhibition and aversion: acute tryptophan depletion abolishes punishment-induced inhibition in humans. *J. Neurosci.* 29, 11993–11999. doi: 10.1523/JNEUROSCI.2513-09.2009

Crockett, M. J., Clark, L., Roiser, J. P., Robinson, O. J., Cools, R., Chase, H. W., et al. (2012). Converging evidence for central 5-HT effects in acute tryptophan depletion. *Mol. Psychiatry* 17, 121–123. doi: 10.1038/mp.2011.106

Damasio, A., and Carvalho, G. B. (2013). The nature of feelings: evolutionary and neurobiological origins. *Nat. Rev. Neurosci.* 14, 143–152. doi: 10.1038/nrn3403

Dayan, P., and Huys, J. M. (2008). Serotonin, inhibition and negative mood. *PLoS Comput. Biol.* 4:e4. doi: 10.1371/journal.pcbi.0040004

Dayan, P., and Huys, Q. J. (2009). Serotonin in affective control. *Annu. Rev. Neurosci.* 32, 95–126. doi: 10.1146/annurev.neuro.051508.135607

Deakin, J. F., and Graeff, F. G. (1991). 5-HT and mechanisms of defense. *J. Psychopharmacol.* 5, 305–315. doi: 10.1177/026988119100500414

Diana, M. (2011). The dopamine hypothesis of drug addiction and its potential therapeutic value. *Front. Psychiatry* 2:64. doi: 10.3389/fpsyt.2011.00064

Dougherty, D. D., Bonab, A. A., Spencer, T. J., Rauch, S. L., Madras, B. K., and Fischman, A. J. (1999). Dopamine transporter density in patients with attention deficit hyperactivity disorder. *Lancet* 354, 2132–2133. doi: 10.1016/S0140-6736(99)04030-1

Ekman, P. (1992). An argument for basic emotions. *Cogn. Emot.* 6, 169–200. doi: 10.1080/02699939208411068

Eshel, N., Tian, J., Bukwich, M., and Uchida, N. (2016). Dopamine neurons share common response function for reward prediction error. *Nat. Neurosci.* 19, 479–486. doi: 10.1038/nn.4239

Feist, G. J. (1998). A meta-analysis of personality in scientific and artistic creativity. *Pers. Soc. Psychol. Rev.* 2, 290–309. doi: 10.1207/s15327957pspr0204_5

Frank, S., Veit, R., Sauer, H., Enck, P., Friederich, H. C., Unholzer, T., et al. (2016). Dopamine depletion reduces food-related reward activity independent of BMI. *Neuropsychopharmacology* 41, 1551–1559. doi: 10.1038/npp.2015.313

Friis-Olivarius, M., Hulme, O. J., Skov, M., Ramsoy, T. Z., and Siebner, H. R. (2017). Imaging the creative unconscious: reflexive neural responses to objects in the visual and parahippocampal region predicts state and trait creativity. *Sci. Rep.* 7:14420. doi: 10.1038/s41598-017-14729-7

Gu, S., Wang, F., Yuan, T., Guo, B., and Huang, H. (2015). Differentiation of primary emotions through neuromodulators: review of literature. *Int. J. Neurol. Res.* 1, 43–50. doi: 10.17554/j.issn.2313-5611.2015.01.19

Gu, S., Wang, W., Wang, F., and Huang, J. H. (2016). Neuromodulator and emotion biomarker for stress induced mental disorders. *Neural Plast.* 2016, 1–6. doi: 10.1155/2016/2609128

Haber, S. N., and Knutson, B. (2010). The reward circuit: linking primate anatomy and human imaging. *Neuropsychopharmacology* 35, 4–26. doi: 10.1038/npp.2009.129

He, L., Mao, Y., Sun, J., Zhuang, K., Zhu, X., Qiu, J., et al. (2018). Examining brain structures associated with emotional intelligence and the mediated effect on trait creativity in young adults. *Front. Psychol.* 9:925. doi: 10.3389/fpsyg.2018.00925

Helie, S., and Sun, R. (2010). Incubation, insight, and creative problem solving: a unified theory and a connectionist model. *Psychol. Rev.* 117, 994–1024. doi: 10.1037/a0019532

Herrmann, N., Lanctot, K. L., Eryavec, G., and Khan, L. R. (2004). Noradrenergic activity is associated with response to pindolol in aggressive Alzheimer's disease patients. *J. Psychopharmacol.* 18, 215–220. doi: 10.1177/0269881104042625

Holm-Hadulla, R. M. (2013). Goethe's anxieties, depressive episodes and (self-)therapeutic strategies: a contribution to method integration in psychotherapy. *Psychopathology* 46, 266–274. doi: 10.1159/000345169

Holm-Hadulla, R. M., Roussel, M., and Hofmann, F. H. (2010). Depression and creativity - the case of the German poet, scientist and statesman J. W. v. Goethe. *J. Affect. Disord.* 127, 43–49. doi: 10.1016/j.jad.2010.05.007

Huron, D. (2006). *Sweet Anticipation: Music and the Psychology of Expectation*. Cambridge, MA: MIT press.

Izard, C. E. (2009). Emotion theory and research: highlights, unanswered questions, and emerging issues. *Annu. Rev. Psychol.* 60, 1–25. doi: 10.1146/annurev.psych.60.110707.163539

Jack, R. E., Garrod, O. G., and Schyns, P. G. (2014). Dynamic facial expressions of emotion transmit an evolving hierarchy of signals over time. *Curr. Biol.* 24, 187–192. doi: 10.1016/j.cub.2013.11.064

Justin, P., and Sloboda, J. (2010). *Handbook of Musci and Emotion: Theory, Research, Applications*. Oxford: Oxford University Press.

Kim, E., Zeppenfeld, V., and Cohen, D. (2013). Sublimation, culture, and creativity. *J. Pers. Soc. Psychol.* 105, 639–666. doi: 10.1037/a0033487

Lazarus, R. S. (1999). *Stress and Emotion: A New Synthesis*. New York, NY: Springer Publishing Co.

Leonard, B. E. (2001). Stress, norepinephrine and depression. *J. Psychiatry Neurosci.* 26(Suppl.), S11–S16.

Leung, A. K., Liou, S., Qiu, L., Kwan, L. Y., Chiu, C. Y., and Yong, J. C. (2014). The role of instrumental emotion regulation in the emotions-creativity link: how worries render individuals with high neuroticism more creative. *Emotion* 14, 846–856. doi: 10.1037/a0036965

Lovheim, H. (2012). A new three-dimensional model for emotions and monoamine neurotransmitters. *Med. Hypotheses* 78, 341–348. doi: 10.1016/j.mehy.2011.11.016

Ma, S., and Morilak, D. A. (2005). Norepinephrine release in medial amygdala facilitates activation of the hypothalamic-pituitary-adrenal axis in response to

acute immobilisation stress. *J. Neuroendocrinol.* 17, 22–28. doi: 10.1111/j.1365-2826.2005.01279.x

MacCabe, J. H., Sariaslan, A., Almqvist, C., Lichtenstein, P., Larsson, H., and Kyaga, S. (2018). Artistic creativity and risk for schizophrenia, bipolar disorder and unipolar depression: a Swedish population-based case-control study and sib-pair analysis. *Br. J. Psychiatry* 212, 370–376. doi: 10.1192/bjp.2018.23

Moons, W. G., Eisenberger, N. I., and Taylor, S. E. (2010). Anger and fear responses to stress have different biological profiles. *Brain Behav. Immun.* 24, 215–219. doi: 10.1016/j.bbi.2009.08.009

Morilak, D. A., Barrera, G., Echevarria, D. J., Garcia, A. S., Hernandez, A., Ma, S., et al. (2005). Role of brain norepinephrine in the behavioral response to stress. *Prog. Neuropsychopharmacol. Biol. Psychiatry* 29, 1214–1224. doi: 10.1016/j.pnpbp.2005.08.007

Oriol, X., Amutio, A., Mendoza, M., Da Costa, S., and Miranda, R. (2016). Emotional creativity as predictor of intrinsic motivation and academic engagement in university students: the mediating role of positive emotions. *Front. Psychol.* 7:1243. doi: 10.3389/fpsyg.2016.01243

Perry, C., Baciadonna, L., and Chittka, L. (2016). Unexpected rewards induce dopamine-dependent positive emotion-like state changes in bumblebees. *Science* 353, 1529–1531. doi: 10.1126/science.aaf4454

Posner, J., Russell, J., and Peterson, B. S. (2005). The circumplex model of affect: an integrative approach to affective neuroscience, cognitive development and pshopathology. *Dev. Psychopathol.* 17, 715–734. doi: 10.1017/S0954579405050340

Reuter, M., Panksepp, J., and Schnable, N. (2005). Personality and biological markers of creativity. *Eur. J. Pers.* 19, 83–95. doi: 10.1002/per.534

Robinson, O. J., Cools, R., and Sahakian, B. J. (2012). Tryptophan depletion disinhibits punishment but not reward prediction: implications for resilience. *Psychopharmacology* 219, 599–605. doi: 10.1007/s00213-011-2410-5

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychol. Rev.* 110, 145–172. doi: 10.1037/0033-295X.110.1.145

Russell, J. A. (2006). Emotions are not modules. *Can. J. Philos.* 32, 53–71. doi: 10.1353/cjp.2007.0037

Sahin, F., Ozer, E., and Deniz, M. E. (2016). The predictive level of emotional intelligence for the domain-specific creativity: a study on gifted students. *Egit. Bilim* 41, 181–197.

Salzman, C., and Fusi, S. (2010). Emotion, cognition, and mental state representation in amygdala and prefrontal cortex. *Annu. Rev. Psychol.* 33, 173–202. doi: 10.1146/annurev.neuro.051508.135256

Sandoval, D., and Seeley, R. (2017). Physiology: gut feeling for food choice. *Nature* 542, 302–303. doi: 10.1038/nature21499

Schildkraut, J. J., and Kety, S. S. (1967). Biogenic amines and emotion. *Science* 156, 21–37. doi: 10.1126/science.156.3771.21

Schultz, W., Dayan, P., and Montague, P. R. (1997). A neural substrate of prediction and reward. *Science* 275, 1593–1599. doi: 10.1126/science.275.5306.1593

Schweizer, T. (2006). The psychology of novelty-seeking, creativity and innovation: neurocognitive aspects within a work-psychological perspective. *Creativ. Innovat. Manag.* 15, 164–172. doi: 10.1111/j.1467-8691.2006.00383.x

Simonton, D. K. (1999). *Origins of Genius: Darwinian Perspectives on Creativity*. Oxford: Oxford University Press.

Spreux-Varoquaux, S.-V. O., Alvarez, J. C., Berlin, I., Batista, G., Despierre, P. G., Gilton, A., et al. (2001). Differential abnormalities in plasma 5-HIAA and platelet serotonin concentrations in violent suicide attempters: relationships with impulsivity and depression. *Life Sci.* 69, 647–657. doi: 10.1016/S0024-3205(01)01158-4

Thomson, P., and Jaque, S. V. (2018). Childhood adversity and the creative experience in adult professional performing artists. *Front. Psychol.* 9:111. doi: 10.3389/fpsyg.2018.00111

Tops, M., Russo, S., Boksem, M. A., and Tucker, D. M. (2009). Serotonin: modulator of a drive to withdraw. *Brain Cogn.* 71, 427–436. doi: 10.1016/j.bandc.2009.03.009

Wallas, G. (1926). *The Art of Thought*. New York, NY: Harcourt, Brace & Company.

Wang, F., Pan, F., Lee, L. A., and Huang, J. H. (2017). Stress induced neuroplasticity and mental disorders. *Neural Plast.* 2017:9634501. doi: 10.1155/2017/9634501

Wang, F., Pan, F., Shapiro, L. A., and Huang, J. H. (2018). Stress induced neuroplasticity and mental disorders 2018. *Neural Plast.* 2018:5382537. doi: 10.1155/2018/5382537

Wang, F., and Pereira, A. (2016). Neuromodulation, emotional feelings and affective disorders. *Mens Sana Monogr.* 14, 5–29. doi: 10.4103/0973-1229.154533

Ward, T. (2003). *Encyclopaedia of Cognition*. New York, NY: Macmillan.

Weierich, M. R., Wright, C. I., Negreira, A., Dickerson, B. C., and Barrett, L. F. (2010). Novelty as a dimension in the affective brain. *Neuroimage* 49, 2871–2878. doi: 10.1016/j.neuroimage.2009.09.047

Wiggins, G., Tyack, P., Scharff, C., and Rohmeier, M. (2015). The evolutionary roots of creativity: mechanisms and motivations. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 370:2014099. doi: 10.1098/rstb.2014.0099

Wise, R. A. (1980). The dopamine synapse and the notion of 'pleasure centers' in the brain. *Trends Neurosci.* 3, 91–95. doi: 10.1016/0166-2236(80)90035-1

Wu, X., Guo, T., Tang, T., Shi, B., and Luo, J. (2017). Role of creativity in the effectiveness of cognitive reappraisal. *Front. Psychol.* 8:1598. doi: 10.3389/fpsyg.2017.01598

Zheng, Z., Gu, S., Le, Y., Wang, W., Li, Y., and Wang, F. (2016). Safety needs mediate stressful events induced mental disorders. *Neural Plast.* 2016:8058093. doi: 10.1155/2016/8058093

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 01 November 2018
doi: 10.3389/fpsyg.2018.01980

Person-Environment Fit and Employee Creativity: The Moderating Role of Multicultural Experience

Kaiqing Wang[1] and Yijie Wang[2]**

[1] Department of Sociology, Jiangsu Normal University, Xuzhou, China, [2] Department of Sociology, Hohai University, Nanjing, China

Previous research has demonstrated the positive effects of congruent personal and environmental characteristics on creativity. None of them, however, has tested the formal theory of person-environment fit for predicting creativity in the context of multicultural experiences. This study examined the effects of two versions of person-environment fit (Demands-abilities fit and Needs-supplies fit) on employee creativity in China, taking into account the moderating role of multicultural experiences. The results, based on the data of East Asian Social Survey in the Chinese General Social Survey (CGSS) in 2015, showed employees with demands-abilities fit have lower creativity than those with demands-abilities misfit; nevertheless, the demands-abilities fit creates a growing impact on employee creativity with increasing multicultural experience. Additionally, the higher the needs-supplies fit, the stronger the employee creativity; and, the needs-supplies fit creates a growing impact on employee creativity with increasing multicultural experience. It shows that different versions of person–environment fit have different effects on employee creativity and multicultural experience moderated the effects of person-environment fit on employee creativity. Implications for research and practice are discussed.

Keywords: person-environment fit, demands-abilities fit, needs-supplies fit, employee creativity, multicultural experience

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Cao Gui Kang,
Southwest University, China
Jilin Zou,
Linyi University, China

****Correspondence:***
Kaiqing Wang
wangkaiqing824@163.com
Yijie Wang
wangyj_73@163.com

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *13 June 2018*
Accepted: *26 September 2018*
Published: *01 November 2018*

Citation:
Wang K and Wang Y (2018) Person-Environment Fit and Employee Creativity: The Moderating Role of Multicultural Experience. Front. Psychol. 9:1980. doi: 10.3389/fpsyg.2018.01980

INTRODUCTION

With the development of economic globalization and modern science and technology, the world economy is marching from the era of industrialization toward that of knowledge economy, and the economic growth is increasingly driven by technological innovation. In this context, creativity has become dramatically pivotal to companies aspiring to gain advantages in an ever-increasingly competitive market environment (e.g., Amabile, 1988; Woodman et al., 1993; Shalley and Gilson, 2004; George and Zhou, 2007; Mumford, 2011). This is not only embodied in the fact that creativity is crucial to an organization's economic success (e.g., Geroski et al., 1993; Eisenhardt and Tabrizi, 1995), but that creativity conduces to improved organizational performance, such as crisis response capability (Tushman and O'Reilly, 1996), organizational planning capability (Mumford et al., 2008), teamwork spirit, and organizational citizenship (Amabile et al., 2004). Individual creativity has been the cornerstone and origin of creativity at all levels (Amabile, 1988; Woodman et al., 1993). For organizations, employee creativity plays a prominent role in organizational innovation

and boom (Amabile, 1996; Shalley et al., 2004). On that account, it is of paramount significance for the survival and boom of companies to probe into driving factors in employee creativity and its mechanism of action so as to motivate employee creativity, which has also become a principal topic for scholars.

Early research on creativity mainly focused on personalities (e.g., Barron and Harrington, 1981), cognitive processes (e.g., Sternberg, 1988; Schooler and Melcher, 1995), lifecycle rules, and individual factors (e.g., Simonton, 1990; Gardner, 1993). Nevertheless, creativity is not completely individualized but rather a function of individual and contextual factors (e.g., Woodman et al., 1993; Amabile, 1996; Amabile and Pillemer, 2012). An increasing amount of recent research has begun to explore creativity from the perspective of the interaction between individual factors and contextual ones (e.g., Oldham and Cummings, 1996; George and Zhou, 2001).

Most researchers usually select certain variables from individual and contextual factors to construct interaction terms, to which the approach can discover the relationship between specific variable combinations and employee creativity, but can hardly explain the relationship between creativity and the interaction between individuals and contexts as a whole (Wang and Sun, 2010). However, the viewpoint of person-environment fit (P-E fit) provides us with a path to explain the interaction between individuals and contexts at large (Livingstone et al., 1997). As the kernel of Organizational Behavioral Science, this viewpoint refers to the consistency, matching, and similarity between the person and the environment (see Edwards, 2008, for a review). Many studies have concentrated on the relationship between P-E fit and its types and employee attitudes and behaviors (e.g., Kristof-Brown et al., 2005b; Oh et al., 2014; Milliman et al., 2017), yet few has paid attention to P-E fit and employee creativity, and even few have focused on the positive impact of objective matching on employee creativity (e.g., Livingstone et al., 1997; Choi, 2004b; Du and Wang, 2009; Wang and Sun, 2010; Zhang and Long, 2013). In such case, what impacts will employees' perceived fit create on creativity?

People in different sociocultural environments may present diverse creative expression patterns (Kharkhurin, 2010). In other words, a specific sociocultural environment leads to discrepancies in employee creative activities (e.g., Simonton, 1975; Csikszentmihalyi, 1999; Chiu and Kwan, 2010). Many scholars have analyzed the differences in individual creativity under different cultural backgrounds from a cross-cultural perspective (e.g., Lubart, 1999; Paletz and Peng, 2008). This cross-cultural perspective holds that, due to different internal structures of diverse cultures, the unity of culture has been exaggerated, whereas the heterogeneity of culture has been ignored; therefore, focusing merely on the comparison of cultural similarities and differences has overlooked the inter-cultural interaction and dynamic process (Morris, 2014). In that way, nowadays with more and more diversified forms and approaches of cultural interaction, how will people's multicultural experience affect the relationship between person-environment and employee creativity? This is also one of the questions demanding an answer in this study.

LITERATURE REVIEW AND HYPOTHESES

Research on Person-Environment Fit

Contemporary P-E fit research is often traced to Parsons (1909) who developed a matching model to describe the fit between attributes of the person and characteristics of different vocations. Afterward, Murray's need-press model and Lewin's field theory lay a theoretical foundation for the research on P-E fit (see Edwards, 2008, for a review). For a long time, P-E fit has been discussed from the two perspectives of supplementary fit and complementary fit (Muchinsky and Monahan, 1987). Supplementary fit usually means that individuals and organizations have similarities in terms of goals, attitudes and values; for example, individuals and organizations deem that autonomy is of greater significance (Kristof, 1996). Complementary fit denotes that the resources owned by the individual or the organization are able to meet each other's needs; for example, the skills possessed by the individual meet the requirements of the organization, or the resources provided by the organization meet the needs of the individual (Cable and Edwards, 2004). That being the case, complementary fit can be divided into demands-abilities fit and needs-supplies fit (Caplan, 1987; Edwards, 1991; Kristof, 1996). Demands-abilities fit considers fit from the angle of the individual meeting the requirements of the organization, that is, the matching between the person and the organization occurs only when the individual has abilities the organization needs. Organizational requirements generally include job requirements, role expectations, organizational norms, and certain aptitudes, skills, time, and energy owned by the individual. Needs-supplies fit considers fit from the angle of the organization satisfying the requirements of the individual, that is, the matching between the person and the organization emerges only when the organization meets needs and preferences of the individual. Individual needs generally include innate biological and psychological needs, values, and achievement motives. Organizational supply refers to satisfying individual needs through internal and external resources such as food, money, social participation, and self-realization opportunities (e.g., Edwards et al., 1998; Cable and Edwards, 2004).

A large number of P-E fit studies center on changes in employee attitudes, physical and psychological responses, and behavior brought by various types of fit (see Kristof-Brown and Guay, 2011 for a review), such as job satisfaction (e.g., Livingstone et al., 1997), organizational commitment (e.g., Kristof-Brown et al., 2005a), organizational identification (e.g., Cable and DeRue, 2002), and work stress (e.g., Livingstone et al., 1997; Edwards and Shipp, 2007). As a result variable of P-E fit, creativity has also been attached importance by some researchers (Schneider et al., 1995; Tierney et al., 1999). One standpoint holds that person-environment interaction will lead to P-E fit, going with which the homogeneity of the person will enhance

as well; yet, the homogeneity may impede the divergent thinking of employees, thus undermining their creativity (Schneider et al., 1995). Another standpoint holds that P-E fit brings good psychological feelings to employees, which in turn leads to improvements in employee creativity (Tierney et al., 1999). It can thus be told that the relationship between P-E fit and creativity is inconclusive. Given that supplementary fit usually involves both the individual and the organization, and that this study places stress on the impact of employees' perceived fit on their creativity, this article looks back at length on the relationship between creativity and demands-abilities fit as well as needs-supplies fit, based on which research hypotheses have been put forward.

Demands-Abilities Fit and Employee Creativity

Considering that knowledge and skills are very crucial or fundamental antecedent variables in individual creativity (Amabile, 1988; Woodman et al., 1993; Ford, 1996), the kernel of demands-abilities fit tends to emphasize that the knowledge and skills of employees fulfill the requirements of their jobs (Edwards, 1996). In other words, knowledge and skills provide a set of cognitive pathways that individuals can follow to resolve a given problem or accomplish a given task (Amabile, 1988). The higher the employee's demands-abilities fit, the more knowledge and skills they acquire to satisfy job requirements; hence, it is easier for them to get rid of their conventional thinking modes. The multidimensional cognitive structure facilitates employees to leverage knowledge and skills more flexibly at work, thus constantly developing new ideas and put them in to practice (Boon et al., 2011).

On top of that, in accordance with the Social Cognitive Theory (Bandura, 1986), demands-abilities fit can motivate individuals to construct positive self-recognition during the work process and promote them to develop inherent driving forces based on implicitness and abilities (Lee and Antonakis, 2014). Integrating self-efficacy with creativity theory, Tierney and Farmer (2002) proposes the concept of creative self-efficacy, which refers to the individual's belief in his ability to creatively accomplish a specific task, embodying his confidence in demonstrating creative abilities and behavior during the work process. When individuals have the abilities to address specific problems and accomplish specific tasks, or when their capabilities exceed the requirements of the job, they believe that they can successfully adopt innovative thoughts and ideas to solve problems at work. On the contrary, when individuals' own abilities are unable to meet job requirements, they show little confidence in creativity (Choi and Price, 2005). Good self-efficacy stimulates creativity (Choi, 2004a). It can thus be seen that demands-abilities fit may produce an indirect effect on creativity through positive self-cognition (e.g., Choi and Price, 2005; Du and Wang, 2009; Wang and Sun, 2010; Zhang and Long, 2013). On account of the above analysis, Hypothesis 1 has been proposed.

> Hypothesis 1: Employees with demands-abilities fit have greater creativity than those with demands-abilities misfit.

Needs-Supplies Fit and Employee Creativity

Needs-supplies fit indicates whether the resources provided by the organization can meet the needs of employees. When the resources provided by the organization are the same as the resources employees expect from the organization, needs and supplies match up with each other (Edwards, 1996). In line with the Social Cognitive Theory, when the resources provided by the organization comply with individual needs of employees, they hold the organization is creating a positive working environment, under which they tend to have higher commitment and loyalty to the organization, and give organizations corresponding rewards based on the principle of exchange and reciprocity, thereby stimulating individual creativity (Wang and Sun, 2010). In addition to the principle of reciprocity, the perception of fairness in social exchanges also exerts an influence on employee creativity. When employees think that their efforts and rewards match, they will show more creativity (Janssen, 2000).

From the perspective of Motivational Theory, when employees' needs are met by the organization to a higher degree, they will have a lasting emotional input in work, show more sense of responsibility in the work process, and are willing to step up efforts, in order to fulfill the psychological needs of autonomy in internal motivations. Proactive work motives make them more willing to think hard in the work process and therefore more likely to pose new problems and come up with new solutions (Farzaneh et al., 2014).

A more painstaking study divides needs-supplies fit into two categories of internality and externality by its nature (Cable and Edwards, 2004). Internality refers to the matching between achievement motivation, self-realization, and values; whereas externality usually refers to material incentives provided by the organization. From this perspective, different aspects of needs-supplies fit produce diverse effects on creativity. When employees can obtain some resources from organizations, such as autonomy and decision-making power, they will express a higher level of creativity. In such research needs-supplies fit is internal (e.g., Shalley et al., 2000). Yet conclusions are inconsistent regarding the relationship between external material incentives and employee creativity (Zhou and Shalley, 2003). The Humanistic Psychology School represented by Amabile believes that external incentives inhibit internal motivation and creativity (Amabile et al., 1986, 1996); on the contrary, the Learning School represented by Eisenberger holds that external incentives promote internal motivation and creativity (Eisenberger and Rhoades, 2001; Eisenberger and Aselage, 2009). Upholding the ideas of freedom and individualism, Amabile et al. (1986, 1996) deems that: mankind's nature lies in the pursuit of freedom, self-expression, and self-realization; external motivation destroys employees' interest in creativity and causes employees to lose their sense of self-determination, resulting in employees paying close attention to short-term results and incentives themselves, but no longer trying new solutions to problems. As a consequence, the Humanistic Psychology School regards external incentives as being inherently destructive for employee creativity to explore new discoveries. In contrast,

upholding utilitarianism, Eisenberger and Rhoades (2001) and Eisenberger and Aselage (2009) believes that through reasonable material incentives, individuals can effectively enhance their self-determination and performance pressure, thereby improving internal motivation and creativity. Be that as it may, new research revealed that external motivation is also conducive to inspiring creativity, indicating that external motivation and internal motivation can synergistically influence creativity (Shalley and Zhou, 2008). The above analysis leads to Hypothesis 2.

> Hypothesis 2: The higher the needs-supplies fit, the higher the employee creativity.

The Moderating Role of Multicultural Experience

Culture is "any knowledge legacy shared and passed down in a community that can satisfy the psychological needs of individuals or communities" (Chiu et al., 2010). The multicultural perspective breaks through the "trait theory" of cross-cultural perspective (see Peng et al., 2017 for a review). Viewing culture as an implicit sharing of knowledge among individuals, it delves into how a particular situation activates the cultural constructs in individuals' brain and influences their mentality and behavior. From this perspective, researchers begin to center on the relationship between multicultural experience and creativity (e.g., Chiu and Hong, 2005; Leung et al., 2008; Maddux et al., 2010). As pointed out by existing studies, multicultural experience can raise the level of individual creativity by improving the epiphany learning, long-distance imagination and concept formulation of individuals, increasing the extraction of unconventional knowledge, and generating new ideas through unfamiliar cultures (Leung et al., 2008). Multicultural experience facilitates individuals to encode information in different ways, to draw new concepts and ways of thinking from other cultures, and to establish multiple connections among concepts (Maddux et al., 2010). Such being the case, individuals draw new ideas from different cultures and integrate them in novel ways when in problem-solving scenarios. Integrating seemingly irrelevant concepts in different cultures conduces to the expansion of conceptual category in the brain (Chiu and Hong, 2005). In brief, the individual creativity can be increased by multicultural experience which exposes individuals to novel concepts and ideas, and enhances their abilities to perceive, process, and arrange cultural information.

As to employees with richer multicultural experience, when their perception ability fulfills job requirements, multicultural experience enables them to encode information in various manners, to draw new concepts and ways of thinking from other cultures, to get rid of conventional thinking modes, thus constantly forming and applying new ideas to the practical problem-solving process.

When the resources provided by the organization meet the needs of employees, needs and supplies match up with each other. For employees with richer multicultural experience, their ability to integrate diverse cultural, together with the proactive work motivation brought by needs-supplies fit, can better enhance their problem-solving creativity. The following hypotheses are thus put forward:

> Hypothesis 3: The impact of demands-abilities fit on employee creativity increases with employees' multicultural experience.

> Hypothesis 4: The impact of needs-supplies fit on employee creativity increases with employees' multicultural experience.

MATERIALS AND METHODS

Data Collection Procedure

Chinese General Social Survey (CGSS) is the first nationwide, comprehensive, and continuous academic survey in China. CGSS system collects data from multiple levels of society, community, family, and individual, summarizes the trends of social change, and dives into topics of major scientific and practical significance.

Similar to former surveys, the CGSS sampling method in 2015 adopted a multi-stage, stratified probability sampling design, which, at the level of village, employed the sampling method based on map addresses that has been generally recognized by large-scale domestic social and economic surveys. The 2015 CGSS field survey put to use the Ominisurvey questionnaire survey system for the first time, drastically raising the timeliness and quality of data collection. The survey covered 478 villages in 28 provinces/cities/autonomous regions across China and completed 10,968 valid personal questionnaires.

In addition to the core module, the 2015 CGSS project also included the work module of East Asian Social Survey (EASS), which had an average probability of 1/6. The EASS work module in CGSS 2015 was applied to analyze the relationship between P-E fit and employee creativity and completed a total of 1,743 valid questionnaires. As P-E fit questions in the data were only for non-agricultural workers, this study chose samples of "currently engaged in non-agricultural work" for analysis according to the work experience in the questionnaire. After removing the cases with missing data, a number of 543 valid questionnaires were obtained.

Measurement

Person-Environment Fit

P-E fit measurement contains direct measurement and indirect measurement (Kristof, 1996). Direct measurement is conducted by the fit degree perceived by the individual, such as "My abilities meet the needs of organizational development"; while indirect measurement includes crossover and individual methods. The former involves the measurement of two objects – the individual and the organization, as well as the statistics of fit degree; the latter uses different questioning methods to put questions only to the individual, such as "I often have new ideas" and "My company is filled with dense innovation atmosphere," and then analyzes the match between individual creativity and organizational creativity atmosphere.

Both direct and indirect measurement has pros and cons (Kristof, 1996). Indirect measurement can produce a separate

and meaningful demonstration of the internal psychological process of comparison between the person and the environment (Edwards, 1994). However, it is possible that people who make intuitive judgments about a subject rather than going through a process of actual comparison and the subject in question (Choi and Price, 2005). In comparison, though failing to discriminate between independent effects of the individual and the environment and subject to potential response bias, direct measurement can obtain unique information that indirect measurement cannot (Choi and Price, 2005), and in fact it has been considered more effective than indirect measurement (Cable and Judge, 1997). This study thus employs the direct measurement of P-E fit. This measurement method means that employees directly report the level of matching they perceive; moreover, in whatever circumstances, the matching is achieved as long as the individual perceives it (Kristof-Brown et al., 2005b).

The indicators for the measurement of demands-abilities fit are: "Whether you think the education you received matches the needs of your current job" and "Whether you think the skills you gained match the needs of your current job." Options for the questions are cross-combined to form "Both fit," "Either fit," and "Neither fit."

For the measurement of needs-supplies fit, it has been divided into two categories of internality and externality by its nature. The conclusion on the relationship between internality fit and creativity is relatively consistent, whereas that on between externality fit and creativity is not (Zhou and Shalley, 2003). To verify the relationship between externality fit and employee creativity, this study attaches more importance to externality fit without regard to internality fit for the time being. The questionnaire developed a five-item index ($\alpha = 0.930$) to obtain participants' self-reported assessments of their needs-supplies fit. Sample items were "From the perspective of work skills, do you think your company offers you a reasonable salary" "From the perspective of job performance, do you think your company offers you a reasonable salary."

Employee Creativity

Former studies have defined creativity as outcome-oriented or process-oriented. Researchers like Amabile tend to adopt the "outcome-oriented" definition. They define creativity as the creation of newfangled and useful ideas or opinions related to product, service, and process (e.g., Shalley, 1991; Amabile et al., 1996; Ford, 1996; Oldham and Cummings, 1996). By contrast, researchers like Parnes are prone to adopt the "process-oriented" definition. They define creativity as a process in which employees attempt to create new outcomes from behavior, cognition, and emotion, and concentrate on the individual's creative behavior in complicated situations (e.g., Parnes, 1967; Drazin et al., 1999). In accordance with the orientation of creative process measurement, this study defines employee creativity as the creative behavior of employees when solving problems in daily life as well as work situations.

From the angle of measurement, the measurement of creativity includes subjective evaluation and objective measurement. Subjective evaluation includes self-evaluation, expert evaluation, and superior evaluation (e.g., Shalley, 1995; Zhou, 1998; George and Zhou, 2001; Tierney and Farmer, 2002); while objective measurement involves patent disclosures, technical reports, and ideas submitted to suggestion programs (Shalley et al., 2004). Although each measurement method has its own pros and cons, this study applies the method of employee self-evaluation to measure employee creativity. The reasons are: (1) the employee's knowledge of job information and perception of their own behavioral motives are more delicate than their superiors; (2) the creativity assessment is highly susceptible to the preference of evaluators, bringing about various understandings and thus vast differences in evaluation results; (3) the superior assessment is easily induced or blinded by the surface behavior of employees good at performance, however, superiors turn a blind eye to the truly creative behavior of some honest employees (Janssen, 2000). In addition, previous research has focused on the creativity of employees in the face of specific tasks; whereas this study focuses on the creativity of employees in entire workdays (Elsbach and Hargadon, 2006), which can be either the creativity in a particular task at work or the creativity in addressing daily problems.

The questionnaire developed a five-item index ($\alpha = 0.720$) to obtain participants' self-reported assessments of employee creativity. Sample items were "I often like to try new unusual things" and "When learning new things, I prefer to try my own unique method."

Multicultural Experience

Multicultural experience implies the opportunity to communicate directly or indirectly with foreign cultural elements or members (Leung et al., 2008). It consists of big multicultural experience and little multicultural experience. The former denotes years of experience of living abroad or emigration and thus in-depth comprehension of and exchanges with foreign cultural elements; however, the latter indicates foreign cultural elements exposed to daily life other than emigration or living abroad, for example, the experience of people who have not gone abroad learning foreign languages and watching American dramas (Rich, 2009). Previous studies have laid emphasis on big multicultural experience rather than little multicultural experience. Yet, in today's globalization, people have more opportunities and easier access to foreign cultural elements, such as language learning, media reading, cultural activities, and consumer behavior (Stürmer et al., 2013), hence little multicultural experience deserves more concern and thus the focus of this study. Since bilingualism is a pivotal indicator for measuring little multicultural experience, bilingual immersion can develop the individual's multicultural identity and promote them to better comprehend multiculturalism, which is a tool to measure multicultural experience (Bialystok, 2001). Bilingualism in the article refers to the two languages of Chinese and English. Due to a large number of dialects in China, the dialects will no longer be subdivided here, but Mandarin and dialects are considered as a whole. The English ability hence represents the level of bilingualism. The questionnaire developed a five-item index ($\alpha = 0.966$) to measure employees' bilingualism. Sample items were "What do you think of your English listening ability?" and "What do you think of your English speaking ability?". The

TABLE 1 | Descriptive variables (N = 543).

Variable	Percent	Mean	*SD*	Minimum	Maximum
Gender					
Male	59.85%				
Female	40.15%				
Education level					
Primary school or lower	9.58%				
Junior high school	32.41%				
High school	24.49%				
College and higher	33.52%				
Demands-abilities fit					
Both fit	67.59%				
Either fit	16.94%				
Neither fit	15.47%				
Age		39.57	11.365	18	75
Needs-supplies fit		3.41	0.840	1	5
Multicultural experience		1.87	0.955	1	5
Employee creativity		3.14	0.860	1	5

higher the total score is, the stronger the bilingual ability, and the richer the multicultural experience. Variables description is shown in **Table 1**.

RESULTS

Demands-Abilities Fit and Employee Creativity

In this study, stepwise linear regression analysis has been used to verify relevant hypotheses. Based on the procedure in stepwise linear regression analysis suggested by Baron and Kenny (1986), the first to input into the regression equation is control variable; the second is the variable of demands-abilities fit (this variable is a three-category variable and thus converted into two dummy variables) and multicultural experience; the third, the interaction between demands-abilities fit and multicultural experience.

Model 2 and model 3 in **Table 2** reflects the impact of demands-abilities fit on employee creativity. Including merely control variable, Model 1 indicates gender and age are negatively correlated with employee creativity. In other words, women's creativity is lower than men's ($B = -0.168$, $P < 0.05$); the creativity becomes lower with age ($B = -0.018$, $P < 0.001$). With demands-abilities fit and multicultural experience added in, Model 2 shows employees whose education and skills both match the requirements of the job have lower creativity than those not ($B = -0.218$, $P < 0.05$), and the same with those either of whose education or skills match the requirements ($B = -0.288$, $P < 0.05$), which is the opposite of Hypothesis 1; Multicultural experience exerts a dramatic impact on employee creativity ($B = 0.122$, $P < 0.05$), that is, the richer the multicultural experience, the higher the employee creativity. Model 2 significantly increases the explanation of employee creativity ($\Delta R^2 = 0.021$, $P < 0.05$).

Model 3 takes into account the interaction variable between demands-abilities fit and multicultural experience, which is highly significant, and its coefficient is positive ($B = 0.236$, $P < 0.05$). It is nevertheless implausible to verify the significance of overall interaction simply based on the significance of product term coefficient, because the overall interaction has over one degree of freedom and it depends on whether the R^2 variation of the main effect model (Model 2) and product term model (Model 3) is remarkable or not. The result exhibits that R^2 variation changes dramatically ($\Delta R2 = 0.009$, $P < 0.1$). This implies that as long as an additional unit is included in multicultural experience, the average difference in creativity increases by 0.236 between employees whose education and skills match job requirements and whose education or skills match the requirements. In other words, the impact of education and skills matching with job requirements on employee creativity increases with employees' multicultural experience getting richer. Hypothesis 3 has been therefore validated.

Needs-Supplies Fit and Employee Creativity

Likewise, the stepwise linear regression analysis has been applied to validate hypotheses related to needs-supplies and employee creativity. The first to input into the regression equation is control variable; the second is the variable of needs-supplies fit and multicultural experience; the third, the interaction between needs-supplies fit and multicultural experience.

Model 4 and model 5 in **Table 2** reflects the impact of needs-supplies fit on employee creativity. With needs-supplies fit taken into consideration, Model 4 tells that the higher the needs-supplies fit, the higher the employee creativity ($B = 0.1050$, $P < 0.05$), significantly increasing the explanation of employee creativity ($\Delta R^2 = 0.011$, $P < 0.01$). Hypothesis 2 hence has been verified.

Model 5 adds in the interaction variable between needs-supplies fit and multicultural experience. The interaction term of between needs-supplies fit and multicultural experience is outstanding and its coefficient is positive, implying that as long as an additional unit is included in multicultural experience,

TABLE 2 | Stepwise linear regression of person-environment fit and employee creativity (N = 543).

Dependent variable	Model 1		Model 2		Model 3		Model 4		Model 5	
	B	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*
Female	−0.168**	0.072	−0.194***	0.072	−0.201***	0.072	−0.172**	0.072	−0.165**	0.072
Age	−0.018****	0.003	−0.016****	0.003	−0.015****	0.003	−0.015****	0.003	−0.016****	0.003
Education (primary school or lower = 0)										
Junior high school	−0.198	0.130	−0.196	0.129	−0.202	0.129	−0.210	−0.207	0.129	−0.207
High school	−0.077	0.136	−0.143	0.137	−0.152	0.136	−0.123	−0.124	0.136	−0.124
College and higher	0.155	0.134	−0.009	0.148	−0.007	0.148	0.000	0.018	0.148	0.018
Multicultural experience			0.122**	0.049	−0.091	0.106	0.117**	0.049	0.105**	0.050
Demands-abilities fit (Neither fit = 0)										
Both fit			−0.218**	0.095	−0.237**	0.095				
Either fit			−0.288**	0.123	−0.288**	0.124				
Both fit × multicultural experience					0.236**	0.109				
Either fit × multicultural experience					0.326**	0.149				
Needs-supplies fit							0.105**	0.042	0.111***	0.042
needs-supplies fit × multicultural experience									0.082*	0.044
Constant	4.130****	0.226	4.328****	0.236	4.327****	0.235	3.502****	0.290	3.497****	0.290
R^2	0.109		0.130		0.139		0.130		0.135	
Adjusted R^2	0.101		0.117		0.123		0.118		0.122	
ΔR^2	0.109****		0.021**		0.009*		0.021**		0.006*	
F	13.141		9.976		8.622		11.372		10.427	

*$P < 0.1$, **$P < 0.05$, ***$P < 0.01$, and ****$P < 0.001$.

the impact of needs-supplies fit on employee creativity increases by 0.082. In other words, the impact of needs-supplies fit on employee creativity increases with employees' multicultural experience getting richer.

DISCUSSION

Differing from former studies, this article has revealed that demands-abilities fit produces a negative impact on employee creativity (Wang and Sun, 2010; Zhang and Long, 2013). Wang and Sun (2010) data analysis of 209 employees and their direct superiors has pointed out that the matching degree between job requirements and employee competence is markedly correlated with creativity. Likewise, Zhang and Long (2013) has also proved that demands-abilities fit exercises an outstanding and positive effect on employee creativity by stimulating their innovation self-efficacy. Their research focuses on creativity in the work process, and the creativity of this article includes both work processes and daily life.

Many past studies implied that employees with a low fit lacked sufficient motivation to improve their professional skills by indirect imitation and learning, thus failing to gain more experience needed for more creativity (Shalley et al., 2004; Zhang and Long, 2013). That being the case, when demands and abilities mismatch, does the employee necessarily go through frustration, low self-esteem, indifference, cognitive disorder, or even disharmony (Chatman, 1991) which in turn inhibits creativity? Livingstone et al. (1997) has discovered a U-shaped relationship between demands-abilities fit and pressure. When the individual's perceived ability falls short of or exceeds the job requirements, the pressure increases; conversely, when the individual's ability matches the job requirements, the pressure is the minimum. That is to say, demands-abilities misfit puts employees under considerable pressure. Despite that, pressure is not always a conundrum (LePine et al., 2005; Podsakoff et al., 2007), because pressure exposes competitive disadvantages to the individual and forces them to employ new ideas and procedures to solve problems (e.g., Hon et al., 2013). Being indicators of abilities, education and skills have always been considered as critical factors influencing creativity (Amabile, 1983, 1988; Cohen and Levinthal, 1989), on which the research targets at specific domains or specific tasks, such as art, literature, and music. The measurement of creativity in this study does not involve specific domains or specific tasks, but centering on the employee creativity in entire workdays. Demands-abilities fit is a favorable condition for the individual, but it is in this favorable condition that employees may be more inclined to habitual actions and give up on creative actions (Ford, 1996). On the contrary, when the employee is in a misfit condition, pressure is more likely to inspire employee creativity.

In terms of needs-supplies fit, it turns out that the higher the needs-supplies fit, the greater the employee creativity. When exploring the work context of creativity, Amabile et al. (1996) suggest that the degree to which the individual's work resources are assigned (Amabile et al., 1996) is positively correlated with creativity, but this hypothesis has not been proven yet. They believe this may be related to the nature of individual needs and work supplies as well as individual motivation (Amabile, 1983). This study delves into the reasonable level of material treatment provided by the organization perceived by employees, which not only includes the degree of fit, but also implies the sense of fairness of employees. The more reasonable the material treatment provided by the organization perceived by

employees, the greater the needs-supplies fit on the one hand, and the stronger the sense of fairness of employees on the other. In spite of being external fit from its nature, the material treatment can effectively raise the individual's self-determination and performance pressure to improve intrinsic motivation and creativity (Eisenberger and Aselage, 2009). Moreover, employees will compare their efforts and rewards. If employees perceive that the treatment provided by the organization is fair, the organization and the individual will form a driving force for social exchange (Masterson et al., 2000), and the employee will work hard to pay back for the organization's care and trust. In such case, employees may proactively seek creative ideas to improve organizational processes or to develop new products and services (Amabile et al., 1996).

According to some studies, multicultural experience is conducive to promoting creativity (Lee and Kim, 2011; Leikin, 2013). Yet, few have explored the moderating role of multicultural experience in P-E fit and employee creativity. This study has proved that multicultural experience plays a moderating role in the impact of demands-abilities fit and needs-supplies fit on employee creativity. Although the combination of education and skills with organizational requirements is not conducive to stimulating employee creativity, this negative effect is weaker for employees with high multicultural experience and stronger for employees with low multicultural experience. Because employees with high multicultural experience learn new concepts and ways of thinking in other cultures, it is easier to get rid of the inherent thinking patterns, constantly form new ideas and apply them to the practical process of problem solving. When needs-supplies fit, compared with employees with low multicultural experience, employees with high multicultural experience have the ability to integrate diverse cultural. Together with the proactive work motivation brought by needs-supplies fit, They can better enhance their problem-solving creativity. The inspiration drawn from this study to organizational management is: the organization should attach great importance to the creativity of employees with demands-abilities misfit, as well as to the role of little multicultural experience while in a context of deepening globalization, so as to expand employees' multicultural experience through a variety of approaches.

Limitations and Future Directions

In spite of some valuable research results obtained, there are some limitations that should not be overlooked in this study. The method of self-evaluation has been employed to measure independent variables (demands-abilities fit and needs-supplies fit), dependent variable (creativity), and moderator variable (multicultural experience), of which the analysis results may be influenced by common method variation. In order to avoid the influence of common method variation, process control and statistical test methods were adopted. In the process control, the unnamed questionnaire method is adopted, and the items measuring different variables are randomly arranged and mixed, and the questionnaire is designed by using the reverse problem. In the statistical test, we used Harman's one-factor test, all the items in the questionnaire scale were used for factor analysis, and 5 factors were extracted from the principal component analysis results when the rotation was not rotated, Total Variance Explained is 69.635%. The first factor explained the variation was 25.415%, and the common method variation was not serious. More methods will be used to avoid the influence of common method variation in the future. Due to data limitations, this study has probed into the relationship between personal-environment fit, multicultural experience, and employee creativity from a multicultural perspective. However, multicultural experience is measured only from a bilingual perspective, and it will be measured in multiple dimensions in future. In addition, as pointed out by Zhao Zhiyu et al., "The research on cultural and social psychology has undergone the paradigms of cross-cultural psychology, cultural psychology, multicultural psychology, as well as polycultural psychology emphasizing the influence of intercultural relationships on psychological processes" (Chiu et al., 2013). Under the polycultural psychology paradigm, culture mixing has taken culture and psychology research a step forward. Scholars have carried forward the research tradition of multicultural psychology and have a profound understanding of the forms and categories of intercultural interactions and their social, cultural and psychological consequences thus caused (Morris et al., 2015). On this account, the next-step research should be carried out on the impact of cultural mixing on employee creativity and its influencing mechanism.

CONCLUSION

In compliance with the complementary perspective of person-environment fit, this study has dived into the relationship between demands-abilities fit, needs-supplies fit and employee creativity, as well as the impact of multicultural experience on the relationship. It has been revealed that, unlike previous research findings, employees with demands-abilities fit have lower creativity than those with demands-abilities misfit; nevertheless, the demands-abilities fit creates a growing impact on employee creativity with increasing multicultural experience. Additionally, the higher the needs-supplies fit, the stronger the employee creativity; and, the needs-supplies fit creates a growing impact on employee creativity with increasing multicultural experience.

DATA AVAILABILITY STATEMENT

The datasets (GENERATED) for this study can be found in the (Chinese National Survey Data Archive) (http://cnsda.ruc.edu.cn/).

ETHICS STATEMENT

An ethics approval was not required as per institutional guidelines and national laws and regulations because no unethical behaviors existed in this study. The data of this study were collected by questionnaire survey through a professional service institute. The content of the questionnaire was not involved with any ethical problem. All respondents were informed of the aims of this research and it was indicated that they approved this

study when they filled out the questionnaire. For these reasons, the authors considered that we did not need to provide ethics approval and written informed consent.

AUTHOR CONTRIBUTIONS

YW organized the database. KW performed the statistical analysis and wrote the first draft of the manuscript. All authors contributed to conception and design of the study, manuscript revision, and read and approved the submitted version.

FUNDING

This research was supported by the National Social Science Fund of China (15CSH006 and 17ASH010).

ACKNOWLEDGMENTS

The authors thank Wangbin Shen, Bairen Ding, Qiuxia Shi, Liufei Wang, and Nan Lu for their valuable comments on an earlier version of this article.

REFERENCES

Amabile, T. M. (1983). The social psychology of creativity: a componential conceptualization. *J. Personal. Soc. Psychol.* 45, 357–376. doi: 10.1037/0022-3514.45.2.357

Amabile, T. M. (1988). "A model of creativity and innovation in organizations," in *Research in Organizational Behavior*, Vol. 10, eds B. M. Staw and L. L. Cummings (Greenwich, CT: JAI Press), 123–167.

Amabile, T. M. (1996). *Creativity in Context*. Boulder, CO: Westview.

Amabile, T. M., Conti, R., Coon, H., Lazenby, J., and Herron, M. (1996). Assessing the work environment for creativity. *Acad. Manage. J.* 39, 1154–1184. doi: 10.2307/256995

Amabile, T. M., Hennessey, B. A., and Grossman, B. S. (1986). Social influences on creativity: the effects of contracted-for reward. *J. Pers. Soc. Psychol.* 50, 14–23. doi: 10.1037/0022-3514.50.1.14

Amabile, T. M., and Pillemer, J. (2012). Perspectives on the social psychology of creativity. *J. Creat. Behav.* 461, 3–15. doi: 10.1002/jocb.001

Amabile, T. M., Schatzel, E. A., Moneta, G. B., and Kramer, S. J. (2004). Leader behaviors and the work environment for creativity: perceived leader support. *Leadersh. Q.* 15, 5–32. doi: 10.1016/j.leaqua.2003.12.003

Bandura, A. (1986). *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice-Hall.

Baron, R. M., and Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* 51, 1173–1182. doi: 10.1037/0022-3514.51.6.1173

Barron, F., and Harrington, D. M. (1981). "Creativity, intelligence, and personality," in *Annual Review of Psychology*, eds M. R. Rosenzweig and L. W. Porter (Palo Alto, CA: Annual Reviews), 439–476. doi: 10.1146/annurev.ps.32.020181.002255

Bialystok, E. (2001). *Bilingualism in Development: Language, Literacy, and Cognition*. New York, NY: Cambridge University Press. doi: 10.1017/CBO9780511605963

Boon, C., Den Hartog, D. N., Boselie, P., and Paauwe, J. (2011). The relationship between perceptions of HR practices and employee outcomes: examining the role of person–organization and person–job fit. *Int. J. Hum. Resour. Manage.* 22, 138–162. doi: 10.1080/09585192.2011.538978

Cable, D. M., and DeRue, D. S. (2002). The convergent and discriminant validity of subjective fit perceptions. *J. Appl. Psychol.* 87, 875–884. doi: 10.1037//0021-9010.87.5.875

Cable, D. M., and Edwards, J. R. (2004). Complementary and supplementary fit: a theoretical and empirical integration. *J. Appl. Psychol.* 89, 822–834. doi: 10.1037/0021-9010.89.5.822

Cable, D. M., and Judge, T. A. (1997). Interviewers' perceptions of person–organization fit and organizational selection decisions. *J. Appl. Psychol.* 82, 546–561. doi: 10.1037/0021-9010.82.4.546

Caplan, R. D. (1987). Person-environment fit theory and organizations: commensurate dimensions, time perspectives, and mechanisms. *J. Vocat. Behav.* 31, 248–267. doi: 10.1016/0001-8791(87)90042-X

Chatman, J. A. (1991). Matching people and organizations: selection and socialization in public accounting firms. *Adm. Sci. Q.* 36, 459–484. doi: 10.2307/2393204

Chiu, C. Y., and Hong, Y. Y. (2005). "Cultural competence: dynamic processes," in *Handbook of Motivation and Competence*, eds A. Elliot and C. S. Dweck (New York, NY: Guilford Press), 489–505.

Chiu, C. Y., and Kwan, L. Y. Y. (2010). Culture and creativity: a process model. *Manage. Organ. Rev.* 6, 447–461. doi: 10.1111/j.1740-8784.2010.00194.x

Chiu, C. Y., Kwan, L. Y. Y., and Liou, S. (2013). Culturally motivated challenges to innovations in integrative research: theory and solutions. *Soc. Issues Policy Rev.* 7, 149–172. doi: 10.1111/j.1751-2409.2012.01046.x

Chiu, C. Y., Leung, A. Y., and Hong, Y. Y. (2010). "Cultural processes: an overview," in *Cultural Processes: a Social Psychological Perspective*, eds A. Y. Leung, C. Y. Chiu, and Y. Y. Hong (New York, NY: Cambridge University Press), 3–22. doi: 10.1017/CBO9780511779374.003

Choi, J. N. (2004a). Individual and contextual predictors of creative performance: the mediating role of psychological processes. *Creat. Res. J.* 16, 187–199. doi: 10.1080/10400419.2004.9651452

Choi, J. N. (2004b). Person–environment fit and creative behavior: differential impacts of supplies–values and demands–abilities versions of fit. *Hum. Relat.* 57, 531–552. doi: 10.1177/0018726704044308

Choi, J. N., and Price, R. H. (2005). The effects of person–innovation fit on individual responses to innovation. *J. Occup. Organ. Psychol.* 78, 83–96. doi: 10.1348/096317904X22953

Cohen, W. M., and Levinthal, D. A. (1989). Innovation and learning: the two faces of R & D. *Econ. J.* 99, 569–596. doi: 10.2307/2233763

Csikszentmihalyi, M. (1999). "Implications of a systems perspective for the study of creativity," in *Handbook of Creativity*, ed. R. J. Sternberg (New York, NY: Cambridge University Press), 313–335.

Drazin, R., Glynn, M. A., and Kazanjian, R. K. (1999). Multilevel theorizing about creativity in organizations: a sensemaking perspective. *Acad. Manage. J.* 24, 286–307. doi: 10.5465/AMR.1999.1893937

Du, J., and Wang, D. N. (2009). Person-environment fit and creativity: the moderating role of collectivism. *Acta Psychol. Sin.* 10, 980–988. doi: 10.3724/SP.J.1041.2009.00980

Edwards, J. R. (1991). "Person-job fit: a conceptual integration, literature review, and methodological critique," in *International Review of Industrial and Organizational Psychology*, eds C. L. Cooper and I. T. Robertson (New York, NY: Wiley), 283–357.

Edwards, J. R. (1994). The study of congruence in organizational behavior research: critique and a proposed alternative. *Organ. Behav. Hum. Decis. Process.* 58, 51–100. doi: 10.1006/obhd.1994.1029

Edwards, J. R. (1996). An examination of competing versions of the person-environment fit approach to stress. *Acad. Manage. J.* 39, 292–339. doi: 10.2307/256782

Edwards, J. R. (2008). Person–environment fit in organizations: an assessment of theoretical progress. *Acad. Manag. Ann.* 2, 167–230. doi: 10.1080/19416520802211503

Edwards, J. R., Caplan, R. D., and Harrison, R. V. (1998). "Person-environment fit theory: conceptual foundations, empirical evidence, and directions for future research," in *Theories of Organizational Stress*, ed. C. L. Cooper (Oxford: Oxford University Press), 28–67.

Edwards, J. R., and Shipp, A. J. (2007). "The relationship between person-environment fit and outcomes: an integrative theoretical framework," in

Perspectives on Organizational Fit, eds C. Ostroff and T. A. Judge (San Francisco, CA: Jossey-Bass), 209–258.

Eisenberger, R., and Aselage, J. (2009). Incremental effects of reward on experienced performance pressure: positive outcomes for intrinsic interest and creativity. *J. Organ. Behav.* 30, 95–117. doi: 10.1002/job.543

Eisenberger, R., and Rhoades, L. (2001). Incremental effects of reward on creativity. *J. Pers. Soc. Psychol.* 81, 728–741. doi: 10.1037/0022-3514.81.4.728

Eisenhardt, K., and Tabrizi, B. (1995). Accelerating adaptive processes: product innovation in the global computer industry. *Adm. Sci. Q.* 40, 84–110. doi: 10.2307/2393701

Elsbach, K. D., and Hargadon, A. B. (2006). Enhancing creativity through "mindless" work: a framework of workday design. *ıOrgan. Sci.* 17, 470–483. doi: 10.1287/orsc.1060.0193

Farzaneh, J., Dehghanpour Farashah, A., and Kazemi, M. (2014). The impact of person-job fit and person-organization fit on OCB: the mediating and moderating effects of organizational commitment and psychological empowerment. *Pers. Rev.* 43, 672–691. doi: 10.1108/PR-07-2013-0118

Ford, C. M. (1996). A theory of individual creative action in multiple social domains. *Acad. Manage. J.* 21, 1112–1142. doi: 10.5465/AMR.1996.9704071865

Gardner, H. (1993). *Creating Minds: An Anatomy of Creativity Seen through the Lives of Freud, Einstein, Picasso, Stravinsky, Eliot, Graham, and Gandhi*. New York, NY: Basic Books.

George, J. M., and Zhou, J. (2001). When openness to experience and conscientiousness are related to creative behavior: an interactional approach. *J. Appl. Psychol.* 86, 513–524. doi: 10.1037//0021-9010.86.3.513

George, J. M., and Zhou, J. (2007). Dual tuning in a supportive context: joint contributions of positive mood, negative mood, and supervisory behaviors to employee creativity. *Acad. Manage. J.* 50, 605–622. doi: 10.5465/AMJ.2007.25525934

Geroski, P., Machin, S., and Van Reenen, J. (1993). The profitability of innovating firms. *Rand. J. Econ.* 24, 198–211. doi: 10.2307/2555757

Hon, A. H., Chan, W. W., and Lu, L. (2013). Overcoming work-related stress and promoting employee creativity in hotel industry: the role of task feedback from supervisor. *Int. J. Hosp. Manage.* 33, 416–424. doi: 10.1016/j.ijhm.2012.11.001

Janssen, O. (2000). Job demands, perceptions of effort-reward fairness and innovative work behaviour. *J. Occup. Organ. Psychol.* 73, 287–302. doi: 10.1348/096317900167038

Kharkhurin, A. V. (2010). Sociocultural differences in the relationship between bilingualism and creative potential. *J. Cross Cult. Psychol.* 41, 776–783. doi: 10.1177/0022022110361777

Kristof, A. L. (1996). Person-organization fit: an integrative review of its conceptualizations, measurement, and implications. *Pers. Psychol.* 49, 1–49. doi: 10.1111/j.1744-6570.1996.tb01790.x

Kristof-Brown, A., Barrick, M. R., and Stevens, C. K. (2005a). When opposites attract: a multi-sample demonstration of complementary person-team fit on extraversion. *J. Pers.* 73, 935–957. doi: 10.1111/j.1467-6494.2005.00334.x

Kristof-Brown, A., and Guay, R. P. (2011). "Person– environment fit," in *Handbook of Industrial/Organizational Psychology*, Vol. 3, ed. S. Zedeck (Washington, DC: American Psychological Association), 3–50.

Kristof-Brown, A. L., Zimmerman, R. D., and Johnson, E. C. (2005b). Consequences of individuals' fit at work: a meta-analysis of person-job, person-organization, person-group, and person-supervisor fit. *Pers. Psychol.* 58, 281–342. doi: 10.1111/j.1744-6570.2005.00672.x

Lee, H., and Kim, K. H. (2011). Can speaking more languages enhance your creativity? Relationship between bilingualism and creative potential among Korean American students with multicultural link. *Pers. Individ. Dif.* 50, 1186–1190. doi: 10.1016/j.paid.2011.01.039

Lee, Y. T., and Antonakis, J. (2014). When preference is not satisfied but the individual is: how power distance moderates person–job fit. *J. Manage.* 40, 641–675. doi: 10.1177/0149206311436080

Leikin, M. (2013). The effect of bilingualism on creativity: developmental and educational perspectives. *Int. J. Billing.* 17, 431–447. doi: 10.1177/1367006912438300

LePine, J. A., Podsakoff, N. P., and LePine, M. A. (2005). A meta-analytic test of the challenge stressor–hindrance stressor framework: an explanation for inconsistent relationships among stressors and performance. *Acad. Manage. J.* 48, 764–775. doi: 10.2307/20159696

Leung, A. K., Maddux, W. W., Galinsky, A. D., and Chiu, C. Y. (2008). Multicultural experience enhances creativity: the when and how. *Am. Psychol.* 63, 169–181. doi: 10.1037/0003-066X.63.3.169

Livingstone, L. P., Nelson, D. L., and Barr, S. H. (1997). Person-environment fit and creativity: an examination of supply-value and demand-ability versions of fit. *J. Manage.* 23, 119–146. doi: 10.1177/014920639702300202

Lubart, T. I. (1999). "Creativity across cultures," in *Handbook of Creativity*, ed. R. J. Sternberg (Cambridge: Cambridge University Press), 339–350.

Maddux, W. W., Adam, H., and Galinsky, A. D. (2010). When in Rome. Learn why the Romans do what they do: how multicultural learning experiences facilitate creativity. *Pers. Soc. Psychol. Bull.* 36, 731–741. doi: 10.1177/0146167210367786

Masterson, S. S., Lewis, K., Goldman, B. M., and Taylor, M. S. (2000). Integrating justice and social exchange: the differing effects of fair procedures and treatment on work relationships. *Acad. Manage. J.* 43, 738–748. doi: 10.2307/1556364

Milliman, J., Gatling, A., and Bradley-Geist, J. C. (2017). The implications of workplace spirituality for person–environment fit theory. *Psychol. Relig. Spiritual.* 9, 1–12. doi: 10.1037/rel0000068

Morris, M. W. (2014). Values as the essence of culture: foundation or fallacy? *J. Cross Cult. Psychol.* 45, 14–24. doi: 10.1177/0022022113513400

Morris, M. W., Chiu, C. Y., and Liu, Z. (2015). Polycultural psychology. *Annu. Rev. Psychol.* 66, 631–659. doi: 10.1146/annurev-psych-010814-015001

Muchinsky, P. M., and Monahan, C. J. (1987). What is person-environment congruence? Supplementary versus complementary models of fit. *J. Vocat. Behav.* 31, 268–277. doi: 10.1016/0001-8791(87)90043-1

Mumford, M. D. (2011). *Handbook of Organizational Creativity*. New York, NY: Academic Press.

Mumford, M. D., Bedell-Avers, K. E., and Hunter, S. T. (2008). "Planning for innovation: a multi-level perspective," in *Innovation in Organizations: A Multi-Level Perspective*, eds M. D. Mumford, S. T. Hunter, and K. E. Bedell (Oxford: Elsevier), 107–154.

Oh, I. S., Guay, R. P., Kim, K., Harold, C. M., Lee, J. H., Heo, C. G., et al. (2014). Fit happens globally: a meta-analytic comparison of the relationships of person–environment fit dimensions with work attitudes and performance across East Asia, Europe, and North America. *Pers. Psychol.* 67, 99–152. doi: 10.1111/peps.12026

Oldham, G. R., and Cummings, A. (1996). Employee creativity: personal and contextual factors at work. *Acad. Manage. J.* 39, 607–634. doi: 10.2307/256657

Paletz, S. B., and Peng, K. (2008). Implicit theories of creativity across cultures: novelty and appropriateness in two product domains. *J. Cross Cult. Psychol.* 39, 286–302. doi: 10.1177/0022022108315112

Parnes, S. (1967). *Creative Behavior Guidebook*. New York, NY: Scribner's.

Peng, L., Zheng, X., and Peng, S. (2017). The status quo of culture mixing research and its future directions. *Adv. Psychol. Sci.* 25, 1240–1250. doi: 10.3724/SP.J.1042.2017.01240

Podsakoff, N. P., LePine, J. A., and LePine, M. A. (2007). Differential challenge stressor-hindrance stressor relationships with job attitudes, turnover intentions, turnover, and withdrawal behavior: a meta-analysis. *J. Appl. Psychol.* 92, 438–454. doi: 10.1037/0021-9010.92.2.438

Rich, G. J. (2009). Big C, little c, big M, little m. *Am. Psychol.* 64, 155–156. doi: 10.1037/a0014533

Schneider, B., Goldstiein, H. W., and Smith, D. B. (1995). The ASA framework: an update. *Pers. Psychol.* 48, 747–773. doi: 10.1111/j.1744-6570.1995.tb01780.x

Schooler, J. W., and Melcher, J. (1995). "The ineffability of insight," in *The Creative Cognition Approach*, eds S. M. Smith, T. B. Ward, and R. A. Finke (Cambridge, MA: The MIT Press), 97–133.

Shalley, C. E. (1991). Effects of productivity goals, creativity goals, and personal discretion on individual creativity. *J. Appl. Psychol.* 76, 179–185. doi: 10.1037/0021-9010.76.2.179

Shalley, C. E. (1995). Effects of coaction, expected evaluation, and goal setting on creativity and productivity. *Acad. Manage. J.* 38, 483–503. doi: 10.2307/256689

Shalley, C. E., and Gilson, L. L. (2004). What leaders need to know: a review of social and contextual factors that can foster or hinder creativity. *Leadersh. Q.* 15, 33–53. doi: 10.1016/j.leaqua.2003.12.004

Shalley, C. E., Gilson, L. L., and Blum, T. C. (2000). Matching creativity requirements and the work environment: effects on satisfaction and intentions to leave. *Acad. Manage. J.* 43, 215–223. doi: 10.2307/1556378

Shalley, C. E., and Zhou, J. (2008). "Organizational creativity research: a historical overview," in *Handbook of Organizational Creativity*, eds J. Zhou and C. E. Shalley (New York, NY: Taylor and Francis), 95–123.

Shalley, C. E., Zhou, J., and Oldham, G. R. (2004). The effects of personal and contextual characteristics on creativity: where should we go from here? *J. Manage.* 30, 933–958. doi: 10.1016/j.jm.2004.06.007

Simonton, D. K. (1975). Sociocultural context of individual creativity: a transhistorical time-series analysis. *J. Pers. Soc. Psychol.* 32, 1119–1133. doi: 10.1037/0022-3514.32.6.1119

Simonton, D. K. (1990). *Psychology, Science, and History*. New Haven, CT: Yale University Press. doi: 10.2307/j.ctt22726rf

Sternberg, R. J. (1988). *The Nature of Creativity: Contemporary Psychological Perspectives*. New York, NY: Cambridge University Press.

Stürmer, S., Benbow, A. E., Siem, B., Barth, M., Bodansky, A. N., and Lotz-Schmitt, K. (2013). Psychological foundations of xenophilia: the role of major personality traits in predicting favorable attitudes toward cross-cultural contact and exploration. *J. Pers. Soc. Psychol.* 105, 832–851. doi: 10.1037/a0033488

Tierney, P., and Farmer, S. M. (2002). Creative self-efficacy: its potential antecedents and relationship to creative performance. *Acad. Manage. J.* 45, 1137–1148. doi: 10.2307/3069429

Tierney, P., Farmer, S. M., and Graen, G. B. (1999). An examination of leadership and employee creativity: the relevance of traits and relationships. *Pers. Psychol.* 52, 591–620. doi: 10.1111/j.1744-6570.1999.tb00173.x

Tushman, M. L., and O'Reilly, C. A. III (1996). Ambidextrous organizations: managing evolutionary and revolutionary change. *Calif. Manage. Rev.* 38, 8–30. doi: 10.2307/41165852

Wang, Z., and Sun, J. M. (2010). Person-organization fit and employee's innovative work behavior: in three type fit model perspective. *Econ. Manage. J.* 32, 74–79.

Woodman, R. W., Sawyer, J. E., and Griffin, R. W. (1993). Toward a theory of organizational creativity. *Acad. Manage. Rev.* 18, 293–321. doi: 10.5465/AMR.1993.3997517

Zhang, Y., and Long, L. R. (2013). Effects of person-job fit and job insecurity on employees' creativity: test of a mediated moderator model. *Nankai Bus. Rev.* 5, 16–25.

Zhou, J. (1998). Feedback valence, feedback style, task autonomy, and achievement orientation: interactive effects on creative performance. *J. Appl. Psychol.* 83, 261–276. doi: 10.1037/0021-9010.83.2.261

Zhou, J., and Shalley, C. E. (2003). "Research on employee creativity: a critical review and directions for future research," in *Research in Personnel and Human Resource Management*, Vol. 22, ed. J. Martocchio (Oxford: Elsevier), 165–217.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling Editor declared a shared affiliation, though no other collaboration, with one of the authors YW.

frontiers in Psychology

ORIGINAL RESEARCH
published: 02 November 2018
doi: 10.3389/fpsyg.2018.02106

The Interaction of *TPH1* A779C Polymorphism and Maternal Authoritarianism on Creative Potential

Jinghuan Zhang, Xiao Han, Si Si and Shun Zhang**

Department of Psychology, Shandong Normal University, Jinan, China

Exploring the possible mechanisms through which gene may interact with environment to influence creativity has been one of the leading issues in creativity research. In a sample of four hundred and twenty-one Chinese undergraduate students, the present study investigated for the first time the interaction of *TPH1* A779C polymorphism and maternal parenting styles on creative potential. The results showed that there was a significant interaction of *TPH1* A779C polymorphism and maternal authoritarianism on creative potential. Moreover, the analysis of regions of significance (Ros) provided supporting evidences for both the diathesis-stress model (flexibility) and the differential susceptibility model (originality). These findings extend our understanding concerning the mechanisms by which gene and environment may act in coordination to contribute to creativity.

Keywords: creativity, creative potential, *TPH1*, maternal authoritarianism, gene-environment interaction

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Ning Hao,
East China Normal University, China
Jiang Qiu,
Southwest Normal University, China

****Correspondence:***
Jinghuan Zhang
zhangjinghuan@sdnu.edu.cn
Shun Zhang
yinxingren1986@hotmail.com

Specialty section:
This article was submitted to Cognitive Science, a section of the journal Frontiers in Psychology

Received: *09 September 2018*
Accepted: *12 October 2018*
Published: *02 November 2018*

Citation:
Zhang J, Han X, Si S and Zhang S (2018) The Interaction of TPH1 A779C Polymorphism and Maternal Authoritarianism on Creative Potential. Front. Psychol. 9:2106. doi: 10.3389/fpsyg.2018.02106

INTRODUCTION

Recent developments in molecular genetics have inspired a number of studies to explore the genetic correlates of creativity and to identify genes associated with creativity. Among the candidate genes, the most extensively studied is the tryptophan hydroxylase 1 gene (*TPH1*). *TPH1* is located on chromosome 11, and is expressed in both human central and peripheral nervous system (Zill et al., 2007). The enzyme encoded by this gene is the rate-limiting enzyme in the biosynthesis of serotonin, and regulates serotonin levels by converting tryptophan to 5-hydroxytryptophan which is the direct precursor of serotonin (Hamon et al., 1981).

Previous studies examining the association of *TPH1* and creative potential generally focused on the role of *TPH1* A779C polymorphism (rs1799913), but yielded inconsistent results (Reuter et al., 2006; Runco et al., 2011; Zhang and Zhang, 2017). Reuter et al. (2006) first examined the association of *TPH1* A779C polymorphism and creative potential, and the results indicated that this polymorphism was associated with total creative potential score. Based on Reuter et al.'s work, Runco et al. (2011) further investigated the association of *TPH1* A779C polymorphism and the three core dimensions (fluency, flexibility, and originality) of creative potential, and demonstrated that *TPH1* A779C polymorphism was only associated with fluency. By including both tag single nucleotide polymorphisms (SNPs) and functional SNPs, Zhang and Zhang (2017) recently for the first time systematically explored the association of *TPH1* and creative potential, but found that *TPH1* A779C polymorphism was not related to any of the three core dimensions of creative potential.

As for these inconsistent results, there are a number of possible reasons (e.g., sample size, age, and gender). However, since creativity, like most of other complex traits, is determined by the interplay of gene and environment, it is reasonable to suspect that the primary reason that accounts for the discrepancy may be attributed to the neglect of gene–environment (G × E) interaction (Rutter et al., 2006).

One possible environmental factor that may interact with *TPH1* A779C polymorphism to influence creative potential is maternal parenting styles. Parenting styles represent the emotional connections and the quality of contacts parents make with their children, and it has been shown that maternal parenting styles are critical environmental factors for individual's creativity (Nichols, 1964; Lim and Smith, 2008). Existing studies regarding the relationship between maternal parenting styles and creativity have yielded inconsistent results (Miller et al., 2012; Fearon et al., 2013; Mehrinejad et al., 2015), while a recent study provided a new perspective to re-evaluate the relationship by showing that *DRD2* genotype (rs1799732) could interact with maternal parenting styles to affect creative potential (Si et al., 2018). This finding suggested that the influence of maternal parenting styles on creativity may depend on the genotypes of specific genes, and the true effect of relevant genes on creativity may not be detected unless the target sample is stratified by environmental factors (e.g., maternal parenting styles). Thus, to test whether the discrepancy regarding the effect of *TPH1* A779C polymorphism on creativity is caused by the neglect of potential G × E interaction, the present study was designed to examine the interaction of *TPH1* A779C polymorphism and maternal parenting styles on creative potential. It is hypothesized that creative potential of individuals carrying different genotypes of *TPH1* A779C polymorphism may be differently affected by maternal parenting styles.

To interpret the mechanisms by which gene may interact with environment, two overarching theoretical perspectives have been proposed: the diathesis-stress model and the differential susceptibility model. The diathesis-stress model largely focuses on the negative environments and suggests that only individuals with the "risk" alleles are more prone to be affected by negative environments (Belsky, 1997; Caspi and Moffitt, 2006). In contrast, the differential susceptibility model focuses on both the positive and the negative environments, and suggests that genes could be "plasticity" rather than "risk." Individuals with the "plasticity" alleles are not only adversely affected by negative environments, but also benefit the most from positive environments (Belsky and Pluess, 2009; Ellis et al., 2011). Among the two perspectives, the diathesis-stress model is most commonly employed, and most of the extant studies regarding G × E interaction have been conducted under this framework (Monroe and Simons, 1991; Burmeister et al., 2008). However, there has also been a rapid growing body of supporting evidence has highlighted the importance of the differential susceptibility model. For example, a recently published meta-analysis showed that many studies, especially in the last 5 years, have found supporting evidence for the differential susceptibility model (Slagt et al., 2016).

As for creativity, to the best of the authors' knowledge, there has been only one study that has examined G × E interaction. Although the study found a significant interaction of *DRD2* and parenting styles on creative potential (Si et al., 2018), whether the finding would be consistent with the diathesis-stress model or the differential susceptibility model was not systematically tested. Thus, until now, little is known about the exact G × E interaction pattern for creativity. To further clarify the G × E interaction pattern for creativity as well as to better explain the potential interaction of *TPH1* A779C polymorphism and maternal parenting styles, the present study also examined whether the potential gene × parenting interaction would coincide with the diathesis-stress model or the differential susceptibility model.

MATERIALS AND METHODS

Participants

The participants were four hundred and twenty-one unrelated healthy Han Chinese undergraduate students from Shandong Normal University (100 males and 321 females, mean age = 18.92 years old). The present study was approved by the Institutional Review Board of Shandong Normal University. Written informed consent was obtained from each participant.

Measures

Creative Potential

Creative potential was assessed by three Uses tasks selected from Runco's Creativity Assessment Battery (rCAB). The Uses tasks asked the participants to list as many as possible uses for three common subjects (toothbrush, tire, and spoon), and were comparable to other assessments of creative potential (Wallach and Kogan, 1965; Guilford, 1968). For each task, four-minute was allowed. The tasks were scored for the three core dimensions of creative potential (fluency, flexibility, and originality). Fluency score was the total number of responses given by the participant. Flexibility score was the number of different categories of the participant's responses. Originality score was the number of unusual responses (given by less than 5% of the sample). Two trained raters scored all three tasks. The inter-rater reliabilities for all three scores were higher than 0.95.

Maternal Parenting Styles

Maternal parenting styles were self-reported by participants using the Parental Authority Questionnaire (PAQ) which was developed to measure the authoritative, authoritarian and permissive parental authority prototypes proposed by Baumrind (1971). It consisted of 30 items rated on a 5-point scale ranging from 1 (weakly disagree) to 5 (strongly agree). The Cronbach's alpha for maternal authoritative parenting, maternal authoritarian parenting and maternal permissive parenting was 0.75, 0.77, and 0.64, respectively.

Genotyping

Peripheral venous blood samples from each participant were first collected with the assistance of medical staff. Genomic

DNA was extracted from peripheral venous blood samples by using the Qiagen QIAamp DNA Mini Kit. Genotyping for *TPH1* A779C polymorphism were performed at Beijing Genomics Institute-Shenzhen by using the Sequenom MassARRAY iPLEX system according to the manufacturer's instructions. For quality control, 5% random DNA samples were genotyped twice to calculate genotyping error. The genotyping accuracy was 100%.

Statistical Analysis

To test the interaction of *TPH1* A779C polymorphism and maternal parenting styles on creative potential, hierarchical multiple linear regression was conducted by using SPSS version 24.0. The procedure was as follows: covariates (gender) were entered in the first step to control for the confounding effects. The main effect of *TPH1* A779C polymorphism (dummy-coded as 0 = CC versus 1 = AA/AC) and maternal parenting styles were entered in the second step. Finally, the interaction terms for *TPH1* A779C polymorphism and maternal parenting styles were added in the third step. When significant interaction was found, simple slope analysis was conducted by using the PROCESS macro for SPSS version 2.16 (Hayes, 2013).

To test whether the significant G × E interaction supported the diathesis-stress or the differential susceptibility model, the analysis of regions of significance (RoS) recommended by Roisman et al. (2012) was carried out by using a web-based program[1]. Briefly, this analysis includes three indexes and a test for non-linearity. First, the RoS on *X* index (Ros *X*) represents the upper and lower bounds of values for the predictor (*X*) at which the regression of the outcome (*Y*) on the moderator (*Z*) is statistically significant. If the association between the moderator (*Z*) and the outcome (*Y*) is significant at both the upper and lower ends of the predictor (*X*) within +/−2 *SD*, then the differential susceptibility model is supported. Second, the proportion of interaction index (PoI) measures the proportion of the total interaction that is represented on the right side or the left side of the crossover point for the interaction, indicating how much a crossover interaction is "for better" or "for worse." PoI values between around 0.40 and 0.60 indicate an interaction highly consistent with the differential susceptibility model, while PoI values close to 0 or 1 suggest strong supporting evidence for the diathesis–stress model. Third, the proportion affected index (PA) estimates the proportion of the population that is differentially affected by the moderator (*Z*). PA values around 0.50 indicate strong evidence for the differential susceptibility model, while PA values close to 0 or 1 provide strong evidence for the diathesis-stress model. Finally, the test of non-linear effects ascertains whether the apparent differential susceptibility effect could be artifacts of imposing a linear model on a non-linear diathesis-stress phenomenon. To support the differential susceptibility effect, the results of the model must show that the linear interaction term remains significant after controlling for the non-linear terms (quadratic effects: X^2 and ZX^2).

[1]http://www.yourpersonality.net/interaction/

RESULTS

Descriptive Statistics

The number of participants as well as the frequencies for *TPH1* A779C polymorphism genotypes were CC (130, 30.9%), AC (201, 47.7%), and AA (90, 21.4%), respectively. No deviation from Hardy-Weinberg equilibrium was observed (p = 0.49). **Table 1** shows the descriptive statistics and the correlation matrix. Most notably, maternal authoritativeness was positively correlated with fluency and originality. Neither *TPH1* A779C polymorphism nor other maternal parenting styles was correlated with the three scores of creative potential.

Regression Models

Hierarchical multiple linear regression analysis revealed significant *TPH1* A779C polymorphism × maternal authoritarianism interactions on flexibility and originality (**Table 2**). No other significant interactions was observed (see **Supplementary Tables S1–S3**). For the significant *TPH1* A779C polymorphism × maternal authoritarianism interactions, simple slopes analysis showed that maternal authoritarianism marginally negatively predicted flexibility for individuals with the CC genotype (β = −0.187, t = −1.96, p = 0.05), but not for those with the AA/AC genotype (β = 0.043, t = 0.757, $p > 0.05$);

TABLE 1 | Descriptive statistics and correlations among the studied variables.

	1	2	3	4	5	6	7	8
1. Gender	1							
2. *TPH1* A779C polymorphism	0.035	1						
3. M-authoritativeness	0.031	−0.013	1					
4. M-authoritarianism	0.072	0.065	−0.248**	1				
5. M-permissiveness	−0.038	−0.007	0.222**	−0.245**	1			
6. Fluency	−0.151**	0.057	0.110*	−0.020	0.075	1		
7. Flexibility	−0.052	0.066	0.050	−0.016	0.065	0.789**	1	
8. Originality	−0.050	0.015	0.118*	−0.033	0.022	0.845**	0.657**	1
M	–	–	25.43	13.44	17.57	8.41	4.42	2.53
SD	–	–	5.48	6.41	4.58	2.92	1.09	1.69

*$p < 0.05$, **$p < 0.01$. M-authoritativeness, maternal authoritativeness; M-authoritarianism, maternal authoritarianism; M-permissiveness, maternal permissiveness; Gender was dummy-coded as 0, female versus 1, male; Genotypes of TPH1 A779C polymorphism were dummy-coded as 0, CC versus 1, AA/AC.

TABLE 2 | Significant results of hierarchical multiple linear regression analysis testing the interaction of *TPH1* A779C polymorphism and maternal authoritarianism on creative potential.

	Flexibility									Originality								
	Model I			Model II			Model III			Model I			Model II			Model III		
	B (SE)	**β**	***t***	***B (SE)***	**β**	***t***	***B (SE)***	**β**	***t***	***B (SE)***	**β**	***t***	***B (SE)***	**β**	***t***	***B (SE)***	***b***	***t***
Control variables																		
Gender	−0.132 (0.125)	−0.052	−1.06	−0.135 (0.125)	−0.053	−1.08	−0.129 (0.125)	−0.051	−1.04	−0.199 (0.194)	−0.050	−1.03	−0.193 (0.195)	−0.048	−0.988	−0.182 (0.194)	−0.046	−0.939
Independent variables																		
M-authoritarianism	–	–	–	−0.003 (0.008)	−0.017	−0.345	−0.005 (0.008)	−0.028	−0.575	–	–	–	−0.008 (0.013)	−0.030	−0.620	−0.012 (0.013)	−0.044	−0.894
TPH1	–	–	–	0.162 (0.115)	0.069	1.41	0.177 (0.115)	0.075	1.54	–	–	–	0.069 (0.179)	0.019	0.384	0.096 (0.179)	0.026	0.539
M-authoritarianism × *TPH1*	–	–	–	–	–	–	0.039 (0.019)	0.101	2.07*	–	–	–	–	–	–	0.072 (0.029)	0.120	2.46*
Model																		
R^2	0.003			0.008			0.018			0.002			0.004			0.018		
ΔR^2	0.003			0.005			0.010			0.002			0.001			0.014		

$^*p < 0.05$; M-authoritarianism, maternal authoritarianism; Gender was dummy-coded as 0, female versus 1, male; Genotypes of TPH1 A779C polymorphism were dummy-coded as 0, CC versus 1, AA/AC.

maternal authoritarianism negatively predicted originality for individuals with the CC genotype (β = −0.232, $t = -2.43$, $p < 0.05$), but not for those with the AA/AC genotype (β = 0.041, $t = 0.714$, $p > 0.05$) (**Figures 1A,B**).

Analysis of RoS

For flexibility, the analysis of RoS provided supporting evidence for the diathesis-stress model (**Figure 1A** and **Table 3**). The RoS on *X* test revealed that the regression of flexibility on *TPH1* A779C polymorphism was significant at the upper bound of maternal authoritarianism within +2 *SD* of the mean, but the lower bound was less than −2 *SD*. The PoI indexes suggested that less than 20% of the interaction occurred left of the crossover point (because maternal authoritarianism negatively predicted flexibility, the left of the crossover point represents "for better"), whereas over 80% was right of the crossover point ("for worse"). The PA indexes indicated that 24% of individuals were affected "for better" (also because maternal authoritarianism negatively predicted flexibility), while 76% were affected "for worse."

For originality, the analysis of RoS demonstrated supporting evidence for the differential susceptibility model (**Figure 1B** and **Table 3**). The RoS on *X* test revealed that the regression of originality on *TPH1* A779C polymorphism was significant at both the upper and lower bound of maternal authoritarianism within +/−2 SD of the mean. Both the PoI and the PA indexes were close to 0.50. Test of non-linearity revealed significant quadratic effects of X^2 (maternal authoritarianism × maternal authoritarianism interaction). However, when controlling for the non-linear term by adding it to the original model, the interaction of *TPH1* A779C polymorphism and maternal authoritarianism remained statistically significant.

DISCUSSION

Previous research focused on the effect of *TPH1* A779C polymorphism and parenting styles on creative potential has both produced mixed results; however, the exact reason concerning the discrepancies has not yet been identified. By revealing the interaction of *TPH1* A779C polymorphism and maternal parenting styles on creative potential, the present study suggested that the neglect of potential G × E interaction might be one of the primary reasons that account for the discrepancies.

In the present study, significant interaction of *TPH1* A779C polymorphism and maternal authoritarianism was found on creative potential. It was shown that the negative effect of maternal authoritarianism on creative potential was only present for individuals with the CC genotype, but not for those with the AA/AC genotype, suggesting that the CC genotype might be more sensitive to high maternal authoritarianism.

The *TPH1* encodes the rate-limiting enzyme for serotonin biosynthesis in the neurons of the raphe nuclei (Nakamura et al., 2006; Zill et al., 2007), and thus regulates serotonin levels and influences behaviors controlled by serotonin. Among *TPH1*-related genetic variants, the most extensively studied is the A779C polymorphism. The A779C polymorphism is located in the intron regions of *TPH1*. Although not directly leading

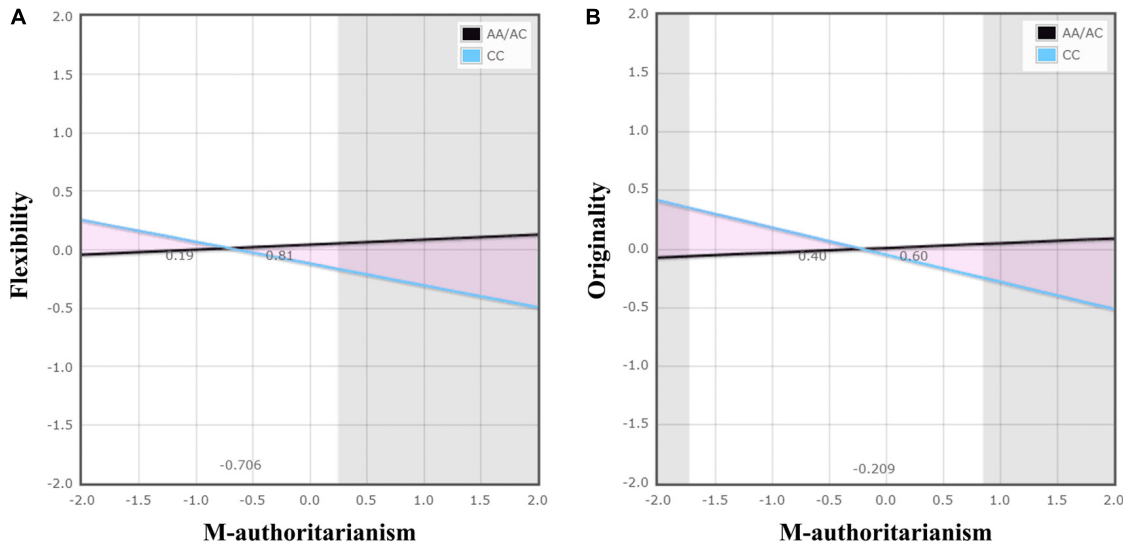

FIGURE 1 | The interaction of *TPH1* A779C polymorphism and maternal authoritarianism on creative potential. The gray shaded areas represent regions of significance (RoS) on *X* and denote where the two lines differ significantly from each other within +/−2 *SD*. The triangular pink shaded areas depict the proportion of the interaction (PoI). Graph **(A)** demonstrates a diathesis-stress effect: the CC genotype differed from the AA/AC genotype, showing significantly lower flexibility when there was high maternal authoritarianism. Graph **(B)** demonstrates a differential susceptibility effect: the CC genotype, with respect to the AA/AC genotype, showing significantly higher originality when there was low maternal authoritarianism, as well as significantly lower originality when there was high maternal authoritarianism. The figure was produced by using a web-based program developed by Chris Fraley http://www.yourpersonality.net/interaction/ to perform the RoS analysis as recommended by Roisman et al. (2012).

to functional change in protein coding, this polymorphism may affect *TPH1* expression by influencing the binding affinity of GATA-1 transcription factor (Nielsen et al., 1997). And it has been shown that this polymorphism was associated with individual differences in serotonin production and basal serotonin levels. Compared with the AA/AC genotype, the CC genotype was associated with higher serotonin production and higher basal serotonin levels (Jönsson et al., 1997).

Serotonin plays a pivotal role in stress management (Chaouloff et al., 1999; Chaouloff, 2000; Holmes, 2008). Serotonin released in response to psychological stress has been demonstrated to serve a stress-buffering function to attenuate the damaging effect, and thus increases the modulatory capacity of the stress response system (Mitchell et al., 1990; Gesing et al., 2001; Laplante et al., 2002). During childhood period, parents largely control and moderate children's life and social environment, and are therefore the main sources of stress to children. Children exposed to harsh parenting, such as high maternal authoritarianism, may perceive the environment as stressful and experience higher levels of psychological control and stress (Deater-Deckard, 1998). To mitigate the damaging effect of high maternal parenting stress, a persistent release of serotonin as well as a prolonged activation of serotonin production may be instinctively induced. Obviously, this process could benefit children by protecting them from the damaging effect of psychological stress associated with high maternal authoritarian parenting; however, accompanied by this process, there might also be long term neurobiological influences on brain development and cognitive functions.

Creativity might be among the cognitive functions that being influenced by this process. Previous findings concerning the effect of serotonin on creativity have suggested that serotonin plays an important but complex role in creativity. While lower serotonin levels may harm creativity by decreasing cognitive flexibility, higher serotonin levels may also impair creativity by decreasing approach motivation and avoidance motivation (Nutt et al., 2007; Cools et al., 2008; Flaherty, 2011). This complicated relationship has particularly important implications for understanding the influence of the prolonged serotonin production on creativity: since the overall higher serotonin levels may harm creativity, when considering the effect of the prolonged serotonin release on creativity, individual differences in serotonin production and basal serotonin levels must be taken into account. And this may partially explain why the negative effect of maternal authoritarianism on creative potential was only present for individuals with the CC genotype. As mentioned above, for individuals exposed to high maternal authoritarianism, a prolonged activation of serotonin production may be instinctively induced to mitigate the negative effect of high psychological stress. Besides increasing the modulatory capacity of stress, the elevated serotonin levels may also exert an effect on individuals' creative potential. Importantly, for individuals who were of higher serotonin production and higher basal serotonin levels (CC genotype), the prolonged activation of serotonin production may result in excessive overall serotonin levels, and thus finally impairs creative potential.

To clarify the G × E interaction pattern for the significant interaction of *TPH1* A779C polymorphism and maternal authoritarianism on creative potential, the present study also examined whether the interaction would coincide with the diathesis-stress model or the differential susceptibility model.

TABLE 3 | Diathesis–stress/differential susceptibility indices for the interaction of *TPH1* and maternal authoritarianism on creative potential.

Creative potential	RoS *X* (M-authoritarianism)		PoI (for better)	PoI (for worse)	Crossover	PA (for better)	PA (for worse)	Test of non-linearity	Best fitting model
	Upper bound	Lower bound							
Flexibility	0.248	−11.92	0.19	0.81	−0.706	0.24	0.76	–	Diathesis–stress
Originality	0.853	−1.73	0.40	0.60	−0.209	0.42	0.58	Passed	Differential susceptibility

RoS X, regions of significance on X; M-authoritarianism, maternal authoritarianism; PoI, proportion of the interaction index; Crossover denotes the value of X (maternal authoritarianism) at which the genotype group regression lines intersected; PA, proportion affected index.

The RoS analysis provided interesting results by showing supporting evidence for both the diathesis-stress model and the differential susceptibility model. For flexibility, it was found that the interaction was consistent with the diathesis-stress model, such that individuals with the CC genotype showed lower flexibility than those of the AA/AC genotypes when there was high maternal authoritarianism, and there was no differences when there was low maternal authoritarianism; while for originality, the differential susceptibility model best explained the interaction, in which individuals with the CC genotype showed higher originality than those of the AA/AC genotype when there was low maternal authoritarianism (i.e., "for better effects" when environment is supportive; the absence of adversities could also be considered as a type of positive environment) but lower originality than those of the AA/AC genotype when there was high maternal authoritarianism (i.e., "for worse effects" when environment is adverse). These findings suggested that the potential mechanisms underlying the G × E interaction on creativity might be complicated. For different dimensions of creativity, there might be different G × E interaction patterns, and genes could be either "risk" or "plasticity" to modulate the effect of environment on creativity.

Moreover, although three different maternal parenting styles were tested in the present study, only maternal authoritarianism was found to be interacted with *TPH1* A779C polymorphism to influence creative potential. This result was coincided with previous finding that, among the three different parenting styles, only authoritarian parenting interacted with *DRD2* to affect creative potential (Si et al., 2018). These evidences together suggested that, unlike authoritative or permissive parenting styles, the effect of authoritarian parenting on creativity might be more dependent on individuals' genetic predispositions. For individuals with particular predispositions (e.g., the CC genotype of *TPH1* A779C polymorphism), to maximize their creative potential, avoiding the effect of adverse environment (e.g., high authoritarian parenting) might be at least as important as, or even more important than proactively creating positive environment (e.g., authoritative parenting).

Several limitations of the present study should be noted. First, the degree to which these findings could generalize to other samples is not clear. Since the participants of the present study were only Han Chinese undergraduate students, replication studies across different age and ethnic groups are necessary. Second, maternal parenting styles were only measured by self-report in the present study, thus the participants' responses may have been subject to recall bias. Future studies combining both family observation and multi-angle measurement (e.g., mother's report and other's report) of maternal parenting styles are guaranteed to provide more comprehensive and convincing results. Third, although the present study provides plausible explanation for the significant interactions, the exact mechanisms underlying these interactions remains to be clarified and refined. Because serotonin is involved in multiple emotional, cognitive and behavioral control process and the modulation of serotonin transmission is a complex network of different biological process (Barnes and Sharp, 1999; Meneses, 1999; Robbins and Roberts, 2007; Cools, 2012; Jenkins et al., 2016), sorting out the nature of

the interactions remains an interpretive challenge. Future studies are required to reveal both the psychological and the biological mechanisms of the interactions. For example, since serotonin has important effects on intelligence-related cognitive functions and intelligence is closely related to creativity (Silvia, 2015; Karwowski et al., 2016), it is possible that general intelligence may contribute to the interaction of *TPH1* A779C polymorphism and maternal authoritarianism on creative potential. However, since intelligence was not measured in the present study, this hypothesis could not be examined. Future studies are warranted to test this hypothesis. And it has also to be elucidated whether the effect of serotonin is directly exerted or by an indirectly interaction with the dopamine system, since it has been shown that serotonin can inhibit dopamine activation (Porras et al., 2002; Abi-Dargham, 2007). Moreover, recent genome-wide association studies (GWAS) of complex traits have shown that most complex phenotypes are highly polygenic (Manolio et al., 2009; Gratten et al., 2014; Robinson et al., 2014). As for creativity, this situation may also hold true. Since only one genetic variant (*TPH1* A779C polymorphism) was examined in the present study, the full contribution of gene and parenting styles interaction to creativity was far more from being revealed. For future studies aimed to fully uncover the interaction of gene and parenting styles on creativity, polygenic score derived from GWAS of creativity may be an ideal candidate genetic index to test the interaction of genes and parenting styles. And there has been one successful attempt using GWAS data to explore both the neural and genetic determinants of creativity (Liu et al., 2018).

In conclusion, the present study shows the first evidence for the interaction of *TPH1* A779C polymorphism and maternal authoritarianism on creative potential. These findings may provide important insight into how gene interacts with environment to influence creativity, and help to explain the origins of individual differences in creativity.

AUTHOR CONTRIBUTIONS

SZ and JZ were involved in the conception and design of the work. SZ, XH, and SS collected the data. SZ analyzed the data and contributed in writing the main manuscript text.

FUNDING

The present study was supported by National Natural Science Foundation of China (Grant Nos. 31470999 and 31771235), MOE (Ministry of Education in China) Project of Humanities and Social Sciences (Grant No. 16YJC190030), Science and Technology Projects of Shandong Province (China; Grant No. ZR2014CQ017), Research Center of Qilu Culture (Shandong Normal University, Jinan, China).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.02106/full#supplementary-material

REFERENCES

Abi-Dargham, A. (2007). Alterations of serotonin transmission in schizophrenia. *Int. Rev. Neurobiol.* 78, 133–164. doi: 10.1016/S0074-7742(06)78005-9

Barnes, N. M., and Sharp, T. (1999). A review of central 5-HT receptors and their function. *Neuropharmacology* 38, 1083–1152. doi: 10.1016/S0028-3908(99)00010-6

Baumrind, D. (1971). Current patterns of parental authority. *Dev. Psychol.* 4, 1–103. doi: 10.1037/h0030372

Belsky, J. (1997). Variation in susceptibility to environmental influence: an evolutionary argument. *Psychol. Inq.* 8, 182–186. doi: 10.1207/s15327965pli0803_3

Belsky, J., and Pluess, M. (2009). Beyond diathesis stress: differential susceptibility to environmental influences. *Psychol. Bull.* 135, 885–908. doi: 10.1037/a0017376

Burmeister, M., Mcinnis, M. G., and Zollner, S. (2008). Psychiatric genetics: progress amid controversy. *Nat. Rev. Genet.* 9, 527–540. doi: 10.1038/nrg2381

Caspi, A., and Moffitt, T. E. (2006). Gene-environment interactions in psychiatry: joining forces with neuroscience. *Nat. Rev. Neurosci.* 7, 583–590. doi: 10.1038/nrn1925

Chaouloff, F. (2000). Serotonin, stress and corticoids. *J. Psychopharmacol.* 14, 139–151. doi: 10.1177/026988110001400203

Chaouloff, F., Berton, O., and Mormede, P. (1999). Serotonin and stress. *Neuropsychopharmacology* 21, 28S–32S. doi: 10.1016/S0893-133X(99)00008-1

Cools, R. (2012). "Chemical neuromodulation of goal-directed behavior," in *Cognitive Search: Evolution, Algorithms, and the Brain*, eds P. M. Todd, T. T. Hills, and T. W. Robbins (Cambridge, MA: Cambridge University Press), 111–124.

Cools, R., Roberts, A. C., and Robbins, T. W. (2008). Serotoninergic regulation of emotional and behavioural control processes. *Trends. Cogn. Sci.* 12, 31–40. doi: 10.1016/j.tics.2007.10.011

Deater-Deckard, K. (1998). Parenting stress and child adjustment: some old hypotheses and new questions. *Clin. Psychol. Sci. Pract.* 5, 314–332. doi: 10.1111/j.1468-2850.1998.tb00152.x

Ellis, B. J., Boyce, W. T., Belsky, J., Bakermans-Kranenburg, M. J., and Van Ijzendoorn, M. H. (2011). Differential susceptibility to the environment: an evolutionary-neurodevelopmental theory. *Dev. Psychopathol.* 23, 7–28. doi: 10.1017/S0954579410000611

Fearon, D. D., Copeland, D., and Saxon, T. F. (2013). The relationship between parenting styles and creativity in a sample of Jamaican children. *Creat. Res. J.* 25, 119–128. doi: 10.1080/10400419.2013.752287

Flaherty, A. W. (2011). Brain illness and creativity: mechanisms and treatment risks. *Can. J. Psychiatry* 56, 132–143. doi: 10.1177/070674371105600303

Gesing, A., Bilang-Bleuel, A., Droste, S. K., Linthorst, A. C., Holsboer, F., and Reul, J. M. (2001). Psychological stress increases hippocampal mineralocorticoid receptor levels: involvement of corticotropin-releasing hormone. *J. Neurosci.* 21, 4822–4829. doi: 10.1523/JNEUROSCI.21-13-04822.2001

Gratten, J., Wray, N. R., Keller, M. C., and Visscher, P. M. (2014). Large-scale genomics unveils the genetic architecture of psychiatric disorders. *Nat. Neurosci.* 17, 782–790. doi: 10.1038/nn.3708

Guilford, J. P. (1968). *Intelligence, Creativity and Their Educational Implications*. New York, NY: Robert R. Knapp.

Hamon, M., Bourgoin, S., Artaud, F., and Nelson, D. (1981). Regulatory properties of neuronal tryptophan hydroxylase. *Adv. Exp. Med. Biol.* 133, 231–251. doi: 10.1007/978-1-4684-3860-4_13

Hayes, A. F. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. New York, NY: Guilford Press.

Holmes, A. (2008). Genetic variation in cortico-amygdala serotonin function and risk for stress-related disease. *Neurosci. Biobehav. Rev.* 32, 1293–1314. doi: 10.1016/j.neubiorev.2008.03.006

Jenkins, T. A., Nguyen, J. C., Polglaze, K. E., and Bertrand, P. P. (2016). Influence of tryptophan and serotonin on mood and cognition with a possible role of the gut-brain axis. *Nutrients* 8:56. doi: 10.3390/nu8010056

Jönsson, E. G., Goldman, D., Spurlock, G., Gustavsson, J. P., Nielsen, D. A., Linnoila, M., et al. (1997). Tryptophan hydroxylase and catechol-O-methyltransferase gene polymorphisms: relationships to monoamine metabolite concentrations in CSF of healthy volunteers. *Eur. Arch. Psychiatry. Clin. Neurosci.* 247, 297–302. doi: 10.1007/BF02922258

Karwowski, M., Dul, J., Gralewski, J., Jauk, E., and Jankowska, D. M. (2016). Is creativity without intelligence possible? A necessary condition analysis, intelligence. *Intelligence* 57, 105–117. doi: 10.1016/j.intell.2016.04.006

Laplante, P., Diorio, J., and Meaney, M. J. (2002). Serotonin regulates hippocampal glucocorticoid receptor expression via a 5-HT7 receptor. *Brain. Res. Dev. Brain. Res.* 139, 199–203. doi: 10.1016/S0165-3806(02)00550-3

Lim, S., and Smith, J. (2008). The structural relationships of parenting style, creative personality, and loneliness. *Creat. Res. J.* 20, 412–419. doi: 10.1080/10400410802391868

Liu, Z., Zhang, J., Xie, X., Rolls, E. T., Sun, J., Zhang, K., et al. (2018). Neural and genetic determinants of creativity. *Neuroimage* 174, 164–176. doi: 10.1016/j.neuroimage.2018.02.067

Manolio, T. A., Collins, F. S., Cox, N. J., Goldstein, D. B., Hindorff, L. A., Hunter, D. J., et al. (2009). Finding the missing heritability of complex diseases. *Nature* 461, 747–753. doi: 10.1038/nature08494

Mehrinejad, S. A., Rajabimoghadam, S., and Tarsafi, M. (2015). The relationship between parenting styles and creativity and the predictability of creativity by parenting styles. *Proc. Soc. Behav. Sci.* 205, 56–60. doi: 10.1016/j.sbspro.2015.09.014

Meneses, A. (1999). 5-HT system and cognition. *Neurosci. Biobehav. Rev.* 23, 1111–1125. doi: 10.1016/S0149-7634(99)00067-6

Miller, A. L., Lambert, A. D., and Speirs Neumeister, K. L. (2012). Parenting style, perfectionism, and creativity in high-ability and high-achieving young adults. *J. Educ. Gift.* 35, 344–365. doi: 10.1177/0162353212459257

Mitchell, J. B., Rowe, W., Boksa, P., and Meaney, M. J. (1990). Serotonin regulates type II corticosteroid receptor binding in hippocampal cell cultures. *J. Neurosci.* 10, 1745–1752. doi: 10.1523/JNEUROSCI.10-06-01745.1990

Monroe, S. M., and Simons, A. D. (1991). Diathesis-stress theories in the context of life stress research: implications for the depressive disorders. *Psychol. Bull.* 110, 406–425. doi: 10.1037/0033-2909.110.3.406

Nakamura, K., Sugawara, Y., Sawabe, K., Ohashi, A., Tsurui, H., Xiu, Y., et al. (2006). Late developmental stage-specific role of tryptophan hydroxylase 1 in brain serotonin levels. *J. Neurosci.* 26, 530–534. doi: 10.1523/JNEUROSCI.1835-05.2006

Nichols, R. C. (1964). Parental attitudes of mothers of intelligent adolescents and creativity of their children. *Child. Dev.* 35, 1040–1049. doi: 10.2307/1126851

Nielsen, D. A., Jenkins, G. L., Stefanisko, K. M., Jefferson, K. K., and Goldman, D. (1997). Sequence, splice site and population frequency distribution analyses of the polymorphic human tryptophan hydroxylase intron 7. *Brain. Res. Mol. Brain. Res.* 45, 145–148. doi: 10.1016/S0169-328X(96)00304-X

Nutt, D., Demyttenaere, K., Janka, Z., Aarre, T., Bourin, M., Canonico, P. L., et al. (2007). The other face of depression, reduced positive affect: the role of catecholamines in causation and cure. *J. Psychopharmacol.* 21, 461–471. doi: 10.1177/0269881106069938

Porras, G., Di Matteo, V., Fracasso, C., Lucas, G., De Deurwaerdere, P., Caccia, S., et al. (2002). 5-HT2A and 5-HT2C/2B receptor subtypes modulate dopamine release induced in vivo by amphetamine and morphine in both the rat nucleus accumbens and striatum. *Neuropsychopharmacology* 26, 311–324. doi: 10.1016/S0893-133X(01)00333-5

Reuter, M., Roth, S., Holve, K., and Hennig, J. (2006). Identification of first candidate genes for creativity: a pilot study. *Brain Res.* 1069, 190–197. doi: 10.1016/j.brainres.2005.11.046

Robbins, T. W., and Roberts, A. C. (2007). Differential regulation of fronto-executive function by the monoamines and acetylcholine. *Cereb. Cortex* 17, i151–i160. doi: 10.1093/cercor/bhm066

Robinson, M. R., Wray, N. R., and Visscher, P. M. (2014). Explaining additional genetic variation in complex traits. *Trends Genet.* 30, 124–132. doi: 10.1016/j.tig.2014.02.003

Roisman, G. I., Newman, D. A., Fraley, R. C., Haltigan, J. D., Groh, A. M., and Haydon, K. C. (2012). Distinguishing differential susceptibility from diathesis-stress: recommendations for evaluating interaction effects. *Dev. Psychopathol.* 24, 389–409. doi: 10.1017/S0954579412000065

Runco, M. A., Noble, E. P., Reiter-Palmon, R., Acar, S., Ritchie, T., and Yurkovich, J. M. (2011). The genetic basis of creativity and ideational fluency. *Creat. Res. J.* 23, 376–380. doi: 10.1080/10400419.2011.621859

Rutter, M., Moffitt, T. E., and Caspi, A. (2006). Gene-environment interplay and psychopathology: multiple varieties but real effects. *J. Child. Psychol. Psychiatry* 47, 226–261. doi: 10.1111/j.1469-7610.2005.01557.x

Si, S., Zhang, S., Yu, Q., and Zhang, J. (2018). The interaction of DRD2 and parenting style in predicting creativity. *Think. Skills Creat.* 27, 64–77. doi: 10.1016/j.tsc.2017.11.001

Silvia, P. J. (2015). Intelligence and creativity are pretty similar after all. *Educ. Psychol. Rev.* 27, 599–606. doi: 10.1007/s10648-015-9299-1

Slagt, M., Dubas, J. S., Dekovic, M., and Van Aken, M. A. G. (2016). Differences in sensitivity to parenting depending on child temperament: a meta-analysis. *Psychol. Bull.* 142, 1068–1110. doi: 10.1037/bul0000061

Wallach, M. A., and Kogan, N. (1965). *Modes of Thinking in Young Children: A Study of the Creativity-Intelligence Distinction*. New York, NY: Holt, Rinehart & Winston.

Zhang, S., and Zhang, J. H. (2017). The association of TPH genes with creative potential. *Psychol. Aesthet. Creat. Arts* 11, 2–9. doi: 10.1037/aca0000073

Zill, P., Büttner, A., Eisenmenger, W., Möller, H. J., Ackenheil, M., and Bondy, B. (2007). Analysis of tryptophan hydroxylase I and II mRNA expression in the human brain: a post-mortem study. *J. Psychiatr. Res.* 41, 168–173. doi: 10.1016/j.jpsychires.2005.05.004

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 26 November 2018
doi: 10.3389/fpsyg.2018.02257

The Effect of the Embodied Guidance in the Insight Problem Solving: An Eye Movement Study

Qiang Xing[1], Cuiliang Rong[1], Zheyi Lu[1], Yanfeng Yao[1,2], Zhonglu Zhang[1]* and Xue Zhao[3]*

[1] *Department of Psychology, School of Education, Guangzhou University, Guangzhou, China,* [2] *Jiangcun Primary School, Guangzhou, China,* [3] *Shunde Experiment Middle School, Foshan, China*

Insight is an important cognitive process in creative thinking. The present research applied embodied cognitive perspective to explore the effect of embodied guidance on insight problem solving and its underlying mechanisms by two experiments. Experiment 1 used the matchstick arithmetic problem to explore the role of embodied gestures guidance in problem solving. The results showed that the embodied gestures facilitate the participants' performance. Experiment 2 investigated how embodied attention guidance affects insight problem solving. The results showed that participants performed better in prototypical guidance condition. Experiment 2a adopted the Duncker's radiation problem to explore how embodied behavior and prototypical guidance influence problem solving by attention tracing techniques. Experiment 2b aimed to further examine whether implicit attention transfer was the real cause which resulted in participants over-performing in prototypical guidance condition in Experiment 2a. The results demonstrated that overt physical motion was unnecessary for individuals to experience the benefits of embodied guidance in problem solving, which supported the reciprocal relation hypothesis of saccades and attention. In addition, the questionnaire completed after experiments showed that participants did not realize the relation between guidance and insight problem solving. Taken together, the current study provided further evidence for that embodied gesture and embodied attention both facilitated the insight problem solving and the facilitation is implicit.

Keywords: insight problem solving, creativity, attention guidance, embodied effect, eye movement track

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Zhiya Liu,
South China Normal University, China
Ding Xiaobin,
Northwest Normal University, China

****Correspondence:***
Qiang Xing
xingqiang@gzhu.edu.cn
Zhonglu Zhang
zzllzz_zz_2005@126.com

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *30 July 2018*
Accepted: *30 October 2018*
Published: *26 November 2018*

Citation:
Xing Q, Rong C, Lu Z, Yao Y, Zhang Z and Zhao X (2018) The Effect of the Embodied Guidance in the Insight Problem Solving: An Eye Movement Study. Front. Psychol. 9:2257. doi: 10.3389/fpsyg.2018.02257

INTRODUCTION

Insight is an important cognitive process in creative thinking. Exploring insight and its underlying mechanism helped us understand creative thinking better. Insight is a special form of problem solving, namely insight problem solving. Other than solving general problem, individuals cannot specifically explain problem solving steps or process; insight problem solving is an "aha" experience in which participants suddenly and intuitively understand complex situations or seize the key to the problem (Bowden and Jung-Beeman, 2007). The well-established cognitive theories interpreting insight problem solving are representational change theory, progress monitor theory, and prototype heuristic theory (Zhang et al., 2004). However, recently increasing attention has been focused on how individual's body (*e.g., feelings*, *motion*, and *active state*) influences problem representation and transformation (Stepper and Strack, 1993; Williams and Bargh, 2008; Ball and Litchfield, 2017).

It has been realized that human cognition relies on body and sensory motor system, while body plays an essential role in the cognitive process. The bodied behavior is not only influenced by internal cognitive processes, but also affects cognitive processes conversely (Brouillet et al., 2010; Hao-Sheng, 2011; Jones, 2017). How do embodied behavior influence insight problem solving, and could embodied cognition theory interpret insight problem solving process? Although some studies have found that embodied behavior and active state promotes problem solving (Bowden and Jung-Beeman, 2007; Cook et al., 2008; Cook and Tanenhaus, 2009; Schubert and Semin, 2009; Werner and Raab, 2014), how the effect works is not clear. Hence, it is necessary to explore how embodied behavior and active state influences insight problem solving using embodied cognition theory. The present study aimed to explore the function and underlying mechanisms about how embodied guidance affect insight problem solving.

Embodied cognitive can be understood that cognition is influenced by the environment and the body, including its potential actions (Adam and Galinsky, 2012; Goldinger et al., 2016). Embodied effect refers to changes in cognition, attitude, social perception, emotion, and others related to the tasks involved when experience or simulate the movement or state of body, and this kind of functional dependence theory is embodied theory (Qiu-Ping et al., 2011; Horchak et al., 2014). According to embodied theory, bodied behavior and states of the body could change cognitive status (Wilson and Sabrina, 2013). The insight experience is a special experience in the process of insight problem solving, and it existed in the whole process of insight problem solving (Shen et al., 2015). Shen et al. (2018b) showed that insight experience was a complex, multidimensional construction with cognitive, affective, and embodied characteristics. Some researches supported that insight problem solving or insight experience is embodied (Leung et al., 2012; Jarman, 2014). And some studies found that gestures or speech could help to understand knowledge and solve problems. The information of problem would lead into mental representation by gestures or speech, then promote thinking and problem solving (Broaders et al., 2007; Cook et al., 2008; Cook and Tanenhaus, 2009; Beilock and Goldin-Meadow, 2010; Cook et al., 2010; Chu and Kita, 2011). Chu and Kita (2011) used mental rotation task and origami task to investigate whether the gesture can improve visual space problem solving, and the results showed that the group allowed to use gestures performed better in task than that not allowed to use gestures, which indicates that gestures not only reflect the process of thinking, but also affect it and then promote problem solving.

Previous research have found that embody gestures or speech play an important role in promoting insight problems solving, and others have found that body movement also affects the insight problems solving, such as patterns of eye movement or attention (Knoblich et al., 2001; Grant and Spivey, 2003; Thomas and Lleras, 2007, 2009; Litchfield and Ball, 2011; Werner and Raab, 2014). Knoblich et al. (2001) used matchstick equation problems by eye movement technology to investigate mechanism of insight problem solving. They found that the behavior of eyes gazing on problem characteristics revealed the mechanism of the predicament and insight. It was found that individuals tended to focus their look differently at the former and later stage of problem solving. Problem solving winners tended to shift their attention to the key areas before the occurrence of insight. Grant and Spivey (2003) demonstrated that there is relation between eye movement and the cognitive process. They used tumors-laser radiation problem (Duncker and Lees, 1945) and recorded eye movement of participants. The result showed that problem solving winners gazed at the skin area more and made more fixation and switch of skin-crossing in-and out. This pattern of eye movements could draw the outline of solution to problems. Litchfield and Ball (2011) found that other people's eye movement patterns could also guide participants in insight problems solving. It is concluded that eye movement leads the cognitive process of problem solving. Based on this, can it be possible to improve the accuracy of problem solving by giving problem solvers a hint of attention or guiding them to pay attention to the key areas of problem solving? Therefore, a task was designed to guide the individuals' eye movement and reflect the pattern of problem solving by moving their eyes, so as to explore prototypical guidance mechanism of insight solution. Research found that heuristic prototype was important in solving scientific innovation insight problems (Yang et al., 2016).

In addition, it was still controversial whether an individual can realize the process of insight problem solving. Most research found that the process of insight problem solving is implicit, and individuals do not realize the hints of problem solving (Grant and Spivey, 2003; Ollinger et al., 2013; Riffert, 2013; Branchini et al., 2016). Ollinger et al. (2013) on eight-coin problem found that implicit use the third dimension to find the solution. Conversely, some research found individuals are aware of the hints or trains (Dow and Mayer, 2004; Patrick and Ahmed, 2014). It may be related to feature of the problem hints or trains. Therefore, we intended to explore whether individuals realize the connection between embodied guidance and problem solving in this study, and it is inferred that the process of insight problem solving is implicit or explicit.

To sum up, some studies have found that embodied behavior and eye movement could guide individual thinking, thus affect problem solving. However, it is still not clear what the underlying mechanism is between the embodied active state and cognition. Therefore, we used the eye movement technology to explore how embodied guidance influences insight problem solving and its underlying mechanisms. And whether the embodied effect of insight problem solving truly need external behavior or just only internal attention-transfer? The present study consisted of two experiments, respectively, to explore the effects of embodied behavior and embodied attention guidance on insight problem solving, and the mechanism of embodied effect in insight problem solving. In Experiment 1, we used matchstick arithmetic problem to explore the role of embodied behavior (*gestures guidance* and *speech guidance*) in problem solving. The matchstick arithmetic problem is the most suitable experimental material to explore the problem representation influencing the problem solving for it has different degrees of representation transformation. In Experiment 2a, we adopted

the Duncker's radiation problem to explore how embodied behavior and prototypical guidance influence problem solving by attention tracing techniques. In Experiment 2b, aimed to further examine whether implicit attention transfer was the real cause which resulted in participants over-performing in prototypical guidance condition in Experiment 2a. We used Duncker's radiation problem as Experiment 2 material because the components of the problem and its answer are relatively simple. There are three components (*tumor*, *healthy tissue*, and *skin outside*) and the answer involves only two key components (*low-density multiple lasers*). It not only allows us to achieve embodied attention guidance through digital tracking tasks, but also to operate different digital tracking tasks to study the impact of prototype heuristic on the insight problem solving.

EXPERIMENT 1

Materials and Methods

Participants

Ninety-two undergraduate students (55 females, mean age = 22.56 years, *SD* = 3.82) were recruited for course credit or proper reward. All participants reported normal or corrected to normal vision. They signed the informed consent and they had not participated in similar experiments before. All participants were randomly assigned to four groups.

Design

The design of Experiment 1 was a single factor between participants. The independent variable is guidance pattern (gestures guidance, speech guidance, mix guidance, no guidance). The accuracy, reaction time, fixation duration, and the number of fixation of each areas of interest (AOI) are dependent variable.

Materials and Apparatus

We collected 70 matchstick arithmetic problems in total by looking up the online math problem library and various books. All arithmetic did not exceed two digits (41 addition; 29 subtraction), including 40 numerical constraint problem, 30 symbol constraint problem. Numerical constraint problem refers to that participants need to change the figure to make equation valid in this kind of problem while they have to change the operation symbol in symbol constraint problem. All materials were made in Photoshop with font being Time New Roman, font size being 72, white background, and black character.

Sixteen additional undergraduate students (7 females, mean age = 20 years, *SD* = 2), who had no prior experience in solving matchstick arithmetic problems, were asked to evaluate the difficulty of problems by five points. In order to balance the order of problems, half of the participants made evaluation in the order from the front to the back, while the other half otherwise. Finally, 23 matchstick arithmetic problems (excluding 17 more than the only answer problems, 11 interacted problems, and 19 too hard or too easy problems) were chosen as experiment materials. The difficulty is moderate (M = 2.87). The numerical constraint problem is more difficult than symbolic constraint problem. The problem type of matchstick arithmetic is shown in **Figure 1**.

An SR Research (Mississauga, ON, Canada) EyeLink Plus Eye-Tracking System recorded participants' eye movements with a sampling rate of 500 Hz. This eye tracker has a high spatial (0.01° of visual angle) using pupil tracking and corneal reflection. The materials were displayed on a 19-in Dell monitor with a refresh rate of 75 Hz (resolution 1,024 × 768 pixels), and the viewing distance was approximately 60 cm. Viewing was binocular and only right eye was tracked as permitted by the quality of the calibration for right eye. The experiment was run with E-Prime 1.10 software.

Procedure

There were four experimental conditions: Gesture guidance condition (G): after each problem is presented, participants were asked to draw a horizontal line on the left of it using left hand and another one using right hand. Speech guidance condition (S): after each problem is presented, participants were asked to utter the phase "How can you do to complete the equation by moving only one matchstick?" Mix guidance (M): after each problem is presented, participants were asked to perform both. Control (no guidance) condition (C): without any guidance.

There were 23 trials in Experiment 1. The matchstick arithmetic problems were lasting on the screen for 50 s, during which participants were asked to make the equation valid by moving only one matchstick. If participants came up with the answer, they should report it orally and the experimenter would record it, otherwise the next problem would be presented after 50 s.

At the end of the experiment, participants were asked to assess the difficulty of the problem by five point, whose scale ranging from 1 (*very difficult to solve*) to 5 (*very easy to solve*). The sense of surprise about problems solving by five points, whose scale ranging from 1 (*very surprised*) to 5 (*not surprised at all*). Participants should also answer that whether they realize the connection between guidance and problem solving? 1 refers to no relation, 2 guidance providing clues and hints, and 3 guidance interfering thinking. The detailed procedures of the experiment are in **Figure 2**.

Results

Post-experiment Questionnaires Analyses

Post-experiment questionnaires aimed to find out whether participants realized the connection between guidance and problem solving, and the results showed that 5 participants realized that there was a link between the guidance and problem solving (2 in G condition, 3 in M condition), the other 87 participants didn't realize the connection. Data of 85 participants were in final analysis excluding 5 realizing the connection and 2 uncompleted recording. The results of difficulty level and the sense of surprise about problem solving are shown in **Table 1**.

Chi-square test showed that there was no significant difference in four experimental conditions: $\chi^2_{(9)} = 12.634$, $p = 0.180$. It indicated that experimental condition did not affect the

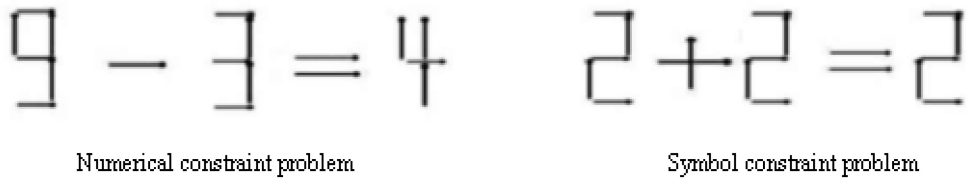

FIGURE 1 | Matchstick arithmetic problems type diagram.

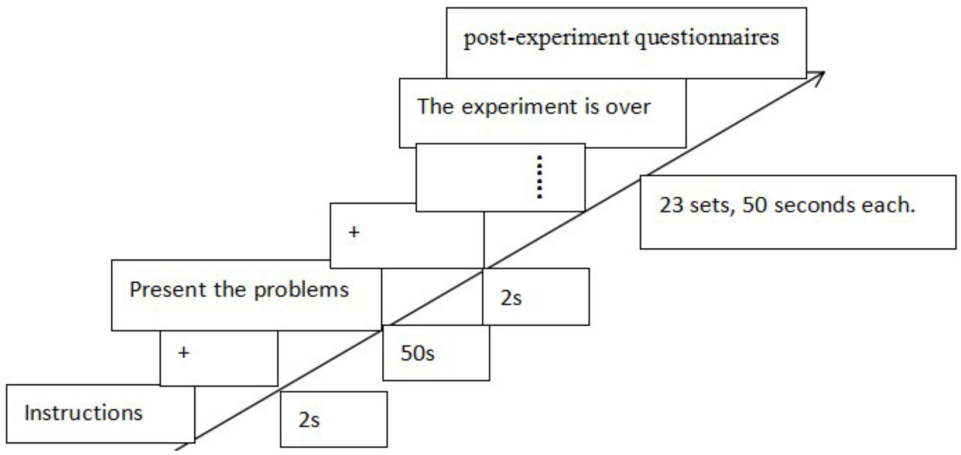

FIGURE 2 | The detailed procedures of Experiment 1.

TABLE 1 | Evaluation of difficulty level and the sense of surprise about problem solving (one).

Guidance condition	Difficulty level of problem					A sense of surprise				
	1	2	3	4	5	1	2	3	4	5
G	1	5	13	3	0	0	12	7	3	0
S	2	9	9	1	0	2	8	9	1	1
M	0	9	6	5	0	0	8	4	8	0
C	0	9	12	1	0	0	7	12	1	2

G is the gesture guidance condition; S is the speech guidance condition; M is the mix guidance condition; and C is the control condition.

solution of the problem. There was a significant difference in the sense of surprise: $\chi^2_{(12)} = 25.953$, $p = 0.011$, suggesting that participants had different "aha" experience in the four experimental conditions.

Accuracy, Reaction Time, and Ratio of Accuracy Analyses

To test the effect of different guidance conditions on insight problem solving, we analyzed the accuracy and response time in different guidance conditions. And we analyzed the ratio of accuracy in different guidance conditions to test the effect of different guidance conditions on problem type. A one-way ANOVA showed that there was a significant difference in accuracy under different experimental conditions, $F_{(3,81)} = 4.863$, $p = 0.004$, $\eta_p^2 = 0.152$. And there was a significant difference in reaction time under different experimental conditions, $F_{(3,81)} = 4.208$, $p = 0.008$, $\eta_p^2 = 1.348$. After the Tukey-HSD examination, accuracy in both G and M condition was significantly higher than that in S condition ($p = 0.043$, $p = 0.004$). Accuracy in both G and M condition was significantly higher than C condition ($p = 0.023$, $p = 0.002$). Response time in G condition was significantly shorter than C condition ($p = 0.002$). There were not significant different in other conditions ($p > 0.05$). The result showed that the accuracy was the highest and the response time was shortest in the gesture guidance condition. It suggested that the gesture guidance promoted the insight problem solving. The results were shown in **Figure 3**.

A two-way repeated measures ANVOA with guidance condition and problem type on ratio of accuracy showed that the main effect of guidance condition was not significant, $F_{(3,81)} = 1.590$, $p = 0.098$, $\eta_p^2 = 0.056$. The main effect of problem type was significant, $F_{(3,81)} = 8.077$, $p = 0.006$, $\eta_p^2 = 0.091$, indicating that participants solved more numerical

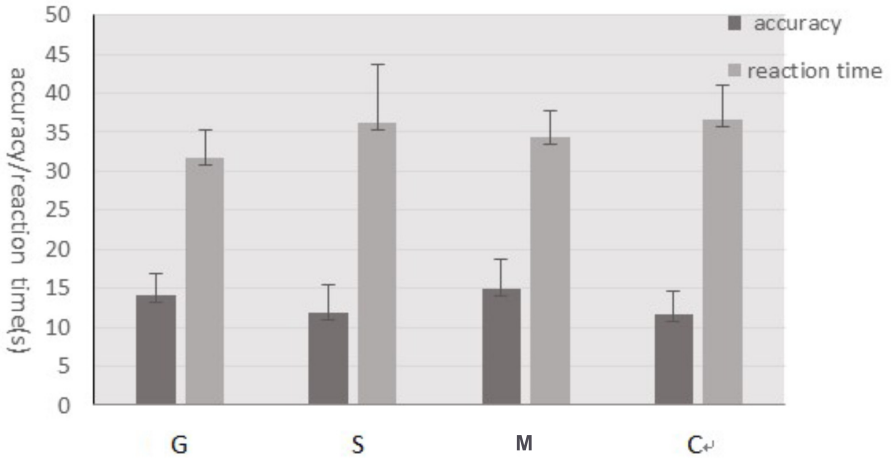

FIGURE 3 | Accuracy and reaction time of the participants under different guidance conditions (error bars: 95% confidence interval).

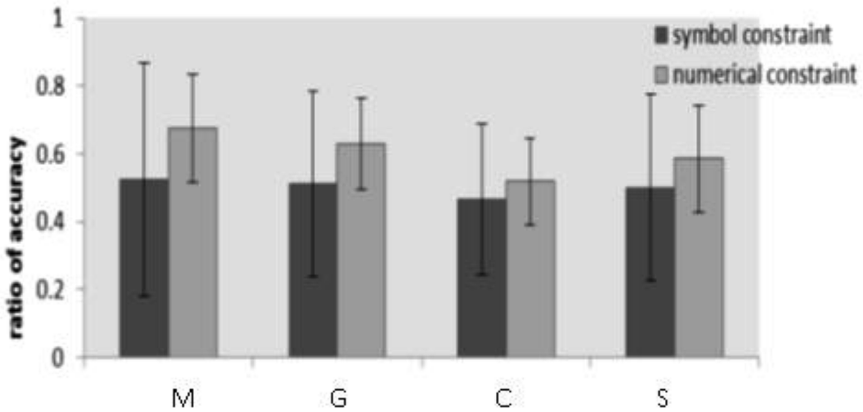

FIGURE 4 | Ratio of accuracy under different guidance condition (error bars: 95% confidence interval).

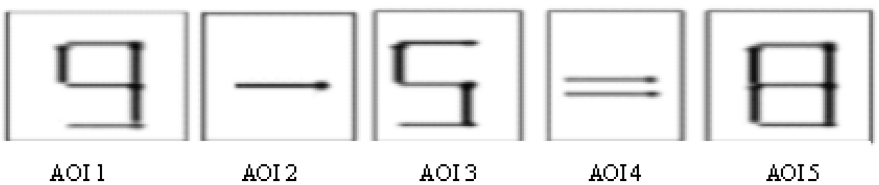

FIGURE 5 | Each AOIs.

constraint problems ($M \pm SD = 0.499 \pm 0.03$). The interaction between guidance condition and problem type was not significant ($p > 0.05$). The results were shown in **Figure 4**.

The Total Fixation Duration and Number of Fixation Analysis

To explore the underlying mechanism of the insight problem solving, we analyzed the total fixation duration and number of fixation. First, the AOIs were defined according to the research purpose and hypothesis. In this study, each component of the matchstick arithmetic equation (figure and symbol) was defined as AOI, and the specific division of AOI is shown in **Figure 5**.

A three-way repeated measures ANVOA with problem type, guidance condition, and AOIs on duration of fixation showed that the main effect of the problem type was not significant, $F_{(1,81)} = 1.516$, $p = 0.222$, $\eta_p^2 = 0.08$. The main effect of guidance condition was not significant, $F_{(3,81)} = 1.422$, $p = 0.242$, $\eta_p^2 = 0.07$. The main effect of AOIs was significant, $F_{(4,324)} = 249.490$, $p < 0.001$, $\eta_p^2 = 0.755$. The interaction of AOIs, problem type, and guidance condition was not significant, $F_{(12,324)} = 1.097$,

$p = 0.362$, $\eta_p^2 = 0.052$. The interaction of problem type and guidance condition was not significant, $F_{(3,81)} = 0.223$, $p = 0.88$, $\eta_p^2 = 0.071$. AOIs interacted with guidance condition, $F_{(12,324)} = 1.802$, $p = 0.047$, $\eta_p^2 = 0.063$. For four conditions, fixation duration in the AOI 3 and AOI 4 was significantly different from the other three AOIs ($p < 0.001$). And fixation duration in AOI 3 was significantly longer than other AOIs, but fixation duration in AOI 4 was significantly shorter than other AOIs. Nothing else was different on M condition. Fixation duration in AOI 1 and AOI 5 was significantly longer than AOI 2 on G condition ($p < 0.001$, $p = 0.012$). Fixation duration in AOI 1 and AOI 5 was significantly longer than AOI 2 on C and S condition ($p < 0.001$). Two conditions were not significant in AOI 1–AOI 5, exception, M and G conditions were significantly shorter than C condition ($p = 0.042$, $p = 0.018$) in AOI 5. M was significant longer than G condition, G was significant shorter than S and C condition in AOI 2 ($p = 0.007$, $p = 0.04$, $p = 0.018$). The result suggested that the participants paid more attention to the numbers than symbols in the formula in all guidance conditions. And the participants in gesture guidance condition spent shorter time than other condition in AOI 5 and AOI 2. AOIs interacted with the problem type, $F_{(4,324)} = 24.459$, $p < 0.001$, $\eta_p^2 = 0.324$. Numerical constraints problem was significantly more symbol constraints problem on AOI 1 and AOI 5 ($p = 0.021$, $p < 0.001$). However, numerical constraints problem was significantly less than symbol constraints problem on AOI 3 and AOI 4 ($p = 0.029$, $p = 0.002$). The result showed that the participants paid more attention to the first number and result in numerical constraints problem, and more attention to the second number and equal mark in symbol constraints problem.

A three-way repeated measures ANVOA with problem type, guidance condition, and AOIs on the number of fixation showed that the main effect of problem type was not significant, $F_{(1,81)} = 1.416$, $p > 0.05$, $\eta_p^2 = 0.019$. The main effect of guidance condition was not significant, $F_{(3,81)} = 0.988$, $p > 0.05$, $\eta_p^2 = 0.036$. The main effect of the AOIs was significant, $F_{(4,324)} = 282.449$, $p < 0.001$, $\eta_p^2 = 0.776$. The interaction of AOIs, problem type, and guidance condition was not significant, $F_{(12,324)} = 0.529$, $p > 0.05$, $\eta_p^2 = 0.037$. The problem type did not interact with the guidance condition, $F_{(3,81)} = 0.105$, $p > 0.05$, $\eta_p^2 = 0.038$. AOIs interacted with guidance condition, $F_{(12,324)} = 2.031$, $p = 0.021$, $\eta_p^2 = 0.069$. For four conditions, AOI 3 and AOI 4 were significantly different from the other three AOIs ($p < 0.001$). And the number of fixation of AOI 3 was significantly longer than other AOIs, but the number of fixation of AOI 4 was significantly shorter than other AOIs. The number of fixation of AOI 1 was significantly longer than AOI 5 ($p = 0.043$) on M condition. The number of fixation of AOI 1 and AOI 5 was significantly longer than AOI 2 ($p = 0.033$, $p = 0.007$) on S condition. AOI 1 and AOI 5 were significantly longer than AOI 2 ($p = 0.007$, $p < 0.001$) on C condition. Four conditions were not significant in AOI 1 to AOI 4. However, M and G were significantly less than S and C condition ($p = 0.022$, $p = 0.013$, $p = 0.016$, $p = 0.009$) in the number of fixation of AOI 5. It suggested that participants paid more attention to the numbers in the formula in all guidance conditions. AOIs interacted with the problem type, $F_{(4,324)} = 18.554$, $p < 0.001$, $\eta_p^2 = 0.091$. Numerical constraints problem was significantly longer than symbol constraints problem on the number of fixation of AOI 1, AOI 2, and AOI 5 ($p = 0.018$, $p = 0.031$, $p < 0.001$). Numerical constraints problem was significantly shorter than symbol constraints problem on the number of fixation of AOI 4 ($p = 0.002$), and marginal significance in AOI 3 ($p = 0.08$). The result showed that participants paid more attention to the first number, symbol, and result in numerical constraints problem; and more attention to the second number and equal mark in symbol constraints problem.

Discussion

The results of Experiment 1 showed that most participants did not realize the link between the guidance and problem solving based on post-experiment questionnaire analysis. The different guidance conditions have different effects on insight problem solving. Compared with those in the control condition, the participants in guidance condition reached higher accuracy and indeed shorter reaction time. Therefore, we can conclude that gesture guidance promotes the problem solving. The results are consistent with previous research (Cook et al., 2008). We interpreted that the gestures produced mental images in the participants' mind, helping to complete the representational transformation of insight problem, which was the key to solving the problem. And gestures are indicative, which can lead participants to correspond to mental representation of the problem and the relevant position of the problem, and activate the connection between them (Wesp et al., 2001; Grant and Spivey, 2003; Morsella and Krauss, 2004). It is also possible that gestures can unload parts of the working memory. Researchers have shown that using both speech and gesture to express required less working memory than speech alone (Goldin-Meadow, 2001; Wagner et al., 2004). Based on the analysis of fixation time and the number of fixation in each AOI, the results showed that almost all participants paid more attention to the number regardless of the problem type, especially the second number. Meanwhile, they gazed less at the equal mark, indicating that participants preferred number in insight problem solving. Other researchers also found that the participants preferred to numerical in solving matches formula (Knoblich et al., 2001), they believed that participants short focused on the composition of problem meant that they understood the problem though a scan. While long gazed meant that the participants tried to solve the problem. The participants gazed on one element of the problem for a long time meant that they thought it was a key point in solving the problem.

EXPERIMENT 2A

Materials and Methods

Participants

Sixty-three undergraduate students (36 female, mean age = 23 years, *SD* = 3) were recruited for course credit or

proper reward. All participants reported normal or corrected-to-normal vision. They signed the informed consent and they had not participated in similar experiments before. All participants were randomly assigned to three conditions.

Design

The design of Experiment 2a was a single factor between-participants design. The independent variable was eye movement guidance patterns (prototypical guidance, non-prototypical guidance, and non-guidance). The accuracy, reaction time, and the saccade counts were the dependent variables.

Materials

Radiation problem was introduced by Karl Duncker in 1945 (**Figure 6**). The instructions: if a person has stomach tumor and cannot be treated by surgery or medication but only by lasers radiation method. Lasers power needed to kill tumor would do harm to healthy tissue because it pass through them as well. So how can we use lasers radiation to treat patients and avoid harming other healthy tissues? There are three related areas of this problem: one is the tumor which is solid black ellipse in **Figure 6**. The second is the healthy tissue of the skin surrounding the tumor which is between the black ellipse and the area. The third is the area outside the skin, where the laser is emitted. The solution consists of two key components, the low-density lasers and the multiple lasers. Participants need to emit a large amount of low density and focus on the multiple lasers in the central tumor from different parts of outside the skin, only in this way can it ensure that the intensity of a single lasers won't hurt the healthy tissue, and the multiple lasers focused on the tumor whose strength is enough to kill tumor.

The digital tracking task formed different guidance condition, and the digital tracking task of prototypical guidance condition is shown in **Figure 7**, which highlights a kind of skin-crossing or in-and-out saccades: the sight goes out of the skin into the tumor and comes out from another place. The position of numbers appearing in tracking task is: left, middle, right, middle, right, middle, left, and middle. The digital tracking task of non-prototypical guidance condition is shown in **Figure 8** with different appearing position of digit: upper left, upper right, lower right, lower left, middle, middle, middle, middle. It stresses the composition of problem solving but does not highlight the key to solve the problem (emit several lasers which gather in the center of tumor from different corner). Non-guidance is designed as a control condition without digital tracking task.

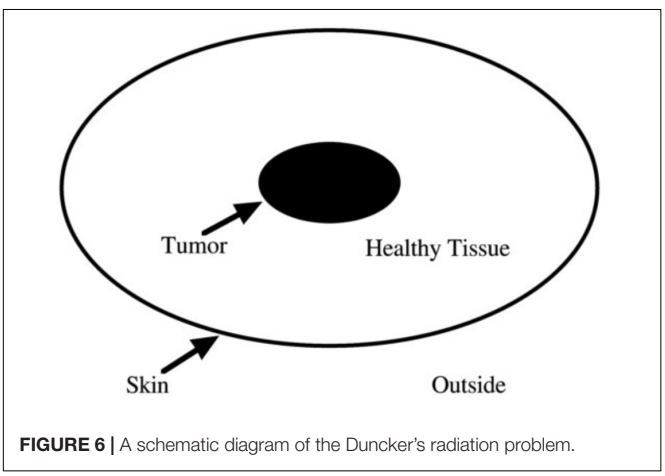

FIGURE 6 | A schematic diagram of the Duncker's radiation problem.

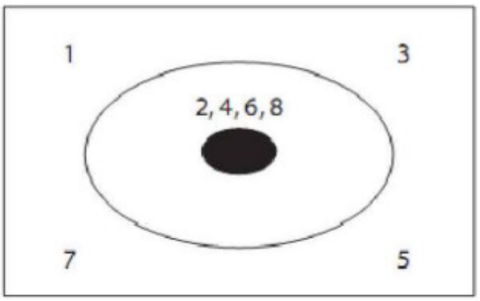

FIGURE 7 | Digital tracking task of prototypical guidance condition.

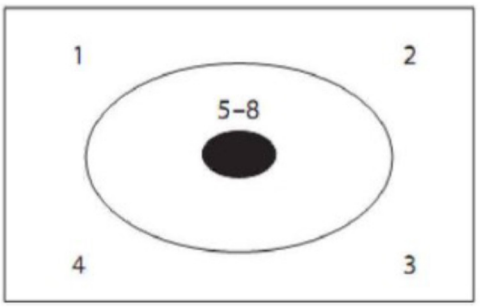

FIGURE 8 | Digital tracking task of non-prototypical guidance condition.

Procedure

Experimental equipment was identical to Experiment 1. The 63 participants were randomly assigned to the experimental condition (prototypical guidance condition and non-prototypical guidance condition and non-guidance condition).

The experiment lasted for 10 min in total with 20 trails, each lasting for 30 s, including 26 s free observation time and 4 s digital tracking task. Before the start of each trail, all participants would complete a short drift correction. Then, the problem was presented and lasted for 26 s, during which participants were free to observe the problem on the screen and tried to figure out how to solve the problem. For the digital tracking task, a sequence of numbers or letters would appear on the different location of screen randomly, each lasting for 500 ms. Participants were asked to detect number and report it. The accuracy of reported number was recorded. In control condition, the participants were free to observe the problem diagram and tried to answer it without the limitation of time.

Once the participants came up with the answer, they could report it to the experimenter and tried to solve the problem. If the answer was correct (drawing two lines at least from different areas outside the skin pointing to the center of the

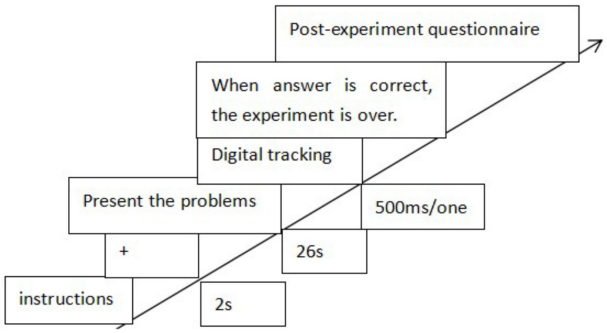

FIGURE 9 | The procedures of Experiment 2a.

tumor), the experiment was completed. If the answer was not correct, the participants would continue thinking and reporting until the end of the experiment. Participants were asked to complete a short post-experiment questionnaire, including whether participants realized the relationship between the digital tracking task and the problem, difficulty level, and a sense of surprise about problem solving, which part of the experiment (digital tracking phase, free observation phase) was the most conducive to solve the problem. The detailed procedure was shown in **Figure 9**.

Results

Post-experiment Questionnaires Analyses

Post-experiment questionnaires intended to find out whether participants realized the relationship between the digital tracking task and the problem solving, and the results showed that three participants realized a link between the digital tracking task and problem solving. We excluded these three data in the following analysis. The specific results of difficulty level and a sense of surprise about problem solving were shown in **Table 2**.

Chi-square test showed that there was no significant difference in problem difficulty among three experimental conditions: $\chi^2_{(6)} = 5.507$, $p = 0.493$, which indicating that different experimental condition did not affect the solution of the problem. There was also no significant difference in the sense of surprise: $\chi^2_{(8)} = 5.548$, $p = 0.698$. In addition, most of the participants thought that free observation phase was the most helpful to solve the problem ($M \pm SD = 71.78 \pm 3.22$).

Response Accuracy and Saccade Counts Analyses

To test whether the prototype heuristic effect exists in the attention tracing guidance by embodied attention, we analyzed the response accuracy and saccade counts. If the effect exists, the response accuracy and the saccade counts in prototypical condition would be higher than other conditions. Otherwise, there was no difference. The specific results of response accuracy and saccade counts were shown in **Table 3**.

The Chi-square test showed that there was a significant difference in response accuracy: $\chi^2_{(2)} = 6.575$, $p = 0.037$. There was a marginal significant difference in the response accuracy in the prototypical guidance and the non-prototypical guidance condition: $\chi^2_{(1)} = 3.313$, $p = 0.069$. There was a significant difference in the response accuracy in the prototypical guidance and the non-guidance condition, $\chi^2_{(1)} = 4.262$, $p = 0.039$. There was no significant difference in the response accuracy in the prototypical guidance and non-prototypical guidance condition, $\chi^2_{(1)} = 0.302$, $p = 0.583$. It indicated that the prototypical cue had heuristic effect on the insight problem solving.

An one-way ANOVA on saccade counts in free observation phase showed that there was no significant difference under different guidance condition: $F_{(2,57)} = 2.579$, $p = 0.085$, $\eta^2_p = 0.067$, indicating that participants in three conditions performed similar saccade counts in free observation phase. In other world, digital tracking task did not affect participants' saccade counts in the free observation phase. We analyzed saccade counts in digital tracking task and showed that there was a significant difference in the prototypical guidance and the non-prototypical guidance condition: $t_{(29)} = 5.577$, $p < 0.001$, $d = 1.03$. And saccade counts in the prototypical guidance were significantly more than that in non-prototypical guidance condition. It suggested that the free observation phase and the digital tracking task were independent of each other, and the difference in eye movement in different guidance conditions was caused by the digital tracking task. It also indicated that the eye movement affected spatial cognitive activity implicitly.

Discussion

The results of this experiment showed that most participants did not realize the connection between digital tracking task and problem solving, considering tracking task interfered with their thinking. It indicated that the connection between eye movement and spatial cognitive activity is implicit. The guidance of eye movement can affect their performance in solving insight problems. Response accuracy in prototypical guidance condition was significantly higher than non-guidance condition. And the non-prototypical guidance was not different significantly with prototypal guidance condition. The present experiment not only re-verify the effect of prototypical hint in insight problem solving heuristic effect, supporting (Grant and Spivey, 2003), viewing that the special mode of eye movements may play an embodied mechanism function. The results also enriched the theoretical background of embodied cognition: the process of cognitive activities can not only be offloaded in the environment, but also can produce interaction between our body and the surrounding environment, being influenced by the interaction in return. Comparing the results in the free observation phase and the digital tracking task phase, we can see that the differences in eye movement in different guidance conditions were caused by the digital tracking task. It not only suggested the free observation phase and the digital tracking task were independent of each other, but also indicated that the eye movement affected spatial cognitive activity implicitly. If participants realized the connection between digital tracking task and problem solving, those eye-movement trajectories should be similar during the free observation phase and the tracking task phase.

TABLE 2 | Evaluation of difficulty level of radiation problem and a sense of surprise about problem solving (one).

Guidance condition	Difficulty level of problem					A sense of surprise				
	1	2	3	4	5	1	2	3	4	5
Prototypical	2	8	8	2	0	1	5	7	3	4
Non-prototypical	4	3	10	2	0	2	6	7	2	2
Non-guidance	2	10	8	1	0	2	8	9	2	0

TABLE 3 | The response accuracy and saccade counts under different experimental conditions.

Guidance condition	Experiment samples	Saccade counts (s/one)		Response accuracy
		Free observation stage	Digital tracking task	
Prototypical	20	2.43 ± 0.38	1.51 ± 0.38	11 (55%)
Non-prototypical	19	2.13 ± 0.55	0.81 ± 0.29	5 (26.3%)
Non-guidance	21	2.50 ± 0.62		4 (19%)

EXPERIMENT 2B

Materials and Methods

Participants

Sixty-two undergraduate students (38 female, mean age = 22.34 years, *SD* = 3.85) were recruited for course credit or proper reward. All participants reported normal or corrected-to-normal vision. They signed the informed consent and they had not participated in similar experiments before.

Design

The design of Experiment 2b was a single factor between-participants design. The independent variable is attention guidance type (attention-tracing, attention-transfer, and attention-fixation), and the accuracy, reaction time, and the saccade counts were dependent variable.

Materials

The materials were identical to Experiment 2a. The different types of attention guidance are operated by digital tracking task, and the digital tracking task in attention-tracing condition was shown in **Figure 10** with different appearing position of digit: upper, middle, upper, middle, lower, middle, bottom left, middle; the participants in attention-tracing condition required were asked to fix on the stimulus (fixation should always attach to where the stimulus appears), and report the digit once found it. The digital tracking task in attention transfer condition was similar to that in attention tracing condition, as shown in **Figure 10**, with the difference that the fixation cannot follow stimulus moving and should always be fixed on the center of the screen only reported the digit once found it. The digital tracking task in attention-fixation condition was shown in **Figure 11**, requiring participants' fixation follow stimulus. All stimuli appeared on the center of the screen.

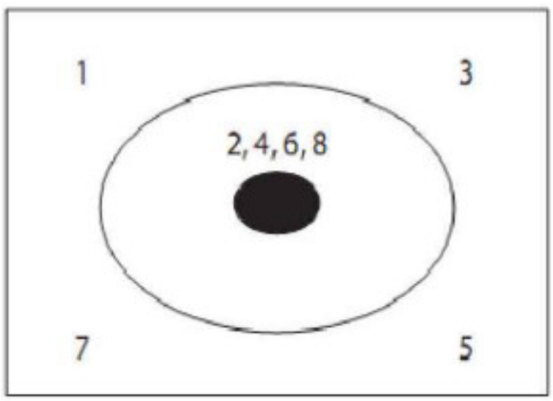

FIGURE 10 | The digital tracking task of attention-tracing and attention-transfer condition.

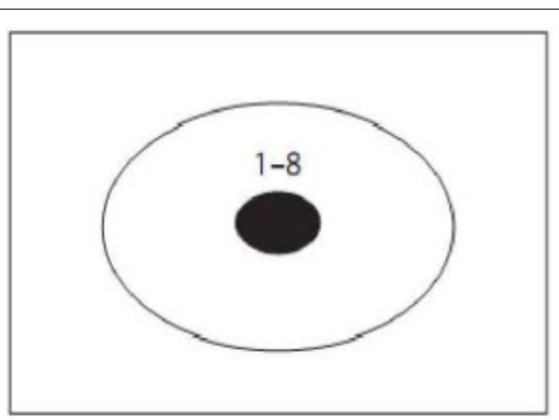

FIGURE 11 | The digital tracking task of attention-fixation condition.

Procedure

The apparatus was identical to Experiment 1. Sixty-two participants were randomly assigned to the experimental condition (attention-tracing condition, attention-transfer, and attention-fixation condition). The procedure was identical to Experiment 2a with the difference namely digital tracking task.

Results

To test whether embodied effect of attention guidance on the problem solving need physical behavior, we analyzed the accuracy and response time in the digital task, even including the accuracy in problem solving, saccade counts in the free observation

phase, and digital tracking task. Three participants realized the connection between guidance and problem solving, and other three participants whose accuracy didn't reach 75% in digital tracing task, so these six data were excluded in final analysis. Fifty-six valid data were analyzed.

The Digital Tracking Task and Response Accuracy Analyses

There was a significant difference in accuracy under different experimental conditions, $F_{(2,53)} = 8.60$, $p = 0.001$, $\eta_p^2 = 0.347$. The accuracy of digital tracking task in attention-fixation condition was significantly higher than that in attention-tracking and attention-transfer condition ($p = 0.011$, $p = 0.001$). There was no significant difference between attention-tracking and attention-transfer condition ($p = 0.525$). The results of the reaction time in digital tracking task showed that there was a significant difference under different experimental conditions, $F_{(2,53)} = 4.599$, $p = 0.014$, $\eta_p^2 = 0.159$. Participants took shorter time in attention-fixation than attention-transfer condition ($p = 0.012$). There were no other significant differences ($p > 0.05$).

The Chi-square test showed that there was a significant difference in response accuracy under different experimental conditions, $\chi^2_{(2)} = 8.875$, $p = 0.012$. There was no difference in attention-tracking and attention-transfer condition ($p > 0.05$). The accuracy in attention-tracking and attention-transfer was significantly higher than that in attention-fixation condition ($p = 0.007$, $p = 0.013$).

The Saccade Counts Analyses

The average saccade counts in free observation phase and digital tracking task under different attention guidance were shown in **Figure 12**.

An one-way ANOVA saccade counts showed that there was a significant difference in saccade counts during the free observation phase under different attention guidance conditions, $F_{(2,53)} = 3.748$, $p = 0.030$, $\eta_p^2 = 0.141$. Saccade counts in attention-fixation were significantly higher than that in attention-transfer condition ($p = 0.036$). There were no other significant differences ($p > 0.05$). For different attention guidance conditions, there were significant differences in saccade counts in the digital tracking task, $F_{(2,53)} = 28.370$, $p < 0.001$, $\eta_p^2 = 0.521$. Attention-tracking and attention-transfer condition were significantly more than attention-fixation condition ($p < 0.001$), there was no significant difference in attention-tracking condition and attention-transfer condition ($p = 0.643$).

The above results indicated that the embodied effect of attention guidance on the problem solving did not need physical activity necessarily. Even though there was no physical activity involved, the attention transfer can also promote the emergence of insight.

Discussion

The results of Experiment 2b showed that the difference of accuracy between attention-tracking and attention-transfer condition was not significant. Compared with the attention-fixation condition, attention-tracking and attention-transfer condition enjoyed higher response accuracy. However, in free observation phase, saccade counts in attention-fixation condition were significantly more than that in the attention-transfer condition. So we can infer that spontaneously produced saccade through skin didn't cause the increase of accuracy. The increase of accuracy was due to the eye movement of participants or the transfer of attention in a short time which inspired insight in a particular pattern. In other words, the embodied effect of attention guidance on the problem solving not necessarily physical behavior involved.

The results showed that the accuracy in attention-fixation condition was higher than that in the attention-tracking condition and attention-transfer condition, and reaction time in the attention-fixation condition was shorter than that in the attention-tracking condition and attention-transfer condition.

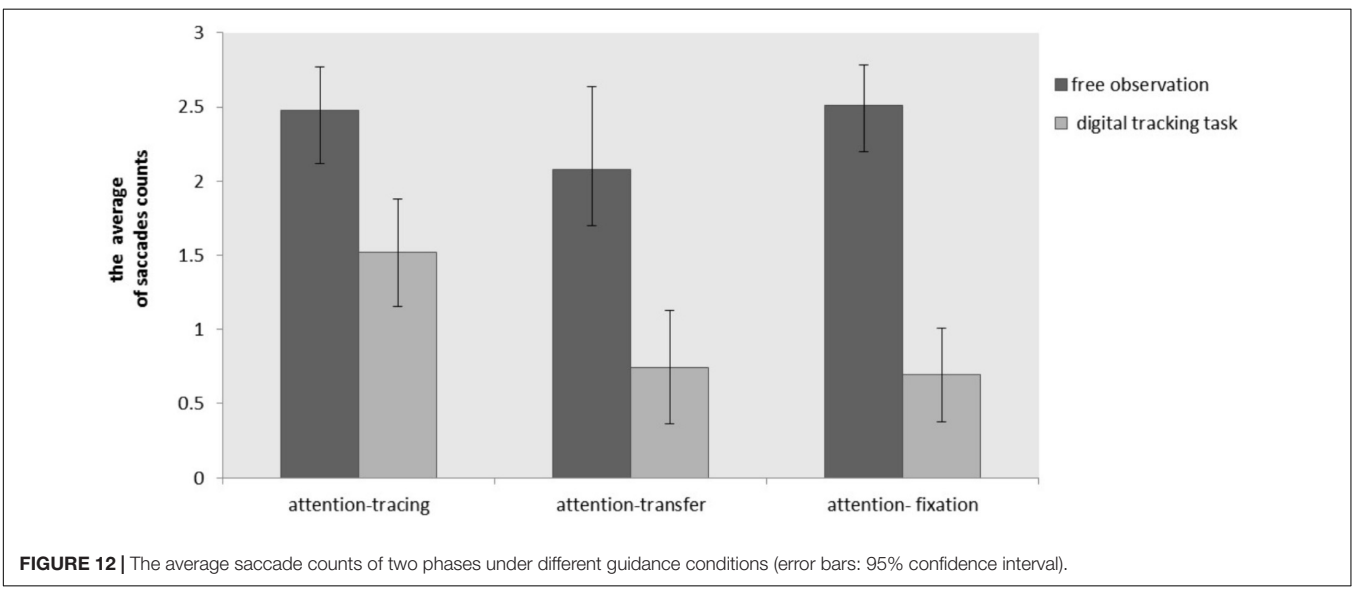

FIGURE 12 | The average saccade counts of two phases under different guidance conditions (error bars: 95% confidence interval).

This is understandable because the fixation of participants kept fixing in the center of the screen in attention-fixation condition, and the stimulus for tracking also appeared in the center. However, there was no significant difference of accuracy and response time in the digital tracking task between attention-tracking and attention-transfer condition. It interpreted that the saccade counts in attention-tracking condition and attention-transfer condition may enjoy the same cognitive mechanism. And the increase of accuracy in attention-tracing condition may not be caused by the eye movement itself but by the attention transfer prior to the eye movements.

GENERAL DISCUSSION

The current study had four main important findings. First, the results of Experiment 1 showed that embodied gesture promoted the insight problem solving, and participant focused more on the number in formula in both two kinds of problems. According to the representational theory, the problem of matchstick can only be solved by transforming its representation to break through the dilemma and insight occurs (Knoblich et al., 1999). Participants focused on the number more than the symbol in the symbol constraint problems, which easily led participants to represent improper problem representations and then prevent the process of the problem solution. Thus, that's why the accuracy was lower than that in numerical constraint problem.

Some researchers claimed that the influence of gesture in problem solving may result from space compatibility of the visual space template in working memory. Tversky (2004) found that gesture could unload and organize space working memory to improve problem solving. Previous studies have confirmed that hand gestures could maintain the outcome of study (Cook et al., 2008), which results from that gesture provides a representation which needed comparatively less cognitive resource, and then sparse cognitive resource could be used to record new information. Other studies have verified that working memory for using both language and hand gesture to express information is less than that for using language only, so participants can use strategy occupied less working memory to represent and learn (Goldin-Meadow, 2001; Wagner et al., 2004). Wagner et al. (2004) proved that the gesture itself boosted the encoding of long-term memory in the research. Grant and Spivey (2003) thought that indication of gestures could lead participants to correspond the mental representation of the problem and the related position and spatial information of the problem. And which is good for gesture perception activation in mind and for representation of space-related position. Hung et al. (2018) found that video lectures could improve people's understanding and retention of knowledge. Thus, even if participants did not aware these representation activation, the gesture was also good for them to put the movement of matchsticks in their spatial representation (Penz and Ghosh, 2016). It may be interpreted that the participants were guided to combine their own gestures to solve the same type of problems, and the performance would be better than that under verbal instructions.

Second, the result of Experiment 2a showed that the guidance of eye movement affected their performance in solving insight problems and prototypical guidance cuing facilitated participants to solve the problem. Attention guidance had prototype heuristic effect in insight problem solving. The result could be interpreted by the prototype heuristic theory. The theory indicated that the process of insight problem solving is a process of prototype heuristic. In this process, if the proper prototype and its key heuristic information in the mind could be activated, individuals could break through the dilemma and solve the problem (Zhang et al., 2004). The key heuristic information refers to the information that plays a key role in solving the problem, and the activation of key heuristic information is a controllable and explicit process (Cao et al., 2006; Zhen-Zhen, 2008). Thus, compared with non-prototypical guidance cuing and no cuing, prototypical guidance cuing comprised more heuristic information, which was benefit for activating the prototype of the solution and its key heuristics information and then facilitated the insight problem solving. However, compared with prototypical guidance cuing, non-prototypical guidance cuing similarly guide participants to pay attention to the key area of problem solving, but didn't significantly improve the performance of problem solving, which may resulted in non-prototypical guidance didn't provide participants with key heuristics information in problem solving. Although a study have proved that when attention was guided to the key area of problem, the performance would be facilitated (Groen and Noyes, 2010), but if the key area didn't include the key information to solve problem, participants could not reach for insight. It demonstrated that activating key heuristic information was important for insight problem solving.

Third, the result of Experiment 2b showed that attention tracing and attention transferring in prototypical guidance condition both facilitated the solution of insight problem. Thus, we concluded that saccades in attention-tracing condition may have the similar mechanism with that in attention-transfer condition. In the process of visual–spatial motion, there is close relation between attention and saccades. Saccades refer to physical performance of visual information extracting, which reflect the selection pattern of individual processing visual information, and it has direct or indirect relation with consciousness. Saccades are one fundamental representation of eye movement, which is quick moving of fixation. Godijn and Pratt (2002) found that the position of attention transfer is the same as the saccades (Godijn and Pratt, 2002). And some of the studies that followed supported this result (Peterson et al., 2004; Song and Hao, 2010; Kristjánsson, 2011). However, some researches showed that attention is not consistent with eye movement (Lawrence et al., 2004; Belopolsky and Theeuwes, 2009). At present, there are some hypothesis explaining the relation of saccades and attention. One was independent hypothesis, which demonstrated that one system could not control attention and saccades at the same time so they are separated. Another was reciprocal relation hypothesis, which demonstrated that the two processes of attention and saccades share some resource in the procedure of cognitive motion so the interaction exists. The preparation to move to some

position could enhance the distribution of attention on the circular position and when attention was attached to objective position the incubation period of saccades would be shorter. And another was functional relation hypothesis, which believed that the relation between attention and saccades depended on how to explain the importance of circular events, if the circular event is not important, participants would not transfer their attention (Song and Hao, 2010; Song and Wang, 2012). Thus, the data of the present study supported the reciprocal relation hypothesis, because we found there was no difference between attention tracing and attention transfer. Song and Wang (2012) also found that saccades and attention transfer shared some resource in certain cognitive period, and saccades inferring certain position could facilitate the distribution of attention to circular positions. Meanwhile, saccades and attention transfer were not equal completely, because we can transfer our attention while we keep focusing, but can no keep attention while moving our eyes in the same time.

The final point is that the process of insight problem solving is unconsciously implicit activating process. At present, there are three arguments concerning insight problem solving: one is whether the mechanism underlying insight problem solving is consciously explicit searching process or unconsciously implicit activating process. Our data supported that insight problem solving is unconsciously and implicitly activating process and participants unconsciously process the relation of guidance and insight problem. Growing evidence has suggested that the process of insight problem solving is largely governed by an implicit learning mechanism that detects the differences between current and goal states, and regulates the strengths of the operators (Suzuki and Fukuda, 2013; Suzuki et al., 2014; Ball and Litchfield, 2017; Lebed and Korovkin, 2017). Suzuki and Fukuda (2013) study found that unconscious nature of insight problem solving was operator modulating the strengths during the impasse gradually, and roles of subliminal hint information in the problem solving processes. Consequently, the participants subconsciously used the gesture as a cue to facilitate insight problem solving. Gao and Zhang (2014) suggested that creative problem solving can be modulated by unconscious processing of enlightening information. Therefore, although participants didn't realize the indicated relation of digit tracking task and to-be-solved problem, participants who moved eye fixations and transferred attention performed better.

Overall, this research mainly investigated the process of prompting insight problem solving and the nature of the embodied effect of insight problem solving. The findings of this experiment proved that embodied gesture and attention can promote the problem solving, and the result supported the reciprocal relation hypothesis between attention and saccades. It is important to note that we did not directly explore the brain mechanism of embodied action facilitating insight problem solving, but previous studies found that the temporal lobe played an important role in insight problem solving (Kounios and Beeman, 2013; Shen et al., 2017). And there were mainly four insight-activated brain regions, including the right medial frontal gyrus, the left inferior frontal gyrus, the left amygdala, and the right hippocampus. Importantly, various brain regions were variably activated during the four stages, and the gesture might lead to activation of one brain region and then help improved performance Shen et al. (2018a). However, the exact activated brain region was still not clear in the process of embodied action facilitating insight problem solving, and it should be studied further.

CONCLUSION

Embodied gesture could facilitate the performance of insight problem solving, which indicated that embodied gesture enhance insight problem solving and gesture guidance was better than speech guidance. Compared with non-prototypical guidance cuing and no cuing, prototypical guidance cuing was the best cuing in insight problem solving. Attention guidance had prototype heuristic effect in insight problem solving. Attention tracing and attention transferring in prototypical guidance condition both facilitated the solution of insight problem, which supported the reciprocal relation hypothesis of saccades and attention. Embodied guidance facilitated insight problem solving implicitly.

ETHICS STATEMENT

The study reported in the manuscript entitled "The Effect of the Embodied Guidance in the Insight Problem Solving: An Eye Movement Study" has been approved by the Institutional Review Board at Guangzhou University.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

This work was supported by the National Natural Science Foundation of China (31571144). The "12th Five-Year plan" of Guangzhou Education Science (No. 1201421342).

REFERENCES

Adam, H., and Galinsky, A. D. (2012). Enclothed cognition. *J. Exp. Soc. Psychol.* 48, 918–925. doi: 10.1016/j.jesp.2012.02.008

Ball, L. J., and Litchfield, D. (2017). *Interactivity and Embodied Cues in problem Solving, Learning and Insight: Further Contributions to a "Theory of Hints". Cognition Beyond the Brain*. London: Springer, 223–239. doi: 10.1007/978-1-4471-5125-8_12

Beilock, S. L., and Goldin-Meadow, S. (2010). Gesture changes thought by grounding it in action. *Psychol. Sci.* 21, 1605–1610. doi: 10.1177/0956797610385353

Belopolsky, A. V., and Theeuwes, J. (2009). When are attention and saccade preparation dissociated? *Psychol. Sci.* 20, 1340–1347. doi: 10.1111/j.1467-9280.2009.02445.x

Bowden, E. M., and Jung-Beeman, M. (2007). Methods for investigating the neural components of insight. *Methods* 42, 87–99. doi: 10.1016/j.ymeth.2006.11.007

Branchini, E., Bianchi, I., Burro, R., Capitani, E., and Savardi, U. (2016). Can contraries prompt intuition in insight problem solving? *Front. Psychol.* 7:1962. doi: 10.3389/fpsyg.2016.01962

Broaders, S. C., Cook, S. W., Mitchell, Z., and Goldinmeadow, S. (2007). Making children gesture brings out implicit knowledge and leads to learning. *J. Exp. Psychol. Gen.* 136, 539–550. doi: 10.1037/0096-3445.136.4.539

Brouillet, T., Heurley, L., Martin, S., and Brouillet, D. (2010). The embodied cognition theory and the motor component of "yes" and "no" verbal responses. *Acta Psychol.* 134, 310–317. doi: 10.1016/j.actpsy.2010.03.003

Cao, G., Yang, D., and Zhang, Q. (2006). Activation of prototypal matters in insight problem solving: an automatic or controllable processing? *Psychol. Sci.* 29, 1123–1127. doi: 10.16719/j.cnki.1671-6981.2006.05.023

Chu, M., and Kita, S. (2011). The nature of gestures' beneficial role in spatial problem solving. *J. Exp. Psychol. Gen.* 140, 102–116. doi: 10.1037/a0021790

Cook, S. W., Mitchell, Z., and Goldin-Meadow, S. (2008). Gesturing makes learning last. *Cognition* 106, 1047–1058. doi: 10.1016/j.cognition.2007.04.010

Cook, S. W., and Tanenhaus, M. K. (2009). Embodied communication: speakers' gestures affect listeners' actions. *Cognition* 113, 98–104. doi: 10.1016/j.cognition.2009.06.006

Cook, S. W., Yip, K. Y., and Goldinmeadow, S. (2010). Gesturing makes memories that last. *J. Mem. Lang.* 63, 465–475. doi: 10.1016/j.jml.2010.07.002

Dow, G. T., and Mayer, R. E. (2004). Teaching students to solve insight problems: evidence for domain specificity in creativity training. *Creat. Res. J.* 16, 389–398. doi: 10.1080/10400410409534550

Duncker, K., and Lees, L. S. (1945). On problem-solving. *Psychol. Monogr.* 58:i-113. doi: 10.1037/h0093599

Gao, Y., and Zhang, H. (2014). Unconscious processing modulates creative problem solving: evidence from an electrophysiological study. *Conscious. Cogn.* 26, 64–73. doi: 10.1016/j.concog.2014.03.001

Godijn, R., and Pratt, J. (2002). Endogenous saccades are preceded by shifts of visual attention: evidence from cross-saccadic priming effects. *Acta Psychol.* 110, 83–102. doi: 10.1016/S0001-6918(01)00071-3

Goldinger, S. D., Papesh, M. H., Barnhart, A. S., Hansen, W. A., and Hout, M. C. (2016). The poverty of embodied cognition. *Psychon. Bull. Rev.* 23, 959–978. doi: 10.3758/s13423-015-0860-1

Goldin-Meadow, S. (2001). Explaining math: gesturing lightens the load. *Psychol. Sci.* 12, 516–522. doi: 10.1111/1467-9280.00395

Grant, E. R., and Spivey, M. J. (2003). Eye movements and problem solving: guiding attention guides thought. *Psychol. Sci.* 14, 462–466. doi: 10.1111/1467-9280.02454

Groen, M., and Noyes, J. (2010). Solving problems: how can guidance concerning task-relevancy be provided? *Comput. Hum. Behav.* 26, 1318–1326. doi: 10.1016/j.chb.2010.04.004

Hao-Sheng, Y. E. (2011). Embodied cognition: a consideration from theoretical psychology. *Acta Psychol. Sin.* 43, 589–598. doi: 10.3724/SP.J.1041.2011.00589

Horchak, O. V., Giger, J. C., Cabral, M., and Pochwatko, G. (2014). From demonstration to theory in embodied language comprehension: a review. *Cogn. Syst. Res.* 29–30, 66–85. doi: 10.1016/j.cogsys.2013.09.002

Hung, I. C., Kinshuk, and Chen, N. S. (2018). Embodied interactive video lectures for improving learning comprehension and retention. *Comput. Educ.* 117, 116–131. doi: 10.1016/j.compedu.2017.10.005

Jarman, M. S. (2014). Quantifying the qualitative: measuring the insight experience. *Creat. Res. J.* 26, 276–288. doi: 10.1080/10400419.2014.929405

Jones, D. (2017). Embodied cognitive ecosophy: the relationship of mind, body, meaning and ecology. *Geogr. Ann.* 99, 156–171. doi: 10.1080/04353684.2017.1306971

Knoblich, G., Ohlsson, S., Haider, H., and Rhenius, D. (1999). Constraint relaxation and chunk decomposition in insight problem solving. *J. Exp. Psychol. Learn. Mem. Cogn.* 25, 1534–1555. doi: 10.1037/0278-7393.25.6.1534

Knoblich, G., Ohlsson, S., and Raney, G. E. (2001). An eye movement study of insight problem solving. *Mem. Cogn.* 29, 1000–1009. doi: 10.3758/BF03195762

Kounios, J., and Beeman, M. (2013). The cognitive neuroscience of insight. *Annu. Rev. Psychol.* 65, 71–93. doi: 10.1146/annurev-psych-010213-115154

Kristjánsson, Á (2011). "The intriguing interactive relationship between visual attention and saccadic eye movements," in *The Oxford Handbook of Eye Movements*, eds S. P. Liversedge, I. D. Gilchrist, and S. Everling (Oxford: Oxford University Press), 455–469. doi: 10.1093/oxfordhb/9780199539789.013.0025

Lawrence, B. M., Myerson, J., and Abrams, R. A. (2004). Interference with spatial working memory: an eye movement is more than a shift of attention. *Psychon. Bull. Rev.* 11, 488–494. doi: 10.3758/BF03196600

Lebed, A. A., and Korovkin, S. Y. (2017). The unconscious nature of insight: a dual-task paradigm investigation. *Psychol. Russ. State Art* 10, 107–119. doi: 10.11621/pir.2017.0307

Leung, A. K. Y., Kim, S., Polman, E., Ong, L. S., Qiu, L., Goncalo, J. A., et al. (2012). Embodied metaphors and creative "acts". *Psychol. Sci.* 23, 502–509.

Litchfield, D., and Ball, L. J. (2011). Using another's gaze as an explicit aid to insight problem solving. *Q. J. Exp. Psychol.* 64, 649–656. doi: 10.1080/17470218.2011.558628

Morsella, E., and Krauss, R. M. (2004). The role of gestures in spatial working memory and speech. *Am. J. Psychol.* 117, 411–424. doi: 10.2307/4149008

Ollinger, M., Jones, G., Faber, A. H., and Knoblich, G. (2013). Cognitive mechanisms of insight: the role of heuristics and representational change in solving the eight-coin problem. *J. Exp. Psychol. Learn. Mem. Cogn.* 39, 931–939. doi: 10.1037/a0029194

Patrick, J., and Ahmed, A. (2014). Facilitating representation change in insight problems through training. *J. Exp. Psychol. Learn. Mem. Cogn.* 40, 532–543. doi: 10.1037/a0034304

Penz, M., and Ghosh, S. (2016). "Embodied material guidance: augmenting material for carving," in *Proceedings of the 9th Forum Media Technology 2016,* St. Pölten, 100–104.

Peterson, M. S., Kramer, A. F., and Irwin, D. E. (2004). Covert shifts of attention precede involuntary eye movements. *Percept. Psychophys.* 66, 398–405. doi: 10.3758/BF03194888

Qiu-Ping, W. U., Feng, C., and Chen, B. B. (2011). Embodiment in social cognition. *Adv. Psychol. Sci.* 19, 336–345. doi: 10.3724/SP.J.1042.2011.00336

Riffert, F. (2013). On the effectiveness of incidental hints in problem solving: revisiting norman maier and Karl Duncker. *Gestalt Theory* 35, 349–364.

Schubert, T. W., and Semin, G. R. (2009). Embodiment as a unifying perspective for psychology. *Eur. J. Soc. Psychol.* 39, 1135–1141. doi: 10.1002/ejsp.670

Shen, W., Tong, Y., Li, F., Yuan, Y., Hommel, B., Liu, C., et al. (2018a). Tracking the neurodynamics of insight: a meta-analysis of neuroimaging studies. *Biol. Psychol.* 138, 189–198. doi: 10.1016/j.biopsycho.2018.08.018

Shen, W., Yuan, Y., Zhao, Y., Zhang, X., Liu, C., Luo, J., et al. (2018b). Defining insight: a study examining implicit theories of insight experience. *Psychol. Aesthet. Creat. Arts* 12, 317–327. doi: 10.1037/aca0000138

Shen, W., Yuan, Y., Liu, C., and Luo, J. (2015). In search of the 'Aha!' experience: elucidating the emotionality of insight problem-solving. *Br. J. Psychol.* 107, 281–298. doi: 10.1111/bjop.12142

Shen, W., Yuan, Y., Liu, C., and Luo, J. (2017). The roles of the temporal lobe in creative insight: an integrated review. *Think. Reason.* 23, 321–375. doi: 10.1080/13546783.2017.1308885

Song, Y. W., and Hao, H. J. (2010). The relationship between attention shift and saccade in the maintenance stage and integration stage of visual information. *J. Hebei Univ.* 35, 44–49.

Song, Y. W., and Wang, Y. N. (2012). The time course of attention shifts before endogenous saccades. *J. Hebei Univ.* 37, 54–58.

Stepper, S., and Strack, F. (1993). Proprioceptive determinants of emotional and nonemotional feelings. *J. Pers. Soc. Psychol.* 64, 211–220. doi: 10.1037//0022-3514.64.2.211

Suzuki, H., and Fukuda, H. (2013). Unconscious nature of insight problem solving: an analysis using subliminal priming by continuous flash suppression. *Cogn. Stud.* 20, 353–367. doi: 10.11225/jcss.20.353

Suzuki, H., Miyata, H., Fukuda, H., and Tsuchiya, K. (2014). "Exploring the unconscious nature of insight using continuous flash suppression and a dual

task," in *Proceedings of the 36th Annual Conference of Cognitive Science Society*, Quebec, 2955–2960.

Thomas, L. E., and Lleras, A. (2007). Moving eyes and moving thought: on the spatial compatibility between eye movements and cognition. *Psychon. Bull. Rev.* 14, 663–668. doi: 10.3758/BF03196818

Thomas, L. E., and Lleras, A. (2009). Covert shifts of attention function as an implicit aid to insight. *Cognition* 111, 168–174. doi: 10.1016/j.cognition.2009.01.005

Tversky, B. (2004). Narratives of space, time, and life. *Mind Lang.* 19, 380–392. doi: 10.1111/j.0268-1064.2004.00264.x

Wagner, U., Gais, S., Haider, H., Verleger, R., and Born, J. (2004). Sleep inspires insight. *Nature* 427, 352–355. doi: 10.1038/nature02223

Werner, K., and Raab, M. (2014). Moving your eyes to solution: effects of movements on the perception of a problem-solving task. *Q. J. Exp. Psychol.* 67, 1578–1578. doi: 10.1080/17470218.2014.889723

Wesp, R., Hesse, J., Keutmann, D., and Wheaton, K. (2001). Gestures maintain spatial imagery. *Am. J. Psychol.* 114, 591–600. doi: 10.2307/1423612

Williams, L. E., and Bargh, J. A. (2008). Experiencing physical warmth promotes interpersonal warmth. *Science* 322, 606–607. doi: 10.1126/science.1162548

Wilson, A. D., and Sabrina, G. (2013). Embodied cognition is not what you think it is. *Front. Psychol.* 4:58. doi: 10.3389/fpsyg.2013.00058

Yang, W., Dietrich, A., Liu, P., Ming, D., Jin, Y., Nusbaum, H. C., et al. (2016). prototypes are key heuristic information in insight problem solving. *Creat. Res. J.* 28, 67–77. doi: 10.1080/10400419.2016.1125274

Zhang, Q., Qiu, J., and Cao, G. (2004). A review and hypothesis about the cognitive mechanism of insight. *Psychol. Sci.* 27, 1435–1437. doi: 10.16719/j.cnki.1671-6981.2004.06.041

Zhen-Zhen, W. U. (2008). Exploring the mechanism for prototype elicitation effect in insight. *Psychol. Dev. Educ.* 2008, 31–36. doi: 10.16187/j.cnki.issn1001-4918.2008.01.004

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 11 December 2018
doi: 10.3389/fpsyg.2018.02319

Mechanisms of Creativity Differences Between Art and Non-art Majors: A Voxel-Based Morphometry Study

Tan Xurui[1†], Yu Yaxu[2,3†], Li Qiangqiang[4], Mao Yu[2,3], Zhou Bin[5] and Bao Xueming[6]*

[1] School of Communication of East China Normal University, Shanghai, China, [2] Department of Psychology, Southwest University, Chongqing, China, [3] Key Laboratory of Cognition and Personality, Ministry of Education, Chongqing, China, [4] College Students Psychological Counseling and Health Center, Party Committee Student Work Department, East China University of Technology, Nanchang, China, [5] Institute of Cultural and Creative Industry of Shanghai Jiao Tong University, Shanghai, China, [6] School of Sports and Health of East China Normal University, Shanghai, China

Creativity is considered the ability to generate new ideas or behaviors, an ability that have diverse expressions in different human groups, such as painters and non-painters. Art major students require more creative activities than non-art students do. In this study, we plan to explore the figural creativity abilities of art major students and whether these students exhibited higher figural creativity scores and why their brain structure of gray matter are lower which may benefit from their professional training relative to non-art majors. Therefore, in this study, we use voxel-based morphometry (VBM) to identify different behavioral and brain mechanisms between art major students and non-art major students by using the figural Torrance Test of Creative Thinking. Our results showed that the TTCT-figural (TTCT-F) scores of art majors were higher than those of non-art majors. The TTCT-F score of art major students and practicing and study time have positive correlations which means art major's figural creativity score benefit from there art professional training in some degree. Subsequently, the interaction analysis revealed that the TTCT-figural scores of art majors and non-majors exhibited significant correlations with the gray matter volumes (GMV) of the left anterior cingulate cortex (ACC) and the left medial frontal gyrus (MFG). While the simple slope analysis showed that art majors, compared with non-art majors, exhibited a marginal significantly positive association with the left ACC and MFG, non-art majors exhibited a significantly negative association with the left ACC and MFG. Overall, our study revealed that people who major in artistic work are more likely to possess enhanced figural creative skills relative to non-artistic people. These results indicated that professional artistic programs or training may increase creativity skills via reorganized intercortical connections.

Keywords: creativity, art major students, non-art major students, GMV, MFG, ACC

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Yuan Yuan,
Nanjing Normal University, China
Fei Luo,
Institute of Psychology (CAS), China

***Correspondence:**
Bao Xueming
xmbao@tyxx.ecnu.edu.cn

[†] These authors have contributed equally to this work

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *13 June 2018*
Accepted: *05 November 2018*
Published: *11 December 2018*

Citation:
Xurui T, Yaxu Y, Qiangqiang L, Yu M, Bin Z and Xueming B (2018) Mechanisms of Creativity Differences Between Art and Non-art Majors: A Voxel-Based Morphometry Study. Front. Psychol. 9:2319. doi: 10.3389/fpsyg.2018.02319

INTRODUCTION

There have been many different theories of creativity until recently, and the general idea regarding creativity is that it refers to the generation of original, novel ideas through mental habits of thinking (Torrance, 1966, 1988; Guilford, 1967; Guilford et al., 1978; Ruscio et al., 1998; Howard-Jones et al., 2005; Chavez-Eakle et al., 2007; Gibson et al., 2009; Storm et al., 2011). Simonton

argued that creativity is certainly the most important and common of all human activities, being seen as an attribute for people to possess (Simonton, 2000). Torrance also said that creativity is seen as contributing original ideas, distinct points of view and new angles to looking at problems (Torrance, 1988). In recent decades, creativity research mostly began with Guilford who claimed creativity is consisted of convergent thinking and divergent thinking (Guilford, 1967). While Divergent thinking includes thinking out solutions to a problem, which means multiple solutions. An example like Alternate Uses Task where individuals aer asked to think of as many possible ways to use an object, such as brick (e.g., "House build"). Solutions should be novel and appropriately useful (Guilford et al., 1978). Several studies have probed the neural mechanisms of creative-thinking abilities, including those utilizing functional magnetic resonance imaging (fMRI), positron emission tomography (PET), measurements of regional cerebral blood flow (rCBF), and electroencephalograms (Heilman et al., 2003). Many psychometric instruments have been used to develop tests of people's creative abilities, among which, one of the most common ones is Torrance Test of Creative Thinking (Torrance, 1966).

Individual creative abilities differ, dividing people into diverse groups according to the work they do. In previous studies, researchers usually divided people into two groups according to the TTCT sub or total scores and then analyzed this phenomenon. An fMRI study revealed that TTCT-figural (TTCT-F) scores were prominently higher in high group than those in low group (Jiao et al., 2017). A creativity study revealed that creative scores were higher in high group than those in the low creativity group (Li et al., 2017). An innovative study of improvisation intervention showed better abilities of divergent thinking and become more creativity after intervention, suggesting improvisation as one of the simple and art-based interventions would have formal field of common benefits for creative cognitive processes. In addition, these findings indicated primary school children could make better use of subsistent art education provision that could offer an efficient way to obtain creativity abilities (Sowden et al., 2015). Participants who accept creative training programs' content with exercises or activities relative to control group shown significantly increase in their creative thinking abilities (Ulger, 2016). In addition, a study of neural networks about expert and novice group that higher creativity scores showed by the expert subject were compared the novice groups (Kowatari et al., 2009).

As mentioned, studies have also divided people according to their skills that have been mastered such as professional dancers and novice dancers or musicians and novices, and creativity (Byron and Khazanchi, 2011). An EEG study about generating of alternative uses between professional and novice dancers found that in posterior parietal brain regions, professional dancers show stronger alpha synchronization than novice dancers did. During improved dance, greater right-hemispheric alpha synchronization showed in professional dancers than novice did (Fink et al., 2009). In a study of musicians and non-musicians, participants used a creativity task named novel divergent thinking task to explore and generate uses for them alone and in combination with one another. The results indicates that musicians generate a greater number of "uses" than the non-musicians in both single objects and combinatory uses (Gibson et al., 2009). Another study about musicians conclude that the brain regions of prefrontal and paralimbic areas, including insula are related to network integration, these areas mostly related to cognitive, motivational, and emotional processes. Specifically highly creativity ability's individual completed their creations based on the original rhythm, the activation of brain regions include bilateral prefrontal regions and right insula. While low creativity ability's individual completed their creations, the changes only express in original musical patterns (Villarreal et al., 2013). In an EEG study of gifted, intelligent, creative, and average individuals, in solving creative problems, highly creative individuals were revealed less mental activity than average individuals were. In brain areas interaction, creative individuals also showed better than gifted ones, who exhibited substantial decoupling of brain areas when solving ambiguous problems (Jaušovec, 2000). The prefrontal cortex (PFC) is also a pivotal structure that is involved in divergent thinking, which is a crucial factor of creative innovation (Heilman et al., 2003; Ghacibeh and Heilman, 2013).

Recently, several studies have proven differences in figural creative processes between painters and non-painters (Eindhoven and Vinacke, 1952; Wallach and Kogan, 1964; Berlin and Kay, 1991; Wolff and Lundberg, 2002; Bhattacharya and Petsche, 2005; Burch et al., 2006; Bos et al., 2006). Eindhoven used naturalistic methodology to observe the behavior of painters and non-painters working on sketching paper. The researchers observed painters completing their works using four stages, namely, the gradual, experimental, concentration, and reorganization stages. In contrast, non-painters displayed no staging strategies (Eindhoven and Vinacke, 1952). Moreover, reports by Kay indicated that the reaction times of painters during problem-solving tests are longer than those of non-painters. Wolff conducted an objective test wherein they found that art students had significantly worse phonological skills and less reported risks associated with dyslexia than non-art students. Burch used the instances task to test creative ability and found that visual painters scored higher than non-painters on uniqueness. Likewise, Bhattacharya and Petsche demonstrated differences in the patterns of functional integration between cortical regions during the mental creation of drawings created by painters and non-painters. An EEG study also showed that creative ability in a figural creativity task was associated with significantly stronger desynchronization of upper alpha power, indicating high figural processing demands (Rominger et al., 2018). An fMRI study showed that TTCT-F scores in the high group were associated with several brain regions, including the left temporal cortex, left precuneus, left thalamus, and right fusiform gyrus, right posterior occipital cortex. In contrast, TTCT-F scores in low group were associated with the right posterior cingulate cortex, ventral medial prefrontal cortex, right dorsal frontal cortex, and right inferior parietal lobule (Jiao et al., 2017). Another fMRI study of artists and creative individuals also demonstrated significantly strong functional connectivity in the right angular gyrus, bilateral inferior frontal

gyrus, and bilateral superior frontal gyrus (de Souza et al., 2010).

As mentioned above, the creativity skills related to special and normal domains are still controversial, particularly the basic differences among brain regions. Therefore, in this study, art and non-art majors underwent structural MRI scans after they performed a figural creative thinking task. Creativity scores were then assessed using the TTCT-F and related gray matter volume changes were observed during brain scanning. We expected that the figural scores of the art major students would be higher than those of the non-art major students due to the long professional training regarding art. Moreover, interaction effects of the GMV in the brain and TTCT-F scores were expected: the GMVs of specific cerebral areas were expected to have significant effects [e.g., the medial frontal gyrus (MFG), anterior cingulate cortex (ACC), and superior temporal gyrus (STG)] on figural creativity within the brain activation of art majors. The results of this study may provide insight into the cultivation of creative education among art major students in the aspect of figural creativity brain activation of art majors.

MATERIALS AND METHODS

Participants

Eighty painting subjects (40 art majors and 40 non-art majors; (33 men, aged 18–22 years, mean = 20.24 years; 47 women, aged 18–24 years, mean = 20.23 years) participated in this research as part of our project investigating associations among brain imaging, intelligence, and the TTCT. Inclusion criteria for the 40 art major group were as follows: current studying and professional paint training time for more than 1 years and practiced for more than 1 h each day. Majors included sculpture, traditional Chinese painting, watercolor, sketch and oil painting. 40 non-art major students had no painting training beyond the regular curricular exposure to painting during the kindergarten to university years. All participants were right-handed, had normal vision, had no history of psychiatric or neurological illness and were undergraduates at Southwest University. After providing written informed consent, participants received payment for their time.

Assessment of Creativity

The TTCT (Torrance, 1966), which was used to assess creativity (i.e., divergent thinking ability), consists of verbal, figural, and auditory tests (Huang et al., 2013). In our study, the TTCT-figural (TTCT-F) test was used to measure individual divergent thinking ability (Torrance, 1988; Carson et al., 1994; Kim, 2006). We employed the TTCT-F test to evaluate both art and non-art students. Three factors were concluded in TTCT-F total score: flexibility (the number of different types of answers, demonstrating the ability to switch conceptual fields); fluency (the number of relevant and meaningful answers, which are relative to the ability to generate a number of pictures or objects); and originality (the number of unique ideas, which reflects the ability to produce unique or uncommon answers) (Kim, 2006). Heausler and Thompson (1988) declared that the TTCT-F total score is highly associated with scores of the three parts (fluency, flexibility, and originality) and that the scores of the three parts are highly associated with each other (The correlation coefficient between these three parts > 0.81). Further, strong correlations among the three components of the TTCT do not provide meaningfully different data; thus, the total TTCT score used as an accurate index of creativity (Heausler and Thompson, 1988).

Assessment of General Intelligence

To assess mental capacity, all participants finished Chinese-revised edition of the Combined Raven's Test (Li & Chen), which has a reliability coefficient of 0.92 (Li and Chen, 1989; Ming, 1989). The CRT contains Raven's standard progressive matrix and Raven's colored progressive matrix, which includes 72 items that were revised by the Psychology Department of East China Normal University in 1989. The CRT test score (number of correct answers given in 40 min) was used as a psychometric index of personal intelligence. In line with standard practice, this study focused on the total score of the test (Takeuchi et al., 2011).

Image Acquisition

All images were gathered using a 3-T Siemens Trio MRI scanner (Siemens Medical, Erlangen, Germany). High-resolution T1-weighted structural images were collected using a magnetization-prepared rapid gradient echo (MPRAGE) sequence. The parameters were as follows: repetition time = 1900 ms, inversion time = 900 ms, flip angle = 9 degrees, echo time = 2.52 ms, 256 × 256 matrix, 176 slices, 1.0 mm slice thickness, and voxel size = 1 mm^3 × 1 mm^3 × 1 mm^3.

MRI Preprocessing

All images were processed using SPM8[1] implemented in MATLAB R2014a (MathWorks Inc., Natick, MA, United States). First, every magnetic resonance (Semrud-Clikeman et al., 2016) image was displayed in SPM8 to monitor artifacts and obvious anatomical abnormalities. In addition, VBM was performed with diffeomorphic anatomical registration using exponentiated lie algebra (DARTEL) (Ashburner, 2007). The New Segment Toolbox from SPM8 was applied to every T1-weighted MR image to extract tissue maps corresponding to gray matter, white matter and cerebrospinal fluid in the native space. Using the DARTEL template-creation toolbox, the resliced images of the gray and white matter were then registered to a subject-specific template to improve intersubject alignment. Subsequently, the normalization function in the DARTEL toolbox was used to normalize the individual images of gray and white matter to the MNI space (1.5-mm isotropic voxels). Finally, the gray and white matter maps of each subject were warped using their corresponding smoothed (8-mm full-width at half-maximum (FWHM) Gaussian kernel), reversible deformation parameters to the custom template space and then to the MNI standard space. Gray matter volume (GMV) images were modulated by calculating the Jacobian determinants derived from the special normalization step and by multiplying each voxel by the relative change in volume.

[1] https://www.fil.ion.ucl.ac.uk/spm/

Statistical Analysis

In order to test our hypothesis of art major students' TTCT-F scores are higher than non-art major students may result in professional training mostly than other reasons, we collect art major student's professional paint training duration and practicing time each day last month. Then correlated to the TTCT-F score of art major students. It is shown that these two variances are significant positive with art major student's TTCT-F score. This shows a certain degree of professional training of art may enhance their creativity skill of figural.

We investigated whether there was an interaction effect between the majors and figural creativity on brain structure. At the whole-brain level, a voxelwise analysis of covariance (ANCOVA) was performed using the full factorial option in SPM8, in which major was defined as a group factor. Age, sex, general intelligence, total score on the TTCT-F, and total GMV were entered as covariates; the total score on the TTCT-F underwent interaction analysis with majors using the interactions option in SPM8, which facilitated investigation of the interaction effect between majors and the covariates of brain structure. These interaction effects were assessed using t-contrasts, and the t-contrasts were performed by setting the voxelwise intensity threshold at $p < 0.005$, as determined by the non-stationary cluster extent correction (NS) in SPM.

RESULTS

Descriptive Statistics

The demographic data and behavioral results are shown in **Table 1**. Art majors showed significantly higher total TTCT-figural scores than the non-art majors ($p < 0.01$, $t = 3.87$, two-tailed t-test). Intelligence, as measured using the CRT, was not significantly different between majors ($p > 0.05$, $t = -1.052$, two-tailed t-test).

Correlation Analysis Between Behavioral Measures

The correlation between behavioral measures of TTCT-F score and practicing time are significantly positive, which means the higher TTCT-score participants get, the more practicing time they need. On the other hand, the TTCT-F score of art major students and professional paint training duration had marginal, significant positive correlations, which also certified TTCT-F score of art major students are owing to professional art practice mostly, see **Table 2**.

Interaction Effect of Major and Creativity on Regional GMVs

An interaction effect between figural creativity scores among art majors and non-art majors was shown on GMV in the left anterior cingulate cortex (ACC) and left medial frontal gyrus (MFG) (peak voxel MNI coordinates: -2, 18, -2, $T = 4.5$; -11, 50, 19, $T = 4.2$), see **Figure 1A** and **Table 3**, corrected with the non-stationary cluster extent correction (NS) at the whole-brain level. In particular, the figural creativity scores of the art majors had marginal, significant positive correlations with the GMVs of the left ACC and MFG ($p > 0.05$), while those of the in non-art majors ha significant negative correlations ($p < 0.05$), see **Figures 1B,C**. To further validate our findings, we conducted independent samples t-tests with active regions as seeds (see **Table 4**). The results supported our hypothesis that the voxel sizes of art majors are smaller than those of non-art majors.

DISCUSSION

In this study, we investigated associations between brain structures and individual figural creativity. Our behavioral results showed that art majors had significantly higher total TTCT-figural scores than non-art majors. Further, the VBM analysis results showed that figural creativity scores were related to GMVs of the left ACC and MFG. Specifically, in a simple slope analysis, a marginal, significant positive effect occurred in art majors and figural creativity in the GMV regions, while in non-art major, a significantly negative relationship was shown between figural creativity and the GMVs of specific brain regions. These differences indicated that art major students likely spend more time engaging in professional courses and have more chances to engage in creative activities, such as novel painting or original works. We figured that the impact of this factor on the results of the test would be significantly different between major and non-major students.

In the present study, the TTCT-figural scores of art majors were higher than those of non-art majors. Some researchers have postulated that individual differences in creativity skills are modulated by certain cognitive skills (Fischer and Rose, 1998; Gibson et al., 2009). Brain plasticity is a theme that has been verified in many studies (Chugani, 1994; Kolb and Whishaw, 1998; Johansson, 2000; Cotman and Berchtold, 2002; Ungerleider et al., 2002; Mahncke et al., 2006; Smith et al., 2009; Chan et al., 2016). Cotman clarified that brain-derived

TABLE 1 | Demographic data and behavioral results.

Measures	Art majors (n = 40) Means	SD	Non-art majors (n = 40)Means	SD
TTCT (total)***	71.750	20.208	55.633	16.838
CRT	64.725	4.867	65.775	4.022
Age	20.375	1.030	20.100	1.033

*TTCT, figural torrance tests of creative thinking; CRT, the combined Raven's test. ***$p < 0.01$.*

TABLE 2 | Correlation analysis between behavioral measures.

	TTCT-F (total)	Study time	Practicing time
TTCT-F (total)	–	0.076*	0.003***
Training duration		–	0.609
Practicing time			–

$^{***}p < 0.001$; $^{*}p < 0.01$.

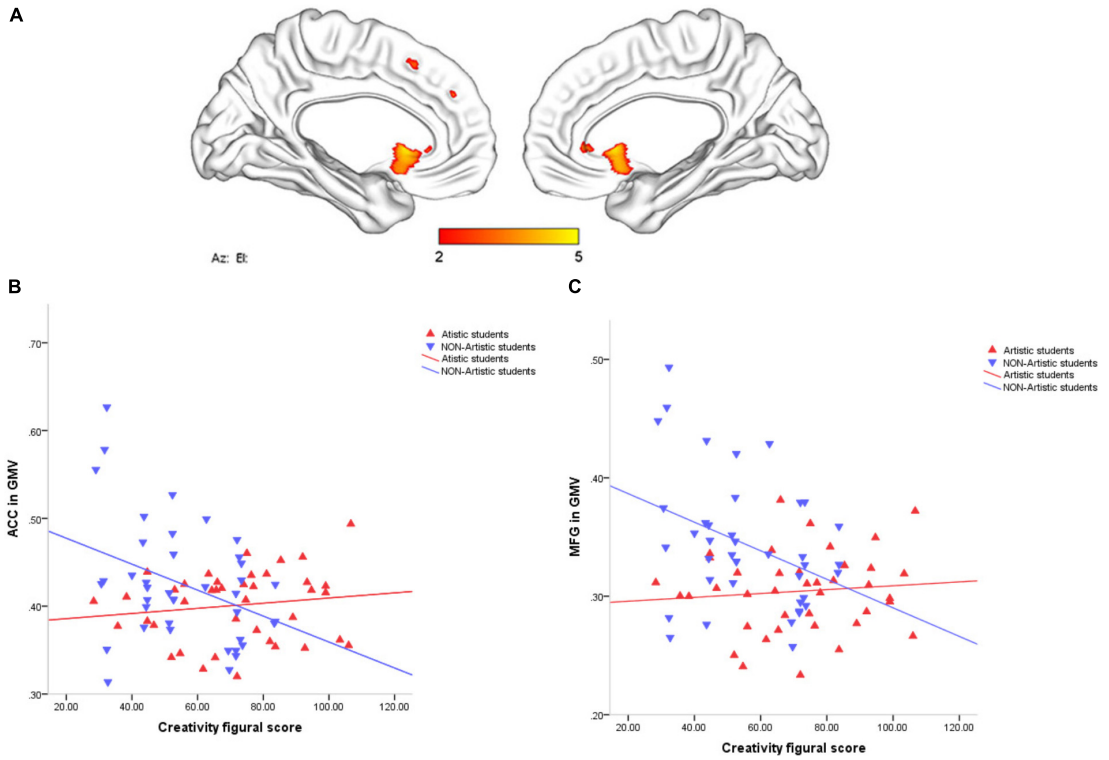

FIGURE 1 | (A) The interaction effect of TTCT-F scores in art majors and non-art majors and the GMVs of the left anterior cingulate cortex (ACC) and left medial frontal gyrus (MFG) (peak voxel MNI coordinate: -2, 18, -2, T = 4.5; -11, 50, 19, T = 4.2), corrected with the non-stationary cluster extent correction (NS) at the whole-brain level. **(B,C)** Figural creativity scores of the art majors demonstrated a marginal significant positive correlation with the GMVs of the left ACC and MFG ($p > 0.05$), whereas a significant negative correlation was observed in the non-art majors ($p < 0.05$).

TABLE 3 | The interaction effect of brain regions significantly correlated with creativity.

Item	Clustersize	H	Peak Tvalue	Peak MNI coordinate	Brain regions
TTCT-F creativity (NS Corrected $p < 0.005$)	45	L	4.2	−11 50 19	Medial frontal gyrus
	614	L	4.5	−2 18 −2	Left cingulate cortex

MNI, Montreal Neurological Institute; H, hemisphere; L, left; NS, non-stationary cluster extent correction for SPM.

neurotrophic factor and other growth factors can increase through conscious exercise, it also can increase the level of stimulate neurogenesis, increase resistance when encounter brain insult, and improve learning ability and mental performance. While solving divergent thinking tasks, subjects with high scores had lower EEG dimensions than the subjects with low scores, particularly in frontal cortical areas (Mölle et al., 1996). Prior research indicates that the adolescent brain is indeed sensitive to the effect of training of different cognitive functions including working memory and mathematical skills (Qin et al., 2004; Jolles et al., 2010). This means that people with different knowledge backgrounds solve problems in different ways (Schoenfeld, 2014). A creativity study of imagery involving high- and low-imagery subjects showed some differences in performance on cognitive tasks obtained in the studies (Campos and Pérez, 1989). In a training study, in the improvisation group subjects express higher creativity score, which means better divergent thinking ability in some degree (Sowden et al., 2015). Another study of topological organization and creativity showed that TTCT-F scores were significantly higher in the high group relative to the low group. A spontaneous improvisation and figural creativity which pictionary-based fMRI study showed that drawings is a good form with a given word were also creative (Saggar et al., 2015). Regarding the neurobiology of creativity, the creative strength of high groups mostly scored high (Carlsson et al., 2000). Urban stated that the training and learning with an open structure are highly important for creative education, which encourages non-conformist behavior, including problem solving and divergent thinking (Urban, 1995). Another study of creativity showed that lecturers could choose learning outcomes as open-ended serial constructions to encourage creativity in students (Giloi and du Toit, 2013). An EEG study showed that figural field especially creative ideation is associated with many specific task and sensory-based visual mental operations (Marks and Isaac, 1995; Petsche et al., 1997). From the above studies, we may conclude that subjects with high figural creativity ability are

TABLE 4 | Independent sample *t*-test analysis with active regions as seeds.

Seed ROI	Art majors (n = 40) Means	SD	Non-art majors (n = 40) Means	SD
Left MFG***	0.425	0.0682	0.344	0.055
Left ACC*	0.401	0.0401	0.304	0.034

*MFG, medial frontal gyrus; ACC, anterior cingulate cortex. ***$p < 0.01$; *$p > 0.05$ (marginal significance).*

mainly associated with executive control, attention, and memory retrieval networks in functional connectivity.

In the analysis of the brain, our results showed that the TTCT-figural scores of art majors have a marginal significant positive effect on the GMVs of the left ACC and MFG. In terms of the marginal significant positive effect of figural creativity on the GMV in the left ACC, as mentioned before, divergent thinking has consistently been shown to be related to widespread brain regions, such as the PFC and anterior cingulate cortex (Wu et al., 2015; Sun et al., 2016; Shi et al., 2018). A meta-analysis which activation likelihood estimation was used to detect divergent thinking of neuroimaging found that lateral prefrontal cortex, posterior parietal cortex, preceneus, anterior cingulate cortex, and temporal gyrus were the key regions (Wu et al., 2015). Additionally, our team's work regarding creativity training found that the dACC changes between pre- and posttests, both in terms of functional activity and gray matter (Sun et al., 2016). Furthermore, a combined VBM and resting-state functional connectivity study of creative achievement indicated that the ACC and bilateral frontal-insular cortex are negatively correlated (Sridharan et al., 2008; Chen et al., 2014). An fMRI study showed that between creative and uncreative in participants the activation located in bilateral medial frontal gyri and the left anterior cingulate cortex which belong to prefrontal areas (Howard-Jones et al., 2005).

As for the interaction results of the left MFG between majors and VBM, the fMRI study also showed that there were increases in the medial frontal gyri (MFG). The left ACC and MFG in the left hemisphere of the brain may have a facilitatory effect on art major students. The MFG, known as the "inhibitory area," has been verified in tasks that require associations of stimulus-response (Kreitzer and Malenka, 2008; Brass et al., 2009; Dwyer et al., 2009; Hill and Miller, 2010; Westerhausen et al., 2010; Gautam et al., 2011; Kozasa et al., 2012). Westerhausen also clarified that the MFG might be associated with top-down control of attentional processes. The MFG may also play a part crucial role in working memory during the manipulation of actively maintained information (Bunge and Zelazo, 2006; Woodward et al., 2006; DeYoung et al., 2010). These findings suggest that the reduced GMV in the MFG revealed in the present study might be associated with reduced inhibitory control, which may be associated with particular characteristics of higher trait creativity, such as challenge and risk taking.

We concluded that the educational environment of art majors is largely different from that of non-art majors. This view has also been confirmed by previous researchers (Golomb and Galasso, 1995). For example, art majors are typically tested on visual information and on the long-term practice of art skills that are required to generate creative outputs, which can better exercise your brain (Cotman and Berchtold, 2002). These behaviors, such as professional art training for art major students, may enhance divergent thinking. To some degree, a reduced left hemisphere itself inhibits. Art majors engage more in professional training skills than non-art majors, skills that are linked to improving visual orientation abilities to determine the correct direction to be taken and the ability to make complicated hand movements, which can enhance their cranial nerve more effectively (Griffin, 2017). Moreover, some functional studies revealed cingulate involved in internal selection and frontal region engagement relevant to task complexity (Starchenko et al., 2003). These differences in the interaction between the creativity scores of the two types of college majors could be explained on the one hand by the professional learning experience of art students. On the other hand, the results suggested that creativity could be promoted in art majors by reducing the level of inhibition in the brain hemisphere and task execution. A further analysis in our study regarding ROI value *t*-tests revealed that the values of art majors were smaller than those of non-art majors. However, in general, non-art major students rarely engage in designing art or in creative activities relative to art majors. In particular, the left ACC and MFG of art majors are smaller than those of non-art majors. As one of the forms of information representation, visual mental images involve top-down information processing based on experience. The idea is that the material of the thinking process, of which a person has different expression forms of information in the brain, is more suitable for generating creative thinking if understanding of composition occurs.

CONCLUSION

In the present study, the behavioral results indicated that the TTCT-figural score of art majors are higher than non-art majors. In addition, this fMRI study revealed that the TTCT-figural scores of art majors exhibited a marginal significant positive correlation with left ACC and MFG GMVs. These results show that, in art majors with high figural creativity, long-term exercise of artistic training may broaden their creativity skills and enhance their brain plasticity more than in non-art majors. Prolonged art training broadens the ability of the brain to think openly and may, in some ways, reduce the inhibitory effect on the right hemisphere.

ETHICS STATEMENT

The protocol was approved by Southwest University Brain Imaging Center Institutional Review Board and written informed consent.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

This work was supported by the project of study on the cross-cultural communication psychology of Chinese Calligraphy Culture (Grant No. 16JZD031-zkt01) which is one part of Key Projects of Philosophy and Social Sciences Research, Ministry of Education (Research on the theory and practice of international dissemination of Chinese Calligraphy Culture) (Grant No. 16JZD031), project of research on emotion measurement and intelligent interactive design supported by Shanghai Summit Discipline in Design.

REFERENCES

Ashburner, J. (2007). A fast diffeomorphic image registration algorithm. *Neuroimage* 38, 95–113. doi: 10.1016/j.neuroimage.2007.07.007

Berlin, B., and Kay, P. (1991). *Basic Color Terms: Their Universality and Evolution*. Berkeley, CA: University of California Press.

Bhattacharya, J., and Petsche, H. (2005). Drawing on mind's canvas: differences in cortical integration patterns between artists and non-artists. *Hum. Brain Mapp.* 26, 1–14. doi: 10.1002/hbm.20104

Bos, J. I., Kanneganti, T. D., Young, C., Cakir, C., Huitema, E., Win, J., et al. (2006). The C-terminal half of *Phytophthora infestans* RXLR effector AVR3a is sufficient to trigger R3a-mediated hypersensitivity and suppress INF1-induced cell death in *Nicotiana benthamiana*. *Plant J.* 48, 165–176. doi: 10.1111/j.1365-313X.2006.02866.x

Brass, M., Wenke, D., Spengler, S., and Waszak, F. (2009). Neural correlates of overcoming interference from instructed and implemented stimulus-response associations. *J. Neurosci.* 29, 1766–1772. doi: 10.1523/JNEUROSCI.5259-08.2009

Bunge, S. A., and Zelazo, P. D. (2006). A brain-based account of the development of rule use in childhood. *Curr. Dir. Psychol. Sci.* 15, 118–121.

Burch, G. S., Pavelis, C., Hemsley, D. R., Corr, P. J., Pavelis, C., Hemsley, D. R., et al. (2006). Schizotypy and creativity in visual artists. *Br. J. Psychol.* 97, 177–190. doi: 10.1348/000712605X60030

Byron, K., and Khazanchi, S. (2011). A meta-analytic investigation of the relationship of state and trait anxiety to performance on figural and verbal creative tasks. *Pers. Soc. Psychol. Bull.* 37, 269–283. doi: 10.1177/0146167210392788

Campos, A., and Pérez, M. J. (1989). High and low imagers and their scores on creativity. *Percept. Mot. Skills* 68, 403–406. doi: 10.2466/pms.1989.68.2.403

Carlsson, I., Wendt, P. E., and Risberg, J. (2000). On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects. *Neuropsychologia* 38, 873–885. doi: 10.1016/s0028-3932(99)00128-1

Carson, D. K., Bittner, M. T., Cameron, B. R., Brown, D. N., and Meyer, S. S. (1994). Creative thinking as a predictor of school-aged children's stress responses and coping abilities. *Creat. Res. J.* 7, 145–158. doi: 10.1080/10400419409534520

Chan, J. S. Y., Wang, Y., Yan, J. H., and Chen, H. (2016). Developmental implications of children's brain networks and learning. *Rev. Neurosci.* 27, 713–727. doi: 10.1515/revneuro-2016-0007

Chavez-Eakle, R. A., Graff-Guerrero, A., García-Reyna, J. C., Vaugier, V., and Cruz-Fuentes, C. (2007). Cerebral blood flow associated with creative performance: a comparative study. *Neuroimage* 38, 519–528. doi: 10.1016/j.neuroimage.2007.07.059

Chen, Q., Yang, W., Li, W., Wei, D., Li, H., Lei, Q., et al. (2014). Association of creative achievement with cognitive flexibility by a combined voxel-based morphometry and resting-state functional connectivity study. *Neuroimage* 102(Pt 2), 474–483. doi: 10.1016/j.neuroimage.2014.08.008

Chugani, H. T. (1994). "Development of regional brain glucose metabolism in relation to behavior and plasticity," in *Human Behavior and the Developing Brain*, eds G. Dawson and K. W. Fischer (New York, NY: Guilford Press), 153–175.

Cotman, C. W., and Berchtold, N. C. (2002). Exercise: a behavioral intervention to enhance brain health and plasticity. *Trends Neurosci.* 25, 295–301. doi: 10.1016/S0166-2236(02)02143-4

de Souza, L. C., Volle, E., Bertoux, M., Czernecki, V., Funkiewiez, A., Allali, G., et al. (2010). Poor creativity in frontotemporal dementia: a window into the neural bases of the creative mind. *Neuropsychologia* 48, 3733–3742. doi: 10.1016/j.neuropsychologia.2010.09.010

DeYoung, C. G., Hirsh, J. B., Shane, M. S., Papademetris, X., Rajeevan, N., Groy, J. R., et al. (2010). Testing predictions from personality neuroscience. Brain structure and the big five. *Psychol. Sci.* 21, 820–828. doi: 10.1177/0956797610370159

Dwyer, L., Edwards, D., Mistilis, N., Roman, C., and Scott, N. (2009). Destination and enterprise management for a tourism future. *Tour. Manag.* 30, 63–74. doi: 10.1016/j.tourman.2008.04.002

Eindhoven, J. E., and Vinacke, W. E. (1952). Creative processes in painting. *J. Gen. Psychol.* 47, 139–164. doi: 10.1080/00221309.1952.9710660

Fink, A., Graif, B., and Neubauer, A. C. (2009). Brain correlates underlying creative thinking: EEG alpha activity in professional vs. novice dancers. *Neuroimage* 46, 854–862. doi: 10.1016/j.neuroimage.2009.02.036

Fischer, K. W., and Rose, S. P. (1998). Growth cycles of brain and mind. *Educ. Leadersh.* 56, 56–60.

Gautam, S., Sood, A. D., Puri, R. K., and Aichelin, J. (2011). Sensitivity of the transverse flow towards symmetry energy. *Phys. Rev. C* 83:034606. doi: 10.1103/PhysRevC.83.034606

Ghacibeh, G. A., and Heilman, K. M. (2013). Creative innovation with temporal lobe epilepsy and lobectomy. *J. Neurol. Sci.* 324, 45–48. doi: 10.1016/j.jns.2012.09.029

Gibson, C., Folley, B. S., and Park, S. (2009). Enhanced divergent thinking and creativity in musicians: a behavioral and near-infrared spectroscopy study. *Brain Cogn.* 69, 162–169. doi: 10.1016/j.bandc.2008.07.009

Giloi, S., and du Toit, P. (2013). Current approaches to the assessment of graphic design in a higher education context. *Int. J. Art Des. Educ.* 32, 256–268. doi: 10.1111/j.1476-8070.2013.01758.x

Golomb, C., and Galasso, L. (1995). Make believe and reality: explorations of the imaginary realm. *Dev. Psychol.* 31, 800–810. doi: 10.1037/0012-1649.31.5.800

Griffin, A. (2017). Adolescent neurological development and implications for health and well-being. *Healthcare* 5:E62. doi: 10.3390/healthcare5040062

Guilford, J. P. (1967). The nature of human intelligence. *Am. Educ. Res. J.* 5:249.

Guilford, J. P., Christensen, P. R., Merrifield, P. R., and Wilson, R. C. (1978). *Alternate Uses: Manual of Instructions and Interpretations*. Orange, CA: Sheridan Psychological Services.

Heausler, N. L., and Thompson, B. (1988). Structure of the Torrance tests of creative thinking. *Educ. Psychol. Meas.* 48, 463–468. doi: 10.1177/0013164488482021

Heilman, K. M., Nadeau, S. E., and Beversdorf, D. O. (2003). Creative innovation: possible brain mechanisms. *Neurocase* 9, 369–379. doi: 10.1076/neur.9.5.369.16553

Hill, K. T., and Miller, L. M. (2010). Auditory attentional control and selection during cocktail party listening. *Cereb. Cortex* 20, 583–590. doi: 10.1093/cercor/bhp124

Howard-Jones, P. A., Blakemore, S. J., Samuel, E. A., Summers, I. R., and Claxton, G. (2005). Semantic divergence and creative story generation: an fMRI investigation. *Cogn. Brain Res.* 25, 240–250. doi: 10.1016/j.cogbrainres.2005.05.013

Huang, P., Qiu, L., Shen, L., Zhang, Y., Song, Z., Qi, Z., et al. (2013). Evidence for a left-over-right inhibitory mechanism during figural creative thinking in healthy nonartists. *Hum. Brain Mapp.* 34, 2724–2732. doi: 10.1002/hbm.22093

Jaušovec, J. (2000). Differences in cognitive processes between gifted, intelligent, creative, and average individuals while solving complex problems: an EEG study. *Intelligence* 28, 213–237. doi: 10.1016/S0160-2896(00)00037-4

Jiao, B., Zhang, D., Liang, A., Liang, B., Wang, Z., Li, J., et al. (2017). Association between resting-state brain network topological organization and creative ability: evidence from a multiple linear regression model. *Biol. Psychol.* 129, 165–177. doi: 10.1016/j.biopsycho.2017.09.003

Johansson, B. B. (2000). Brain plasticity and stroke rehabilitation: the Willis lecture. *Stroke* 31, 223–230. doi: 10.1161/01.STR.31.1.223

Jolles, D. D., Grol, M. J., Van Buchem, M. A., Rombouts, S. A., and Crone, E. A. (2010). Practice effects in the brain: changes in cerebral activation after working memory practice depend on task demands. *Neuroimage* 52, 658–668. doi: 10.1016/j.neuroimage.2010.04.028

Kim, K. H. (2006). Can we trust creativity tests? A review of the Torrance Tests of Creative Thinking (TTCT). *Creat. Res. J.* 18, 3–14. doi: 10.1207/s15326934crj1801_2

Kolb, B., and Whishaw, I. Q. (1998). Brain plasticity and behavior. *Annu. Rev. Psychol.* 49, 43–64. doi: 10.1146/annurev.psych.49.1.43

Kowatari, Y., Lee, S. H., Yamamura, H., Nagamori, Y., Levy, P., Yamane, S., et al. (2009). Neural networks involved in artistic creativity. *Hum. Brain Mapp.* 30, 1678–1690. doi: 10.1002/hbm.20633

Kozasa, E. H., Sato, J. R., Lacerda, S. S., Barreiros, M. A., Radvany, J., Russell, T. A., et al. (2012). Meditation training increases brain efficiency in an attention task. *Neuroimage* 59, 745–749. doi: 10.1016/j.neuroimage.2011.06.088

Kreitzer, A. C., and Malenka, R. C. (2008). Striatal plasticity and basal ganglia circuit function. *Neuron* 60, 543–554. doi: 10.1016/j.neuron.2008.11.005

Li, D., and Chen, G. P. (1989). *Combined Reven's teat (CRT)-Chinese Revised Version*. Shanghai: East China Normal University.

Li, J., Zhang, D., Liang, A., Liang, B., Wang, Z., Cai, Y., et al. (2017). High transition frequencies of dynamic functional connectivity states in the creative brain. *Sci. Rep.* 7:46072. doi: 10.1038/srep46072

Mahncke, H. W., Connor, B. B., Appelman, J., Ahsanuddin, O. N., Hardy, J. L., Wood, R. A., et al. (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proc. Natl. Acad. Sci. U.S.A.* 103, 12523–12528. doi: 10.1073/pnas.0605194103

Marks, D. F., and Isaac, A. R. (1995). Topographical distribution of EEG activity accompanying visual and motor imagery in vivid and non-vivid imagers. *Br. J. Psychol.* 86, 271–282.

Ming, W. D. Q. (1989). Revision on the combined raven's test for the rural in China [J]. *Psychol. Sci.* 5:004.

Mölle, M., Marshall, L., Lutzenberger, W., Pietrowsky, R., Fehm, H. L., and Born, J. (1996). Enhanced dynamic complexity in the human EEG during creative thinking. *Neurosci. Lett.* 208, 61–64. doi: 10.1016/0304-3940(96)12539-8

Petsche, H., Kaplan, S., von Stein, A., and Filz, O. (1997). The possible meaning of the upper and lower alpha frequency ranges for cognitive and creative tasks. *Int. J. Psychophysiol.* 26, 77–97. doi: 10.1016/S0167-8760(97)00757-5

Qin, Y., Carter, C. S., Silk, E. M., Stenger, V. A., Fissell, K., Goode, A., et al. (2004). The change of the brain activation patterns as children learn algebra equation solving. *Proc. Natl. Acad. Sci. U.S.A.* 101, 5686–5691. doi: 10.1073/pnas.0401227101

Rominger, C., Papousek, I., Perchtold, C. M., Weber, B., Weiss, E. M., Fink, A., et al. (2018). The creative brain in the figural domain: distinct patterns of EEG alpha power during idea generation and idea elaboration. *Neuropsychologia* 118(Pt A), 13–19. doi: 10.1016/j.neuropsychologia.2018.02.013

Ruscio, C., Papousek, I., Perchtold, C. M., Weber, B., Weiss, E. M., and Fink, A. (1998). Looking inside the fishbowl of creativity: verbal and behavioral predictors of creative performance. *Creat. Res. J.* 11, 243–263. doi: 10.1207/s15326934crj1103_4

Saggar, M., Quintin, E. M., Kienitz, E., Bott, N. T., Sun, Z., Hong, W. C., et al. (2015). Pictionary-based fMRI paradigm to study the neural correlates of spontaneous improvisation and figural creativity. *Sci. Rep.* 5:10894. doi: 10.1038/srep10894

Schoenfeld, A. H. (2014). *Mathematical Problem Solving*. Amsterdam: Elsevier.

Semrud-Clikeman, M., Fine, J. G., and Bledsoe, J. (2016). Social functioning using direct and indirect measures with children with High Functioning Autism, nonverbal learning disability, and typically developing children. *Child Neuropsychol.* 22, 318–335. doi: 10.1080/09297049.2014.994487

Shi, L., Sun, J., Xia, Y., Ren, Z., Chen, Q., Wei, D., et al. (2018). Large-scale brain network connectivity underlying creativity in resting-state and task fMRI: cooperation between default network and frontal-parietal network. *Biol. Psychol.* 135, 102–111. doi: 10.1016/j.biopsycho.2018.03.005

Simonton, D. K. (2000). Creativity. Cognitive, personal, developmental, and social aspects. *Am. Psychol.* 55, 151–158. doi: 10.1037/0003-066X.55.1.151

Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., et al. (2009). A cognitive training program based on principles of brain plasticity: results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) Study. *J. Am. Geriatr. Soc.* 57, 594–603. doi: 10.1111/j.1532-5415.2008.02167.x

Sowden, P. T., Clements, L., Redlich, C., and Lewis, C. (2015). Improvisation facilitates divergent thinking and creativity: realizing a benefit of primary school arts education. *Psychol. Aesthet. Creat. Arts* 9, 128–138. doi: 10.1037/aca0000018

Sridharan, D., Levitin, D. J., and Menon, V. (2008). A critical role for the right fronto-insular cortex in switching between central-executive and default-mode networks. *Proc. Natl. Acad. Sci. U.S.A.* 105, 12569–12574. doi: 10.1073/pnas.0800005105

Starchenko, M. G., Bekhtereva, N. P., Pakhomov, S. V., and Medvedev, S. V. (2003). Study of the brain organization of creative thinking. *Hum. Physiol.* 29, 652–653. doi: 10.1023/A:1025836521833

Storm, B. C., Angello, G., and Bjork, E. L. (2011). Thinking can cause forgetting: memory dynamics in creative problem solving. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 1287–1293. doi: 10.1037/a0023921

Sun, J., Chen, Q., Zhang, Q., Li, Y., Li, H., Wei, D., et al. (2016). Training your brain to be more creative: brain functional and structural changes induced by divergent thinking training. *Hum. Brain Mapp.* 37, 3375–3387. doi: 10.1002/hbm.23246

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., et al. (2011). Regional gray matter density associated with emotional intelligence: evidence from voxel-based morphometry. *Hum. Brain Mapp.* 32, 1497–1510. doi: 10.1002/hbm.21122

Torrance, E. P. (1966). *Torrance Tests of Creative Thinking*. Lexington, KY: Personnel Press.

Torrance, E. P. (1988). "The nature of creativity as manifest in its testing," in *The Nature of Creativity: Contemporary Psychological Perspectives*, ed. R. J. Sternberg (New York, NY: Cambridge University Press), 43–75.

Ulger, K. (2016). The creative training in the visual arts education. *Think. Skills Creat.* 19, 73–87. doi: 10.1016/j.tsc.2015.10.007

Ungerleider, L. G., Doyon, J., and Karni, A. (2002). Imaging brain plasticity during motor skill learning. *Neurobiol. Learn. Mem.* 78, 553–564. doi: 10.1006/nlme.2002.4091

Urban, K. K. (1995). Openness: a "magic formula" for an adequate development and promotion of giftedness and talents?! *Gifted Talent. Int.* 10, 15–19. doi: 10.1080/15332276.1995.11672808

Villarreal, M. F., Cerquetti, D., Caruso, S., Schwarcz López Aranguren, V., Gerschcovich, E. R., Frega, A. L., et al. (2013). Neural correlates of musical creativity: differences between high and low creative subjects. *PLoS One* 8:e75427. doi: 10.1371/journal.pone.0075427

Wallach, M. A., and Kogan, N. (1964). The roles of information, discussion, and consensus in group risk taking. *J. Exp. Soc. Psychol.* 1, 1–19. doi: 10.1016/j.encep.2016.01.011

Westerhausen, R., Moosmann, M., Alho, K., Belsby, S. O., Hämäläinen, H., Medvedev, S., et al. (2010). Identification of attention and cognitive control networks in a parametric auditory fMRI study. *Neuropsychologia* 48, 2075–2081. doi: 10.1016/j.neuropsychologia.2010.03.028

Wolff, U., and Lundberg, I. (2002). The prevalence of dyslexia among art students. *Dyslexia* 8, 34–42. doi: 10.1002/dys.211

Woodward, T. S., Cairo, T. A., Ruff, C. C., Takane, Y., Hunter, M. A., and Ngan, E. T. (2006). Functional connectivity reveals load dependent neural systems underlying encoding and maintenance in verbal working memory. *Neuroscience* 139, 317–325. doi: 10.1016/j.neuroscience.2005.05.043

Wu, X., Yang, W., Tong, D., Sun, J., Chen, Q., Wei, D., et al. (2015). A meta-analysis of neuroimaging studies on divergent thinking using activation likelihood estimation. *Hum. Brain Mapp.* 36, 2703–2718. doi: 10.1002/hbm.22801

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 22 January 2019
doi: 10.3389/fpsyg.2019.00014

Emotional Responses to Visual Art and Commercial Stimuli: Implications for Creativity and Aesthetics

Mei-Chun Cheung[1], Derry Law[2], Joanne Yip[2] and Christina W. Y. Wong[2]*

[1] Department of Social Work, The Chinese University of Hong Kong, Shatin, Hong Kong, [2] Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

There is an ongoing debate about whether emotional responses to artworks are similar to those produced by the commercial stimuli experienced in everyday life. In this study, we evaluated the emotional responses to the visual art and commercial stimuli by using electroencephalography (EEG) to obtain an objective measure of emotional responses of the brain, namely the frontal alpha asymmetry. Positive frontal alpha asymmetry suggests positive emotional responses, and vice versa. The visual art stimuli consisted of 80 artistic and naturally colored paintings whereas the commercial stimuli consisted of 80 different window displays of fashion collections. The results revealed that positive frontal alpha asymmetry was elicited when the participants judged the visual art stimuli as either beautiful or not beautiful. For the commercial stimuli, positive frontal alpha asymmetry was observed when they were considered as beautiful, whereas negative frontal alpha asymmetry was exhibited toward those perceived as not beautiful. These findings suggest more positive emotional responses to the visual art stimuli, regardless of their aesthetics. However, favorable emotional responses were only elicited toward the commercial stimuli regarded as beautiful. The implications for the creative and aesthetic design of the commercial stimuli in Chinese society in influencing consumers' emotional responses are discussed.

Keywords: emotional responses, window displays, visual art, aesthetics, creativity, EEG

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Yuan Zhao,
Soochow University, China
Ronald Hübner,
Universität Konstanz, Germany

****Correspondence:***
Mei-Chun Cheung
meichun@swk.cuhk.edu.hk

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *24 August 2018*
Accepted: *04 January 2019*
Published: *22 January 2019*

Citation:
Cheung M-C, Law D, Yip J and Wong CWY (2019) Emotional Responses to Visual Art and Commercial Stimuli: Implications for Creativity and Aesthetics. Front. Psychol. 10:14. doi: 10.3389/fpsyg.2019.00014

INTRODUCTION

The visual arts, such as painting and sculpture, are the most prevalent forms of visual artistic expression in the West that are considered to be creative products (Kaufman et al., 2008; Lan and Kaufman, 2013). In addition, the visual arts are often associated with aesthetics; hence investigations into the neural processing involved in art appreciation has rapidly evolved as an objective and scientific approach to understanding aesthetics (Zaidel, 2010; Shimamura and Palmer, 2012; Chatterjee, 2014). Researchers have used the visual arts to identify the neural correlates of aesthetic appreciation (Vartanian and Goel, 2004; Lengger et al., 2007; Cela-Conde et al., 2009, 2013; Cupchik et al., 2009; Munar et al., 2012; Vessel et al., 2012; Ishizu and Zeki, 2013; Pang et al., 2013; Boccia et al., 2014; Gerger et al., 2014). By using magnetoencephalography and functional magnetic resonance imaging (fMRI), widely distributed brain regions have been identified as being associated with aesthetic appreciation of the visual arts; these regions overlap with the functionally

connected brain networks involved in reward representation, affective motor planning, attention-related sensory processing, and evaluative judgments of social and moral cues (Leder and Nadal, 2014). These brain regions include the medial orbitofrontal cortex (Kawabata and Zeki, 2004; Ishizu and Zeki, 2011, 2013; Cela-Conde et al., 2013; Zeki et al., 2014); the fronto-median cortex (Jacobsen et al., 2006; Jacobs et al., 2012); the prefrontal cortex (Jacobsen et al., 2006); the posterior cingulate gyrus (Jacobsen et al., 2006; Jacobs et al., 2012); the left temporal pole (Jacobsen et al., 2006); the temporoparietal junction (Jacobsen et al., 2006); the left angular gyrus (Zeki et al., 2014); the left superior temporal gyrus (Zeki et al., 2014); and the amygdala (Jacobs et al., 2012). When stimuli are perceived to be beautiful, rather than ugly, additional brain regions are recruited in the orbitofrontal cortex (Jacobsen et al., 2006; Tsukiura and Cabeza, 2011; Zeki et al., 2014), the right amygdala (Di Dio et al., 2007), and the secondary visual cortex (Jacobs et al., 2012). Moreover, a delayed brain network is more synchronized during aesthetic judgment of beautiful stimuli compared with those that are not considered beautiful. The network consists of the medial occipital, the lateral occipital, the lateral posterior parietal, the medial parietal, the medial frontal, and the prefrontal regions of the left hemisphere (Cela-Conde et al., 2013).

Visual stimuli that have received academic attention include sculptures (Di Dio et al., 2007); faces (Roye et al., 2008; Chatterjee et al., 2009; Tsukiura and Cabeza, 2011; Zhang and Deng, 2012); textures (Jacobs et al., 2012); geometrical shapes (Jacobsen and Höfel, 2001, 2003; Jacobsen et al., 2006; Höfel and Jacobsen, 2007; de Tommaso et al., 2008); and even mathematical formulae (Zeki et al., 2014). However, despite extensive studies using a variety of different visual stimuli, few examine the neural processing of aesthetic experiences using the commercial stimuli. Using fMRI, significantly stronger brain activation in specific affective areas were found during aesthetic product presentation; those areas include the ventromedial prefrontal cortex, the nucleus accumbens, and the cingulate cortex (Reimann et al., 2010; Jiang and Cai, 2013). In addition, the commercial products with aesthetic packaging significantly induced an increase in the reaction time of the consumers' choice responses (Reimann et al., 2010). The difference in the response time between non-aesthetic and aesthetic commercial products was also revealed in an event-related brain potential (ERP) study by Jiang and Cai (2013), in which less beautiful color combinations elicited higher P2 and P300 amplitudes than more beautiful ones. The results suggested that the negative emotional responses aroused by the less beautiful color were elicited at an early stage. It was also suggested, therefore, that aesthetic experiences with beautiful stimuli, regardless of whether these are artistic or commercial stimuli, involve a delayed dynamic and functionally integrated brain network, requiring a longer reaction time to make a judgment compared with that induced by stimuli that are not beautiful. In our previous study (Cheung et al., 2014), we demonstrated brain activities suggestive of an integrative process involved in attention with central executive processing, and more positive emotional responses when the personal-appearance styles were judged to be beautiful. In addition, aesthetic judgment engaged a delayed synchronized brain network, involving long-range coherence between the frontal and parietal regions in both hemispheres, and coherence between the two hemispheres in the frontal and central regions.

Unlike Western society which views a creative product as merely a creation, creative products in Chinese society can be regarded as the outcome of a creative industry (Wang et al., 2007), and as saleable goods that are associated with economic activities (Lan and Kaufman, 2013). Therefore, the present study uses fashion window displays as the commercial stimuli, as they combine both aesthetics and creativity (Pieters et al., 2010; Law et al., 2013), and are considered as creative products in China (Lan and Kaufman, 2013). Apart from increasing the attractiveness of the displayed products to draw the attention of customers, window displays differ from simple merchandise-focused displays that convey implicit messages (Diamond and Diamond, 2007). This is because customers need to rely on their own interpretation of the inferred message projected from the window displays for the overall feeling and perception of the products, store and brand, thereby determining the subsequent decision to shop; that is, whether they will enter the store (Sen et al., 2002; Oh and Petrie, 2012). Unlike artworks that mainly fulfill a hedonic need, window displays provide utilitarian motives, which induce approach-motivated reactions and goal-oriented behavior. Therefore, a comparison of the neural processing of aesthetic experiences and emotional responses to the visual arts and commercial stimuli can address the research gap in differentiating the elicited emotional responses from the art and aesthetics of everyday life by objective and scientific measures of neural activity in the brain, therefore substantiating theoretical knowledge of aesthetics and creative products in Western and Chinese culture. To the best of our knowledge, very few studies have been carried out that provide insight into the emotional responses to window displays.

Different emotions are associated with different EEG patterns in the frontal regions of the brain (Ekman et al., 1990; Fox, 1991). One of the well-documented measures of emotional responses is the frontal alpha asymmetry (see reviews by Coan and Allen, 2004; Harmon-Jones et al., 2010). This is calculated by subtracting the log-transformed absolute alpha power of the left frontal region from the analogous log-transformed alpha power of the right frontal region; i.e., log right minus log left (Davidson et al., 2000b). This asymmetry is proposed by Davidson (1998), who conducted a series of EEG studies using this asymmetry to reflect human mood states, and repeatedly identified a positive association between greater relative left-side activation in the anterior part of the frontal region and positive mood. Specifically, positive emotion is associated with greater relative left-sided frontal activation, as compared to right-sided (Davidson, 2000; Davidson et al., 2000a, 2003), whereas negative emotion is accompanied by greater relative right-sided frontal activation, as compared to left-sided (Davidson et al., 1990, 2000b; Davidson, 1992). As alpha power is inversely associated with brain activation, positive frontal alpha asymmetry that denotes greater alpha power on the right and less alpha power on the left suggests greater relative left-sided activation – that is, positive emotion. In contrast, negative frontal alpha

asymmetry represents greater relative activation on the right, suggesting negative emotion. Our empirical and clinical studies also demonstrated that the frontal alpha asymmetry is effective and reliable in discriminating between positive and negative emotions (Chan et al., 2008, 2011; Cheung et al., 2014).

The current literature has proposed that emotions produced from viewing the arts are different from those experienced in everyday life (Frijda, 1988; Frijda and Schram, 1995; Scherer, 2005). For instance, Frijda's emotion theory concluded that appraisal of artworks is not relevant to the current needs and goals of individuals (Frijda, 1988). Hence laypeople are psychologically removed (Cupchik, 2002), which results in less intense emotional responses. Motivational and goal-oriented reactions might also be reduced. However, Levinson (1996); Goldstein (2009), and others have argued that perceivers can indulge in their aesthetic experiences with art with comparable or even more intense emotional responses than those experienced in everyday life, as artworks are usually viewed in a safe and relaxed environment. Given that there is an ongoing debate about whether emotional responses to artworks are similar to those elicited by aesthetic objects found in everyday life, in this study we compare the neural processing of emotional responses to aesthetic experiences using two creative products: paintings versus fashion window displays. In particular, we use the frontal alpha asymmetry to investigate whether the brain is involved in a similar way in the emotional responses to the visual art and commercial stimuli that are regarded as beautiful and not beautiful.

MATERIALS AND METHODS

Participants

Twenty university students (4 males, 16 females) with specialism in design or business were recruited from the Institute of Textiles and Clothing at The Hong Kong Polytechnic University and participated in the study voluntarily. The participants had a mean age of 21.15 years (SD $\pm$ 1.18), had spent 15 years in full-time education, and reported a negative history of neurological and psychiatric problems. They completed some fundamental courses in which their creativity and design skills were nurtured and had basic knowledge related to fashion business. Given their academic background, they were competent to make aesthetic judgments of visual art and commercial stimuli. The study followed the research guidelines of the Helsinki Declaration of the World Medical Association Assembly, and the research protocol was approved by the Human Subjects Ethics Sub-committee (HSESC) of The Hong Kong Polytechnic University. Informed consent was obtained from all participants prior to the study in accordance with institutional guidelines.

Selection of Visual Stimuli

The visual art stimuli consisted of 80 artistic and naturally colored Western paintings. They downloaded from the classification of paintings in the ARTStor Digital Library[1], which consists of more than one million images from 100s of different collections. Based on the painting styles, such as visual elements, movement or school, these stimuli were categorized into four types of painting with twenty in each group, as follows: (i) impressionist art; (ii) post-impressionist art; (iii) abstract art; and (iv) surrealist art. Of the 20 paintings in each group, 10 were considered to be beautiful and 10 were considered to be not beautiful, according to the criteria below. The commercial stimuli consisted of 80 different window displays, of which 40 were considered to be beautiful and 40 to be not beautiful. They were taken from a collection of fashion displays used in teaching and research (Law et al., 2012). The displays consisted of different clothing categories from classic wear to fashionable casual wear and mass market items. They were also representative of different types of customer segments, from the High Street shopper to those with more affluent tastes, and were thus an effective stimulus for measuring aesthetic-related issues. To emphasize the relevance of the commercial stimuli on the needs and goals of the viewer, mannequins were used in the fashion window displays because they are an important element for retailers in projecting a three-dimensional space in terms of fit and style when dressing a physical body (Oh and Petrie, 2012). In addition, mannequins provide non-verbal cues which attract attention more easily (Palermo and Rhodes, 2007) and can stimulate mental visualizations of wearing the displayed clothing (Elder and Krishna, 2012). Mannequins are therefore an important visual element for consumers (Kerfoot et al., 2003). The stimuli of paintings and fashion window displays can be found in the **Supplementary Material**.

Prior to the EEG recording, a pilot pool of 160 paintings (40 from each of the four categories) and 160 fashion window displays were initially chosen by an independent expert with arts background who was blind to the experiment. These stimuli were printed on sheets of A4 paper and were given to 20 anonymous university students who were not involved in the study, to rate whether they were perceived as beautiful or not beautiful. The most beautiful and "absolutely not" beautiful stimuli were chosen for the experiment, based on the highest consensus from this pilot pool of paintings and fashion window displays.

EEG Recording

The EEG signals were collected from 64 silver/silver chloride (Ag/AgCl) sintered electrodes mounted on a stretch Lycra Quik-Cap (Compumedics Neuroscan, El Paso, TX, United States). The electrode placement was arranged in accordance with the international 10–10 system (Chatrian et al., 1985; American Electroencephalographic Society, 1994). A ground electrode was located on the forehead anterior to the Fz electrode and the linked-ears reference was adopted. Eye movements and blinking were recorded by vertical electrooculograms from the electrodes on the supraorbital and suborbital regions of the left eye, and horizontal electrooculograms from the electrodes on the outer canthi of both eyes. The impedance was less than 10 kΩ and homologous sites were within 1 kΩ of each other. A Neuroscan SynAmps2 amplifier unit (El Paso, TX, United States) with a bandpass filter of 0.05 to 200 Hz and a sampling rate of 1000 Hz was utilized to amplify the EEG signals.

[1] www.artstor.com

EEG Paradigm

The EEG paradigm included one 4-min resting condition with eyes open as the baseline, and two experimental conditions (aesthetic judgment of paintings vs. fashion window displays). The sequence of the two experimental conditions was randomized and counterbalanced among the 20 participants. During the EEG recording, the participants performed aesthetic judgments of the 80 paintings and 80 fashion window displays, which were presented for 5 s with an inter-trial interval of 5.5 s. The visual stimuli were generated, controlled, and presented using software called STIM2 (Compumedics Neuroscan, El Paso, TX, United States). The participants were invited to assess the perceived visual stimuli as either "beautiful" or "not beautiful" by pressing the corresponding buttons of the STIM2 Response Pad. The stimuli of paintings and fashion windows displays were randomly presented (**Figure 1**). Besides EEG signals, the behavioral measures included the time taken by the participants to make aesthetic judgments and the number of visual stimuli perceived as beautiful or not beautiful. After two trials of the experimental conditions, the participants fully relaxed with eyes open for 4 min as the baseline measurement.

EEG Processing

The EEG signals of the experimental conditions were imported into the EEGLAB software program to extract the EEG epochs that corresponded to the visual stimuli perceived as beautiful or not beautiful, according to aesthetic judgments of the participants. The epochs were spanned at intervals from 100 ms pre-stimulus to 1900 ms post-stimulus. The epochs of the visual stimuli and the EEG signals for the 4-min resting state were processed by the NeuroGuide (v2.7.9) software program to remove artifacts. Individual EEG files were first visually inspected for any gross abnormalities by a trained technician who was blind to the purpose of the study. Using an EEG template that was artifact-free for at least 10 s, the data were edited by the built-in automated artifact detection and rejection toolbox to remove all non-EEG artifacts, including eye movement and blink artifacts and drowsiness. Split-half and test–retest reliability tests were performed on the selected EEG segments with built-in tools in the NeuroGuide software. For the subsequent spectral analysis of fast Fourier transformation (FFT), we chose only those segments with minimum split-half and test–retest reliability ratios of 90%, and with at least 1 min in the resting state or at least 25 artifact-free epochs for "beautiful" and "not beautiful." In the FFT, the

FIGURE 1 | Experimental paradigm of visual stimulus. **(A)** Random presentation of paintings with 20 visual stimuli (10 beautiful and 10 not beautiful) in each of the four categories: (i) impressionist art; (ii) post-impressionist art; (iii) abstract art; and (iv) surrealist art. **(B)** Random presentation of fashion window displays (40 beautiful and 40 not beautiful). Participants were asked if they perceived the visual stimuli as either "beautiful" or "not beautiful" and responded by pressing a STIM2 Response Pad. Red rectangles indicate examples of visual stimuli perceived to be not beautiful and blue rectangles indicate examples of those perceived to be beautiful.

EEG data from each channel were transformed into predefined frequency ranges.

The EEG data for the resting condition and the epochs for the visual stimuli were analyzed over 64 electrode placements in the alpha frequency band (8 to 12 Hz) to calculate the frontal alpha asymmetry (Chan et al., 2008, 2011; Cheung et al., 2014) by subtracting the log-transformed absolute alpha power of the left frontal region (F3) from the analogous log-transformed alpha power of the right frontal region (F4); i.e., log F4 minus log F3. Based on Davidson's findings (Davidson, 1992, 1998, 2000; Davidson et al., 1990, 2000a,b, 2003), which associate the frontal alpha asymmetry with emotional responses, the frontal alpha asymmetry index was used in this study to compare the emotional responses between the baseline (resting with eyes open) and the experimental conditions (aesthetic judgment of paintings or fashion window displays). A positive asymmetry index – that is, higher alpha power on the right frontal region of the brain (F4) and lower alpha power on the left frontal region (F3) – represents a more positive emotional response. Conversely, a negative asymmetry index represents a more negative emotional response.

Statistical Data Analysis

The statistical data analysis was carried out using SPSS Version 21.0 for Windows (SPSS, Inc., Chicago, IL, United States). The normal distribution of the data was confirmed by Kolmogorov–Smirnov tests and parametric statistics were used for comparisons. Comparisons of the EEG data during resting condition with EEG epochs for the "beautiful" and "not beautiful" stimuli were conducted through paired-sample *t*-tests with 19 degrees of freedom. Repeated measures analysis of variance (ANOVA) with two within-subject factors was conducted to compare the frontal alpha asymmetry across conditions and stimuli to detect any overall differences between related means [(Condition: beautiful vs. not beautiful) × (Stimuli: paintings vs. fashion window displays)]. To indicate the effect sizes, partial eta-squared (η_p^2) values were also reported for ANOVA tests. For significant factors from the ANOVAs, further *post hoc* comparisons were made using paired-sample *t*-tests with 19 degrees of freedom.

RESULTS

Behavioral Performance

The participants endorsed 98.5% (or 78.8) of the 80 paintings as either beautiful or not beautiful. The remaining 1.5% (or 1.2) did not receive a response. Of the 80 fashion window displays, 97.9% (or 78.3) were endorsed as either beautiful or not beautiful, while 2.1% (or 1.7) did not receive a response. **Table 1** shows the mean judgment latency (calculated only for the trials that had responses), number of visual stimuli perceived as beautiful and not beautiful, and their standard deviations. There were no significant differences between the judgment latency and number of paintings and fashion window displays perceived as beautiful or not beautiful ($p > 0.05$).

Frontal Alpha Asymmetry

Visual Stimuli Versus Resting

The paired-sample *t*-tests revealed a positive frontal alpha asymmetry when the paintings were perceived to be beautiful ($M = 0.048$), in comparison with the resting condition ($M = -0.003$; $t = 2.325$, $p = 0.031$). Negative frontal alpha asymmetry was found when the fashion window displays were judged to be not beautiful ($M = -0.067$; $t = -2.967$, $p = 0.008$). There was no significant difference in the frontal alpha asymmetry between the resting condition and paintings perceived to be not beautiful, or between the resting condition and fashion window displays perceived to be beautiful.

Visual Art Versus Commercial Stimuli

A repeated measures ANOVA with two within-subject factors was conducted to compare the frontal alpha asymmetry [(Stimuli: paintings vs. fashion window displays) × (Condition: beautiful vs. not beautiful)]. The main effects of Stimuli [$F(1,19) = 33.402$, $p = 0.000$, $\eta_p^2 = 0.637$] and Condition [$F(1,19) = 16.305$, $p = 0.001$, $\eta_p^2 = 0.462$] and the interaction effect of Stimuli and Condition [$F(1,19) = 5.113$, $p = 0.036$, $\eta_p^2 = 0.212$] were all significant, which means that there were significant and condition-specific differences in the frontal alpha asymmetry between the paintings and fashion window displays. Subsequent *post hoc* pairwise comparisons showed that the frontal alpha asymmetry induced by the paintings ($M = 0.043$) was generally more positive and significantly higher than that induced by the fashion window displays ($M = -0.013$, with $p = 0.000$). In addition, the frontal alpha asymmetry induced by visual stimuli that were perceived to be beautiful ($M = 0.044$) was also more positive and significantly higher than that induced by visual stimuli that were perceived to be not beautiful ($M = -0.015$, with $p < 0.001$).

As shown by the *post hoc* paired-sample *t*-test (**Figure 2**), there was no significant difference in the frontal alpha asymmetry between the paintings that were perceived to be beautiful ($M = 0.048$) and not beautiful ($M = 0.037$; $t = 0.912$, $p = 0.373$). However, the frontal alpha asymmetry of the fashion window displays that were judged to be beautiful ($M = 0.041$) was generally more positive than that of the fashion window displays that were perceived to be not beautiful ($M = -0.067$; $t = 3.139$, $p = 0.005$). Comparison between the paintings and fashion window displays indicated that there was no significant difference in the frontal alpha asymmetry between the paintings ($M = 0.048$) and fashion window displays ($M = 0.041$) that were perceived to be beautiful ($t = 0.387$, $p = 0.703$). However, the frontal alpha asymmetry of the fashion window displays that were perceived to be not beautiful ($M = -0.067$) was significantly lower than that of the paintings that were perceived to be beautiful ($M = 0.048$; $t = 6.238$, $p = 0.000$) and not beautiful ($M = 0.037$; $t = 4.008$, $p = 0.001$).

DISCUSSION

Aesthetic emotions, as modeled by both Chatterjee (2004) and Leder et al. (2004), are one of the outputs of aesthetic experiences. Using fMRI, several brain regions have been identified as

TABLE 1 | Number of visual stimuli perceived to be beautiful or not beautiful and mean judgment latency using EEG experimental paradigm.

	Beautiful	Not beautiful	*t*-Test	*p*-Value	Cohen's *d*
Paintings	38.45 ± 9.49	40.35 ± 9.75	−0.443	0.663	0.099
Fashion window displays	38.10 ± 13.89	40.25 ± 14.37	−0.344	0.735	0.015
Response time to paintings (ms)	1498.81 ± 364.98	1493.23 ± 423.06	0.068	0.947	0.077
Response time to fashion window displays (ms)	1573.71 ± 348.95	1561.83 ± 358.51	0.159	0.876	0.035

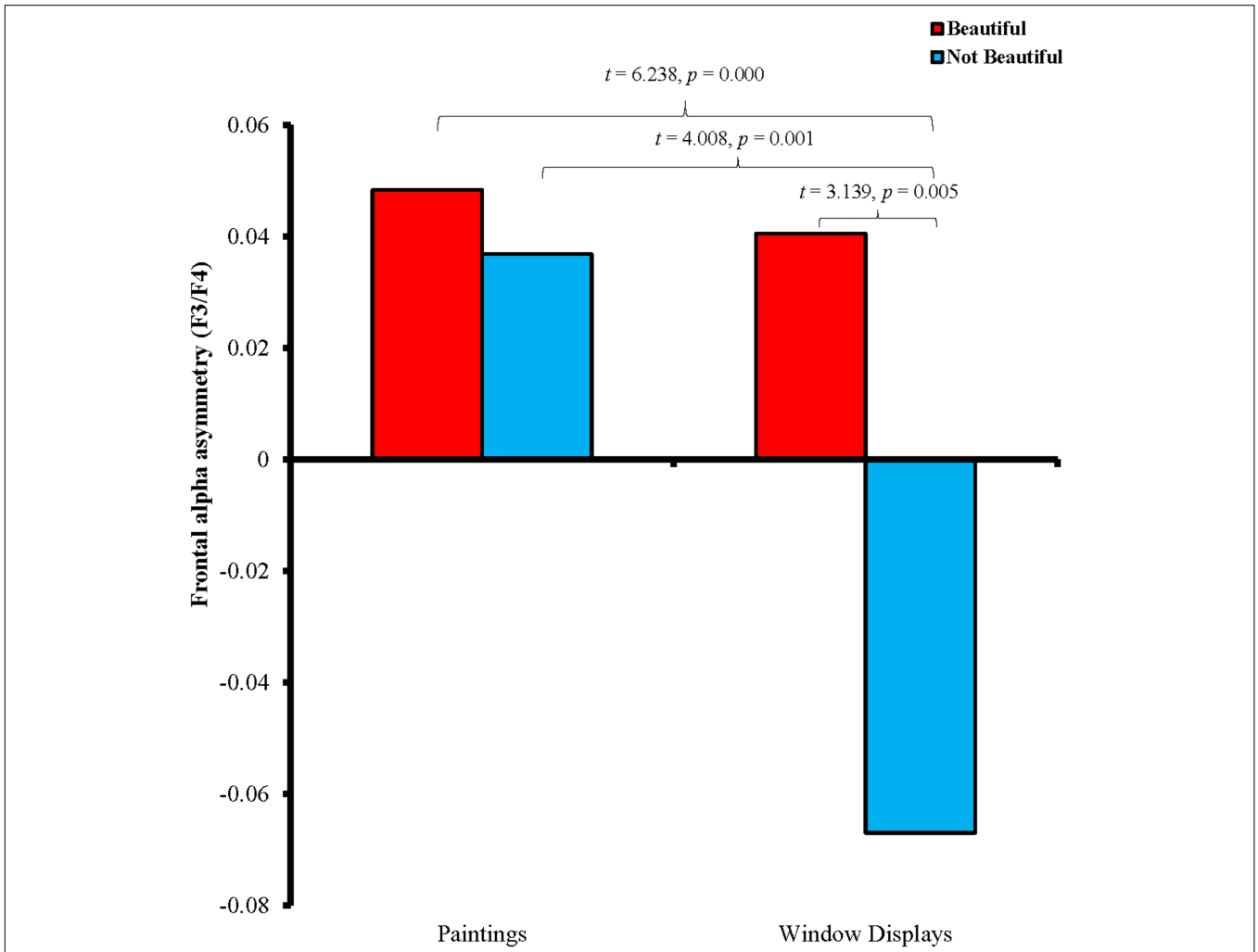

FIGURE 2 | Frontal alpha asymmetry (log F4 minus log F3) of visual stimuli perceived to be beautiful or not beautiful. More positive frontal alpha asymmetry value was observed when participants perceived paintings and fashion window displays to be beautiful or paintings to be not beautiful, and more negative frontal alpha asymmetry value was exhibited when fashion window displays were perceived to be not beautiful.

being related to aesthetic emotions, including the temporal pole (Jacobsen et al., 2006), the bilateral insular cortex (Cupchik et al., 2009), the orbitofrontal cortex (Cela-Conde et al., 2004; Kawabata and Zeki, 2004), the caudate nucleus, and the anterior cingulate cortex (Vartanian and Goel, 2004). These results suggest that positive aesthetic experiences involve affective processes related to the reward value of the aesthetically judged stimuli. More functional activity has also been observed in the right amygdala, which has the primary role of processing emotional responses when images are perceived to be beautiful, compared to images that are regarded to be not beautiful (Di Dio et al., 2007). These fMRI studies focus on localizing the brain regions during aesthetic experiences, but cannot determine whether pleasurable emotional responses are elicited during aesthetic experiences. Given this limitation, we recently carried out a study that used the frontal alpha asymmetry as an index of mood states to examine whether aesthetic judgment of personal-appearance styles as beautiful resulted in a pleasurable experience for the perceiver (Cheung et al., 2014). We found that, compared to the resting condition, positive frontal alpha asymmetry,

which points to a positive emotional response, was observed when the participants perceived the personal-appearance styles to be beautiful. On the other hand, negative frontal alpha asymmetry, which points to a negative emotional response, was found when the personal-appearance styles were regarded as not beautiful. As an extension to previous studies, the present study investigated and compared the emotional responses to the aesthetic experiences of the visual art stimuli (paintings) versus commercial stimuli found in everyday life (fashion window displays) to determine if emotional responses to the former were similar to those elicited by the latter. Using paintings as the visual art stimuli, the findings demonstrated that regardless of whether they were perceived to be beautiful, we found positive frontal alpha asymmetry, and no significant difference in the frontal alpha asymmetry between them. Compared to the resting condition, the frontal alpha asymmetry was significantly higher and more positive when the paintings were considered to be beautiful. Changes in the frontal alpha asymmetry are closely related to affective-state manipulation. Studies indicate that environmental stimuli triggering positive or approach-related emotions (such as joy) result in greater relative left frontal activation (more positive frontal alpha asymmetry) than environmental stimuli encouraging negative or withdrawal-related emotions (such as disgust, fear, and sadness). The latter emotions produce greater relative right frontal activation (more negative frontal alpha symmetry) (Davidson and Fox, 1982; Ekman et al., 1990; Coan et al., 2001). Therefore, positive affective responses or approach-related emotions were produced when the participants viewed the paintings. Moreover, aesthetic judgments of the visual art stimuli as beautiful or not beautiful produced similar emotional responses. Indeed, the findings of the positive emotional responses toward artworks negatively perceived are consistent with the findings of Gerger et al. (2014), who found that in an art context, negative stimuli are viewed more positively. Therefore, aesthetic experiences of creative products in an art context, such as paintings, facilitate more pleasurable emotional responses in the perceiver, and aesthetics does not seem to play a significant role in determining the emotional response. Even though the visual stimuli are perceived to be not beautiful, positive or approach-related emotions are still produced if the visual stimuli are viewed in an art context.

As compared to the paintings that are considered to be creative products in the West (Kaufman et al., 2008; Lan and Kaufman, 2013), the emotional response to the aesthetic experience of fashion window displays, which are considered to be products of the creative industry in China, was similar only when the visual stimuli were perceived to be beautiful. Positive frontal alpha asymmetry was found when the fashion window displays were perceived to be beautiful. Therefore, the results suggest that emotional responses to the visual art stimuli were similar to those to the commercial stimuli regarded as creative products in Chinese society only when the latter were considered to be beautiful. These findings are not consistent with those of Gerger et al. (2014), who found a slightly less positive reaction toward positive stimuli in the art context compared to a non-art context, thus suggesting distanced processing of the former (Cupchik, 2002). One possible reason for the discrepancy might be the perceived relevance during aesthetic judgments. In our study, the participants judged the visual art stimuli purely in term of aesthetics (i.e., beautiful versus not beautiful) and without subjective preferences, whereas the participants in Gerger et al. (2014) were asked to determine how much they liked the stimuli, thus incorporating their personal preferences and affecting the psychological distance toward the stimuli. Therefore, the intensity of the emotional response toward stimuli during aesthetic experiences may differ if both subjective judgments of likeableness and aesthetic judgments are taken into consideration, because the intensity of emotional responses toward aesthetics may not necessarily be equivalent to those involved in likeableness. Whether aesthetic responses and common emotions are mediated by a similar mechanism has not yet been resolved (Leder and Nadal, 2014). Given that subjective preference was not controlled in the present study, it would be worthwhile to investigate and compare the emotional responses during aesthetic judgments and subjective preferences.

In contrast to Gerger et al. (2014) findings, the present study found a significant difference in the frontal alpha asymmetry in judging fashion window displays that were not perceived to be beautiful, as compared to the paintings as well as fashion window displays that were considered to be beautiful. A more negative frontal alpha asymmetry was found when the fashion window displays were not perceived to be beautiful. This is consistent with the findings of our previous study (Cheung et al., 2014), in which a negative frontal alpha asymmetry was found when personal-appearance styles were judged to be not beautiful, thus suggesting a negative emotional state. The intention or behavior of the participants following the observed change in emotional state was not investigated in this or the previous study. Nevertheless, emotional responses are likely to elicit corresponding behaviors; that is, "coping" or "motivated" (approach or withdrawal) behavior (Harmon-Jones and Sigelman, 2001; Harmon-Jones et al., 2003). Therefore, if fashion window displays are perceived to be not beautiful, the perceiver will experience a negative or withdrawal-related emotional response, which therefore substantially affects consumer behavior, such as alienating them from entering the premises. If such displays are perceived as beautiful by a customer, they may trigger a positive or approach-related emotional response that would instead motivate the customer, such as facilitating their entry into a store and making a purchase. Therefore, our findings highlight the significance of aesthetically pleasing fashion displays in which both creativity and aesthetics play important roles in encouraging favorable emotional responses. Unlike the creative products in an art context in the West, products from the creative industry in Chinese society, like fashion, largely rely on aesthetics to elicit a more pleasurable emotional response in the perceiver. Given that the visual art stimuli can produce a more positive emotional response, incorporating art elements into fashion displays may facilitate more prominent positive or approach-related emotional responses.

One of the limitations of this study is the laboratory setting in investigating the aesthetic experiences of paintings and fashion window displays. There is growing evidence that there are differences between the processes that underlie aesthetic

experiences in the laboratory and in real-life contexts. For instance, Brieber et al. (2014) compared aesthetic experiences in a museum and laboratory and found that the participants preferred the artworks, found them more interesting, and viewed them longer in a museum as opposed to a laboratory. Context is therefore an important modulating factor in the aesthetic experience of artworks and commercial stimuli. It would be worthwhile therefore to examine emotional responses in real-life contexts and compare them with laboratory results to gain a better idea of the differences in emotional responses. In addition, most of the fashion window displays used as visual stimuli in this study were new to the participants, whereas some of the paintings might have been more familiar as they could have encountered them during museum visits. Several studies have investigated the relationship between novelty and aesthetic experience in product design (e.g., Hekkert et al., 2003; Blijlevens et al., 2012; Hung and Chen, 2012). When the relationship between novelty and aesthetic preferences toward environmental stimuli is plotted, the result is an inverted U-shaped curve, which means that moderate levels of novelty are associated with the stimuli that are perceived to be the most beautiful. Therefore, the intensity of emotional responses to novel versus familiar stimuli may differ in art and non-art contexts and should be controlled in future experiments.

As in our previous study (Cheung et al., 2014), the present study found no significant difference in response time between "beautiful" and "not beautiful" judgments. Some studies have suggested early impression formation of aesthetic evaluation of the "not beautiful" pattern (Höfel and Jacobsen, 2007; Roye et al., 2008; Jiang and Cai, 2013), whereas larger decision times were found to be involved in aesthetic judgment of beautiful objects (Zhang and Deng, 2012). The discrepancy may be due to differences in the recording process. Electrophysiological responses revealed in ERP were utilized in these previous studies to directly record brain activity, whereas our study used a behavioral approach (pressing the response pad) to record the response time, thus resulting in less precision.

Finally, another limitation is related to uneven gender distribution, as only four males were recruited for the present study. Recent studies have demonstrated gender differences in the neural underpinning of aesthetic appreciation of environmental stimuli, such as attractive faces (Zhang and Deng, 2012), physical bodies (Cazzato et al., 2014), and artistic paintings or natural objects (Cela-Conde et al., 2009). In addition, females generally enjoy shopping to a greater extent than males, so fashion displays may arouse a more intense emotional response, both positively and negatively, than artworks. Therefore, as in our previous study (Cheung et al., 2014), a biased gender distribution in the present study (16 of the 20 participants were female) may have had a differential impact on emotional responses when the participants viewed the paintings and fashion displays.

AUTHOR CONTRIBUTIONS

M-CC, DL, and CW: conceptualization. M-CC and DL: methodology. M-CC: data analysis. M-CC, DL, CW, and JY: contribution of reagents, materials, and analysis tools. M-CC, DL, CW, and JY: manuscript preparation and revision. All authors have approved the work for publication.

FUNDING

This study was supported by the Direct Grant for Research 2016–2017 from The Chinese University of Hong Kong (M-CC, SS16618) and the internal funding entitled "International Collaboration in Healthcare Product Development and Evaluation" from the Institute of Textiles and Clothing, The Hong Kong Polytechnic University (JY, 1-ZVLJ).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00014/full#supplementary-material

REFERENCES

American Electroencephalographic Society (1994). Guideline thirteen: guidelines for standard electrode position nomenclature. *J. Clin. Neurophysiol.* 11, 111–113. doi: 10.1097/00004691-199401000-00014

Blijlevens, J., Carbon, C. C., Mugge, R., and Schoormans, J. P. L. (2012). Aesthetic appraisal of product designs: independent effects of typicality and arousal. *Br. J. Psychol.* 103, 44–57. doi: 10.1111/j.2044-8295.2011.02038.x

Boccia, M., Barbetti, S., Margiotta, R., Guariglia, C., Ferlazzo, F., and Giannini, A. M. (2014). Why do you like Arcimboldo's portraits? Effect of perceptual style on aesthetic appreciation of ambiguous artworks. *Atten. Percept. Psychophys.* 76, 1516–1521. doi: 10.3758/s13414-014-0739-7

Brieber, D., Nadal, M., Leder, H., and Rosenberg, R. (2014). Art in time and space: context modulates the relation between art experience and viewing time. *PLoS One* 9:e99019. doi: 10.1371/journal.pone.0099019

Cazzato, V., Mele, S., and Urgesi, C. (2014). Gender difference in the neural underpinning of perceiving and appreciating the beauty of body. *Behav. Brain Res.* 264, 188–196. doi: 10.1016/j.bbr.2014.02.001

Cela-Conde, C. J., Ayala, F. J., Munar, E., Maestu, F., Nadal, M., Capó, M. A., et al. (2009). Sex-related similarities and differences in the neural correlates of beauty. *Proc. Natl. Acad. Sci. U.S.A.* 106, 3847–3852. doi: 10.1073/pnas.0900304106

Cela-Conde, C. J., Garcia-Prieto, J., Ramasco, J. J., Mirasso, C. R., Bajo, R., Munar, E., et al. (2013). Dynamics of brain networks in the aesthetic appreciation. *Proc. Natl. Acad. Sci. U.S.A.* 110(Suppl. 2), 10454–10461. doi: 10.1073/pnas.1302855110

Cela-Conde, C. J., Marty, G., Maestú, F., Ortiz, T., Munar, E., Fernández, A., et al. (2004). Activation of the prefrontal cortex in the human visual aesthetic perception. *Proc. Natl. Acad. Sci. U.S.A.* 101, 6321–6325. doi: 10.1073/pnas.0401427101

Chan, A. S., Cheung, M. C., Tsui, W. J., Sze, S. L., and Shi, D. (2011). Dejian mind-body intervention on depressive mood of community-dwelling adults: a randomized controlled trial. *Evid. Based Complement. Alternat. Med.* 2011:473961. doi: 10.1093/ecam/nep043

Chan, A. S., Han, Y. M. Y., and Cheung, M. C. (2008). Electroencephalographic (EEG) measurements of mindfulness-based Triarchic body-pathway relaxation techniques: a pilot study. *Appl. Psychophysiol. Biofeedback* 33, 39–47. doi: 10.1007/s10484-008-9050-5

Chatrian, G. E., Lettich, E., and Nelson, P. L. (1985). Ten percent electrode system for topographic studies of spontaneous and evoked EEG activity. *Am. J. EEG Technol.* 25, 83–92. doi: 10.1080/00029238.1985.11080163

Chatterjee, A. (2004). Prospects for a cognitive neuroscience of visual aesthetics. *Bull. Psychol. Arts* 4, 55–60.

Chatterjee, A. (2014). *The Aesthetic Brain: How We Evolved to Desire Beauty and Enjoy Art*. Oxford: Oxford University Press.

Chatterjee, A., Thomas, A., Smith, S. E., and Aguirre, G. (2009). The neural response to facial attractiveness. *Neuropsychology* 23, 135–143. doi: 10.1037/a0014430

Cheung, M. C., Law, D., and Yip, J. (2014). Evaluating aesthetic experience through personal-appearance styles: a behavioral and electrophysiological study. *PLoS One* 9:e115112. doi: 10.1371/journal.pone.0115112

Coan, J. A., and Allen, J. J. B. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biol. Psychol.* 67, 7–49. doi: 10.1016/j.biopsycho.2004.03.002

Coan, J. A., Allen, J. J. B., and Harmon-Jones, E. (2001). Voluntary facial expression and hemispheric asymmetry over the frontal cortex. *Psychophysiology* 38, 912–925. doi: 10.1111/1469-8986.3860912

Cupchik, G. C. (2002). The evolution of psychical distance as an aesthetic concept. *Cult. Psychol.* 8, 155–187. doi: 10.1177/1354067X02008002437

Cupchik, G. C., Vartanian, O., Crawley, A., and Mikulis, D. J. (2009). Viewing artworks: contribution of cognitive control and perceptual facilitation to aesthetic experience. *Brain Cogn.* 70, 84–91. doi: 10.1016/j.bandc.2009.01.003

Davidson, R. J. (1992). Anterior cerebral asymmetry and the nature of emotion. *Brain Cogn.* 20, 125–151. doi: 10.1016/0278-2626(92)90065-T

Davidson, R. J. (1998). Affective style and affective disorders: perspective from affective neuroscience. *Cogn. Emot.* 12, 307–330. doi: 10.1080/026999398379628

Davidson, R. J. (2000). Affective style, psychopathology, and resilience: brain mechanisms and plasticity. *Am. Psychol.* 55, 1196–1214. doi: 10.1037/0003-066X.55.11.1196

Davidson, R. J., Ekman, P., Saron, C., Senulis, J. A., and Friesen, W. V. (1990). Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology. I. *J. Pers. Soc. Psychol.* 58, 330–341. doi: 10.1037/0022-3514.58.2.330

Davidson, R. J., and Fox, N. A. (1982). Asymmetrical brain activity discriminates between positive and negative affective stimuli in human infants. *Science* 218, 1235–1236. doi: 10.1126/science.7146906

Davidson, R. J., Jackson, D. C., and Kalin, N. H. (2000a). Emotion, plasticity, context, and regulation: perspectives from affective neuroscience. *Psychol. Bull.* 126, 890–909.

Davidson, R. J., Jackson, D. C., and Larson, C. L. (2000b). "Human electroencephalography," in *Handbook of Psychophysiology*, 2nd Edn, eds J. T. Cacioppo, L. G. Tassinary, and G. G. Berntson (New York, NY: Cambridge University Press), 27–52.

Davidson, R. J., Kabat-Zinn, J., Schumacher, J., Rosenkranz, M., Muller, D., Santorelli, S. F., et al. (2003). Alterations in brain and immune function produced by mindfulness meditation. *Psychosom. Med.* 65, 564–570. doi: 10.1097/01.PSY.0000077505.67574.E3

de Tommaso, M., Pecoraro, C., Sardaro, M., Serpino, C., Lancioni, G., and Livrea, P. (2008). Influence of aesthetic perception on visual event-related potentials. *Conscious. Cogn.* 17, 933–945. doi: 10.1016/j.concog.2007.09.003

Di Dio, C., Macaliso, E., and Rizzolatti, G. (2007). The golden beauty: brain response to classical and renaissance sculptures. *PLoS One* 2:e1201. doi: 10.1371/journal.pons.0001201

Diamond, E., and Diamond, J. (2007). *Contemporary Visual Merchandising*. Upper Saddle River, NJ: Prentice Hall.

Ekman, P., Davidson, R. J., and Friesen, W. V. (1990). Duchenne's smile: emotional expression and brain physiology. II. *J. Pers. Soc. Psychol.* 58, 342–353. doi: 10.1037/0022-3514.58.2.342

Elder, R. S., and Krishna, A. (2012). The "visual depiction effect" in advertising: facilitating embodied mental stimulation through product orientation. *J. Consum. Res.* 38, 988–1003. doi: 10.1086/661531

Fox, N. A. (1991). If it's not left, it's right. *Am. Psychol.* 46, 863–872. doi: 10.1037/0003-066X.46.8.863

Frijda, N. H. (1988). The laws of emotion. *Am. Psychol.* 43, 349–358. doi: 10.1037/0003-066X.43.5.349

Frijda, N. H., and Schram, D. (1995). Introduction. *Poetics* 23, 1–6. doi: 10.1016/0304-422X(95)90009-W

Gerger, G., Leder, H., and Kremer, A. (2014). Context effects on emotional and aesthetic evaluations of artworks and IAPS paintings. *Acta Psychol.* 151, 174–183. doi: 10.1016/j.actpsy.2014.06.008

Goldstein, P. (2009). "Aesthetic theory," in *Modern American Reading Practices*, ed. P. Goldstein (New York, NY: Palgrave Macmillan), 21–32. doi: 10.1057/9780230617827_2

Harmon-Jones, E., Gable, P. A., and Peterson, C. K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: a review and update. *Biol. Psychol.* 84, 451–462. doi: 10.1016/j.biopsycho.2009.08.010

Harmon-Jones, E., and Sigelman, J. (2001). State anger and prefrontal brain activity: evidence that insult-related relative left prefrontal activation is associated with experienced anger and aggression. *J. Pers. Soc. Psychol.* 80, 797–803. doi: 10.1037/0022-3514.80.5.797

Harmon-Jones, E., Sigelman, J., Bohlig, A., and Harmon-Jones, C. (2003). Anger, coping, and frontal cortical activity: the effect of coping potential on anger-induced left frontal activity. *Cogn. Emot.* 17, 1–24. doi: 10.1080/02699930302278

Hekkert, P., Snelders, D., and van Wieringen, P. C. W. (2003). Most advanced, yet acceptable: typicality and novelty as joint predictors of aesthetic preference in industrial design. *Br. J. Psychol.* 94, 111–124. doi: 10.1348/000712603762842147

Höfel, L., and Jacobsen, T. (2007). Electrophysiological indices of processing aesthetics: spontaneous or intentional processes? *Int. J. Psychophysiol.* 65, 20–31. doi: 10.1016/j.ijpsycho.2007.02.007

Hung, W. K., and Chen, L. L. (2012). Effects of novelty and its dimensions on aesthetic preference in product design. *Int. J. Design.* 6, 81–90.

Ishizu, T., and Zeki, S. (2011). Toward a brain-based theory of beauty. *PLoS One* 6:e21852. doi: 10.1371/journal.pone.0021852

Ishizu, T., and Zeki, S. (2013). The brain's specialized systems for aesthetic and perceptual judgment. *Eur. J. Neurosci.* 37, 1413–1420. doi: 10.1111/ejn.12135

Jacobs, R. H. A. H., Renken, R., and Cornelissen, F. W. (2012). Neural correlates of visual aesthetics – Beauty as the coalescence of stimulus and internal state. *PLoS One* 7:e31248. doi: 10.1371/journal.pone.0031248

Jacobsen, T., and Höfel, L. (2001). Aesthetics electrified: an analysis of descriptive symmetry and evaluative aesthetic judgment processes using event-related brain potentials. *Empir. Stud. Arts* 19, 177–190. doi: 10.2190/P7W1-5F1F-NJK9-X05B

Jacobsen, T., and Höfel, L. (2003). Descriptive and evaluation judgment processes: behavioural and electrophysiological indices of processing symmetry and aesthetics. *Cogn. Affect. Behav. Neurosci.* 3, 289–299. doi: 10.3758/CABN.3.4.289

Jacobsen, T., Schubotz, R. I., Höfel, L., and Cramon, D. Y. (2006). Brain correlates of aesthetic judgment of beauty. *Neuroimage* 29, 276–285. doi: 10.1016/j.neuroimage.2005.07.010

Jiang, X., and Cai, L. (2013). Evaluation of aesthetic response to clothing color combination: a behavioral and electrophysiological study. *J. Fiber Bioeng. Inform.* 6, 405–414.

Kaufman, J. C., Plucker, J. A., and Baer, J. (2008). *Essentials of Creativity Assessment*. New York, NY: Wiley.

Kawabata, H., and Zeki, S. (2004). Neural correlates of beauty. *J. Neurophysiol.* 91, 1699–1705. doi: 10.1152/jn.00696.2003

Kerfoot, S., Davis, B., and Ward, P. (2003). Visual merchandising and the creation of discernible retail brands. *Int. J. Retail Distrib. Manag.* 31, 143–152. doi: 10.1108/09590550310465521

Lan, L., and Kaufman, J. C. (2013). American and Chinese similarities and differences in defining and valuing creative product. *J. Creat. Behav.* 46, 285–306. doi: 10.1002/jocb.19

Law, D., Wong, C., and Yip, J. (2012). How does visual merchandising affect consumer affective response? An intimate apparel experience. *Eur. J. Mark.* 46, 112–133. doi: 10.1108/03090561211189266

Law, D., Yip, J., Wong, C., and Cheung, M. C. (2013). Enhancing the process of idea generation in Hong Kong Chinese University students: the fashion visual merchandising experience. *Art Des. Comm. High. Educ.* 12, 103–122. doi: 10.1386/adch.12.1.103_1

Leder, H., Belke, B., Oeberst, A., and Augustin, D. (2004). A model of aesthetic appreciation and aesthetic judgments. *Br. J. Psychol.* 95, 489–508. doi: 10.1348/0007126042369811

Leder, H., and Nadal, M. (2014). Ten years of a model of aesthetic appreciation and aesthetic judgments: the aesthetic episode – developments and challenges in empirical aesthetics. *Br. J. Psychol.* 105, 443–464. doi: 10.1111/bjop.12084

Lengger, P. G., Fischmeister, F. P. S., Leder, H., and Bauer, H. (2007). Functional neuroanatomy of the perception of modern art: a DC–EEG study on the influence of stylistic information on aesthetic experience. *Brain Res.* 1158, 93–102. doi: 10.1016/j.brainres.2007.05.001

Levinson, J. (1996). *The Pleasures of Aesthetics: Philosophical Essays*. London: Cornell University Press.

Munar, E., Nadal, M., Castellanos, N. P., Flexas, A., Maestú, F., Mirasso, C., et al. (2012). Aesthetic appreciation: event-related field and time-frequency analyses. *Front. Hum. Neurosci.* 5:185. doi: 10.3389/fnhum.2011.00185

Oh, H., and Petrie, J. (2012). How do storefront window displays influence entering decisions of clothing stores? *J. Retailing Consum. Serv.* 19, 27–35. doi: 10.1016/j.jretconser.2011.08.003

Palermo, R., and Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychology* 45, 75–92. doi: 10.1016/j.neuropsychologia.2006.04.025

Pang, C. Y., Nadal, M., Müller-Paul, J. S., Rosenberg, R., and Klein, C. (2013). Electrophysiological correlates of looking at paintings and its association with art expertise. *Biol. Psychol.* 93, 246–254. doi: 10.1016/j.biopsycho.2012.10.013

Pieters, R., Wedel, M., and Batra, R. (2010). The stopping power of advertising: measures and effects of visual complexity. *J. Mark.* 74, 48–60. doi: 10.1509/jmkg.74.5.048

Reimann, M., Zaichkowsky, J., Neuhaus, C., Bender, T., and Weber, B. (2010). Aesthetic package design: a behavioral, neural and psychological investigation. *J. Consum. Psychol.* 20, 431–441. doi: 10.1016/j.jcps.2010.06.009

Roye, A., Höfel, L., and Jacobsen, T. (2008). Aesthetics of faces: behavioral and electrophysiological indices of evaluative and descriptive judgment process. *J. Psychophysiology* 22, 41–57. doi: 10.1027/0269-8803.22.1.41

Scherer, K. R. (2005). What are emotions? And how can they be measured? *Soc. Sci. Inform.* 44, 695–729. doi: 10.1177/0539018405058216

Sen, S., Block, L. G., and Chandran, S. (2002). Window displays and consumer shopping decisions. *J. Retailing Consum. Serv.* 9, 277–290. doi: 10.1016/S0969-6989(01)00037-6

Shimamura, A. P., and Palmer, S. E. (2012). *Aesthetic Science: Connecting Minds, Brains, and Experience*. New York, NY: Oxford University Press.

Tsukiura, T., and Cabeza, R. (2011). Shared brain activity for aesthetic and moral judgments: implication for the Beauty-is-Good stereotype. *Soc. Cogn. Affect. Neurosci.* 6, 138–148. doi: 10.1093/scan/nsq025

Vartanian, O., and Goel, V. (2004). Neuroanatomical correlates of aesthetic preference for paintings. *Neuroreport* 15, 893–897. doi: 10.1097/00001756-200404090-00032

Vessel, E. A., Starr, G. G., and Rubin, N. (2012). The brain on art: intense aesthetic experience activates the default mode network. *Front. Hum. Neurosci.* 6:66. doi: 10.3389/fnhum.2012.000066

Wang, Z., Xie, P., and Chen, J. (2007). Factor analysis and positive research for development of creative industry in city. *China Ind. Econ.* 8, 49–57.

Zaidel, D. W. (2010). Art and brain: insights from neuropsychology, biology and evolution. *J. Anat.* 216, 177–183. doi: 10.1111/j.1469-7580.2009.01099.x

Zeki, S., Romaya, J. P., Benincasa, D. M. T., and Atiyah, M. F. (2014). The experience of mathematical beauty and its neural correlates. *Front. Hum. Neurosci.* 8:86. doi: 10.3389/fnhum.2014.00068

Zhang, Z., and Deng, Z. (2012). Gender, facial attractiveness, and early and late event-related potential components. *J. Integra. Neurosci.* 11, 477–487. doi: 10.1142/S0219635212500306

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 04 February 2019
doi: 10.3389/fpsyg.2019.00155

Neuroanatomical Correlates of Creativity: Evidence From Voxel-Based Morphometry

Wenfu Li[1†], Gongying Li[1†], Bingyuan Ji[1†], Qinglin Zhang[2] and Jiang Qiu[2*]*

[1] School of Mental Health, Jining Medical University, Jining, China, [2] School of Psychology, Southwest University, Chongqing, China

Creativity was a special cognitive capacity which was crucial to human survival and prosperity. Remote associates test (RAT), identifying the relationships among remote ideas, was one of the most frequently used methods of measuring creativity. However, the structural characteristics associated with RAT remains unclear. In the present study, the relationship between gray matter density (GMD)/white matter density (WMD) and RAT was explored using voxel-based morphometry (VBM) in a larger healthy college student sample (144 women and 117 men). Results showed that the score of RAT was significantly positively related with the GMD in the right anterior superior temporal gyrus (aSTG) and negatively correlated with the GMD in the right dorsal anterior cingulate cortex (dACC). Meanwhile, results also showed that the score of RAT was significantly positively related with the WMD in the right dACC and negatively correlated with the WMD in the left inferior frontal gyrus (IFG). These findings indicate that individual creativity, as measured by the RAT, was mainly related to the regional gray /white matter density of brain regions in the aSTG, dACC and IFG, which might have been involved in the forming of novel combinations, breaking of mental set, monitoring of conflict and semantic integration.

Keywords: creativity, remote associates test, voxel-based morphometry, anterior superior temporal gyrus, gray matter density

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Wei Liao,
University of Electronic Science and Technology of China, China
Rex Eugene Jung,
The University of New Mexico, United States

***Correspondence:**
Wenfu Li
wenfulee@126.com
Jiang Qiu
qiuj318@swu.edu.cn

†These authors have contributed equally to this work

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *26 September 2018*
Accepted: *16 January 2019*
Published: *04 February 2019*

Citation:
Li W, Li G, Ji B, Zhang Q and Qiu J (2019) Neuroanatomical Correlates of Creativity: Evidence From Voxel-Based Morphometry. Front. Psychol. 10:155. doi: 10.3389/fpsyg.2019.00155

INTRODUCTION

Creativity is an important cognitive ability which was crucial to human survival and prosperity (Ashtari and Cyckowski, 2012). It was considered as the creation of something unusual as well as potentially useful (Rex Eugene Sternberg and Lubart, 1993; Jung et al., 2013). The systematic exploration of creativity within psychology begins with the Guilford's (Guilford, 1950) seminal address at the American Psychological Association (APA).

Creativity can be the result of divergent as well as convergent thinking (Guilford, 1950; Arden et al., 2010; Dietrich and Kanso, 2010). In the divergent thinking task, subjects were asked to generate multiple answers to open-ended questions, such as "describe what would happen if there is no sun" or "generate as many alternative uses as possible for brick". In the convergent thinking task, participants were required to generate single answers to closed-ended problems, such as the Remote Associates Task (Mednick, 1962). The creative thinking process had been further defined ". . .as the forming of associative elements into new combinations which either meet specified requirements or are in some way useful" (Mednick, 1962). Mednick (1962) proposed the associative theory of the

creative process and developed the remote association test (RAT), assessed the ability to identify relationships among remote ideas, as the form of a test of creative convergent thinking. Two university-level versions of RAT were constructed and each version consisted of thirty problems (Mednick and Mednick, 1967; Mednick, 1968). Each problem consisted of three stimulus words that can be combined with a fourth word in several ways, such as with synonymy, compound word and semantic association (Mednick and Mednick, 1967; Bowden and Jung-Beeman, 2003). Based on RAT, Bowden and Jung-Beeman (2003) had created a whole set of 144 Compound Remote Associate (CRA) problems which can be solved through formation of a compound word with all three given words. Overall, RAT or similar problems had been widely used in the investigation of insightful problem solving and creative thinking (e.g., Bowers et al., 1990; Schooler and Melcher, 1995; Kihlstrom et al., 1996; Ansburg, 2000; Qiu et al., 2008).

Previous studies indicate the importance of associative processing for convergent thinking (Mednick et al., 1964; Brown, 1973; Benedek et al., 2012). Higher associative fluency and more unusual association were found in more creative people rather than less creative people (Benedek et al., 2014). Other studies also found that there were more abundant and flexible connection networks in more creative people compared to less creative people (Carlsson et al., 2000; Jausovec and Jausovec, 2000). These inter-individual creative behavioral differences might be revealed by the structural brain imaging method (Kanai and Rees, 2011).

Recent investigations utilized electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) to explore the neuromechanism of remote associates problems (for reviews see Arden et al., 2010; Dietrich and Kanso, 2010). Previous studies found that the superior temporal gyrus (STG) was consistently associated with creative thinking (Jung-Beeman et al., 2004; Kounios et al., 2008). For example, Jung-Beeman et al. (2004) investigated remote associate problems solving with fMRI and EEG. They found that increased brain activity in the right anterior STG was associated with insightful solutions relative to non-insightful solutions. With EEG they found that insightful problem solving was accompanied by high frequency EEG activity in the same brain region. These results might suggest that the STG area was involved in the linking of unrelated concepts together or the changing of representation.

A growing number of studies have centered on the inter-individual behavioral differences (Kanai and Rees, 2011) and its associated neuroanatomical correlates using non-invasive structural magnetic resonance imaging (sMRI) (e.g., Takeuchi et al., 2010a; Jung et al., 2010b; Li et al., 2015). T1-weighted imaging was the frequently- used sMRI sequence, which offered brain images with higher resolution and lower noise. Some indicators, regional gray matter density (rGMD), regional gray matter volume (rGMV) and cortical thickness, were obtained from T1-weighted image. Both rGMV and rGMD could be obtained from voxel-based morphometry (VBM) method which was used usually and possessed high validity in measuring brain structure. The rGMV measure reflected the absolute gray and white matter volume, whereas the rGMD reflected the relative gray and white matter concentrations (Takeuchi et al., 2011). The results of both rGMD and rGMV were typically similar (Good et al., 2001). These two kinds of measures were used frequently in brain anatomical researches (Andrea et al., 2005). Because of the gray matter which was thinning during natural maturing process (Sowell et al., 1999; Sowell et al., 2003; Sowell et al., 2014) and adolescents who were in the key period of cortical thinning (Ashtari and Cyckowski, 2012; Fuhrmann et al., 2015), rGMD was used more frequently than rGMV in studies in which subjects were adolescents.

Although creative thinking was a pervasive research topic in the domains of psychology and cognitive neuroscience, the neural basis of creativity remains largely unclear. Previous studies have investigated the neuroanatomical correlates underlying the measures of divergent thinking using sMRI. One review article indicated that convergent thinking was related to an increase as well as a decrease of cortical volume and thickness (Jung et al., 2013). Increased brain regions consisted of superior parietal lobule (Gansler et al., 2011), precuneus, midbrain, dorsolateral prefrontal cortex and striatum (Takeuchi et al., 2010a), and right angular gyrus and posterior cingulate (Jung et al., 2010b). Cousijn et al. (2014) further found that visuo-spatial divergent thinking was associated with increased cortical thickness in the right superior frontal gyrus and various occipital, parietal, and temporal areas. At the same time, Fink et al. (2014) explored the relationship between rGMD and divergent thinking and found that divergent thinking was positively correlated with the rGMD in the right cuneus and the right precuneus which might be involved in vivid imaginative ability in more creative individuals. Other studies further manifested that divergent thinking was associated with the increased rGMV in left and right inferior frontal gyrus (Zhu et al., 2013) and precuneus and caudate nucleus (Jauk et al., 2015) and the increased rGMD in the right precuneus and cuneus (Fink et al., 2014). These brain structure studies indicated that the structural basis of divergent thinking was associated with widely distributed brain regions (Dietrich, 2007; Takeuchi et al., 2017) and not a supporter of the notion of "more is better" (Jung et al., 2010a). These inconsistent results might be because of the complicacy of divergent thinking which depends on several cognitive functions (Dietrich, 2004; Dietrich and Kanso, 2010; Takeuchi et al., 2010b; Jung et al., 2013).

On the other hand, relatively few studies investigated the structural correlates of convergent thinking (e.g., RAT) using sMRI. Bendetowicz et al. (2017) employed 54 participants to investigate the brain anatomical basis of RAT and found the problem-solving associated with the decreased rGMV in the left rostrolateral prefrontal cortex as well as the left inferior parietal lobule. Ogawa et al. (2018) explored the neural basis of the insightful task (e.g., RAT) in a large sample (232 subjects) and found the task score correlated with the increased rGMV in the right insula and the middle cingulate cortex/precuneus and the decreased rGMV in the left crus 1 of cerebellum and the right supplementary motor area. A recent study explored the anatomical basis of remote association test in bipolar depression patients and found this test associated with the increased rGMV in the medial prefrontal gyrus.

Although these results conflicted with previous fMRI study of convergent thinking (Jung-Beeman et al., 2004), it was consistent with the findings of divergent thinking associated with widely distributed brain regions. A recent meta analysis study investigated the neural basis of insight and found that extensive brain regions, containing the left inferior frontal gyrus and the amygdala, and the right medial frontal gyrus and the hippocampus, were activated by insight problem solving (Shen et al., 2018). Another review specialized in the function of the temporal lobe in insightful process and revealed an integrated-model on the role of different parts of temporal lobe in insight (Shen et al., 2017). However, no study investigating the association between convergent thinking and structural regions examined whether intelligence may also moderate the relationship between creative potential and brain structure in light of rGMD.

In the present study, we focused on the convergent thinking measured by the Chinese version of RAT modified from the compound association task (Bowden and Jung-Beeman, 2003) and the structural basis of convergent thinking using the measure of rGMD derived from VBM method. The latest study found that divergent thinking training could increase the rGMV in the dorsal anterior cingulate cortex (Sun et al., 2016). Other research indicated that frequently recruited brain regions would increase its volume (Maguire et al., 2000). We assumed that brain regions activated by convergent thinking would correspond with brain structural characteristic (e.g., increased and/or decreased rGMD) with the purpose of creativity performance. One of the goals of the present study was to confirm whether brain regions activated by compound remote association task in Mark Jung-Beeman et al. (2004) could be found again in the matter of rGMD. Previous studies indicated the importance of prefrontal gyrus for creativity. Besides, Broca's area, a portion of inferior frontal gyrus, was known for involvement in language comprehension and production. Hence, the prefrontal gyrus or inferior frontal gyrus might likely to rediscovered. Consider that the anterior cingulate cortex was proved repeatedly and reliably by numerous studies to be involved in cognitive conflict detecting and mental set breaking (Dietrich and Kanso, 2010). Based on the notion that brain regions involved in some cognitive function would impact the efficiency and quality of the individual's capacity to complete that function, the performance of RAT was assumed to be related with rGMD in anterior cingulate cortex which were certified to be crucial to insightful problem solving.

MATERIALS AND METHODS

Participants

Two hundred and seventy-six university students (150 females and 126 males; the mean = 19.89 years, standard deviation = 1.28), who came from Southwest University (Chongqing, China), participated in the present research. The sample involved in our study was a part of Southwest University Longitudinal Imaging Multimodal (SLIM) data (for more details, please see: http://www.qiujlab.com), which was available for other investigators through the International Neuroimaging Data-sharing Initiative (INDI)[1]. The main purpose of this project was to explore the relationship among individual differences in brain structure and function, creativity, and mental health. The protocols of both behavioral and structural MRI were confirmed by the research ethics committee of Southwest University. The informed consent form was signed by participants before participating, which was authorized by the Institutional Human Participants Review Board of Brain Imaging Research Centre in Southwest University.

Nine subjects were removed because of the unfinished questionnaires of RAT and CRT. Another six participants were excluded because of the excessively large scanning artifacts and unnatural brain structures. Thus, 261 participants remained in the topological properties analysis. There were 117 males (mean age = 20.09 years, standard deviation = 1.33) and 144 females (mean age = 19.69 years, standard deviation = 1.23).

Assessment of Convergent Thinking

The RAT was used to measure convergent thinking, which developed by Mednick (1962) as a means of measuring creativity considered with no need for knowledge specific to any field. We selected 25 items which were evaluated to be insightful (mean score > 1.8) on a scale of 1 (No-insightful feeling) to (strongest insightful feeling) for each items by another group of subjects (total 20). Each of the 25 items consists of three Chinese words that could be connected with an answer word in the way of formation of a compound word. For example, the three words "pai, mai, fan" (拍, 买, 贩) were connected with the solution word "mai" (卖) by way of the forming of compound word (拍卖, 买卖, 贩卖). Reaching a solution needs creative thinking, because the information extracted from memory is usually wrong, and participants must come up with a more remotely related word for the purpose of problem solving. The intra-subject reliability was 0.719 measured by Cronbach's alpha.

Assessment of General Intelligence

The Combined Raven's Matrices Test was used to test subject's general intelligence and corrected for the possible effect of intelligence on brain structures (Haier et al., 2004). This test consisted of 72 items (Li, 1989). More details on what CRT were consisted and how CRT was performed could be found in our previous research (Li et al., 2016). The number of right answers, completed in 40 min, was regarded as the score of CRT.

Data Acquisition

Siemens 3T scanner (MAGENTOM Trio, a Tim System) was used to scan subjects, which was located at the Brain Imaging Research Centre in Southwest University, Chongqing, China. Magnetization-prepared rapid gradient echo sequence was used to acquireT1-weighted structural MRI images (TR = 2530 ms, TE = 3.39 ms, TI = 1100 ms, flip angle = 7°, FOV = 256 × 256 mm, slice number = 128, in-plane resolution = 1 × 1 mm, slice thinkness = 1.33 mm).

[1] http://fcon_1000.projects.nitrc.org/indi/retro/southwestuni_qiu_index.html

Imaging Data Preprocessing

VBM8 toolbox[2] was used, and implemented in SPM8 software[3] to perform the T1-weighted images. Firstly, each image was examined visually and six participants were removed on account of image quality (excessive scanner artifacts or gross anatomical abnormalities). Secondly, each subject image was adjusted manually to the anterior commissure (AC) and posterior commissure (PC). Thirdly, the "new segmentation" in SPM8 was used to segment the image into gray matter, white matter, cerebrospinal fluid and everything else (e.g., skull and scalp) followed the standard segmentation approach (Ashburner and Friston, 2005). Fourthly, the Diffeomorphic Anatomical Registration through Exponential Lie algebra (DARTEL) implemented in SPM8 was used to execute registration, normalization and smoothness analyses. The study-specific template was computed in registration analyses based on the average tissue probability maps. The images were then resampled to 1.5mm × 1.5 mm × 1.5 mm and normalized to the generated study-specific template which was in the MNI space. The normalized images were smoothed using an 8-mm full width at half maximum (FWHM) Gaussian kernel. The images, which represent the regional gray matter density and regional white matter density, were used for the following statistical analyses.

Behavioral Data Analysis

The statistical software SPSS 13.0 (SPSS Inc., Chicago, IL, United Sates) was used to analyze behavioral data. The independent *t*-test was carried out to explore the gender differences in the score of RAT and CRT.

MRI Data Analysis

The multiple regression analysis was used to investigate the relationship between convergent thinking and brain structure. The score of RAT was considered as the variable of interest and the gender, age and the score of CRT were entered simultaneously as the covariates as previous researches (R.E. Jung et al., 2010b; Fink et al., 2014; Li et al., 2015).

Multiple comparisons were calculated by using the Monte Carlo simulation-based Alphasim program (Cox, 1996; Ward, 2000), which was included in the REST toolbox[4] (Song et al., 2011) and similar to the AlphaSim in AFNI. The threshold was set at $P < 0.05$ by combining the voxel-wise $P < 0.005$ and cluster size > 310 voxels (using the global gray matter mask, FWHM = 8 mm, cluster connection radius = 5 mm and 1000 iterations). Generally, AlphaSim was widely used in previous literatures about VBM data analysis (DeYoung et al., 2010; Schwartz et al., 2010; Ding et al., 2012; Zou et al., 2012; Farb et al., 2013; Kong et al., 2013; Yang et al., 2013). Although there might be some limitations with Monte Carlo simulation (Silver et al., 2011), it reduced the rate of false-positive results using the cluster-level threshold.

[2]http://dbm.neuro.uni-jena.de/vbm/

[3]https://www.fil.ion.ucl.ac.uk/spm/software/spm8/

[4]http://restfmri.net/forum/REST_V1.8

RESULTS

Results of Behavioral Data

The results of descriptive analysis of age, the scores of RAT and CRT were displayed in **Table 1**. Two-sample *t* tests revealed that there were no gender differences in the score of RAT and the score of CRT (*Ps* > 0.1). The P-P plot and frequency histogram with a normal distribution curve of the score of RAT and CRT were shown in **Figure 1**. The Skewness of the scores of RAT and CRT were −0.414 and −0.490, respectively and the Kurtosis was 0.067 and −0.539, respectively. These results showed that both the scores of RAT and CRT were approximately normal distribution.

Results of Structural MRI Data

After controlling the effects of age, gender and the score of CRT, the multiple regression analysis showed that RAT was significantly positively correlated with the rGMD in the right STG and negatively correlated with the rGMD in the right dorsal anterior cingulate gyrus (dACC). Meanwhile, the analysis also revealed that RAT was significantly positively related with the rWMD in the right dACC and negatively related with the rWMD in the left inferior frontal gyrus (IFG) expended to pars opercularis. No other significant effects were found. The information of above brain regions was shown in **Figure 2** and **Table 2**.

DISCUSSION

In the present research, the anatomical basis of convergent thinking as measured by RAT was explored using VBM. As far as I knew, it was the first research to explore the relationship between individual convergent thinking measured by RAT and GMD/WMD. Results showed that the rGMD of the right STG was positively correlated with RAT, while the rGMD of the right dACC was negatively correlated with RAT. In addition, the results also revealed that the rWMD of the right dACC was positively correlated with RAT, while the rWMD of the left IFG was negatively correlated with RAT. These results corresponded to the findings that the STG was activated by remote association problem solving and ACC and IFG were involved in creative thinking and insightful problem solving (Jung-Beeman et al., 2004; Aziz-Zadeh et al., 2009; Dietrich and Kanso, 2010; Jung et al., 2010b).

Previous ERP studies had revealed that the STG was a common region involved in remote associates problems solving (Kounios et al., 2008; Qiu et al., 2008). Other research found that sentence and complex discourse increased the activation

TABLE 1 | Participant demographics (*N* = 261; men = 117, women = 144).

Measure	Mean	*SD*	Range
Age	19.86	1.29	17–27
RAT	15.97	3.40	5–24
CRT	66.19	3.47	50–72

N = number; SD = standard deviation.

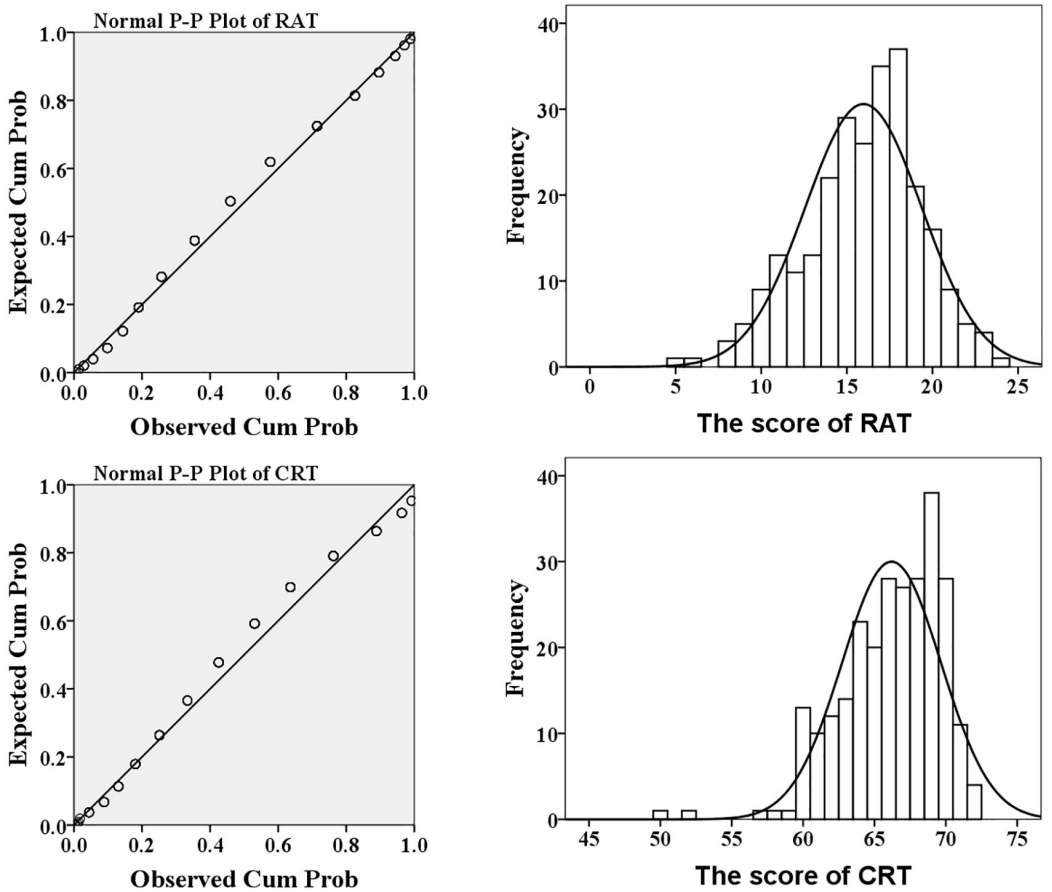

FIGURE 1 | The P-P plot and histogram of the score of RAT (upper) and CRT (lower).

in STG which involved in semantic integration (Mazoyer et al., 1993; Stowe et al., 1999). Moreover, patients with right temporal damage would be in trouble during comprehending metaphors which emphasized distant semantic correlation (Brownell et al., 1990). Especially, Mark Jung-Beeman et al. (2004) used fMRI to explore the neuromechanism of RAT and found the increased activation in the right STG which supposed to conduct coarse semantic coding and accelerate the formation of remote associations. A recent review specialized in the function of the temporal lobe in insightful process and indicated that the aSTG was a critical hub in the novel association forming (Shen et al., 2017). Our findings further proved the notion that brain regions involved in some cognitive function would impact the efficiency and quality of the individual's capacity to complete that function. Taken together, the positive association between the rGMD of the STG and the score of RAT might demonstrate that the right STG was particularly important for tasks which required the using of distant semantic associations between words.

The results also revealed that the rGMD of the right dACC was negatively associated with RAT and the WMD of the right dACC was positively correlated with RAT. Previous study suggested dACC involved in detecting conflicts (Botvinick et al., 1999; Enriquez-Geppert et al., 2013). It was suggested that ACC involved in the process of almost all types of creativity, such as insightful problem solving (Carlsson et al., 2000) and artistic creativity (Bengtsson et al., 2007; Berkowitz and Ansari, 2008; Kowatari et al., 2009). A recent research showed that the scores of creativity achievement questionnaire (CAQ) was positively associated with the rGMV in dACC and rostral ACC. Previous studies suggested that the ACC involved in the suppression of irrelevant thought, the shift of fixed mind-sets (Sawyer, 2011) and the development of general strategies in creative problem solving (Luo and Knoblich, 2007). Howard-Jones et al. (2005) discovered creative story generation activated the ACC which engaged in the selecting contextual information from episodic memory and monitoring extra conflict to form the novel and appropriate story. In consideration of the importance of dorsal ACC in different creative tasks, the critical node of executive network, these results might suggest that the executive network facilitated the process of creative performance.

Meanwhile, the results revealed that the rWMD of the left IFG which extended to pars opercularis was negatively associated with RAT. This was in accordance with research that proved that verbal creative task involved in IFG, supplementary area and premotor cortex (Brown et al., 2006; Mashal et al., 2007). Broca's area, usually located in the triangular and opercular part of IFG

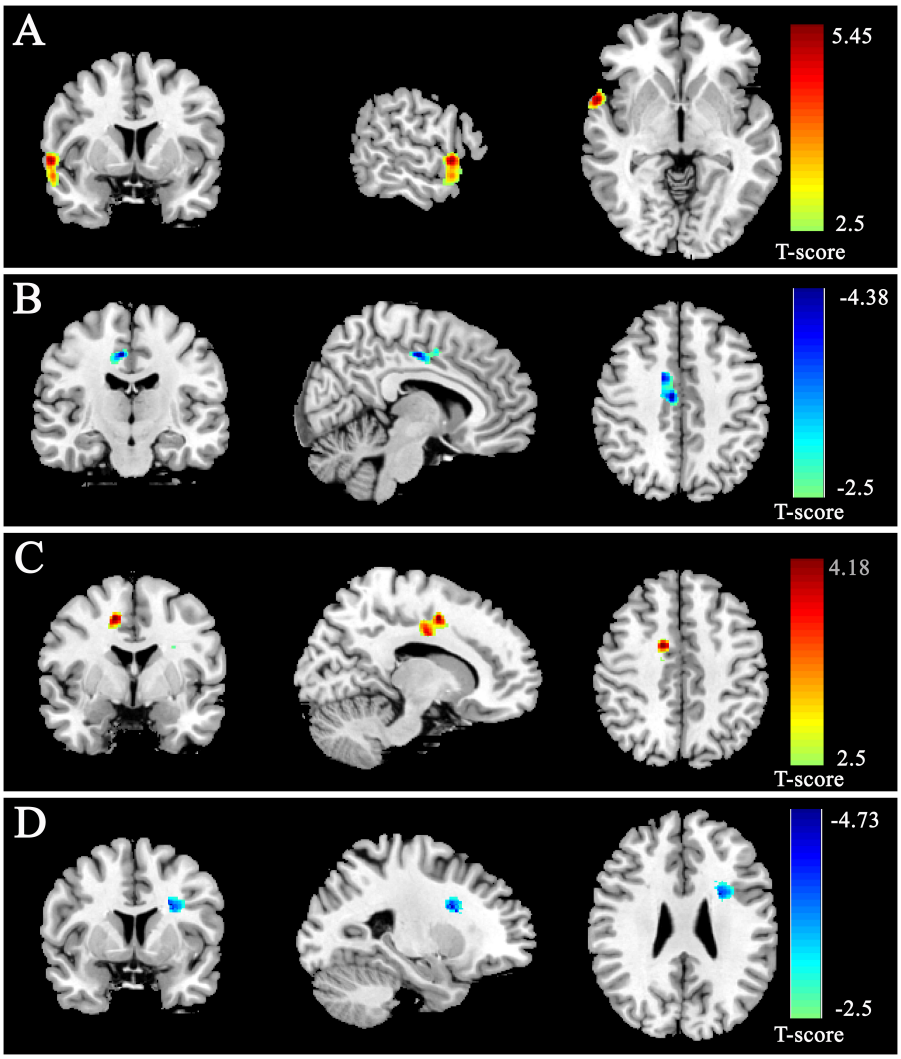

FIGURE 2 | Gray matter density (GMD) and white matter density (WMD) were correlated with RAT scores. GMD was positively correlated with RAT scores in anterior STG **(A)** and negatively correlated with RAT scores in dorsal ACC **(B)**. WMD was positively correlated with RAT scores in dorsal ACC **(C)** and negatively correlated with RAT scores in IFG **(D)**. All results were shown at $t > 2.5$ for visualization purpose.

TABLE 2 | Brain regions significantly correlated with the score of RAT.

Brain regions	H	MNI coordinates			Cluster size (mm^3)	*t*-value (peak voxel)
		x	*y*	*z*		
Gray matter density						
Positive Correlation						
Superior Temporal Gyrus	R	60	6	−3	1474.9	5.45
Negative Correlation						
Anterior Cingulate Gyrus	R	7.5	−15	44.5	1454.6	4.38
White matter density						
Positive Correlation						
Anterior Cingulate Gyrus	R	13.5	−1.5	45	1339.9	4.18
Negative Correlation						
Inferior Frontal Gyrus	L	−25.5	6	27	1067.6	4.73

H, hemisphere; L, left hemisphere; R, Right hemisphere; MNI, Montreal Neurological Institute. The P-value was set at $P < 0.05$ corrected by AlphaSim.

in left hemisphere, was frequently engaged in verbal fluency (Costafreda et al., 2010) and semantic generation (Vidorreta et al., 2015). Other fMRI research also found the left IFG was involved in the generation of creative idea (Bechtereva et al., 2004), inventive conception (Zhang et al., 2014), matchstick problem task (Kleibeuker et al., 2013) and creative writing (Shah et al., 2013). R.E. Jung et al. (2010a) investigated the association between divergent thinking and white matter integrity measured by Fractional Anisotropy (FA) and found the score of divergent thinking task was negatively associated with the FA in the left IFG. In our study, the decreased rGMD in the left IFG was associated with convergent thinking. This might be because the cortical thinning was the inevitable process during cortical maturity. Sowell et al. (1999) found the gray matter density in the frontal lobe decreased from adolescence to adulthood. This reduction was thought be related to the increased efficacy of cognitive processing (Ernst and Korelitz, 2009). This was confirmed by the study's finding that the decreased cortical thickness in frontal lobe was associated with intelligence in early childhood (Shaw et al., 2006) and the reduced cortical thickness in lingual gyrus was related with creative task (Shaw et al., 2006). Shen et al. (2018) also indicated that the left IFG was a part of the brain network involved in insight process and played an important role in the inhibitory of improper associations and the breaking of mental sets. In the present study, the decreased rGMD associated with higher RAT score might indicate that there was higher efficiency and quality of the left IFG in semantic generation and integration, which facilitated the performance of creative behavior.

In our findings, the score of RAT was associated with STG and IFG, and was partially consisted of the model of semantic processing named Bilateral Activation, Integration, and Selection (BAIS) (Jung-Beeman, 2005). This model supposed that semantic function consisted of three parts: semantic activation, semantic integration, and semantic selection. Three different brain regions lived in two brain hemispheres, posterior middle and superior temporal gyrus, anterior middle and superior temporal and inferior frontal gyrus, backed up these semantic parts, respectively (for more details M. Jung-Beeman, 2005). A great deal of research on creativity cognition indicated that one or more of the above brain regions were involved in creative performance (e.g., Jung-Beeman et al., 2004; Bengtsson et al., 2007; Abraham et al., 2012; Aziz-Zadeh et al., 2012; Jung et al., 2013; Kleibeuker et al., 2013; Beaty et al., 2014; Benedek et al., 2014; Zhang et al., 2014; Li et al., 2015). This model reinforced the relationship between creative cognition, semantic integration and semantic selection.

In the present research, the deceased and increased GMD were both found to be related with convergent thinking. But what larger or smaller was more better? Previous results suggested that neural plasticity might be expressed through reorganization of gray matter or white matter and reflected in the deceased and increased in disparate regions (Maguire et al., 2000; Draganski et al., 2006). Similar results also found the gray matter volume were positively and negatively correlated with creativity in disparate brain regions (Chen et al., 2014; Li et al., 2015). This question might be elucidated after the implementation of longitudinal or intervention in further studies. Our results further certified the notion that the functional information can be measured in white-matter and challenged the opinion that the blood oxygenation level-dependent (BOLD) signals in white matter was considered as noise (Logothetis and Wandell, 2004). Previous studies demonstrated the white matter BOLD signals, such as the low-frequency BOLD fluctuations (LFBFs) (Ji et al., 2017), resting-state functional connectivity (Jiang et al., 2018) and functional networks (Huang et al., 2018), can be reliably detected in the white-matter. These findings proposed that the WM signals may be of physiological significance. Other studies also found the relationship between WMD and creativity (Zhu et al., 2013; Fink et al., 2014; Chen et al., 2018).

CONCLUSION

The present research used VBM to identify the GMD correlates of divergent thinking as measured by RAT. The results showed that a positive correlation between GMD in the right STG and RAT, while a negative correlation between GMD in the right dACC and RAT. In addition, the WMD in the dACC was positively correlated with the RAT. These results indicate that higher convergent thinking might be related to the enhanced ability of sentence comprehension, information integration and conflict monitoring. However, several limitations should be noticed. Because the young undergraduate participants with high-level education and right-handed subjects were enrolled, the external validity of our research would be affected. Mismatch of the sex distribution of our study was not matched perfectly (117 men versus 144 women). Although we found the relationship between convergent thinking and brain gray matter, we could not answer the question about the direction of relationship between convergent thinking and the increased/decreased rGMD. Future longitudinal or intervention investigations might promote the solution of the complex relationships between convergent thinking and brain structure. Moreover, because the present research adopted only the rGMD to explore the structural basis of RAT, more method could be used in the investigation of the neural mechanisms of RAT in future. Given that convergent thinking consisted of various task, such as anagram word puzzles (Kounios et al., 2008) and Chinese logogriphs (Qiu et al., 2010), the brain structural basis of other convergent thinking tasks could be explored in the future study.

AUTHOR CONTRIBUTIONS

WL designed the study, collected and analyzed the data, and wrote the paper. JQ and QZ provided the idea of the study, interpreted the results, and revised the paper. GL and BJ revised the paper.

FUNDING

This research was supported by the Natural Science Foundation of Shandong Province (ZR2016CL10) and the NSFC cultivation project of Jining Medical University (JYP201706).

REFERENCES

Abraham, A., Pieritz, K., Thybusch, K., Rutter, B., Kroger, S., Schweckendiek, J., et al. (2012). Creativity and the brain: uncovering the neural signature of conceptual expansion. *Neuropsychologia* 50, 1906–1917. doi: 10.1016/j.neuropsychologia.2012.04.015

Andrea, M., Cathy, J. P., Karl, J. F., and John, A. (2005). Voxel-based morphometry of the human brain: methods and applications. *Curr. Med. Imaging Rev.* 1, 105–113. doi: 10.2174/1573405054038726

Ansburg, P. (2000). Individual differences in problem solving via insight. *Curr. Psychol.* 19, 143–146. doi: 10.1007/s12144-000-1011-y

Arden, R., Chavez, R. S., Grazioplene, R., and Jung, R. E. (2010). Neuroimaging creativity: a psychometric view. *Behav. Brain Res.* 214, 143–156. doi: 10.1016/j.bbr.2010.05.015

Ashburner, J., and Friston, K. J. (2005). Unified segmentation. *Neuroimage* 26, 839–851. doi: 10.1016/j.neuroimage.2005.02.018

Ashtari, M., and Cyckowski, L. (2012). "Brain development during adolescence," in *Handbook of Growth and Growth Monitoring in Health and Disease,* ed. V. R. Preedy (New York, NY: Springer), 1213–1229. doi: 10.1007/978-1-4419-1795-9_72

Aziz-Zadeh, L., Kaplan, J. T., and Iacoboni, M. (2009). "Aha!": the neural correlates of verbal insight solutions. *Hum. Brain Mapp.* 30, 908–916. doi: 10.1002/hbm.20554

Aziz-Zadeh, L., Liew, S. L., and Dandekar, F. (2012). Exploring the neural correlates of visual creativity. *Soc. Cogn. Affect. Neurosci.* 8, 475–480. doi: 10.1093/scan/nss021

Beaty, R. E., Benedek, M., Wilkins, R. W., Jauk, E., Fink, A., Silvia, P. J., et al. (2014). Creativity and the default network: a functional connectivity analysis of the creative brain at rest. *Neuropsychologia* 64, 92–98. doi: 10.1016/j.neuropsychologia.2014.09.019

Bechtereva, N. P., Korotkov, A. D., Pakhomov, S. V., Roudas, M. S., Starchenko, M. G., and Medvedev, S. V. (2004). PET study of brain maintenance of verbal creative activity. *Int. J. Psychophysiol.* 53, 11–20. doi: 10.1016/j.ijpsycho.2004.01.001

Bendetowicz, D., Urbanski, M., Aichelburg, C., Levy, R., and Volle, E. (2017). Brain morphometry predicts individual creative potential and the ability to combine remote ideas. *Cortex* 86, 216–229. doi: 10.1016/j.cortex.2016.10.021

Benedek, M., Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., et al. (2014). To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *Neuroimage* 88, 125–133. doi: 10.1016/j.neuroimage.2013.11.021

Benedek, M., Könen, T., and Neubauer, A. C. (2012). Associative abilities underlying creativity. *Psychol. Aesthet. Creat. Arts* 6, 273–281. doi: 10.1037/a0027059

Bengtsson, S. L., Csíkszentmihályi, M., and Ullén, F. (2007). Cortical regions involved in the generation of musical structures during improvisation in pianists. *J. Cogn. Neurosci.* 19, 830–842. doi: 10.1162/jocn.2007.19.5.830

Berkowitz, A. L., and Ansari, D. (2008). Generation of novel motor sequences: the neural correlates of musical improvisation. *Neuroimage* 41, 535–543. doi: 10.1016/j.neuroimage.2008.02.028

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., and Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature* 402, 179–181. doi: 10.1038/46035

Bowden, E. M., and Jung-Beeman, M. (2003). Normative data for 144 compound remote associate problems. *Behav. Res. Methods Instrum. Comput.* 35, 634–639.

Bowers, K. S., Regehr, G., Balthazard, C., and Parker, K. (1990). Intuition in the context of discovery. *Cogn. Psychol.* 22, 72–110. doi: 10.1016/0010-0285(90)90004-N

Brown, A. S. (1973). An empirical verification of Mednick's associative theory of creativity. *Bull. Psychon. Soc.* 2, 429–430. doi: 10.3758/BF03334439

Brown, S., Martinez, M. J., and Parsons, L. M. (2006). Music and language side by side in the brain: a PET study of the generation of melodies and sentences. *Eur. J. Neurosci.* 23, 2791–2803. doi: 10.1111/j.1460-9568.2006.04785.x

Brownell, H. H., Simpson, T. L., Bihrle, A. M., Potter, H. H., and Gardner, H. (1990). Appreciation of metaphoric alternative word meanings by left and right brain-damaged patients. *Neuropsychologia* 28, 375–383. doi: 10.1016/0028-3932(90)90063-T

Carlsson, I., Wendt, P. E., and Risberg, J. (2000). On the neurobiology of creativity. differences in frontal activity between high and low creative subjects. *Neuropsychologia* 38, 873–885. doi: 10.1016/s0028-3932(99)00128-1

Chen, Q., Beaty, R. E., Wei, D., Yang, J., Sun, J., Liu, W., et al. (2018). Longitudinal alterations of frontoparietal and frontotemporal networks predict future creative cognitive ability. *Cereb. Cortex* 28, 103–115. doi: 10.1093/cercor/bhw353

Chen, Q., Yang, W., Li, W., Wei, D., Li, H., Lei, Q., et al. (2014). Association of creative achievement with cognitive flexibility by a combined voxel-based morphometry and resting-state functional connectivity study. *Neuroimage* 102, (Part 2), 474–483. doi: 10.1016/j.neuroimage.2014.08.008

Costafreda, S. G., Fu, C. H. Y., Lee, L., Everitt, B., Brammer, M. J., and David, A. S. (2010). A systematic review and quantitative appraisal of fMRI studies of verbal fluency: role of the left inferior frontal gyrus. *Hum. Brain Mapp.* 27, 799–810. doi: 10.1002/hbm.20221

Cousijn, J., Koolschijn, P. C. M., Zanolie, K., Kleibeuker, S. W., and Crone, E. A. (2014). The relation between gray matter morphology and divergent thinking in adolescents and young adults. *PLoS One* 9:e114619. doi: 10.1371/journal.pone.0114619

Cox, R. W. (1996). AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Comput. Biomed. Res.* 29, 162–173. doi: 10.1006/cbmr.1996.0014

DeYoung, C. G., Hirsh, J. B., Shane, M. S., Papademetris, X., Rajeevan, N., and Gray, J. R. (2010). Testing predictions from personality neuroscience: brain structure and the big five. *Psychol. Sci.* 21, 820–828. doi: 10.1177/0956797610370159

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychon. Bull. Rev.* 11, 1011–1026. doi: 10.3758/bf03196731

Dietrich, A. (2007). *Introduction to Consciousness*. London: Palgrave Macmillan.

Dietrich, A., and Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychol. Bull.* 136, 822–848. doi: 10.1037/a0019749

Ding, H., Qin, W., Jiang, T., Zhang, Y., and Yu, C. (2012). Volumetric variation in subregions of the cerebellum correlates with working memory performance. *Neurosci. Lett.* 508, 47-51. doi: 10.1016/j.neulet.2011.12.016

Draganski, B., Gaser, C., Kempermann, G., Kuhn, H. G., Winkler, J., Büchel, C., et al. (2006). Temporal and spatial dynamics of brain structure changes during extensive learning. *J. Neurosci.* 26, 6314–6317. doi: 10.1523/jneurosci.4628-05.2006

Enriquez-Geppert, S., Eichele, T., Specht, K., Kugel, H., Pantev, C., and Huster, R. J. (2013). Functional parcellation of the inferior frontal and midcingulate cortices in a flanker-stop-change paradigm. *Hum. Brain Mapp.* 34, 1501–1514. doi: 10.1002/hbm.22002

Ernst, M., and Korelitz, K. E. (2009). Cerebral maturation in adolescence: behavioral vulnerability. *Lencephale* 35(Suppl 6), S182–S189. doi: 10.1016/S0013-7006(09)73469-4

Farb, N. A. S., Grady, C. L., Strother, S., Tang-Wai, D. F., Masellis, M., Black, S., et al. (2013). Abnormal network connectivity in frontotemporal dementia: evidence for prefrontal isolation. *Cortex* 49, 1856–1873. doi: 10.1016/j.cortex.2012.09.008

Fink, A., Koschutnig, K., Hutterer, L., Steiner, E., Benedek, M., Weber, B., et al. (2014). Gray matter density in relation to different facets of verbal creativity. *Brain Struct. Funct.* 219, 1263–1269. doi: 10.1007/s00429-013-0564-0

Fuhrmann, D., Knoll, L. J., and Blakemore, S. J. (2015). Adolescence as a sensitive period of brain development. *Trends Cogn. Sci.* 19, 558–566. doi: 10.1016/j.tics.2015.07.008

Gansler, D. A., Moore, D. W., Susmaras, T. M., Jerram, M. W., Sousa, J., and Heilman, K. M. (2011). Cortical morphology of visual creativity. *Neuropsychologia* 49, 2527–2532. doi: 10.1016/j.neuropsychologia.2011.05.001

Good, C. D., Johnsrude, I., Ashburner, J., Henson, R. N. A., Friston, K. J., and Frackowiak, R. S. J. (2001). Cerebral asymmetry and the effects of sex and handedness on brain structure: a voxel-based morphometric analysis of 465 normal adult human brains. *Neuroimage* 14, 685–700. doi: 10.1006/nimg.2001.0857

Guilford, J. P. (1950). Creativity. *Am. Psychol.* 5, 444–454. doi: 10.1037/h0063487

Haier, R. J., Jung, R. E., Yeo, R. A., Head, K., and Alkire, M. T. (2004). Structural brain variation and general intelligence. *Neuroimage,* 23, 425–433. doi: 10.1016/j.neuroimage.2004.04.025

Howard-Jones, P. A., Blakemore, S. -J., Samuel, E. A., Summers, I. R., and Claxton, G. (2005). Semantic divergence and creative story generation: an fMRI

investigation. *Cogn. Brain Res.* 25, 240-250. doi: 10.1016/j.cogbrainres.2005.05.013

Huang, Y., Bailey, S. K., Wang, P., Cutting, L. E., Gore, J. C., and Ding, Z. (2018). Voxel-wise detection of functional networks in white matter. *Neuroimage* 183, 544–552. doi: 10.1016/j.neuroimage.2018.08.049

Jauk, E., Neubauer, A. C., Dunst, B., Fink, A., and Benedek, M. (2015). Gray matter correlates of creative potential: a latent variable voxel-based morphometry study. *Neuroimage* 111, 312–320. doi: 10.1016/j.neuroimage.2015.02.002

Jausovec, N., and Jausovec, K. (2000). EEG activity during the performance of complex mental problems. *Int. J. Psychophysiol.* 36, 73–88. doi: 10.1016/S0167-8760(99)00113-0

Ji, G. J., Liao, W., Chen, F. F., Zhang, L., and Wang, K. (2017). Low-frequency blood oxygen level-dependent fluctuations in the brain white matter:more than just noise. *Sci. Bull.* 62, 656–657. doi: 10.1016/j.scib.2017.03.021

Jiang, Y., Luo, C., Li, X., Li, Y., Yang, H., Li, J., et al. (2018). White-matter functional networks changes in patients with schizophrenia. *Neuroimage.* doi: 10.1016/j.neuroimage.2018.04.018. [Epub ahead of print].

Jung, R. E., Grazioplene, R., Caprihan, A., Chavez, R. S., and Haier, R. J. (2010a). White matter integrity, creativity, and psychopathology: Disentangling constructs with diffusion tensor imaging. *PLoS One* 5:e9818. doi: 10.1371/journal.pone.0009818

Jung, R. E., Segall, J. M., Jeremy Bockholt, H., Flores, R. A., Smith, S. M., Chavez, R. S., et al. (2010b). Neuroanatomy of creativity. *Hum. Brain Mapp.* 31, 398–409. doi: 10.1002/hbm.20874

Jung, R. E., Mead, B. S., Carrasco, J., and Flores, R. A. (2013). The structure of creative cognition in the human brain. *Front. Hum. Neurosci.* 7:330. doi: 10.3389/fnhum.2013.00330

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends Cogn. Sci.* 9, 512–518. doi: 10.1016/j.tics.2005.09.009

Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambelliu, S., Greenblatt, R., et al. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biol.* 2:E97. doi: 10.1371/journal.pbio.0020097

Kanai, R., and Rees, G. (2011). The structural basis of inter-individual differences in human behaviour and cognition. *Nat. Rev. Neurosci.* 12, 231–242. doi: 10.1038/nrn3000

Kihlstrom, J. F., Shames, V. A., and Dorfman, J. (1996). "Intuition, incubation, and insight: implicit cognition in problem-solving," in *Implicit Cognition*, ed. G. Underwood (Oxford: Oxford University Press), 257–296

Kleibeuker, S. W., Koolschijn, P. C. M. P., Jolles, D. D., Schel, M. A., De Dreu, C. K. W., and Crone, E. A. (2013). Prefrontal cortex involvement in creative problem solving in middle adolescence and adulthood. *Dev. Cogn. Neurosci.* 5, 197–206. doi: 10.1016/j.dcn.2013.03.003

Kong, L., Chen, K., Womer, F., Jiang, W., Luo, X., Driesen, N., et al. (2013). Sex differences of gray matter morphology in cortico-limbic-striatal neural system in major depressive disorder. *J. Psychiatr. Res.* 47, 733–739. doi: 10.1016/j.jpsychires.2013.02.003

Kounios, J., Fleck, J. I., Green, D. L., Payne, L., Stevenson, J. L., Bowden, E. M., et al. (2008). The origins of insight in resting-state brain activity. *Neuropsychologia* 46, 281–291. doi: 10.1016/j.neuropsychologia.2007.07.013

Kowatari, Y., Lee, S. H., Yamamura, H., Nagamori, Y., Levy, P., Yamane, S., et al. (2009). Neural networks involved in artistic creativity. *Hum. Brain Mapp.* 30, 1678–1690. doi: 10.1002/hbm.20633

Li, D. (1989). *The Handbook of Combined Raven's Test in Chinese Version (in Chinese)*. Shanghai: East China Normal University.

Li, W., Xueting, L., Huang, L., Kong, X., Yang, W., Wei, D., et al. (2015). Brain structure links trait creativity to openness to experience. *Soc. Cogn. Affect. Neurosci.* 10, 191–198. doi: 10.1093/scan/nsu041

Li, W., Yang, J., Zhang, Q., Li, G., and Qiu, J. (2016). The association between resting functional connectivity and visual creativity. *Sci. Rep.* 6:25395. doi: 10.1038/srep25395

Logothetis, N. K., and Wandell, B. A. (2004). Interpreting the bold signal. *Annu. Rev. Physiol.* 66, 735–769. doi: 10.1146/annurev.physiol.66.082602.092845

Luo, J., and Knoblich, G. (2007). Studying insight problem solving with neuroscientific methods. *Methods* 42, 77–86. doi: 10.1016/j.ymeth.2006.12.005

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. J., et al. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proc. Natl. Acad. Sci. U.S.A.* 97, 4398–4403. doi: 10.1073/pnas.070039597

Mashal, N., Faust, M., Hendler, T., and Jung-Beeman, M. (2007). An fMRI investigation of the neural correlates underlying the processing of novel metaphoric expressions. *Brain Lang.* 100, 115–126. doi: 10.1016/j.bandl.2005.10.005

Mazoyer, B. M., Tzourio, N., Frak, V., Syrota, A., Murayama, N., Levrier, O., et al. (1993). The cortical representation of speech. *J. Cogn. Neurosci.* 5, 467–479. doi: 10.1162/jocn.1993.5.4.467

Mednick, M. T., Mednick, S. A., and Jung, C. C. (1964). Continual association as a function of level of creativity and type of verbal stimulus. *J. Abnorm. Psychol.* 69, 511–515. doi: 10.1037/h0041086

Mednick, S. A. (1962). The associative basis of the creative process. *Psychol. Rev.* 69, 220-232. doi: 10.1371/journal.pone.0062593

Mednick, S. A. (1968). Remote associates test. *J. Creat. Behav.* 2, 213–214. doi: 10.1002/j.2162-6057.1968.tb00104.x

Mednick, S. A., and Mednick, M. T. (1967). *Examiner's Manual, Remote Associates Test: College and Adult Forms 1 and 2*. Boston, MA: Houghton Mifflin.

Ogawa, T., Aihara, T., Shimokawa, T., and Yamashita, O. (2018). Large-scale brain network associated with creative insight: combined voxel-based morphometry and resting-state functional connectivity analyses. *Sci. Rep.* 8:6477. doi: 10.1038/s41598-018-24981-0

Qiu, J., Li, H., Jou, J., Liu, J., Luo, Y., Feng, T., et al. (2010). Neural correlates of the "Aha" experiences: evidence from an fMRI study of insight problem solving. *Cortex* 46, 397–403. doi: 10.1016/j.cortex.2009.06.006

Qiu, J., Li, H., Yang, D., Luo, Y., Li, Y., Wu, Z., et al. (2008). The neural basis of insight problem solving: an event-related potential study. *Brain Cogn.* 68, 100–106. doi: 10.1016/j.bandc.2008.03.004

Sawyer, K. (2011). The cognitive neuroscience of creativity: a critical review. *Creat. Res. J.* 23, 137–154. doi: 10.1080/10400419.2011.571191

Schooler, J. W., and Melcher, J. (1995). "The ineffability of insight," in *The Creative Cognition Approach*, eds S. M. Smith, T. B. Ward and R. A. Finke (Cambridge, MA: The MIT Press), 97–133.

Schwartz, D. L., Mitchell, A. D., Lahna, D. L., Luber, H. S., Huckans, M. S., Mitchell, S. H., et al. (2010). Global and local morphometric differences in recently abstinent methamphetamine-dependent individuals. *Neuroimage,* 50, 1392–1401. doi: 10.1016/j.neuroimage.2010.01.056

Shah, C., Erhard, K., Ortheil, H. J., Kaza, E., Kessler, C., and Lotze, M. (2013). Neural correlates of creative writing: An fMRI Study. *Hum. Brain Mapp.* 34, 1088-1101. doi: 10.1002/hbm.21493

Shaw, P., Greenstein, D., Lerch, J., Clasen, L., Lenroot, R., Gogtay, N., et al. (2006). Intellectual ability and cortical development in children and adolescents. *Nature* 440, 676–679. doi: 10.1038/nature04513

Shen, W., Tong, Y., Li, F., Yuan, Y., Hommel, B., Liu, C., et al. (2018). Tracking the neurodynamics of insight: a meta-analysis of neuroimaging studies. *Biol. Psychol.* 138, 189–198. doi: 10.1016/j.biopsycho.2018.08.018

Shen, W., Yuan, Y., Liu, C., Luo, J., Shen, W., Yuan, Y., et al. (2017). The roles of the temporal lobe in creative insight: an integrated review. *Think. Reason.* 23, 321–375. doi: 10.1080/13546783.2017.1308885

Silver, M., Montana, G., and Nichols, T. E. (2011). False positives in neuroimaging genetics using voxel-based morphometry data. *Neuroimage* 54, 992–1000. doi: 10.1016/j.neuroimage.2010.08.049

Song, X. W., Dong, Z. Y., Long, X. Y., Li, S. F., Zuo, X. N., Zhu, C. Z., et al. (2011). REST: a toolkit for resting-state functional magnetic resonance imaging data processing. *PLoS One* 6:e25031. doi: 10.1371/journal.pone.0025031

Sowell, E. R., Peterson, B. S., Thompson, P. M., Welcome, S. E., Henkenius, A. L., and Toga, A. W. (2003). Mapping cortical change across the human life span. *Nat. Neurosci.* 6, 309–315. doi: 10.1038/nn1008

Sowell, E. R., Thompson, P. M., Holmes, C. J., Jernigan, T. L., and Toga, A. W. (1999). *In vivo* evidence for post-adolescent brain maturation in frontal and striatal regions. *Nat. Neurosci.* 2, 859–861. doi: 10.1038/13154

Sowell, E. R., Thompson, P. M., Tessner, K. D., and Toga, A. W. (2014). Mapping continued brain growth and gray matter density reduction in dorsal frontal cortex: inverse relationships during postadolescent brain maturation. *J. Neurosci.* 21, 8819–8829. doi: 10.1523/JNEUROSCI.21-22-08819.2001

Sternberg, R. J., and Lubart, T. I. (1993). Investing in creativity. *Psychol. Inquiry* 4, 229–232. doi: 10.1207/s15327965pli0403_16

Stowe, L. A., Paans, A. M., Wijers, A. A., Zwarts, F., Mulder, G., and Vaalburg, W. (1999). Sentence comprehension and word repetition: a positron emission

tomography investigation. *Psychophysiology* 36, 786–801. doi: 10.1111/1469-8986.3660786

Sun, J., Chen, Q., Zhang, Q., Li, Y., Li, H., Wei, D., et al. (2016). Training your brain to be more creative: brain functional and structural changes induced by divergent thinking training. *Hum. Brain Mapp.* 37, 3375–3387. doi: 10.1002/hbm.23246

Takeuchi, H., Taki, Y., Nouchi, R., Yokoyama, R., Kotozaki, Y., Nakagawa, S., et al. (2017). Creative females have larger white matter structures: evidence from a large sample study. *Hum. Brain Mapp.* 38, 414–430. doi: 10.1002/hbm.23369

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., et al. (2010a). Regional gray matter volume of dopaminergic system associate with creativity: evidence from voxel-based morphometry. *Neuroimage,* 51, 578–585. doi: 10.1016/j.neuroimage.2010.02.078

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., et al. (2010b). White matter structures associated with creativity: evidence from diffusion tensor imaging. *Neuroimage,* 51, 11–18. doi: 10.1016/j.neuroimage.2010.02.035

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., et al. (2011). Regional gray matter density associated with emotional intelligence: evidence from voxel-based morphometry. *Hum. Brain Mapp.* 32, 1497–1510. doi: 10.1002/hbm.21122

Vidorreta, J. G., Garcia, R., Moritz-Gasser, S., and Duffau, H. (2015). Double dissociation between syntactic gender and picture naming processing: a brain stimulation mapping study. *Hum. Brain Mapp.* 32, 331–340. doi: 10.1002/hbm.21026

Ward, B. D. (2000). *Simultaneous inference for FMRI Data AFNI Alphasim Documentation*. Milwaukee, WI: Medical College of Wisconsin.

Yang, F. C., Chou, K. H., Fuh, J. L., Huang, C. C., Lirng, J. F., Lin, Y. Y., et al. (2013). Altered gray matter volume in the frontal pain modulation network in patients with cluster headache. *Pain* 154, 801–807. doi: 10.1016/j.pain.2013.02.005

Zhang, H., Liu, J., and Zhang, Q. (2014). Neural representations for the generation of inventive conceptions inspired by adaptive feature optimization of biological species. *Cortex* 50, 162–173. doi: 10.1016/j.cortex.2013.01.015

Zhu, F., Zhang, Q., and Qiu, J. (2013). Relating inter-individual differences in verbal creative thinking to cerebral structures: an optimal voxel-based morphometry study. *PLoS One* 8:e79272. doi: 10.1371/journal.pone.0079272

Zou, L., Ding, G., Abutalebi, J., Shu, H., and Peng, D. (2012). Structural plasticity of the left caudate in bimodal bilinguals. *Cortex* 48, 1197–1206. doi: 10.1016/j.cortex.2011.05.022

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 05 February 2019
doi: 10.3389/fpsyg.2019.00105

The Mediating Role of Cognitive Flexibility in the Influence of Counter-Stereotypes on Creativity

Bin Zuo[1,2,3], *Fangfang Wen*[1,2,3]*, *Miao Wang*[1,2] *and Yang Wang*[1]

[1] School of Psychology, Central China Normal University, Wuhan, China, [2] Center for Studies of Social Psychology, Central China Normal University, Wuhan, China, [3] Key Laboratory of Adolescent Cyberpsychology and Behavior, Ministry of Education, Wuhan, China

The aim of this study is to explore the relationship between counter-stereotypes and creativity, and further explore the mechanism underlying the impact of priming counter-stereotypic information on individual creativity. More importantly, here we have proposed cognitive and emotional dual processing pathways, which may mediate the influences of counter-stereotypes on creativity. Two experiments examined how counter-stereotypes impacted creativity through the dual processing pathways. A total of 152 university students were recruited to test their creativity performance. In Experiment 1, we replicated results of past studies. Participants were randomly allocated to different priming conditions (stereotype or counter-stereotype), in which descriptions of male governors and female nurses served as priming of stereotypes, whereas descriptions of male nurses and female governors served as priming of counter-stereotypes. Measurements of creativity were based on the poster paradigm. The poster paradigm required participants to design a poster for a college fellowship party. In Experiment 2, we recruited 104 participants to examine the mediating roles of emotions and cognitive flexibility. The procedure of Experiment 2 was similar to that of Experiment 1, except for the measurement of creativity, which was Chinese idiom riddle test. Participants who selected more creative answers were more creative, based on the criteria of our experimental design. Also, we included measurements of emotions (i.e., surprise and delight) and cognitive flexibility (using the Cognitive Flexibility Scale) after priming of stereotypes and counter-stereotypes in Experiment 2. We also verified the credibility of our counter-stereotype measurements. The results of Experiment 1—which replicated previous studies—demonstrated that priming of counter-stereotypes promoted creative performance compared with priming of stereotypes in the poster paradigm. However, our proposed dual processing pathways were not fully verified by Experiment 2. The results of this experiment showed that neither surprising nor delighted emotion mediated the influence of counter-stereotypes on creativity, whereas cognitive flexibility did. In conclusion, our current study reveals a mechanism of creative performance in terms of cognitive flexibility, and further inspires us to focus on the positive influence of counter-stereotypes on creativity.

Keywords: counter-stereotypes, creativity, cognition flexibility, meditating effect, emotion

OPEN ACCESS

Edited by:
Chang Liu,
Nanjing Normal University, China

Reviewed by:
Huajian Cai,
University of Chinese Academy of Sciences (UCAS), China
Xiaofei Xie,
Peking University, China

***Correspondence:**
Fangfang Wen
wenff@mail.ccnu.edu.cn

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *26 September 2018*
Accepted: *14 January 2019*
Published: *05 February 2019*

Citation:
Zuo B, Wen F, Wang M and Wang Y (2019) The Mediating Role of Cognitive Flexibility in the Influence of Counter-Stereotypes on Creativity. Front. Psychol. 10:105. doi: 10.3389/fpsyg.2019.00105

INTRODUCTION

Creative ability has played an important role in the development of human society (Gong et al., 2016). Creativity is considered as a primary motivational factor and a core competency for the development of enterprises, organizations, and nations. Similarly, creativity is an indispensable quality for individual development and is in greater demand in modern-day China. Thus, more research is required to develop methods for increasing creativity. On the other hand, China is a collectivistic country (Hofstede, 2001), and the environment here is a disadvantage of personal creativity development comparing with individualistic countries (Goncalo and Staw, 2006; Zha et al., 2006). Former results about creativity promotion method might present differently for collectivism culture. Therefore, it is also necessary to reexamine the effectiveness of creativity training in China. Previously, psychologists have widely explored methods of innovation and creativity training. As early as 1950, JP Guilford had already advocated research in the area of creativity, which then increased the number of researchers focused on its structural components. Today, research on creativity is continuously developing, improving its measurements (Hocevar, 1981; Kim, 2006), training people's creativity (Scott et al., 2004), better understanding its social and cultural influences (Amabile, 1983; Shalley and Gilson, 2004), and exploring its unique cognitive neural mechanisms (Dietrich and Kanso, 2010; Beaty et al., 2016).

Recently, social psychologists have conducted extensive research on factors influencing individual creativity. This research has demonstrated that emotion and cognitive factors both play significant roles in individual creative performance (Ward, 2007; Akinola and Mendes, 2008; De Dreu et al., 2008). Furthermore, from the perspective of social cognition, several scholars have also found a close connection between stereotypes and creativity (Gocłowska et al., 2013). The present study focuses on the relationship between counter-stereotypes and creativity—based on previous research—and further examines the mechanism of counter-stereotypic priming on individual creativity performance in terms of cognitive and emotional factors.

Since the publication of Galton's *Hereditary Genius* in 1869, researchers have constructed a variety of theories on creativity (Huang et al., 2005). Cognitive processing is regarded as an important factor that affects individual creative performance (Hayes, 1989; Batey and Furnham, 2006; Sternberg, 2006), as well as the degree of one's independence, innovation, and flexibility. Many empirical studies have focused on cognitive factors influencing an individual's creativity (Barron and Harrington, 1981; Simonton, 2014; Kandler et al., 2016). For example, Nusbaum and Silvia (2011) found modest correlations between cognitive executive processes and creativity. Next, using multivariate structural equation modeling, recent study further confirmed that both associative and executive processes have a significant impact on the production of novel ideas (Beaty et al., 2014). Furthermore, a subsequent functional Magnetic Resonance Imaging fMRI study revealed the inner-cognitive neural-activation mode of creative thought. A distributed network involving dorsolateral prefrontal cortex—a locus for cognitive executive networks—was found to support this process of creative thought (Beaty et al., 2015). In conclusion, studies have already found a close relationship between cognitive abilities and creativity.

Stereotypes are general and fixed cognitive views of a social group (Zhang et al., 2016; Sun et al., 2016; Song and Zuo, 2016). On the contrary, counter-stereotypes refer to an individual's cognitive views of a social group—in terms of perceived behaviors or traits—which are inconsistent with or contrary to the mindset of the social group in question (Liu and Zuo, 2006; Leicht et al., 2017). Recently, many studies have focused on whether presentation of counter-stereotypic information would influence people's cognitive abilities (Damer et al., 2017; Colombo et al., 2018). These studies have suggested that presentation of counter-stereotypic information not only reduces stereotypes and prejudice related to certain groups (Dasgupta and Greenwald, 2001; Columb and Plant, 2011; Lai et al., 2014; Finnegan et al., 2015), but also promotes an individual's cognitive flexibilities and may concomitantly affect creativity (Asgari et al., 2010; Asgari et al., 2012). Therefore, theoretically, it seems that counter-stereotypic information could affect creativity performance through cognitive pathways.

Several researchers have attempted to examine the influence of counter-stereotypes on creativity directly (Parish and Hudson, 1970; Dumas and Dunbar, 2016). After activating participants' stereotypes through an imagination of an "eccentric poet" or "rigid librarian," researchers conducted divergent thinking tasks to measure participants' creative performance. The results showed that stereotype activation could truly enhance participant's divergent thinking abilities. Furthermore, in view of possible interferences of emotion, some other researches controlled these emotional variables and examined whether priming of counter-stereotypes also have similar effects (Gocłowska et al., 2013, 2014). These studies found that counter-stereotypes could increase cognitive flexibility while improving creativity performance. Cognitive flexibility refers to a kind of strategy or capability for flexible switching from one stimulation, manipulation, or psychological mode to another when necessary (Vartanian, 2009). The interpretation by the researchers was that, after activating counter-stereotypic information, the specific content of stereotypic knowledge was no longer effective. Participants would think more about other possibilities (i.e., exhibit more flexible thinking) and thereby increased their creativity.

Although existing studies have demonstrated the promotion of counter-stereotypes on individuals' cognitive flexibility and creative performance, they have not considered possible mediating roles of cognitive flexibility among them. It is adaptive, as it helps people change their behavioral patterns and strategies effectively when facing new circumstances or environments, in order to solve problems (Heilman et al., 2003; Sligte et al., 2011). Presentation of counter-stereotype information is beneficial to improve an individual's cognitive flexibility (Gocłowska et al., 2013), which is closely related to divergent thinking and creativity (Evans and Stanovich, 2013; Barr et al., 2015). Thus, cognitive flexibility may be an important mediating variable between counter-stereotypes and creativity.

Furthermore, counter-stereotypes may also affect creativity through emotions. Researchers have believed that counter-stereotypic information generates surprise, which interrupts an individual's existing thinking process and diverts their attention to unexpected stimuli (Prati et al., 2015). Meanwhile, surprise may motivate people to analyze differences between cognitive schemas, which evoke curiosity regarding the nature of these differences. Some researchers have pointed out that high-activation positive emotions—such as those found to be exciting, energetic, and interesting—can improve creativity and lead people to perform better on insight tests and divergent thinking tasks (Ashby and Isen, 1999; Hirt et al., 2008; Conner and Silvia, 2015). Therefore, it seems plausible that emotional responses triggered by counter-stereotypes could enhance individual creativity as well.

As for the manipulation of stereotype priming, we selected stereotype and counter-stereotype priming based on previous studies (Gocłowska et al., 2013, 2014), which used gendered or racial exemplars for stereotype or counter-stereotype priming. However, racial cues are not predominant cues for Chinese, even for children (Zhang et al., 2018), so we only took gendered stereotype/counter-stereotype exemplars into account for different priming conditions.

Studies of gender stereotypes are often intertwined with occupational stereotypes (Eagly and Steffen, 1984; White and White, 2006; Bolukbasi et al., 2016). Assertiveness and performance indicate greater agency in men, while warmth and care for others are signs of greater communality in women; these gender biases lead to different occupational selections (Ellemers, 2018). Thus, the priming of our study focused on occupational gender stereotypes as an exemplar, where we selected governing as a high-agency occupation and nursing as a high-communal occupation. We chose male governors and female nurses as stereotype-priming exemplars, while female governors and male nurses were selected as counter-stereotype-priming exemplars. On the other hand, previous research has shown that people, regardless of their own gender, are less tolerant of men behaving in counter-stereotypic ways compared with such behavior in women (Signorella and Liben, 1984; Hughes and Seta, 2003; Sullivan et al., 2018). These findings imply that the promotion of creativity in terms of counter-stereotypes priming may be differed across target's gender. Therefore, the influence of a target's gender is also included in our analysis.

In summary, even though previous studies have illustrated a direct relationship between counter-stereotypes and creativity (Gocłowska et al., 2013, 2014), its mechanism has not been fully examined. Based on previous research, we argue that emotion and cognitive flexibility may both play roles in this process. Thus, the aim of this study is to replicate prior research using the poster paradigm (Gocłowska et al., 2013), as well as via a different paradigm based on Chinese culture. More importantly, this study proposes a two-pathway model to explain the mechanism of counter-stereotypes influencing the promotion of an individual's creativity. This two-pathway model posits that counter-stereotypes affect creativity through emotion and cognitive flexibility; in other words, we hypothesize that emotion and cognitive flexibility play mediating roles in this process.

EXPERIMENT 1: INFLUENCE OF COUNTER-STEREOTYPES ON CREATIVITY

Methods

Participants

There were 48 voluntary participants (24 males) involved in this experiment, M_{age} = 19.17, SD = 1.99. Each participant was randomly arranged to one of the experiment conditions. The specific grouping and age distribution are shown in **Table 1**.

This study was carried out in accordance with the recommendations of American Psychological Association (APA) ethical guidelines. The protocol was approved by the Ethics Committee of the Center for Studies of Social Psychology at Central China Normal University. Before conducting the formal experimental procedure, all participants were given an informed consent form in accordance with the Declaration of Helsinki. The informed consent form included a brief description about our study and some possible uncomfortable situations, as well as the confidentiality of their data in terms of remaining anonymous in any publication related to this study. It also informed them about their rights to withdrawal from the experiment at any time, and also included contact information of the researchers so that participants could inquire about any further details of the study. Participants indicated their willingness by checking the "I agree" option and signed their names. The informed consent procedure was identical for all following experiments.

Materials

We recruited 37 participants (21 males, M_{age} = 20.73, SD = 2.16) to examine the reliability of priming exemplars used in previous studies (i.e., male governor, male nurse; female governor, and female nurse). Participants were required to assess the typicality of four exemplars through the Likert 7-point scale (1 = very typical, 7 = very untypical), where higher scores indicate more counter-stereotypic exemplars. A repeated measure Analysis of Variance (ANOVA) showed that scores of counter-stereotype exemplars (M = 4.76, SD = 4.35) were significantly higher than scores of stereotype exemplars (M = 2.41, SD = 2.54), $p_s < 0.001$. Therefore, these exemplars can be used for stereotype/counter-stereotype priming.

Procedures

This experiment adopted a 2 × 2 randomized block design. The independent variables were targets' gender (male vs. female) and priming type (stereotype priming vs. counter-stereotype priming). The dependent variable was their creativity on the poster design.

The procedures were conducted in our laboratory, and each participant completed the experiment alone. Participants were randomly assigned to one of our priming groups (male stereotype: male governors; male counter-stereotype: male nurses; female stereotype: female nurses; and female counter-stereotype: female governors). First, for stereotype/counter-stereotype priming, participants needed to complete a description

TABLE 1 | Participants' allocation and their age distribution in Experiment 1.

	Stereotype priming group			Counter-stereotype priming group		
Targets' gender	***N***	M_{age}	***SD***	***N***	M_{age}	***SD***
Male	12	18.83	2.17	12	18.83	1.12
Female	12	19.67	1.78	12	19.33	2.71

task (Leicht et al., 2014). They were instructed to describe their corresponding group target with six different adjectives. Then, to test the effectiveness of the priming manipulation, participants also evaluated the typicality of the target using the 7-point Likert scale (1 = very typical, 7 = very atypical), which is identical with the procedure used in previous studies. Participants then had to answer what their perceived typicality was for each target in the target's gender group. For example, if a participant were arranged into the male stereotype group, they needed to answer the question, "What is your perceived typicality of male governors based on male stereotypes?".

To replicate the findings from previous studies, we also used the poster paradigm—which these studies used—to first measure participants' creativity (Gocłowska et al., 2013). After the priming of stereotypes or counter-stereotypes, participants were asked to design a poster for their fellowship party, which needed to be as novel and unique as possible. Participants could draw their own poster in any form which they preferred within 5 min.

Results

We used Statistical Package for the Social Sciences (SPSS) 21.0 to analyze our data. Before starting, three psychology postgraduate students were invited to evaluate the creativity of participants' poster designs on a 7-point Likert scale. The postgraduate students were blinded to the design of our experiment and they made their evaluations individually on separate rating sheets. Once obtained, we calculated their internal consistency reliability, with Cronbach $\alpha = 0.772$, which indicated the reliability of their evaluation. Thus, we averaged their ratings of participants' creativity of poster designs.

Firstly, we conducted an independent sample *t*-test to analyze the effectiveness of priming manipulation. The typicality of targets in stereotype priming groups was significantly lower than that of the counter-stereotype priming groups, which indicated an effective manipulation of priming.

Then, a two-way ANOVA only showed a marginal significant main effect of stereotype priming, $F(1, 44) = 3.43$, $p = 0.074$, $\eta_p^2 = 0.071$. Specifically, the creativity of stereotype priming conditions ($M = 2.42$, $SD = 1.06$) was lower than that of counter-stereotype priming conditions ($M = 2.95$, $SD = 0.94$). Furthermore, we separated our files by the target's gender to examine whether different counter-stereotype exemplars have different promotional effects in creativity. Interestingly, the results revealed that counter-stereotype information only promoted creativity when presented a male counter-stereotype exemplar (e.g., male nurse), $F(1, 22) = 5.36$, $p < 0.05$, $\eta_p^2 = 0.196$, rather than a female counter-stereotype exemplar (e.g., female governor), $F(1, 22) = 0.42$, $p = 0.316$, $\eta_p^2 = 0.014$. On the other hand, we did not find a significant main effect based on the target's gender, $F(1, 44) = 0.00$, $p = 0.981$, $\eta_p^2 = 0.000$, or interaction between independent variables, $F(1, 44) = 0.88$, $p = 0.359$, $\eta_p^2 = 0.019$ (as shown in **Figure 1**).

Discussion

The results of Experiment 1 replicated what previous studies have found (Gocłowska et al., 2013, 2014), in that priming of counter-stereotypes boosted creativity to a certain extent. However, considering differences between the background of Eastern and Western cultures, perhaps the poster design itself was a difficult task for Chinese students since most of them have never previously taken part in a party. Therefore, we decided to transform the measurement of creativity in accordance with our cultural background, which is better reflected in the Chinese Idiom Riddle Test (Zhu et al., 2009). Despite there being insignificant interactions between stereotype priming and the target's gender, we still found differences in creativity promotion for male and female counter-stereotype exemplars. Counter-stereotypic male exemplars promoted creativity performance more than counter-stereotypic female exemplars. This result is in accordance with a previous finding that people have less tolerance to counter-stereotypic male exemplars (Signorella and Liben, 1984; Hughes and Seta, 2003; Sullivan et al., 2018), implying that this effect may not only generate negative attitudes, but also influence relative cognitive processes.

EXPERIMENT 2: THE MEDIATING EFFECTS OF EMOTION AND COGNITIVE FLEXIBILITY

Methods

Participants

We recruited 104 college students in Wuhan as participants. One of the participant's information on gender and age was lost; we assigned this individual to the male counter-stereotype priming group. Considering we did not take participant's gender into account as an independent variable, this participant was still included in our final analysis. Similar to Experiment 1, all the participants were randomly assigned to four experimental conditions and their grouping and age distribution are displayed in **Table 2**. Participants volunteered to be involved in this study. The informed consent procedure was identical to Experiment 1.

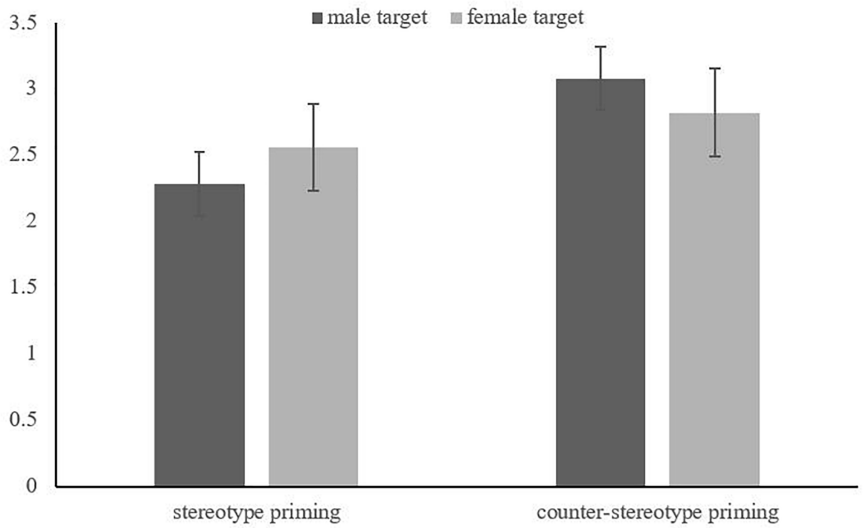

FIGURE 1 | The interaction of target gender and priming type in Experiment 1.

TABLE 2 | Participants' allocation and their age distribution in Experiment 2.

	Stereotype priming group			Counter-stereotype priming group		
Targets' gender	***N***	M_{age}	***SD***	***N***	M_{age}	***SD***
Male	29	19.14	2.15	25	19.16	1.60
Female	23	19.36	2.34	27	18.96	1.61

Measurements

For the measurement of creativity, we adopted the Chinese idiom riddle test with a 10-item idiom riddle (Zhu et al., 2009). This test is one of several insight problem-solving tasks developed from traditional Chinese idioms, and its items and options have been examined in previous studies (Zhu et al., 2009; Huang et al., 2013). Each Chinese idiom riddle item was followed by four options: two irrelevant options, one creative option, and one common option. Participants were required to choose a creative answer which they thought would have the same meaning with the riddle item. A participant's creativity was calculated based on the number of correct selections, with more creative answers indicating a higher level of creativity.

To explore the mediating effect of emotion, especially surprise and delight, participants needed to rate the intensity of their emotions on the 7-point Likert scale (-3 = very unsurprised/undelighted; 3 = very surprised/delighted). A higher score indicated a more intensive emotion activated by stereotype/counter-stereotype priming.

The measurement of cognitive flexibility was developed from a scale examined by Martin and Rubin (1995). This scale consists of 12 items, including 4 reversed items (2, 3, 5, and 10). Participants were required to rate each item on a 7-point Likert scale (1 = very incongruent and 7 = very congruent). After reversing the scores of these four items, we calculated the mean of all the items as the score of the participant's cognitive flexibility. In this study, the Cronbach's α of this scale was 0.83, indicating an accessible reliability of this scale.

Procedures

Design of Experiment 2 was similar to Experiment 1, also adopting a 2 (targets' gender: male vs. female) × 2 (priming type: stereotype vs. counter-stereotype) randomized block design. The dependent variable was the participant's performance on the Chinese idiom riddle test.

The procedure of Experiment 2 was almost identical with that of Experiment 1, except for creativity and the mediation variables measurements. First, participants were instructed to complete a description task to prime stereotypes/counter-stereotypes. Then they needed to report the typicality of the targets in the description task. A Chinese idiom riddle test followed with a 2-min time restriction. In addition, after measuring the independent and dependent variables, the participants were required to rate their intensity of surprise and delight upon completion of the description task. Finally, participants needed to complete a 12-item cognitive flexibility scale.

Results

The Role of Counter-Stereotypes in Creativity Promotion

We checked the effectiveness of manipulations of priming types. An independent-samples *t*-test showed that the

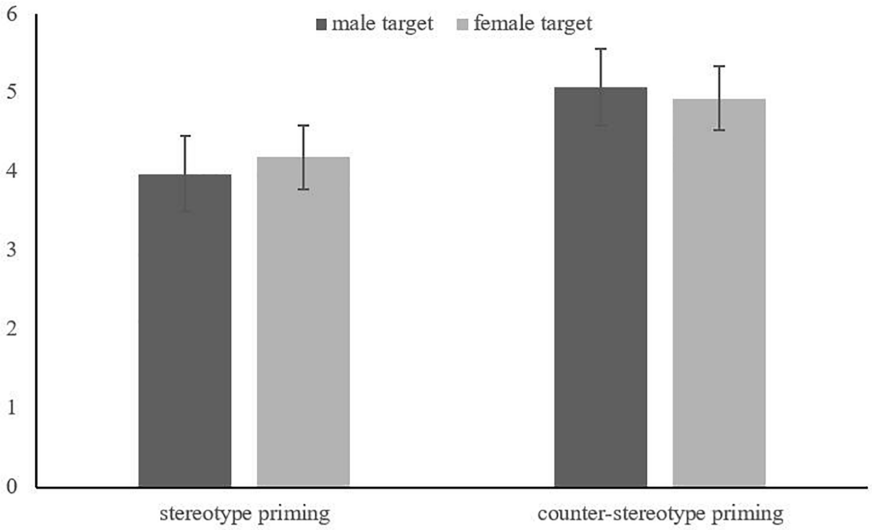

FIGURE 2 | The interaction of targets' gender and priming type in Experiment 2.

typicality of stereotype priming groups (M = 3.29, SD = 2.19) was significantly lower than that of counter-stereotype priming groups (M = 4.29, SD = 1.60), $t(91.42) = 2.62$, $p < 0.05$, $d = 0.51$, $95\%CI$ = [0.24, 1.75]. Thus, the manipulation of priming type was proven effective.

A two-factor ANOVA on participants' creativity showed a main effect of priming type, $F(1, 100) = 3.93$, $p = 0.05$, $\eta_p^2 = 0.04$, while there was no main effect of targets' gender, $F(1, 100) = 0.01$, $p = 0.95$, $\eta_p^2 = 0.000$; the interaction between priming type and targets' gender was not significant, $F(1, 100) = 0.15$, $p = 0.70$, $\eta_p^2 = 0.002$. Compared with stereotype priming ($M = 4.06$, $SD = 2.59$), the counter-stereotype priming (M = 5.00, SD = 2.10) had better effects on the promotion of participants' creativity. Further analysis showed that, although both insignificant, male counter-stereotype priming, $F(1, 53) = 2.68$, $p = 0.11$, $\eta_p^2 = 0.05$, could promote participants' creativity performance better, than female counter-stereotype priming, $F(1, 47) = 1.38$, $p = 0.25$, $\eta_p^2 = 0.03$ (as shown in **Figure 2**).

Examination of the Mediating Effects of Emotion and Cognitive Flexibility

We analyzed the mediating effects of emotion (i.e., delight and surprise) and cognitive flexibility using the Process procedure in SPSS (Hayes, 2013). We assumed that all three mediated the influence of priming type on creativity. The descriptive statistics were conducted first, as shown in **Table 3**.

As shown in **Table 3**, there was a significant correlation between priming type and creativity. Hence, we were able to further analyze any mediating effects. The priming types were independent variables, participants' creativity were dependent variables, while delight, surprise, and cognitive flexibility were mediating variables. The results of the mediating effects are shown in **Table 4**.

From the results of the mediating effects, we can see a significant direct relationship between predictive variables and explanatory variables, with an accessible overall explanatory power of the model. The priming type could significantly predict participants' surprise. Meanwhile, its prediction on cognitive flexibility was marginally significant. Furthermore, after including all the mediating variables into our model, we found an attenuated direct relationship between priming type and creativity, which turned out to become insignificant. On the other hand, only participants' cognitive flexibility could predict their creative performance. Therefore, cognitive flexibility partly mediated the influence of counter-stereotype priming on creativity, as shown in **Figure 3**.

Discussion

Experiment 2 replicated the role of counter-stereotypes on creativity promotion. Moreover, it demonstrated a more important pathway of cognition, which played a significant mediating role in this process. Cognitive flexibility partly mediated the relationship between counter-stereotypic priming and creativity, while the mediating effects of emotion (i.e., surprise and delight) were not significant. Compared with stereotype priming, the participants' cognitive flexibility improved only under counter-stereotype priming conditions, and they performed better on breaking existing mindsets. In addition, the increased cognitive flexibility improved participants' performances in the following creativity test. This study provides further support for the findings of Gocłowska et al. (2013), confirming their inferences about their results. Researchers have found that people tend to overly rely on their stereotypes and newly-activated knowledge to unconsciously limit their flexible thinking (Ward, 2007). Once provided with the opposite information, their stereotyped or schematized knowledge is no longer effective, and they have

TABLE 3 | Means, *SD*s and correlation of mediate model.

Variables	*M*(*SD*)	Priming type	Surprise	Delight	Cognitive flexibility
Surprise	−0.67 (2.17)	0.42***			
Delight	0.87 (1.85)	−0.03	0.08		
Cognitive flexibility	4.57 (0.80)	0.18	0.09	−0.05	
Creativity	4.51 (2.39)	0.20*	0.09	0.15	0.23*

Note: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, $^{+}p < 0.10$.

TABLE 4 | The mediating effect analysis of emotions and cognitive flexibility.

Predictors	Outcome variables	β	*SE*	*t*	*p*
Direct effect					
Priming type	Creativity	0.94	0.46	2.04	0.04
Indirect effect					
Priming type	Cognitive flexibility	0.29	0.16	1.87	0.07
	Surprised	1.796	0.39	4.62	<0.001
	Delighted	−0.083	0.29	−0.28	0.78
Cognitive flexibility	Creativity	0.611	0.29	2.11	0.04
Surprise		−0.017	0.12	−0.15	0.88
Delight		0.269	0.15	1.75	0.08
Priming type		0.819	0.51	1.62	0.11
R^2		0.045			
F		4.16^{+}			

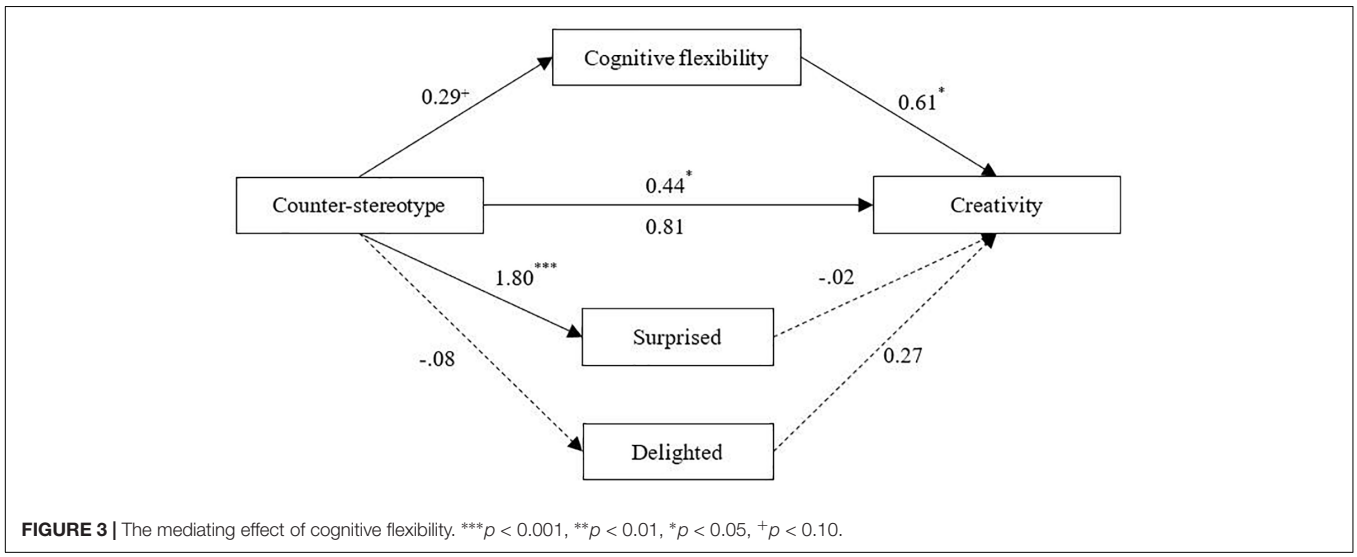

FIGURE 3 | The mediating effect of cognitive flexibility. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, $^{+}p < 0.10$.

to turn from conventional knowledge to newer strategies. In so doing, they construct solutions to problems in a more flexible way, thus demonstrating a higher level of creativity.

GENERAL DISCUSSION

To explore the influence of counter-stereotypes on creativity and its psychological mechanism in a Chinese cultural context, three experiments were designed in this study to verify the relationship between these variables and—for the first time—compared the emotional and cognitive pathways in which counter-stereotypes affect creativity performance. The results demonstrated that in the context of Chinese culture, counter-stereotypes could improve individual creativity while cognitive flexibility played a partial mediating role. The mediating role of surprise and delight was not evident. This study is significant for understanding counter-stereotypes, creativity, and the relationship between the two. First, our replicated results of previous research have demonstrated that the influence of counter-stereotypes on creativity has cross-cultural stability. Second, our study found that creativity performance could be changed through manipulation of counter-stereotypes, which is consistent with

previous research and indicates the malleability of creativity (Dumas and Dunbar, 2016). Finally, the confirmation of the mediating role of cognitive flexibility on the relationship between counter-stereotypes and creativity further reinforces and deepens the findings of Gocłowska et al. (2013).

Cognitive Factors in the Influence of Counter-Stereotypes on Creativity

One of the purposes of this study was to compare the emotional and cognitive pathways through which the counter-stereotype priming affects creativity performance. We found that individual cognitive flexibility can play a partial mediating role in the relationship between counter-stereotypes and creativity. This finding complements previous research on cognitive flexibility (Gocłowska et al., 2014). Although previous research has explored the influence of counter-stereotypes at the cognitive level, most of the research only focused on some concepts in the domain of social cognition (Dasgupta and Greenwald, 2001; Lai et al., 2014; Finnegan et al., 2015). Our present study extends the influence of counter-stereotypic information to a new field, creativity, to which its relevance was previously considered less obvious.

From the perspective of social cognition, we can discover the connection between counter-stereotypic information and creativity. As a simple and quick cognitive schema, stereotypes are key to our social processing. Although this stereotyped way of thinking is fast and effective, it is prone to form an overly-rigid mindset and conflicts with the core process of creativity – the generation of novel connections (Sternberg, 2006; Zhan et al., 2015; Gong et al., 2016). Cognitive-oriented researchers believe that, in our problem-solving process, there are particular scripts which lead to creative thinking (Galinsky et al., 2008). This procedure is also applicable in terms of the influence of counter-stereotypic information. Counter-stereotypic information improves an individual's cognitive flexibility so that they are no longer limited to existing mindsets, knowledge, and experience. With its influence, people unconsciously pay more attention to novel stimulation, regardless of existing knowledge and mindsets, so that they demonstrate a higher level of creativity.

As a new strategy, the improvement of counter-stereotypy on creativity has practicality. Previous research has suggested that diversified experiences (Godart et al., 2015) or counter-stereotypic information presentation has a positive effect on individuals' creativity (female engineers; Anderson et al., 2014). This is also implicated in our research. If people can actively and voluntarily enrich their experience or access more counter-stereotypic information, they will improve their creativity even when living in a common environment.

Emotional Factors in the Influence of Counter-Stereotypes on Creativity

To investigate the mediating effects of surprise and joy, Experiment 2 conducted emotional measurements after priming of stereotype and counter-stereotype information. Even though the results replicated previous studies (Prati et al., 2015), that counter-stereotypes indeed trigger surprise and delight, our results also predicted participants' creativity. However, the mediating effect of either delight or surprise was not significant, which is probably due to the following reasons.

Firstly, from the perspective of the priming task, existing research has suggested the influence of emotion on creativity through cognitive flexibility and persistence (Nijstad et al., 2010). Thus, in our study, cognitive flexibility relates creativity more directly compared with emotions, because we used the adjective description task for counter-stereotype priming. This task required adequate cognitive processing when participants described the targets. In addition, the Chinese idiom riddle test in this study is a type of insight test, which demonstrates automatic association—through unconsciousness—to creative thinking. This measurement relates more with people's existing knowledge about traditional Chinese idioms and memory, which is more likely reflecting people's cognitive abilities. This experiment shows the "matching effect" between counter-stereotype priming tasks and creativity measurements, only connected through cognitive pathways. Therefore, future research could examine whether the promotion of counter-stereotypic information on creativity also acts via emotional pathways, with a more emotional priming approach.

From another perspective, the emotional change due to counter-stereotype priming is momentary. As a result, although the real-time measurement shows that counter-stereotype indeed has triggered the participants' surprise, this emotional arousal might not be maintained throughout the creativity measurement. Therefore, follow-up studies could try to change the method of stereotype priming and make the priming process produce a more lasting and profound emotional experience.

The Effect of Counter-Stereotypes on Creativity Differs Across Target's Gender

Throughout two experiments, we have found a stable difference of creativity promotion between male and female counter-stereotype targets. Male counter-stereotype target improve creativity significantly more than female counter-stereotype target both in poster design and Chinese idiom riddle test.

These results are in accordance with previous findings, which revealed that people have different attitudes toward counter-stereotypic behaviors of male and female (Hughes and Seta, 2003; Signorella and Liben, 1984; Sullivan et al., 2018), i.e., people tend to evaluate negatively to counter-stereotype male rather than counter-stereotype female. This predisposition seems influence subsequent cognitive performance from the view of our study. There are two ways can explain how it works. On the one hand, although the manipulation of stereotype priming was effective in our study, the typicality of counter-stereotype male and female tend to be different. Counter-stereotypic male (i.e., male nurse) was perceived less typical than counter-stereotypic female (i.e., female governor), and it further influence their effect on creativity promotion. On the other hand, because of the negative attitude toward counter-stereotype males, there are less males behaving in counter-stereotypic way in our daily life. Thus, the imagining of a counter-stereotype male (i.e., male nurse) intrigues emotions

with higher intensity, as well as a higher level of cognitive flexibility. Thereby improve participants' creativity.

As mentioned earlier, counter-stereotypes are cognitive views of a social group, which behaviors or traits are contrary to the mindset of its superordinate group (Liu and Zuo, 2006; Leicht et al., 2017). Our findings suggest that the cognitive process of counter-stereotype not only influences the perception and evaluation of a certain group, but also other cognitive functions related, such as cognitive flexibility and creativity. Based on these results, further study can explore whether the typicality of counter-stereotype target mediate the effect of counter-stereotype on creativity, and if counter-stereotype priming has influence on other cognitive functions or processes.

Research Limitations and Future Directions

Based on previous research, this study demonstrated the correlation between counter-stereotypes and creativity and also examined the mediating role of cognitive flexibility in this process. However, there are still several limitations in our study.

Regarding of the research content, although we only identified the mediating role of cognitive flexibility, there is probably a more complicated underlying psychological mechanism between counter-stereotypes and creativity working through the pathway of cognition and emotion. Future studies can use various paradigms to replicate this effect and explore whether there is a "matching effect" between counter-stereotype priming tasks and creativity measurements. Also, other mediating factors in the influence of counter-stereotype on creativity are needed to be discovered. Furthermore, future research can explore the long-lasting effects of creativity promotion from the perspective of social cognition, which may shed light on developing new ways of creativity training.

CONCLUSION

This study adopted different measurements of creativity, both via the poster design and Chinese idiom riddle test. By comparing the participants' creativity performance in stereotype and counter-stereotype priming conditions, we investigated the internal mechanism of counter-stereotypic information priming on creativity to further explore whether emotions (i.e., delight and surprise) or cognitive flexibility played a mediating role. This study revealed that counter-stereotype priming can significantly improve individual creativity performance, while cognitive flexibility plays only a partial mediating role in this process. Our findings suggest a diversified environment might impact our cognitive process unconsciously, and further beneficial our creative performance.

AUTHOR CONTRIBUTIONS

BZ and FW conceived and designed the whole experiments, and wrote the article. MW and YW collected the data.

FUNDING

This research was supported by National Natural Science Foundation of China (31571147), National Social Science Major Project of China (18ZDA331) and Self-determined Research Funds of CCNU from the Colleges' Basic Research and Operation of MOE grants (CCNU18ZDPY12).

REFERENCES

Akinola, M., and Mendes, W. B. (2008). The dark side of creativity: biological vulnerability and negative emotions lead to greater artistic creativity. *Pers. Soc. Psychol. Bull.* 34, 1677–1686. doi: 10.1177/0146167208323933

Amabile, T. M. (1983). The social psychology of creativity: a componential conceptualization. *J. Pers. Soc. Psychol.* 45, 357–376. doi: 10.1037/0022-3514.45.2.357

Anderson, N., Potočnik, K., and Zhou, J. (2014). Innovation and creativity in organizations: a state-of-the-science review, prospective commentary, and guiding framework. *J. Manag.* 40, 1297–1333. doi: 10.1177/0149206314527128

Asgari, S., Dasgupta, N., and Cote, N. G. (2010). When does contact with successful ingroup members change self-stereotypes? A longitudinal study comparing the effect of quantity vs. quality of contact with successful individuals. *Soc. Psychol.* 41, 203–211. doi: 10.1027/1864-9335/a000028

Asgari, S., Dasgupta, N., and Stout, J. G. (2012). When do counterstereotypic ingroup members inspire versus deflate? The effect of successful professional women on young women's leadership self-concept. *Pers. Soc. Psychol. Bull.* 38, 370–383. doi: 10.1177/0146167211431968

Ashby, F. G., and Isen, A. M. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychol. Rev.* 106, 529–550. doi: 10.1037/0033-295X.106.3.529

Barr, N., Pennycook, G., Stolz, J. A., and Fugelsang, J. A. (2015). Reasoned connections: a dual-process perspective on creative thought. *Think. Reason.* 21, 61–75. doi: 10.1080/13546783.2014.895915

Barron, F., and Harrington, D. M. (1981). Creativity, intelligence, and personality. *Annu. Rev. Psychol.* 32, 439–476. doi: 10.1146/annurev.ps.32.020181.002255

Batey, M., and Furnham, A. (2006). Creativity, intelligence, and personality: a critical review of the scattered literature. *Genet. Soc. Gen. Psychol. Monogr.* 132, 355–429. doi: 10.3200/MONO.132.4.355-430

Beaty, R. E., Benedek, M., Kaufman, S. B., and Silvia, P. J. (2015). Default and executive network coupling supports creative idea production. *Sci. Rep.* 5:10964. doi: 10.1038/srep10964

Beaty, R. E., Benedek, M., Silvia, P. J., and Schacter, D. L. (2016). Creative cognition and brain network dynamics. *Trends Cogn. Sci.* 20, 87–95. doi: 10.1016/j.tics.2015.10.004

Beaty, R. E., Silvia, P. J., Nusbaum, E. C., Jauk, E., and Benedek, M. (2014). The roles of associative and executive processes in creative cognition. *Mem. Cogn.* 42, 1186–1197. doi: 10.3758/s13421-014-0428-8

Bolukbasi, T., Chang, K. W., Zou, J. Y., Saligrama, V., and Kalai, A. T. (2016). "Man is to computer programmer as woman is to homemaker? Debiasing word embeddings," in *Paper Presented at the 30th Conference on Neural Information Processing Systems*, (Barcelona, Spain).

Colombo, B., Antonietti, A., and Daneau, B. (2018). The relationships between cognitive reserve and creativity. A study on American aging population. *Front. Psychol.* 9:764. doi: 10.3389/fpsyg.2018.00764

Columb, C., and Plant, E. A. (2011). Revisiting the obama effect: exposure to obama reduces implicit prejudice. *J. Exp. Soc. Psychol.* 47, 499–501. doi: 10.1016/j.jesp.2010.11.012

Conner, T. S., and Silvia, P. J. (2015). Creative days: a daily diary study of emotion, personality, and everyday creativity. *Psychol. Aesthet. Creat. Arts* 9, 463–470. doi: 10.1037/aca0000022

Damer, E., Webb, T., and Crisp, R. J. (2017). *Diversity Helps the Uninterested: Exposure to Counter-Stereotypes Benefits People Low (But not High) in Need for Cognition*. Thousand Oaks, CA: SAGE Publications.

Dasgupta, N., and Greenwald, A. G. (2001). On the malleability of automatic attitudes: combating automatic prejudice with images of admired and disliked individuals. *J. Pers. Soc. Psychol.* 81, 800–814. doi: 10.1037//0022-3514.81.5.800

De Dreu, C. K., Baas, M., and Nijstad, B. A. (2008). Hedonic tone and activation level in the mood-creativity link: toward a dual pathway to creativity model. *J. Pers. Soc. Psychol.* 94, 739–756. doi: 10.1037/0022-3514.94.5.739

Dietrich, A., and Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychol. Bull.* 136, 822–848. doi: 10.1037/a0019749

Dumas, D., and Dunbar, K. N. (2016). The creative stereotype effect. *PLoS One* 11:e0142567. doi: 10.1371/journal.pone.0142567

Eagly, A. H., and Steffen, V. J. (1984). Gender stereotypes stem from the distribution of women and men into social roles. *J. Pers. Soc. Psychol.* 46, 735–754. doi: 10.1037/0022-3514.46.4.735

Ellemers, N. (2018). Gender stereotypes. *Annu. Rev. Psychol.* 69, 275–298. doi: 10.1146/annurev-psych-122216-011719

Evans, J. S. B., and Stanovich, K. E. (2013). Dual-process theories of higher cognition: advancing the debate. *Perspect. Psychol. Sci.* 8, 223–241. doi: 10.1177/1745691612460685

Finnegan, E., Oakhill, J., and Garnham, A. (2015). Counter-stereotypical pictures as a strategy for overcoming spontaneous gender stereotypes. *Front. Psychol.* 6:1291. doi: 10.3389/fpsyg.2015.01291

Galinsky, A. D., Magee, J. C., Gruenfeld, D. H., Whitson, J. A., and Liljenquist, K. A. (2008). Power reduces the press of the situation: implications for creativity, conformity, and dissonance. *J. Pers. Soc. Psychol.* 95, 1450–1466. doi: 10.1037/a0012633

Gocłowska, M. A., Baas, M., Crisp, R. J., and De Dreu, C. K. (2014). Whether social schema violations help or hurt creativity depends on need for structure. *Pers. Soc. Psychol. Bull.* 40, 959–971. doi: 10.1177/0146167214533132

Gocłowska, M. A., Crisp, R. J., and Labuschagne, K. (2013). Can counter-stereotypes boost flexible thinking? *Group Process. Intergroup Relat.* 16, 217–231. doi: 10.1177/1368430212445076

Godart, F. C., Maddux, W. W., Shipilov, A. V., and Galinsky, A. D. (2015). Fashion with a foreign flair: professional experiences abroad facilitate the creative innovations of organizations. *Acad. Manag. J.* 58, 195–220. doi: 10.5465/amj.2012.0575

Goncalo, J. A., and Staw, B. M. (2006). Individualism–collectivism and group creativity. *Organ. Behav. Hum. Decis. Process.* 100, 96–109. doi: 10.1016/j.obhdp.2005.11.003

Gong, Z., Liu, C., and Shen, W. (2016). Several thoughts on measuring creativity. *Adv. Psychol. Sci.* 24, 31–45. doi: 10.3724/SP.J.1042.2016.00031

Hayes, A. F. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. New York, NY: The Guilford Press.

Hayes, J. R. (1989). "Cognitive processes in creativity," in *Handbook of creativity*, ed. R. J. Sternberg (Boston, MA: Springer), 135–145. doi: 10.1007/978-1-4757-5356-1_7

Heilman, K. M., Nadeau, S. E., and Beversdorf, D. O. (2003). Creative innovation: possible brain mechanisms. *Neurocase* 9, 369–379. doi: 10.1076/neur.9.5.369.16553

Hirt, E. R., Devers, E. E., and McCrea, S. M. (2008). I want to be creative: exploring the role of hedonic contingency theory in the positive mood-cognitive flexibility link. *J. Pers. Soc. Psychol.* 94, 214–230. doi: 10.1037/0022-3514.94.2.94.2.214

Hocevar, D. (1981). Measurement of creativity: review and critique. *J. Pers. Assess.* 45, 450–464. doi: 10.1207/s15327752jpa4505_1

Hofstede, G. (2001). *Culture's Consequences: Comparing Values, Behaviors, Institutions And Organizations Across Nations*. Thousand Oaks, CA: Sage publications.

Huang, F., Zhou, Z., and Zhao, Q. (2013). An eye movement study of associate competition in Chinese idiom riddles solving. *Acta Psychol. Sin.* 41, 397–405. doi: 10.3724/SP.J.1041.2013.00035

Huang, S., Lin, C., and Wang, Y. (2005). A review on implicit theories of creativity: origin and prospect. *Adv. Psychol. Sci.* 13, 715–720.

Hughes, F. M., and Seta, C. E. (2003). Gender stereotypes: children's perceptions of future compensatory behavior following violations of gender roles. *Sex Roles* 49, 685–691. doi: 10.1023/B:SERS.0000003341.73966.61

Kandler, C., Riemann, R., Angleitner, A., Spinath, F. M., Borkenau, P., and Penke, L. (2016). The nature of creativity: the roles of genetic factors, personality traits, cognitive abilities, and environmental sources. *J. Pers. Soc. Psychol.* 111, 230–249. doi: 10.1037/pspp0000087

Kim, K. H. (2006). Can we trust creativity tests? A review of the torrance tests of creative thinking (TTCT). *Creat. Res. J.* 18, 3–14. doi: 10.1207/s15326934crj1801_2

Lai, C. K., Marini, M., Lehr, S. A., Cerruti, C., Shin, J.-E. L., Joy-Gaba, J. A., et al. (2014). Reducing implicit racial preferences: I. A comparative investigation of 17 interventions. *J. Exp. Psychol.* 143, 1765–1785. doi: 10.1037/a0036260

Leicht, C., de Moura, R. G., and Crisp, R. J. (2014). Contesting gender stereotypes stimulates generalized fairness in the selection of leaders. *Leadersh. Q.* 25, 1025–1039. doi: 10.1016/j.leaqua.2014.05.001

Leicht, C., Gocłowska, M. A., Breen, J. A. V., Lemus, S. D., and Moura, G. R. D. (2017). Counter-stereotypes and feminism promote leadership aspirations in highly identified women. *Front. Psychol.* 8:883. doi: 10.3389/fpsyg.2017.00883

Liu, X., and Zuo, B. (2006). Psychological mechanism of maintaining gender stereotype. *Adv. Psychol. Sci.* 14, 456–461.

Martin, M. M., and Rubin, R. B. (1995). A new measure of cognitive flexibility. *Psychol. Rep.* 76, 623–626. doi: 10.2466/pr0.1995.76.2.623

Nijstad, B. A., De Dreu, C. K., Rietzschel, E. F., and Baas, M. (2010). The dual pathway to creativity model: creative ideation as a function of flexibility and persistence. *Eur. Rev. Soc. Psychol.* 21, 34–77. doi: 10.1080/10463281003765323

Nusbaum, E. C., and Silvia, P. J. (2011). Are intelligence and creativity really so different? Fluid intelligence, executive processes, and strategy use in divergent thinking. *Intelligence* 39, 36–45. doi: 10.1016/j.intell.2010.11.002

Parish, L., and Hudson, L. (1970). Frames of mind: ability, perception and self perception in the arts and sciences. *Br. J. Educ. Stud.* 18:110. doi: 10.2307/3120148

Prati, F., Crisp, R. J., and Rubini, M. (2015). Counter-stereotypes reduce emotional intergroup bias by eliciting surprise in the face of unexpected category combinations. *J. Exp. Soc. Psychol.* 61, 31–43. doi: 10.1016/j.jesp.2015.06.004

Scott, G., Leritz, L. E., and Mumford, M. D. (2004). The effectiveness of creativity training: a quantitative review. *Creat. Res. J.* 16, 361–388. doi: 10.1080/10400410409534549

Shalley, C. E., and Gilson, L. L. (2004). What leaders need to know: a review of social and contextual factors that can foster or hinder creativity. *Leadersh. Q.* 15, 33–53. doi: 10.1016/j.leaqua.2003.12.004

Signorella, M. L., and Liben, L. S. (1984). Recall and reconstruction of gender-related pictures: effects of attitude, task difficulty, and age. *Child Dev.* 55, 393–405. doi: 10.2307/1129951

Simonton, D. K. (2014). The mad-genius paradox: can creative people be more mentally healthy but highly creative people more mentally ill? *Perspect. Psychol. Sci.* 9, 470–480. doi: 10.1177/1745691614543973

Sligte, D. J., De Dreu, C. K., and Nijstad, B. A. (2011). Power, stability of power, and creativity. *J. Exp. Soc. Psychol.* 47, 891–897. doi: 10.1016/j.jesp.2011.03.009

Song, J., and Zuo, B. (2016). Functional significance of conflicting age and wealth cross-categorization: the dominant role of categories that violate stereotypic expectations. *Front. Psychol.* 7:1624. doi: 10.3389/fpsyg.2016.01624

Sternberg, R. J. (2006). The nature of creativity. *Creat. Res. J.* 18, 87–98. doi: 10.1207/s15326934crj1801_10

Sullivan, J., Moss-Racusin, C., Lopez, M., and Williams, K. (2018). Backlash against gender stereotype-violating preschool children. *PLoS One* 13:e0195503. doi: 10.1371/journal.pone.0195503

Sun, S., Zuo, B., Wu, Y., and Wen, F. (2016). Does perspective taking increase or decrease stereotyping? the role of need for cognitive closure. *Pers. Individ. Dif.* 94, 21–25. doi: 10.1016/j.paid.2016.01.001

Vartanian, O. (2009). Variable attention facilitates creative problem solving. *Psychol. Aesthet. Creat. Arts* 3, 57–59. doi: 10.1037/a0014781

Ward, T. B. (2007). Creative cognition as a window on creativity. *Methods* 42, 28–37. doi: 10.1016/j.ymeth.2006.12.002

White, M. J., and White, G. B. (2006). Implicit and explicit occupational gender stereotypes. *Sex Roles* 55, 259–266. doi: 10.1007/s11199-006-9078-z

Zha, P., Walczyk, J. J., Griffith-Ross, D. A., Tobacyk, J. J., and Walczyk, D. F. (2006). The impact of culture and individualism–collectivism on the creative potential and achievement of American and Chinese adults. *Creat. Res. J.* 18, 355–366. doi: 10.1207/s15326934crj1803_10

Zhan, H., Liu, C., and Shen, W. (2015). Neural basis of creative thinking during four stages. *Adv. Psychol. Sci.* 23, 213–224. doi: 10.3724/SP.J.1042.2015.00213

Zhang, X., Li, Q., Shan, S., and Zuo, B. (2016). The time course from gender categorization to gender stereotype activation. *Soc. Neurosci.* 13, 52–60. doi: 10.1080/17470919.2016.1251965

Zhang, Y., Wen, F., Zuo, B., and Tan, X. (2018). "The priority and stability of children social categorization," in *Development Psychology and Mental Health. Symposium Conducted at the Meeting of Chinese Association of Social Psychology*, ed. J. Chen (Yunnan: Yunnan Minzu University).

Zhu, X., Li, R., and Zhou, Z. (2009). The role of clues in chinese idiom riddle solving. *Acta Psychol. Sin.* 41, 397–405. doi: 10.3724/SP.J.1041.2009.00397

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 07 February 2019
doi: 10.3389/fpsyg.2019.00188

Computational Simulation of Team Creativity: The Benefit of Member Flow

*Chong Zu[1], Hui Zeng[2,3] and Xiang Zhou[1,3]**

[1] Department of Social Psychology, Nankai University, Tianjin, China, [2] School of Economics, Nankai University, Tianjin, China, [3] Collaborative Innovation Center for China Economy, Tianjin, China

This study simulates the team cognition model through NetLogo 6.0.2 to view a dynamic changing of team creativity during knowledge sharing when the team members perform problem-solving tasks. A hypothesis is proposed: (a) when people possess various characteristics, members who own high-level normal knowledge and have high communication frequency are suited to perform problem construction process and members who own high-level creative knowledge and have less communication frequency are suited to perform divergent exploration process; (b) member flow that old-timer is replaced by a new member, can improve the team creativity and keep it more stable. The team cognition model is based on the social network of the team, where members are assigned cognition tasks. Also, the simulation experiments are conducted in 6 conditions and each condition has one situation including "MemberFlow" procedure, and one excluding "MemberFlow" procedure. Each experiment contains 500 repetitive experiments and in each repetition, there are 100 steps of "GO" procedure are performed. The results show that the team creativity is maximal and stable in the condition of hypothesis (a), and member flow can optimize the team creativity.

Keywords: team creativity, member flow, social network, computational simulation, knowledge sharing, NetLogo

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Antonio Francesco Corno,
University of Leicester,
United Kingdom
Xuexin Zhang,
Fudan University, China

****Correspondence:***
Xiang Zhou
zhouxiang@nankai.edu.cn

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *29 September 2018*
Accepted: *21 January 2019*
Published: *07 February 2019*

Citation:
Zu C, Zeng H and Zhou X (2019) Computational Simulation of Team Creativity: The Benefit of Member Flow. Front. Psychol. 10:188. doi: 10.3389/fpsyg.2019.00188

INTRODUCTION

Many influential factors of creativity, on the individual and team level, have been researched, such as openness of personality, intrinsic motivation, social characteristics, knowledge sharing, cognition processes and so on (Hennessey, 2015; Jiang et al., 2018; Lee, 2018; Xu et al., 2018). Most studies are focused on a particular factor to examine their correlations. Comparing with other methods, computational simulation can integrate several influential factors in one experiment to observe the team creativity in the environment approaching the reality. In this study, the team cognition model is simulated through NetLogo 6.0.2, using Logo language, where knowledge is shared during the team communication, and the team members generate the solutions for a specific problem through problem-solving cognitive processes. In this computational simulation, team creativity can be evaluated through how many creative solutions can be found in all solutions that can solve this problem. And the subjects in the virtual experiments are the agents, and the set of agents called "agentset." One of the advantages that computational simulation has is that many potential characteristics can be considered in the simulation experiments, like knowledge structure and communication frequency, which are the important characters that agents possess in the simulation.

Since 1950, researchers have started to turn their interests on creativity (Guilford, 1950). After years of efforts, the essence of creativity could be understood through multi-levels, and psychologists reveal personalities, thinking modes, emotion, cognition, social characteristics can affect creativity on the individual level and organizational level, in order to provide more creative productions and better life quality. Creativity is an ability that can produce novel and useful achievements (Sternberg and Lubart, 1996). The achievements can be creative ideas, solutions for the particular problems, results from task accomplishment, and products of variety kinds of arts and et al. Team can be defined as two or more members possessing distinct characteristics and knowledge who interact dynamically, dependently and adaptively with each other to accomplish a general and valuable task, where every one is distributed specific task to perform with limited time as a member of the team (Salas, 1992). Although individual creativity of members is the foundation of the team creativity, synergistic interaction among members is crucial, so that generating creative productions are base on the individual knowledge, and knowledge sharing through communication can also affect the team creativity.

Knowledge is the base-stone of individual creativity. People cannot create new things surpass their knowledge. Therefore, when the creativity is discussed and researched, knowledge structure is a crucial characteristic in the study. In the simulation, agents need to conduct their problem-solving processes according to the knowledge pool so that their knowledge structure may affect their performance. Beyond that, many other individual characteristics, like the openness of personality, intrinsic motivation, social characteristics, can make an effect to the creativity for a creative production (Feist, 1998; Wolfradt and Pretz, 2001; Sacchetti and Tortia, 2013). These attributes can give individuals a proper intrinsic environment to generate creative achievements based on their knowledge. Besides, in terms of social characteristics, the change of social position and tie strength caused by team communication can affect the efficiency of information acquisition (Perry-Smith and Shalley, 2003; Perry-Smith, 2006). Therefore, the hypothesis has been proposed that member flow, which means in this case that using new member who is willing to communicate to ones who contains the various knowledge, would improve the team creativity and keep it more stable. In this case, member flow can be defined as that old-timer shifts out, and a new member joins this team alternatively.

All the characteristics that can affect individual creativity can be seen as a mediator between their knowledge and their performance in the cognitive processes. Thus, they are simplified in the computational simulation into efficiency variable, which represents how is the performance that people generate creative productions based on their knowledge. In the simulation, the efficiency variable is controlled as a control variable. In addition to the personal level, people collaborate with others as a team or group for a specific task through communication, which forms a social network. Simonton (2000) once suggested that successful research on creativity should place creative individuals among social network; therefore social characteristics play an important role on individual creativity, which contains the strength of the relationship, position in the social network. In terms of strength of the relationship, according to the strength-of-weak-ties theory from Granovetter (1973), weak ties interspersing among social network, which means low frequency and short time interaction and limited intimacy in the relationship, could improve on generating creative ideas. In addition, for the reason that new ideas produce from the interrelationship of previous ideas, creative ideas need an amount of information and knowledge as the basis of competence to generate creative ideas. Hence, the quality and efficiency of information acquisition are crucial. Individuals with weak ties in the social network, who can only get information less repeatedly, would get less redundant information and knowledge thereby improving the efficiency of information acquisition, compared to the ones with strong ties (Granovetter, 1973). Another social characteristic is the position including Centrality and Peripherality. Approaching the central position may increase individual creativity while surpassing a general level can impede developing creativity. That is because that people in central position would experience more relationship conflicts causing anxiety, thus strangling one's creativity (Podolny et al., 1997). Thus, how is an individual's strength of the relationship can be manipulated through team communication in the simulation, which is defined as the frequency of member who shares their knowledge to other members. Meanwhile, the position of the member in the team is a potential characteristic, which is an outcome of communication. In this case, this kind of communication is the knowledge sharing process.

In the individual level, the brain generates creativity, which influenced by personality, intrinsic motivation and social characteristics and other properties; in the team level, communication, and cognition compose to the brain of the team. Cooke brought about Interactive team cognition, considering that team cognition produces from the interaction among members, where people generate dynamic emergence of team cognition through interaction, negotiation, decision, and other mutual actions (Cooke et al., 2013; Cooke, 2015). Consequently, team cognition, as a complicated dynamic model, emerges from simple communication among members, which can be considered as neural connections in the brain. In many measurements, the condition of achieving tasks, producing ideas and works can be evaluated as the criteria for creativity, the processes of which need to integrate all competencies of members and knowledge, where the team communication plays a crucial role. Communication cannot only integrate productions derived from cognitive actions, but communication is also a precondition for knowledge sharing. The knowledge structure is of importance to generate new novel productions, so that knowledge diversity is one of the influence factors (Pelled et al., 1999). When the team executes cognitive activities, performs tasks, members communicate with each other for knowledge sharing to generate creative ideas and works, or solve problems, accomplish tasks. In this research, the knowledge of members is shared among the team and with the other team.

If team communication could be compared to neural connections, team cognition might be viewed as the structure of the brain. Team cognition processes in problem-solving had

been extended from individual level (Reiter-Palmon et al., 2008). The problem-solving task is the research that can be solved by various methods and solutions, based on the information stored in the memory (Chiew and Wang, 2004). Many researchers developed their own models to overview this cognitive process. For instance, Bransford and Stein (1984) designed the problem-solving model as problem identification, problem representation, strategy selection, strategy application, and result evaluation. For computational simulation, an integrated team cognition model can be summarized as problem construction, divergent exploration, evaluation and conclusion. Problem construction can be valued through problem restatements, and a good problem construction can produce creative solutions with high quality (Reiter-Palmon et al., 1997; Reiter-Palmon and Robinson, 2009). In the model of Runco and Chand (1995), it is a problem finding process, aiming to decide the properties of the problem and strategy selection. In this research, agents can construct the range of the problem for subsequent divergent exploration. In the divergent exploration process, the team uses divergent thinking to explore novel and useful solutions for the problem. After exploration, the team combines scattered opinions from members to generate preliminary solutions through communication. With regard to the whole team, the solutions that generate from members independently are, inevitably, resembling or even repetitive. Therefore, in this step, integrating these solutions effectively also will be included. In the last process, evaluation and conclusion, the solutions need to be evaluated if they are useful and novel, in order to measure team creativity. In the simulation, problem construction and divergent exploration are considered and manipulated through agents, who would conduct these procedures based on their knowledge and their efficiency, which can control how many problem restatements and various solutions that they can explore. The evaluation and conclusion part can be developed in the subsequent researches.

This study builds a team cognition model to describe how the members work as a team, and then a computational simulation is programmed through NetLogo 6.0.2 and virtual experiments are performed in the BehaviorSpace in the NetLogo. Knowledge and Efficiency are the characteristics included for each team member agent, and they can share their knowledge, based on which agents execute their corresponding problem-solving processes. The aim of simulation is that a dynamic changing can be viewed in different parameters of agents and problem, and beyond that, a hypothesis can be disclosed which is member flow can improve the team creativity.

MATERIALS AND METHODS

Team Cognition Model

The model is constructed before the simulation to conduct each of the team members what cognitive activities would proceed when they solve a specific problem and the team formation as a social network. The social network is formed from the interaction of members who are belonged to this network and then individual social characteristics are given to every member, like their tie strength and position, which may affect their performance in the team. Besides, knowledge is an important characteristic that can affect the team problem-solving results. Therefore, there are the hypotheses:

(a) When people possess various knowledge structure and communication style, members who have more normal knowledge and communicate with others more frequently, are suited to perform problem construction process; members who have more creative knowledge and communicate with others less frequently, are suited to perform divergent exploration process. This arrangement can optimize team creativity.
(b) When member flows at intervals, team creativity would be more stable and higher.

The team is constituted by two or more members who possess divergent knowledge and members who are distributed the same problem-solving task form a group: supervision group need to perform problem construction task; exploration group need to execute divergent exploration task; evaluation group is in charge of evaluation and conclusion part. In this study, the effect of evaluation and conclusion procedure to the team creativity is not considered. Meanwhile, many other properties of individuals are simplified to the efficiency that is described as a mediator element represented to how efficient members are exchanging knowledge into results of each problem-solving process. The efficiency variation as one of the individual characters is controlled as a control variable, which is affected by personality, motivation and other factors.

According to **Figure 1**, Team Cognition Model, the team is a social network; the lines connect with other members represent the interaction, including information and knowledge sharing and normal communication. And the members separate into three groups, depending on their creativity, social characteristic and responsibility, to execute the corresponding cognitive process. While members' social character will change along with executing cognition tasks, team creativity would change adaptively, which will conduct the computational simulation.

Methods

The simulation is implemented by NetLogo 6.0.2 (Wilensky, 1999), which is a multi-agent programmable simulation tool. The agents and their characteristics and the elements of the world can be set up in the "Setup" procedure. In the "World" (**Figure 2**), every agent and their behaviors can be observed. Also, their behaviors can be manipulated in the "Go" procedure. On the interface, variables can be adjusted in the certain range, and the results can be displayed through "World" and "Plot" function can show the variation of the variable at interest. Meanwhile, virtual experiments can be performed through BehaviorSpace, where the times of "Go" procedure executed in once experiment and the times of experiments can be regulated.

The psychological course is complicated and circuitous so that it is difficult to simulate all the mental processes and consider all the individual characters. Thus, some processes and characters are set up as the control variables, and in

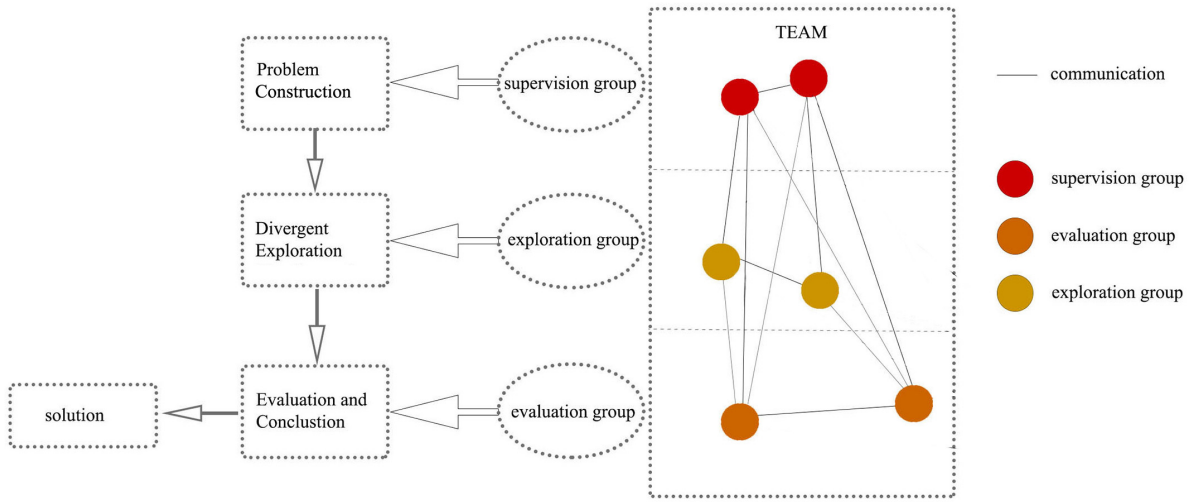

FIGURE 1 | The number of members is adjustable and they communicate with each other in the team. According to the social position in the team, central members form supervision group to execute Problem Construction process, showing with red balls; Peripheral members form exploration group to generate various solutions in Divergent Exploration process, showing with yellow balls; Other members form the evaluation group to perform Evaluation and Conclusion process to integrate scattered solutions and evaluate whether final solution is creative or not, showing with orange balls.

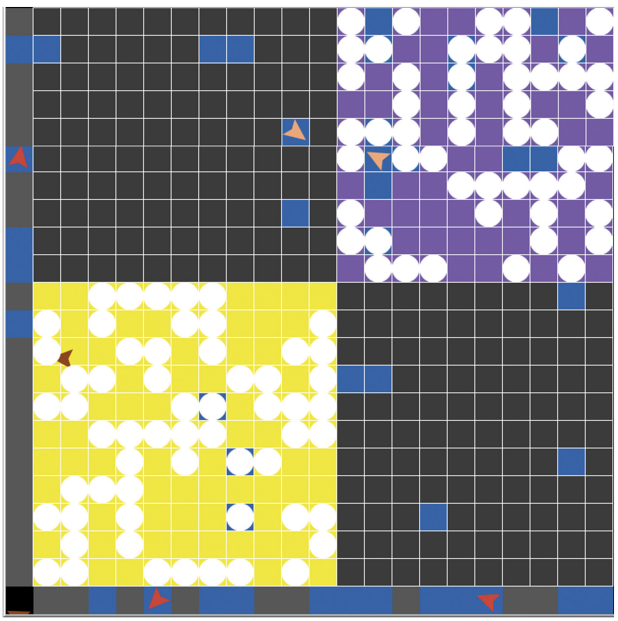

FIGURE 2 | It is the "World" that can observe the member agents (triangle figures) and the rabbit agents (write round figures). The yellow part represents the normal knowledge area (normal solution area) and the purple part represents the creative knowledge area (creative solution area); the blue part represents the solutions that the team generates. When the blue part overlaps with rabbit agents, it means a feasible solution.

this case, they are evaluation and conclusion process and efficiency, which represents to individual characteristics that can affect the efficiency of transforming knowledge into solutions.

In the team, there are three Agentsets: Supervision Group Agentset, Exploration Group Agentset and Evaluation Group Agentsets. Based on the team cognition model that mentioned before, agents' characteristics are knowledge structure, the frequency of communication and efficiency. Knowledge is divided into normal knowledge and creative knowledge; the ratio of them can be adjusted, and also the frequency and efficiency can be modulated. In the experiments, the characteristics of agents in the Evaluation Group Agentset and Efficiency variables of all agents are controlled at a moderate level. The problem in the simulation is a series of coordinates of rabbits who are distributed in the normal knowledge area and creative knowledge area in the "World". The size of the "World" is based on the range of total Knowledge Pool (KP) who is a global array variable where every item of knowledge pool of all the agents are picked stochastically. The main variables are shown in **Table 1**.

Meanwhile, the simulation is a stochastic process so that the study discards the results of the first five steps because the random numbers that are set up in the "Setup" procedure would generate the noise.

The team creativity is calculated through:

$$tc = \frac{NS_{creative}}{NS_{creative} + NS_{normal}}$$

In the equation, tc represents the team creativity, which means the ratio of the number of creative solutions in the total solutions the team got, where $NS_{creative}$ is the number of creative solutions and NS_{normal} is the number of normal solutions.

The aim of simulation is to optimize the team creativity, finding a situation that can make tc maximal and stable, and the hypothesis is when members are arranged in the suitable cognition process group, and member flows at intervals, the team creativity can be maximum and stability.

TABLE 1 | There are three Agentsets of the team members: Supervision Group Agentset, Exploration Group Agentset, Evaluation Group Agentset, and a Rabbits Agentset, whose coordinates (RCoordinate) compose the given problem need to be solved.

Agentset	Variables
Supervision Group Agentset	$SKP = SKP_{normal} + SKP_{creative}$
	SKN_{normal}
	$SKN_{creative}$
	SC
	SE (control variable)
Exploration Group Agentset	$EKP = EKP_{normal} + EKP_{creative}$
	EKN_{normal}
	$EKN_{creative}$
	EC
	EE (control variable)
Rabbits Agentset	RCoordinate
Global	tc
	$KP = KP_{normal} + KP_{creative}$

KP is the total knowledge pool, from which items are stochastically selected into SKP and EKP, which are the knowledge pool of supervision group and exploration group; KP is also decided the range of the "World". SKN_{normal}, $SKN_{creative}$, EKN_{normal}, $EKN_{creative}$ are the variables controlled how many items are in the corresponding knowledge pool arrays. SC and EC represent the frequency of communication of members in each group. In the experiments, Evaluation Group Agentset and Efficiency variable (SE, EE) are controlled and all of their characters are set up at the moderate level. The team creativity variable (tc) is calculated in the experiment and output as the dependent variable.

SIMULATION AND RESULTS

Simulation Procedures

In the "Setup" procedure, Agentsets are bred and every variable is announced, and as well the "World" is created according to the range of total knowledge pool. All the numbers in the normal knowledge pool array compose into the normal problem area, and ones in the creative knowledge pool array compose into the creative problem area. The area formed by numbers' combination of both knowledge pool is the redundant area, where rabbits would not generate.

Then the "Go" procedure is performed, which includes providing the problem, Knowledge sharing process, and problem construction process, divergent exploration process, and member flow process and team creativity measurement. The simulation experiments are conducted by BehaviorSpace function. In the simulation, 500 times repetitive experiments are performed under the same condition of the experiment (A, B, C, D, E, F) and in each repetition 100 steps of "Go" procedures are conducted. For optimizing the team creativity, 6 pair experiments are conducted, and each pair of experiment containing "MemberFlow" procedure and excluding "MemberFlow" procedure, which are A/a, B/b, C/c, D/d, E/e, F/f (e. g., A experiment contains "MemberFlow", an experiment excludes "MemberFlow"). The specific setup can be seen in **Table 2** and the **Supplementary Data Sheets S1–S12** are the output files from BehaviorSpace experiments (1 and 2 for A/a, 3 and 4 for B/b, 5 and 6 for C/c, 7 and 8 for D/d, 9 and 10 for E/e, 11 and 12 for F/f), which are analyzed in the Results section.

TABLE 2 | A/a, B/b, C/c, D/d, E/e, F/f are 6 pair of experiments.

Vabiables	A	a	B	b	C	C	D	d	E	e	F	f
SKN_{normal} [1, 10]	8	8	5	5	8	8	2	2	8	8	8	8
$SKN_{creative}$ [1, 10]	2	2	5	5	2	2	8	8	2	2	2	2
SC [1, 10]	10	10	5	5	2	2	10	10	2	2	10	10
SE (CV) [1, 20]	10	10	10	10	10	10	10	10	10	10	10	10
EKN_{normal} [1, 10]	2	2	5	5	2	2	8	8	8	8	8	8
$EKN_{creative}$ [1, 10]	8	8	5	5	8	8	2	2	2	2	2	2
EC [1, 10]	2	2	5	5	10	10	2	2	10	10	2	2
EE (CV) [1, 20]	10	10	10	10	10	10	10	10	10	10	10	10
MemberFlow On/Off	on	off	on	off	on	off	on	off	on	off	on	off

The range of SKN_{normal} is [1, 10] so that 8 is a high level of number of items in the knowledge pool array. CV means control variable.

Results

In terms of all experiments, the initial knowledge pool arrays of members are limited in 10 items, the ratio of the size of normal knowledge and creative knowledge can be adjusted through variable SKN_{normal}, $SKN_{creative}$, EKN_{normal}, $EKN_{creative}$. Thus, in the A/a experiments, agents in the supervision group agentset own the high level of normal knowledge and high level of communication frequency; on the contrary, agents in the exploration group agentset possess the high level of creative knowledge and low level of communication frequency. The variables in the experiments B/b are set up at the moderate level. Comparing with A/a experiments, the C/c experiments have the different setup in communication frequency; D/d experiments have the different setup in members' knowledge structure. The E/e and F/f experiments perform with the low creative knowledge level of all supervision and exploration group agents and with different setup of communication frequency.

The result of team creativity (tc) is collected and analyzed, which is shown in **Table 3**. In once experiment, each step can generate a value of tc, so that tc_{mean} represents to the general team creativity of this experiment, which is the ratio of creative solutions among all solutions so that the range of tc is [0, 1]. When $tc > 0.5$ means that the virtual team generates more creative solutions and less normal solutions. In the study, a high probability of the mean of team creativity who reaches to 0.8 means that most repetitions of the experiment in certain condition can get a mean above 0.8 in 100 steps, which represents as P_{mean}. $P_{0.95}$ means the probability of repetitive experiments whose values of team creativity in 95% steps are above a certain value so that higher probability means a more stable team in these repetitions of the experiments. P_{mean} shows the team stability

TABLE 3 | tc represents to team creativity, whose range is [0, 1]; tc_{mean} represents to the mean of team creativity in once repetition of each condition of experiments.

	tc ≧ 0.8		tc ≧ 0.7		tc ≧ 0.6		tc ≧ 0.5		tc ≧ 0.4		tc ≧ 0.3		tc_{mean}
	P_{mean}	$P_{0.95}$	P_{mean}	$P_{0.95}$	P_{mean}	$P_{0.95}$	P_{mean}	$P_{0.95}$	P_{mean}	$P_{0.95}$	P_{mean}	$P_{0.95}$	
A	0.664	0.398	0.968	0.846	0.998	0.976	1.000	0.996	1.000	1.000	1.000	1.000	0.820
a	0.656	0.364	0.950	0.832	0.996	0.972	1.000	0.974	1.000	1.000	1.000	1.000	0.817
B	0.090	0.012	0.482	0.252	0.886	0.630	0.984	0.908	1.000	0.976	1.000	1.000	0.693
b	0.082	0.030	0.526	0.248	0.850	0.648	0.986	0.908	1.000	0.988	1.000	1.000	0.694
C	0.000	0.000	0.074	0.024	0.443	0.158	0.742	0.460	0.944	0.760	0.998	0.940	0.559
c	0.000	0.000	0.044	0.010	0.344	0.112	0.722	0.440	0.942	0.740	0.994	0.918	0.553
D	0.000	0.000	0.032	0.002	0.232	0.080	0.666	0.346	0.934	0.686	0.994	0.916	0.535
d	0.002	0.000	0.022	0.006	0.234	0.088	0.604	0.344	0.902	0.672	0.994	0.910	0.528
E	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.002	0.096	0.026	0.386	0.116	0.283
e	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.002	0.108	0.022	0.372	0.114	0.280
F	0.000	0.000	0.000	0.000	0.002	0.000	0.010	0.002	0.076	0.012	0.320	0.090	0.272
f	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.076	0.012	0.300	0.082	0.267

P_{mean} means the probability of the mean of team creativity who reaches to the certain value. $P_{0.95}$ means that the probability of repetitive experiments whose values of team creativity in 95% steps are above a certain value.

in the experiment, and $P_{0.95}$ shows the team stability in all the repetitions of the experiments.

Individual Knowledge Structure

In the F, D, A experiments (**Figure 3**), the communication frequency of both supervision group and exploration group are the same. There are both low level of creative knowledge in both groups in the F experiment, whose mean of team creativity (tc_{mean} = 0.272) of the whole experiment is lowest; in the D experiment, members in the supervision group own high level of creative knowledge, and on the contrary, the exploration group own low level of creative knowledge, whose mean of team creativity is 0.559; a high value of tc_{mean} (0.820) shows in experiment A, whose members in the supervision group own relatively low level of creative knowledge and members in the exploration group possess the high level of it. Also, in the A experiment, most repetitions and steps in the same repetition generate a high value of team creativity, and most of the time the team creates more normal solutions in the F experiment.

Therefore, members who own a high level of creative knowledge are suited in the exploration group and ones who own a high level of normal knowledge are suited in the supervision group. This arrangement can optimize team creativity.

Communication Frequency

When the members are arranged according to their knowledge structure becomingly, such as the A, C experiment. While in the C experiment, members in the supervision group have a low level of communication frequency and members in the exploration group are willing to communicate with others, which leads to a relatively low mean of team creativity (tc_{mean} = 0.559) and nearly 30% of repetitive experiments generate an average of team creativity under 0.5, which means more normal solutions, in the A experiment, members in the exploration group have a low level of communication frequency and members in the supervision group are more willing to communicate with other ones, which leads to a relatively high tc_{mean} (0.820) and, in most repetitive experiments and steps in once repetition, team creativity can reach above 0.7 (P_{mean} = 0.968, $P_{0.95}$ = 0.846) (**Figure 4**).

In the condition that all members of the team own low level of creative knowledge, when members in the supervision group are more willing to communicate, as the performance in the F experiment, tc_{mean} (0.272) is slightly less than the mean of team creativity in the E experiment whose members in the exploration group are more willing to communicate.

Therefore, members who have a high level of communication frequency are suited in the supervision group and members who have a low level of communication frequency are suited in the exploration group. This arrangement can optimize team creativity.

Member Flow

Comparing to the A, C, D, E, F experiment, the different variable is that "MemberFlow" procedure is excluded in the a, c, d, e, f experiments (**Figure 5**), and the result of tc_{mean} are lower than the corresponding experiments who include "MemberFlow" procedure. To the P_{mean} and $P_{0.95}$, the probability of team creativity in the high-level range is higher in the experiments who include "MemberFlow" procedure, such as A, C, D, E, F experiment. However, the improvement is unobserved in the B/b experiment, so that the member flow moderating effect is higher when characteristics of members are divergent.

Therefore, member flow has a positive moderating effect when the team wants to optimize their team creativity.

DISCUSSION AND CONCLUSION

The results display that the member arrangement proposed in the hypothesis can optimize team creativity and member flow can moderate the team creativity in most situation. Many previous pieces of research show that changing membership

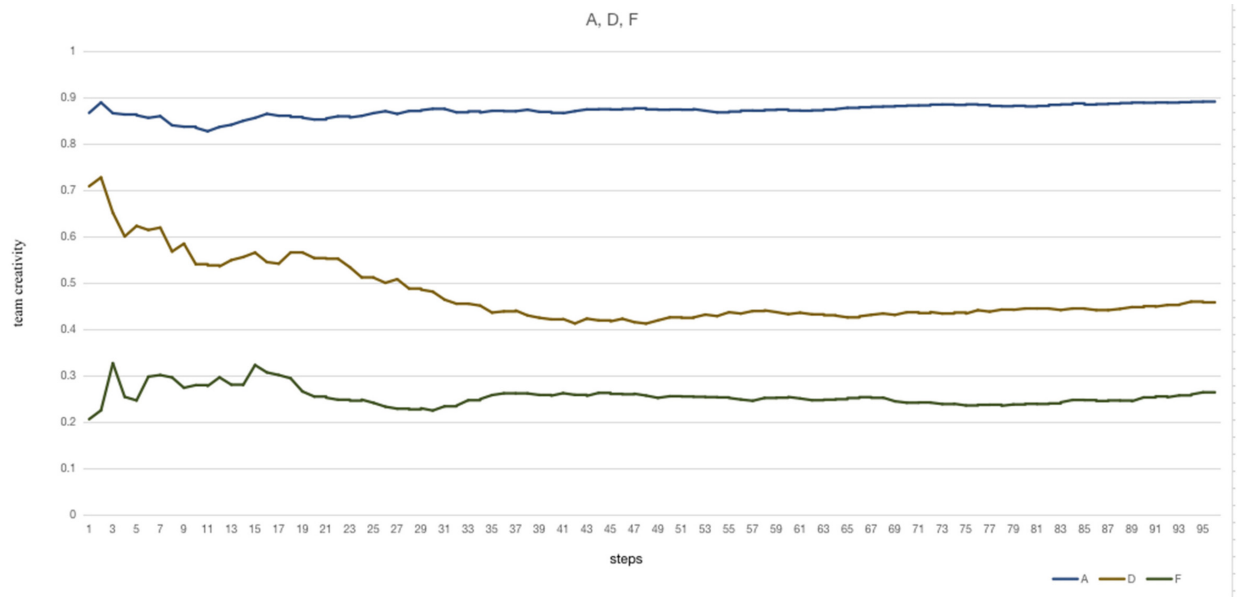

FIGURE 3 | The variations of team creativity in the A, D, F experiment are illustrated.

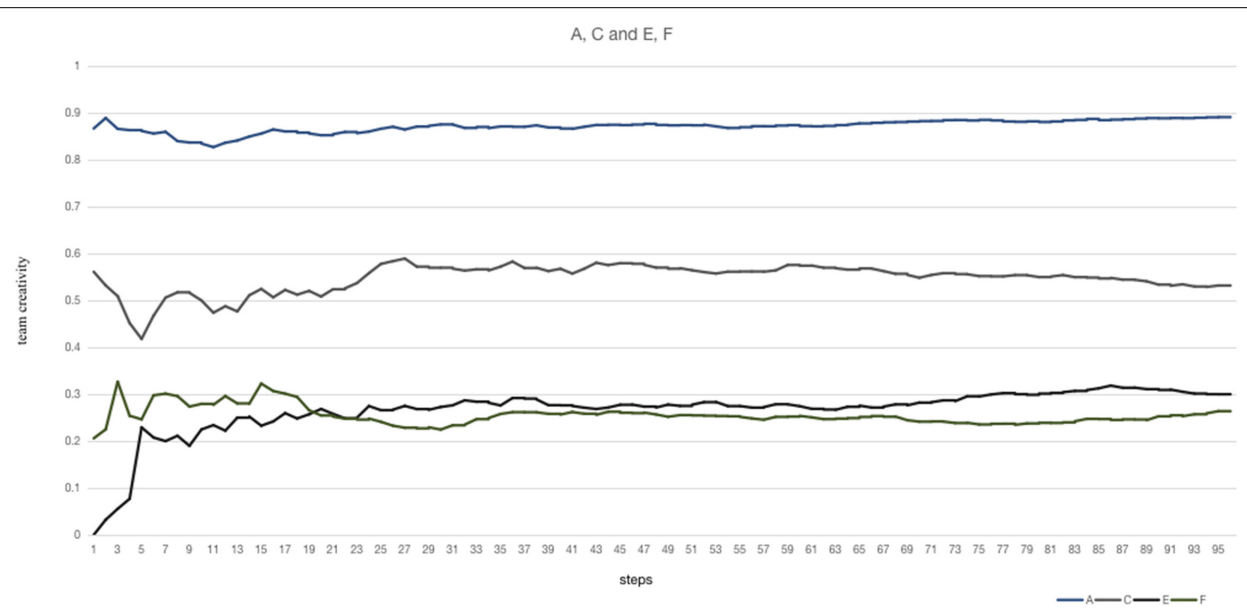

FIGURE 4 | The variations of team creativity in the A, C and E, F experiment are illustrated.

can improve team creativity. Rotating randomly a subset of group members when they performed divergent exploration tasks can enhance group creativity (Choi and Thompson, 2005). Social identity is one reason for the members of an original group to accept rotating member from a different place, and which can increase knowledge stock of this group, hence enhancing their performance (Kane et al., 2005). In accordance with other laboratory studies, the result from the computational simulation is reasonable. In terms of transactive memory system (TMS) of the group, partial membership change creates inefficient TMS processes because TMS structure that new members rely on is developed by old-timers in their original group (Lewis et al., 2007), and anticipating of membership change can make transactive memory more difficult to build (Blanchet and Michinov, 2017). Consequently, in the future, transactive memory system and cognitive conflict should be considered during simulation for a more comprehensive study about member flow, except for the knowledge structure and communication frequency of members in the team. In addition to member flow, many other adaptive changing can affect team

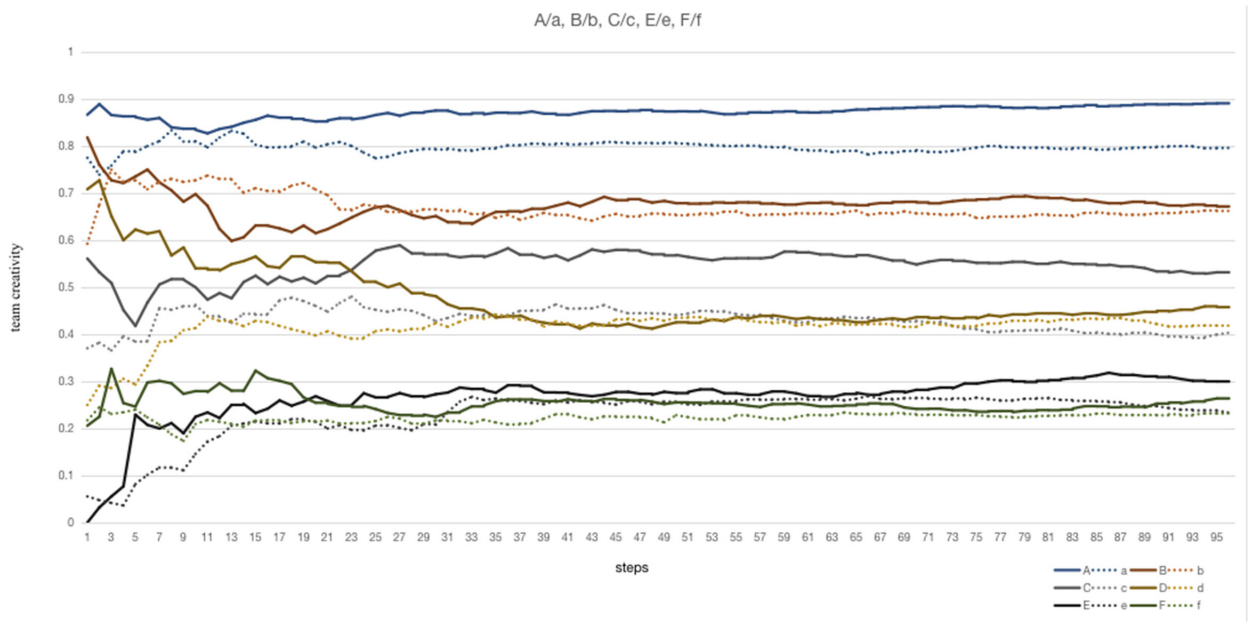

FIGURE 5 | The variations of team creativity in the A/a, B/b, C/c, D/d. E/e, F/f experiment are illustrated.

creativity that researchers cannot examine through traditional laboratory experiments or questionnaires. The computational simulation may be considered as another method to explore team variations through problem-solving processes or other cognition processes. Moreover, people in the peripheral position, who possess more external interaction with other social networks, have a higher level of creativity; correspondingly, people in the central position, who possess less external interaction, also can develop a higher level of creativity (Perry-Smith and Shalley, 2003; Perry-Smith, 2006). Thus, external knowledge sharing can be considered in the next step to simulate. Besides, the evaluation group and efficiency variable are controlled in this study, which can be considered in the following researches.

In addition to many other factors that can affect the team creativity, also the creativity has been researched in various methods and developed various interpretations. In terms of neuroimaging method, insight, as a kind of creative cognition, which is defined as a process that people can solve a problem from the state of not knowing to knowing abruptly, and the 'Aha!' experiences occurred in insight problem-solving have a high positive correlation with positive affect and fluent cognition which can improve individual creative thinking (Shen et al., 2016). This insight process also has been examined through this method and many relative studies have found consistently that anterior cingulate cortex and prefrontal areas are related to insight (Dietrich and Kanso, 2010) and right hemispheric dominance theory of creative thinking also applies to creative insight (Shen et al., 2013). Therefore, if the structure of the team and the interaction among members could be considered as the brain that may construct the team creativity and then generate creative achievements efficiently, the insight problem-solving process may be possible to be found in the team creative problem-solving process, which can be considered in the next stage of computational simulation. Besides and Dietrich (2018) proposed a new theoretical framework of creativity to separate this concept into three modes, and among them the flow mode concept can be made a analogy with the member flow in the team.

In conclusion, the preponderance of computational simulation can be seen in this study. This method can integrate all contents of researches that psychologists concern, to observe variations of team creativity qualitatively through simulating a series of cognition processes and considering various individual characteristics instead of focusing on one of them, although this method cannot obtain a sufficient external validity like other laboratory experiments.

In terms of the process of simulation, before which a team cognition model has been set up including members' responsibility distribution: supervision group, exploration group, evaluation group; besides agent behaviors are included: knowledge sharing and the problem solving cognitive processes: problem construction, divergent exploration, evaluation and conclusion. According to previous researches, knowledge structure and social characteristics can affect the team creativity, so that these properties are put into the simulation; other individual characteristics are also important but they are controlled in the simulation experiments as efficiency variable (SE, EE). Then, the team cognition model is simulated through NetLogo 6.0.2. The results show that knowledge structure and communication frequency can affect the team creativity and when people gain the various characters in both, a suitable arrangement can optimize the team creativity and it can be more stable and higher when member flows.

AUTHOR CONTRIBUTIONS

CZ designed this study, collected and analyzed the data with the assistance of XZ, and wrote the manuscript. XZ and HZ provided the critical emendations.

FUNDING

This research was supported by Key Program of the Tianjin Philosophy and Social Science Research Project of China (TJJX16-001), Key Program of the National Natural Science Foundation of China (71532005), Key Program of Tianjin Science and Technology Development Strategic Research Project of China (15ZLZLZF00770), National Social Science Foundation of China (12BSH053), and the Major Social Science Project of Tianjin Municipal Education Commission of China (2018JWZD41).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00188/full#supplementary-material

DATA SHEETS S1, S2 | The outputs of A/a experiments through BehaviorSpace function.

DATA SHEETS S3, S4 | The outputs of B/b experiments through BehaviorSpace function.

DATA SHEETS S5, S6 | The outputs of C/c experiments through BehaviorSpace function.

DATA SHEETS S7, S8 | The outputs of D/d experiments through BehaviorSpace function.

DATA SHEETS S9, S10 | The outputs of E/e experiments through BehaviorSpace function.

DATA SHEETS S11, S12 | The outputs of F/f experiments through BehaviorSpace function.

REFERENCES

Blanchet, C., and Michinov, E. (2017). Impact of the anticipation of membership change on transactive memory and group performance. *Curr. Res. Soc. Psychol.* 25, 1–10.

Bransford, J. D., and Stein, B. S. (1984). *The Ideal Problem Solver: A Guide for Improving Thinking, Learning, and Creativity*. New York, NY: WH Freeman and Company.

Chiew, V., and Wang, Y. X. (2004). "Formal description of the cognitive process of problem solving," in *Proceedings of the Third IEEE International Conference on Cognitive Informatics*, (Victoria, BC: IEEE), 74–83. doi: 10.1109/COGINF.2004.1327461

Choi, H. S., and Thompson, L. (2005). Old wine in a new bottle: impact of membership change on group creativity. *Organ. Behav. Hum. Decis. Process.* 98, 121–132. doi: 10.1016/j.obhdp.2005.06.003

Cooke, N. J. (2015). Team Cognition as interaction. *Curr. Dir. Psychol. Sci.* 24, 415–419. doi: 10.1177/0963721415602474

Cooke, N. J., Gorman, J. C., Myers, C. W., and Duran, J. L. (2013). Interactive team cognition. *Cogn. Sci.* 37, 255–285. doi: 10.1111/cogs.12009

Dietrich, A. (2018). Types of creativity. *Psychon. Bull. Rev.* 25, 1–12. doi: 10.3758/s13423-018-1517-7

Dietrich, A., and Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychol. Bull.* 136, 822–848. doi: 10.1037/a0019749

Feist, G. J. (1998). A meta-analysis of personality in scientific and artistic creativity. *Pers. Soc. Psychol. Rev.* 2, 290–309. doi: 10.1207/s15327957pspr0204_5

Granovetter, M. S. (1973). The strength of weak ties. *Am. J. Sociol.* 78, 1360–1380. doi: 10.1086/225469

Guilford, J. P. (1950). Creativity. *Am. psychol.* 5, 444–454. doi: 10.1037/h0063487

Hennessey, B. A. (2015). Creative behavior, motivation, environment and culture: the building of a systems model. *J. Creat. Behav.* 49, 194–210. doi: 10.1002/jocb.97

Jiang, H., Zhang, Q. P., and Zhou, Y. (2018). Dynamic Creative interaction networks and team creativity evolution: a longitudinal study. *J. Creat. Behav.* 52, 168–196. doi: 10.1002/jocb.141

Kane, A. A., Argote, L., and Levine, J. M. (2005). Knowledge transfer between groups via personnel rotation: effects of social identity and knowledge quality. *Organ. Behav. Hum. Decis. process.* 96, 56–71. doi: 10.1016/j.obhdp.2004.09.002

Lee, J. (2018). The effects of knowledge sharing on individual creativity in higher education institutions: socio-technical view. *Adm. Sci.* 8, 1–16. doi: 10.3390/admsci8020021

Lewis, K., Belliveau, M., Herndon, B., and Keller, J. (2007). Group cognition, membership change, and performance: investigating the benefits and detriments of collective knowledge. *Organ. Behav. Hum. Decis. process.* 103, 159–178. doi: 10.1016/j.obhdp.2007.01.005

Pelled, L. H., Eisenhardt, K. M., and Xin, K. R. (1999). Exploring the black box: an analysis of work group diversity, conflict and performance. *Adm. Sci. Q.* 44, 1–28. doi: 10.2307/2667029

Perry-Smith, J. E. (2006). Social yet creative: the role of social relationships in facilitating individual creativity. *Acad. Manag. J.* 49, 85–101. doi: 10.5465/amj.2006.20785503

Perry-Smith, J. E., and Shalley, C. E. (2003). The social side of creativity: a static and dynamic social network perspective. *Acad. Manag.* 28, 89–106.

Podolny, J. M., Baron, J. N., Krogh, G. V., Roos, J., Venzin, M., and Engwall, L. (1997). Resources and relationships: social networks and mobility in the workplace. *Am. Sociol. Rev.* 62, 673–693. doi: 10.2307/2657354

Reiter-Palmon, R., Herman, A. E., and Yammarino, F. J. (2008). Creativity and cognitive processes: multi-level linkages between individual and team cognition. *Multi-level Issues Creat. Innov.* 7, 203–267. doi: 10.1016/S1475-9144(07)00009-4

Reiter-Palmon, R., Mumford, M. D., O'Connor Boes, J., and Runco, M. A. (1997). Problem construction and creativity: the role of ability, cue consistency, and active processing. *Creat. Res. J.* 10, 9–23. doi: 10.1207/s15326934crj1001_2

Reiter-Palmon, R., and Robinson, E. J. (2009). Problem identification and construction: what do we know, what is the future? *Psychol. Aesthet. Creat. Arts* 3, 43–47. doi: 10.1037/a0014629

Runco, M. A., and Chand, I. (1995). Cognition and creativity. *Educ. Psychol. Rev.* 7, 243–267. doi: 10.1007/BF02213373

Sacchetti, S., and Tortia, E. C. (2013). Satisfaction with creativity: a study of organizational characteristics and individual motivation. *J. Happiness Stud.* 14, 1789–1811. doi: 10.1007/s10902-012-9410-y

Salas, E. (1992). Toward an understanding of team performance and training. *Teams Train. Perform.* 3–29.

Shen, W., Liu, C., Zhang, X., Zhao, X., Zhang, J., Yuan, Y., et al. (2013). Right hemispheric dominance of creative insight: an event-related potential study. *Creat. Res. J.* 25, 48–58. doi: 10.1080/10400419.2013.752195

Shen, W., Yuan, Y., Liu, C., and Luo, J. (2016). In search of the 'Aha!'experience: elucidating the emotionality of insight problem-solving. *Br. J. Psychol.* 107, 281–298. doi: 10.1111/bjop.12142

Simonton, D. K. (2000). Creativity: cognitive, personal, developmental, and social aspects. *Am. psychol.* 55, 151–158. doi: 10.1037/0003-066X.55.1.151

Sternberg, R. J., and Lubart, T. I. (eds) (1996). *The Concept of Creativity: Prospects and Paradigms*. Cambridge: University of Cambridge.

Wilensky, U. (1999). *NetLogo. Center for Connected Learning and Computer-Based Modeling*. Evanston, IL: Northwestern University.

Wolfradt, U., and Pretz, J. E. (2001). Individual differences in creativity: personality, story writing, and hobbies. *Eur. J. Pers.* 15, 297–310. doi: 10.1002/per.409

Xu, S., Jiang, X., and Walsh, I. J. (2018). The influence of openness to experience on perceived employee creativity: the moderating roles of individual trust. *J. Creat. Behav.* 52, 142–155. doi: 10.1002/jocb.138

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 07 February 2019
doi: 10.3389/fpsyg.2019.00207

The Effect of Zhongyong Thinking on Remote Association Thinking: An EEG Study

*Zhijin Zhou[1], Lixia Hu[1], Cuicui Sun[1], Mingzhu Li[2], Fang Guo[1] and Qingbai Zhao[1]**

[1] School of Psychology, Central China Normal University, Wuhan, China, [2] Special Education Research and Guidance Center, Haidian Education, Beijing, China

The Doctrine of the Mean (zhongyong) introduced by Confucianism is not only an aspect of faith, but also a way of thinking for Chinese individuals. Zhongyong includes two thinking forms: eclectic thinking (ET; i.e., "neither-A-nor-B") and integrated thinking (IT; i.e., "both-A-and-B"). Given the inclination of Asian individuals toward situational cognition, this study used questions about situations familiar to Chinese undergraduates to activate either ET or IT. This was done to investigate the effects of the two divergent thinking forms of zhongyong on performance levels on the Remote Associates Test (RAT). Both behavioral and EEG results found that participants in the IT condition demonstrated higher RAT scores than those in the ET condition. The conclusion was that the RAT and priming tasks shared the same neural mechanism. This meant that the priming tasks of IT allowed participants to enter a state of creative preparation in advance, further affecting resolution of the RAT.

Keywords: Confucianism, zhongyong thinking, integrated thinking, eclectic thinking, creative problem-solving

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Weihua Niu,
Pace University, United States
Thea Ionescu,
Babeş-Bolyai University, Romania
Min Tang,
University of Applied Management, Germany

***Correspondence:**
Qingbai Zhao
zqbznr@mail.ccnu.edu.cn

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *29 September 2018*
Accepted: *21 January 2019*
Published: *07 February 2019*

Citation:
Zhou Z, Hu L, Sun C, Li M, Guo F and Zhao Q (2019) The Effect of Zhongyong Thinking on Remote Association Thinking: An EEG Study. Front. Psychol. 10:207. doi: 10.3389/fpsyg.2019.00207

INTRODUCTION

Creativity is one of the most complex and elusive human behaviors (Agnoli et al., 2018). Exploring the creativity of individuals or groups are gaining momentum across different scientific disciplines. Csikszentmihalyi (1999) argued that creativity is not only a psychological process but also a cultural and social phenomenon. Cultural values influence one's way of thinking and can have a significant impact on their creativity (Liu et al., 2015). It is well known that Chinese individuals who are influenced by Confucianism have long abided the Doctrine of the Mean (i.e., zhongyong) that provides the third perspectives to settle differences (Pang, 1980, 2000; Zhou, 1994). Zhongyong is the basic principle that Chinese people use to confront the world. It allows them to capture the essence of social operation (Yang, 2014). Therefore, examining the influence of zhongyong on creativity can reveal how cultural factors and principles affect creativity. This research attempted to redefine the concept of zhongyong by exploring its structure based on previous literature on zhongyong. This redefined concept could potentially deepen the understanding of how Chinese traditional culture influences creativity. This study used an experimental method with priming technology and cognitive neuroscience research methods. This could provide researchers with possible neural evidence of the effect of zhongyong on creativity and address the gap in the psychological research of zhongyong.

Zhongyong was initially considered a kind of supreme morality. Over time, the concept has evolved into a value system and overall way of thinking, which focuses on being free from

excess/deficiency (i.e., "just right"); however, the concept of zhongyong should not be equated with compromise or egalitarianism (Feng, 1940). Many researchers believe that zhongyong is the basic principle used by the Chinese to confront the world, solve problems, and achieve harmony (Yang and Zhao, 1997; Yang, 2009). The characterization of zhongyong as both mastering extremes, but deploying the mean is part of its dichotomous (zhiliangyongzhong, 执两用中) epistemology. In support of this characterization, Pang (1980, 2000) indicated that zhongyong is not only part of the ethics of the Confucianism, but also how the Chinese understand and interact with the rest of the world. There are four forms of zhongyong: "A and B," which can be conceptualized as being based on A, but with B taken into account, e.g., "the master was mild, and yet dignified," "warm, yet gentle"(wen'er'li, 温而厉), "respectful, yet easy"(gong'er'an, 恭而安); "Both A and B," which can be conceptualized as including A and B at the same time, such as "being skilled in using both the pen and the rifle"(nengwennengwu, 能文能武) and "both serious and facetious" (yizhuangyixie, 亦庄亦谐); "Neither A nor B," which can be conceptualized as the opposite of "Both A and B," such as "neither haughty nor obsequious" (bubeibukang, 不卑不亢), "avoiding leaning to either side" (wupianwupo, 无偏无颇); and "A, yet not A', " which can be conceptualized as possessing features of A, but with A being prevented from being excessive through the removal of B, such as "majestic without being fierce" (wei'er'bumeng, 威而不猛), "enjoyment without being immoral"(le'er'buyin, 乐而不淫). Among the four forms of zhongyong, "A and B" and "both A and B" involve integrative thinking more, while "Neither A nor B" and "A, yet not A'" favor ET.

The systematic study of zhongyong thinking in psychology began in the late 1990s by Yang and colleagues (Yang and Zhao, 1997; Yang, 2009; Yang and Lin, 2012; Yang et al., 2014). They argued that zhongyong thinking is a "practical thinking system" in which people decide how to choose, execute, and correct specific action plans. However, this "system" proposed by Yang et al. (2014) is overcomplicated, involving values, behaviors, and perceptions related to zhongyong, in which multiple, reciprocating relationships exist among the various components. Therefore, on the basis of this "practical thinking system" of zhongyong constructed by Yang, some researchers began to examine the basic meaning of zhongyong thinking, i.e., "master the extremes, but deploy the mean" (zhiliangduan'er'yunzhong, 执两端而允中). For example, Wu and Lin (2005) focused on cognition and behavior while dealing with controversy or disagreements, and defined zhongyong thinking as "thinking about a problem from multi-perspectives, and making behavioral decisions that take into account both the self and the overall situation after considering different views in detail." Western researchers have attributed similar concepts to zhongyong thinking, such as cognitive complexity and integrative thinking. However, zhongyong is still more complex than this, composed of integrated, eclectic, and holistic thinking, and changing according to the situation, which represents an important distinction in cognition between Chinese and West.

The method of cognition influences how individuals and groups develop (Ji et al., 2000). The effect of zhongyong on creativity evoked widespread concern among researchers. However, findings on the subject are inconsistent. A study by Zhang and Gu (2015) adopted the Zhongyong Thinking Scale, which includes three dimensions: multi-thinking, holism, and harmoniousness, finding that an employee's zhongyong thinking score was positively correlated with self-rated creativity. Further, Liao and Dong (2015) found that the zhongyong thinking exerted a positive influence on employee innovation, a relationship partly mediated by organizational harmony. Conversely, some research has found that zhongyong might hinder innovation and the transformation of creative ideas into action (Yao et al., 2010). Liu et al. (2015) utilized the Zhongyong Practical Thinking Scale and the Creative Personality Scale to observe a negative relationship between zhongyong and creative personalities in a group of art majors. We believe the contradictory findings discussed above can be attributed to researchers holding varying concepts of zhongyong, resulting in the use of disparate measurement tools.

Previous research examining zhongyong thinking tended to consider it a static method of thinking, resistant to situation change. However, cross-cultural studies have shown that East Asians practice more situational cognition than Westerners (Ji et al., 2000), paying more attention to background elements of the environment (Nisbett and Miyamoto, 2005), and more likely to attribute elements to the situation (Choi et al., 1999; Morris and Peng, 1994).

As mentioned previously, zhongyong is a combination of various forms of thinking, which can change to suit a given situation. Additionally, Zhou et al. (unpublished) found that integrated thinking (IT), but not eclectic thinking (ET), was associated with significantly higher scores on a Remote Associates Test (RAT), suggesting that the different forms of zhongyong thinking may have different effects on association tasks. These results prompt the question as to whether different forms of zhongyong thinking, applied to different situations, would affect RAT scores and/or neurophysiological measures. In the current study, electroencephalograms (EEGs) were used to record neural activity during various cognitive tasks. EEG designs are an appropriate method to obtain insight in the temporal evolution of cognitive processes (Srinivasan, 2007), allowing for a much more detailed look at brain activation, which can be observed in response to particular cognitive events (e.g., immediately prior to the production of an original idea). Each frequency band of an EEG is related to specific cognitive functions. For instance, the theta frequency band primarily reflects working memory, while the alpha frequency is related to internal attention and semantic processing. Further, the beta plays an important role in language processing pretreatment. A study of creative thinking utilizing EEG measures can better reveal the underlying neural mechanism. Additionally, EEG data contain many different aspects, such as event related synchronization/desynchronization (ERS/D) and task-related power (TRP), which can be used to calculate the coherence of the brain regions, to compare brain activity between the task/baseline states, or to compare differences in neural activity between general and creative thinking.

At present, creative thinking research utilizing EEG primarily focuses on comparing differences in neural activation triggered

by creative and general thinking. For instance, Fink et al. (2007, 2009) found that individuals demonstrate increased alpha waves when performing alternative use tasks (AUTs) when compared to general tasks (e.g., completing word suffixes, object feature generation). This indicates top-down activity or, more specifically, selective inhibition of specific brain regions. Mölle et al. (1999) investigated differences in neuroelectrophysiology between divergent and convergent thinking with EEG, and found that the dimensional complexity of EEG signals was greater during divergent thinking, possibly the result of the concurrent activation of a greater number of independently oscillating processing units. However, theta activity in the frontal lobe decreased during the divergent thinking task and increased convergent thinking task. Further, frontal alpha and beta wave activity during both divergent and convergent thinking tasks was lower compared to the control condition. Similarly, Razumnikova (2007) found widespread enhancement of power and coherence in the beta 2 band, increased desynchronization of alpha 1 and alpha 2 over the posterior cortex, and increased the theta 1 power in the frontal cortex in the RAT, when compared to the Simple Associates Task (SAT). To avoid differences caused by the task itself, some researchers have explored the neural activity of creative thinking through different task requirements (i.e., creative vs. general solutions) in the same task. For example, Jauk et al. (2012) examined EEG brain activation related to convergent vs. divergent modes of thinking within the same task and found increased desynchronization of alpha waves in the frontal cortex during general thinking and synchronization of alpha waves in the same region during divergent thinking. In addition, there were some researchers who tried to explore the cognitive process of creativity in natural situations rather than in controlled laboratory settings. For example, Shen et al. (2018) assessed the implicit conceptual structure of everyday insight in diverse naturalistic settings by collecting participants' descriptions of everyday insight experiences and found that insight experience was a multidimensional construct involving positive affect at the moment of insight, phenomenological experiences relating to the dynamic insight process, solution-related cognitive responses, and post insight reflections.

In summary, previous studies have typically focused on characteristics of EEG power in creative tasks by comparing divergent and convergent thinking, or creative and general thinking. However, this may not be generalizable to the real-world, as individuals are often inspired by others' ideas or methods, and then carry out creative tasks. Fink et al. (2011) explored whether creativity could be improved by exposure to others' perspectives, and found that participants who received cognitive interventions performed better in the AUT, with synchronization of alpha waves in the right hemisphere, and weak desynchronization of alpha waves in the parietal and temporal lobes of the left hemisphere. Another recent study examined the impact of neurofeedback training with creative thinking-related brain activities on creativity. Results of this study indicate that an increase in brain activity related to divergent thinking (i.e., alpha and beta waves located in the right parietal lobe) can improve creativity (Agnoli et al., 2018).

The current study was performed in a sample of Chinese college students, who were deeply influenced by Chinese traditional culture, and focused on the neural mechanisms of two different forms of zhongyong thinking on creative problem-solving. The two forms of zhongyong thinking (IT and ET) were primed through the use of different story scenarios. Integrated thinking in this study was in the form of "both A and B," reflecting the idea of "harmony," while ET was in the form of "Neither A nor B," reflecting the idea of "the mean." Participants were then asked to complete corresponding creative cognitive tasks. During the priming and creative cognitive task period, EEGs of participants were recorded to monitor and evaluate neural activation. Based on the results of previous research, it was hypothesized that IT would improve RAT scores when compared to ET. Further, the current study sought to explore neural evidence of the possible underlying mechanisms responsible for any differences observed.

MATERIALS AND METHODS

Participants

The participants of the study included 36 Chinese college students (19 men, 17 women; mean age 22 years, range 19–26 years). All participants were right-handed, native speakers of Chinese, neurologically healthy by self-report, and normal or corrected-to-normal vision. The participants had no prior experience with RAT or any other similar tests. Participants volunteered to be part of the experiment, provided written informed consent prior beginning the experiment, and received payment following participation. Some data were eliminated from EEG analyses owing to excess artifacts or low superimposition times. In total, data from 31 participants were analyzed for the presence of theta (4–8 Hz), alpha (8–12 Hz), and beta (12–30 Hz) waves in the priming phase, and data from 31 participants were analyzed for the same frequency bands in the RAT phase. Data from 31 participants also were included in behavior analyses.

Experimental Materials

Priming Materials

Sixteen social problems familiar to participants were collected, and each problem was written into a vignette to be solved. The compilation of priming vignettes of IT/ET was based on the meaning of zhongyong (Both A and B, Neither A nor B) proposed by Pang (1980). Two hundred and twenty-three undergraduates participated in completing solutions to social problems. Three psychology postgraduate students were invited to evaluate the solutions to social problems proposed by participants. The evaluators divided responses into IT and ET, taking one side, or invalid according to the definition and characteristics of IT (e.g., foresight, integration, "big picture") and ET. If more than 85% of participants proposed solutions that used ET/IT to solve the problem in the corresponding priming, the vignette of ET/IT was considered as appropriate priming material. According to the above criteria, a total of six vignettes with good priming effect were obtained and adopted in this study after four rounds of test and revision, including three eclectic thinking priming vignettes

and three integrative thinking priming vignettes (one for exercise, two for the formal experiment).

Priming ET requires the subject to stand on the side of an outsider to think about the question. For example, one of the vignettes used to prime ET was the "traffic accident" problem. In the description of the situation, participants found that the perpetrator and victim were both willing to negotiate the problem (i.e., how to handle the traffic accident) privately, but disagreed on the share of responsibility and the amount of compensation. Participants were asked "How do you solve this problem as an outsider?" and were prompted to provide a solution that was acceptable to both sides. Compared to ET, IT was a more complicated form of thinking. To prime IT thinking style, subjects were required to imagine themselves as experts in a certain field and then solve the given problems. For example, in the case of "business in the Internet era," two people plan to jointly run clothing (sales) business. One wished to run a physical store and the other wants to run an online shop. They have discussed the problem many times, but have failed to reach an agreement. Participants were asked, "How would you solve this problem if you were a successful clothing merchant with sales experience?".

Creative Task

It's generally believed that creativity theories do not support the measurement of creativity through a single technique (Gong et al., 2016). Instead, they adopt several tests to measure creativity (Mehta and Zhu, 2009). Zhou et al. (unpublished) with three different types of creativity tasks, an AUT, RAT, and insight problems (i.e., riddles) adopted the priming method to explore the effect of zhongyong on creative problem-solving. Results showed that priming only demonstrated a significant impact on RAT scores. Therefore, a self-compiled Chinese RAT was used in this study to measure the creative problem-solving of subjects. Our Chinese RAT is a variant of the English-language RAT developed by Mednick (1968), in which participants are typically presented with three clue words (two-character words) and then participants are asked to provide a fourth target word (two-character word), which can establish a semantic connection with the first three clue words. The three clue words given to the participants would be given to establish a semantic connection and act as a clue for the fourth word. For example, if the three given clue words are baby (ying'er, 婴儿), glass (boli, 玻璃), and experiment (shiyan, 实验), a correct answer would be test tube (shiguan, 试管); if the given words are invention (faming, 发明), powder (fenmo, 粉末), fireworks (yanhua, 烟花), a correct answer would be gunpowder (huoyao, 火药). Thirty-six RAT items suitable for college students were used (18 items were used in each experiment) in the current study. Our Chinese version has been validated and has been used in research with native Chinese participants (Zhou et al., unpublished). The difficulty of RAT items ranged from 0.5 to 0.65 in a sample of 110 undergraduates.

Experimental Procedure

A within-subjects design was adopted in this study and each subject came to the laboratory twice. Participants were randomly allocated to one of two separate priming conditions randomly (i.e., ET priming condition and IT priming condition), with an interval of 5–7 days between sessions. The participants were automatically assigned to the "other" priming condition for the second experiment.

Prior to the experiment, all participants were asked to verbally report whether they had prior experience with participating in a RAT test or other similar tests. Then, participants who reported to have no prior experience were asked to rest for 2 min, with eyes open for 1 min and closed for 1 min. EEG data of the resting state (eyes open) were recorded during this period. Participants were then given instructions. A short practice exercise followed to familiarize participants with the experimental process, task requirements, and precautions, such as avoiding head movements, facial expressions, grinding teeth, and swallowing, which may affect EEG data collection. The priming effect was also tested during this period. In the practice phase, participants were presented with the correct answers after answering the first priming question to understand what how they were expected to respond. Data collected during this phase were not used for analysis. When the participants were ready, they would begin the formal experiment. Participants were first presented with a problem situation (vignette) used to activate ET or IT, and then were asked complete a RAT (nine items) while EEG measures were recorded. Participants answered questions orally, and the responses were audio recorded. After a 2-min break, participants were asked to read and complete another zhongyong priming question, followed by another creative thinking task (nine items). The experimental program was administered via E-Prime 2.0. As depicted in **Figure 1**, each trial started with the presentation of a fixation cross in the middle of the screen for a duration of 15 s (i.e., reference phase). Then, priming material was presented. The subject was asked to read the material quietly, and to press "ENTER" when a solution was reached, reporting the solution orally. In the following RAT phase, participants were shown a fixation point for 1 s. Then, three cue words appeared in the center of the screen, for a duration of 10 s after the fixation point disappeared. Subjects read the cue words as soon as possible and freely associated target words that held a semantic connection with the first three cue words. Participants would push a response button as soon as they believed that they had reached their answer, and the target word was then orally reported. The interface would then begin requesting target words to be reported automatically after 10 s. After this, participants were asked to orally report the target word after 5 s and pressed the "ENTER" button to move to the next question. Failure to answer within the given time limit would be considered a false answer. Data were analyzed with frequency analysis.

EEG Recording and Analyses

EEG was measured with a 64-channel stretchable electrode cap (Brain Products, Gilching, Germany). The ground electrode and the reference electrode were located at FCz and AFz, respectively. To register eye movements, vertical and horizontal electrooculograms (EOGs) were recorded bipolarly between two electrodes placed diagonally above and below the inner and the outer canthus of the right eye. Electrode impedances were kept

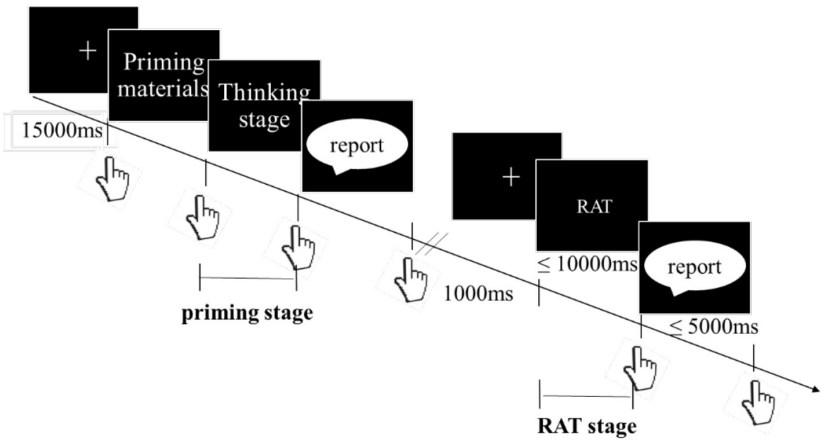

FIGURE 1 | The procedure of a block in the formal experiment. Each experimental condition contains two blocks, each block has 1 priming task and 9 RATs.

below 20 kΩ for the EEG and below 10 kΩ for the EOG. The EEG signals were amplified and bandpass filtered between 0.05 and 100 Hz. All signals were sampled at a frequency of 500 Hz. EEG data were re-referenced by the average signals of Tp9 and Tp10, which were located at left and right ear mastoids, respectively. Analyzer 2.0 software was used to semi-automatically check data for artifacts and artifactual epochs caused by eye blinks, eye movements, or muscle tension. Such anomalies were excluded from further analysis. Band power values (μV^2) were obtained by squaring filtered EEG signals, and extracting the corresponding frequencies (theta frequency band, 4–8 Hz; alpha frequency band 8–12 Hz; beta frequency band, 12–30 Hz).

As in a previous study (Benedek et al., 2011), the current study analyzed three sections of EEG data: (1) Reference stage-fixation cross before the start of each experiment; (2) Priming stage-when participants were thinking about the problem that was presented; (3) RAT stage-when participants were thinking about the fourth target word (**Figure 1**). To investigate the process of creative problem solving within different forms of zhongyong thinking, and to reduce the interference of artifacts, data from each stage were segmented and averaged in units of 4 s. These segments were then used in the subsequent analysis of data in each stage.

Brain activity during the performance of experimental tasks was quantified by means of TRP changes in the EEG (Pfurtscheller, 1999; Pfurtscheller and Lopes da Silva, 1999). The TRP for each electrode position was computed by subtracting the log-transformed power during prestimulus reference intervals ($Pow_{i,reference}$) from the log-transformed power during the activation intervals ($Pow_{i,activation}$) according to the formula: $TRP(i) = \log[Pow_{i,reference}] - \log[Pow_{i,activation}]$. Therefore, negative values indicate decreases in TRP from the reference to the activation period (i.e., desynchronization), while positive values reflect increases in TRP (i.e., synchronization; Pfurtscheller and Lopes da Silva, 1999). For statistical analyses, electrode positions were topographically aggregated as following: frontal left (AF3, AF7, F3, F5, F7), temporal left (FT7, T7, TP7), parietal left (CP1, CP3, P1, P3), and analogously for the right hemisphere.

RESULTS

Behavioral Results

Accuracy rate (i.e., the relative amount of correct responses) and response time (i.e., time until pressing the "ENTER" button in correct trials) were analyzed by means of a repeated measures analysis of variance (ANOVA). Within-subject factors were IT vs. ET. The ANOVA revealed a significant main effect of accuracy rate [$F(1,30) = 2.986$, $p = 0.006$, $\eta_p^2 = 0.229$], with the accuracy rate in the IT condition ($M = 0.710$, $SD = 0.168$) significantly higher than that observed in the ET condition ($M = 0.620$, $SD = 0.152$). Additionally, it was observed that response time of participants was marginally significantly faster [$F(1,30) = -1.771$, $p = 0.087$, $\eta_p^2 = 0.095$] in the IT condition ($M = 4.480$, $SD = 1.137$) than in the ET condition ($M = 4.880$, $SD = 0.840$).

EEG Results

A repeated measures ANOVA was performed for TRPs in the theta (4–8 Hz), alpha (8–12 Hz), and beta (12–30 Hz) bands priming condition (IT vs. ET), cerebral hemisphere (left vs. right), and area of the brain (frontal, temporal, parietal) as within-subjects variables. ANOVA revealed significant main effect of priming in the alpha band [$F(1,30) = 4.772$, $p = 0.038$, $\eta_p^2 = 0.136$]. The main effect of priming condition indicates that desynchronization of alpha in the IT condition is higher than ET condition. The ANOVA further revealed significant triple interactions between priming condition, area, and hemisphere in the alpha band [$F(2,60) = 3.215$, $p = 0.047$, $\eta_p^2 = 0.097$]. The simple effects showed that desynchronization of alpha in the IT condition is higher than ET condition in the left frontal, left temporal and left parietal lobes. The ANOVA further revealed significant triple interactions between priming condition, area, and hemisphere in the beta band [$F(2,60) = 3.430$, $p = 0.039$, $\eta_p^2 = 0.103$], suggesting beta synchronization in the IT condition and beta desynchronization in the ET condition in bilateral parietal lobes. However, differences in theta power were not found to be significant among areas, hemispheres, or priming

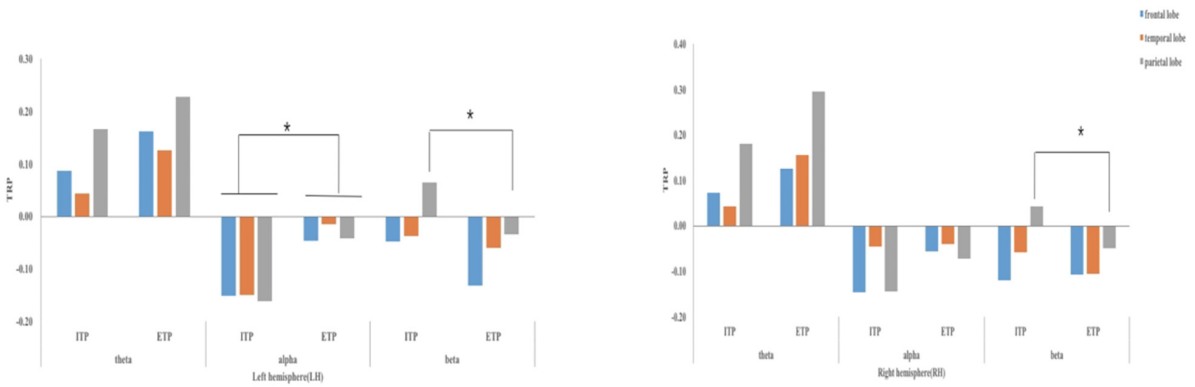

FIGURE 2 | Task-related power of EEG bands (theta, alpha, and beta) in different areas of LH and RH (frontal lobe, temporal lobe, and parietal lobe) in priming stage. *$p < 0.05$; TRP, task-related power; ITP, integrated thinking problems; ETP, eclectic thinking problems.

conditions. The synchronization or desynchronization of theta, alpha, and beta in IT and ET conditions is shown in **Figure 2**.

In the RAT stage, ANOVA revealed a significant double interaction between priming condition and hemisphere in the alpha band [$F(1,30) = 8.912$, $p = 0.006$, $\eta_p^2 = 0.229$]. Specifically, the alpha desynchronization in the IT condition was significantly higher than in the ET condition in the left hemisphere, yet was not significant in the right hemisphere. In addition, analysis revealed significant triple interactions between priming condition, area, and hemisphere in the beta band [$F(1.586,47.568) = 4.816$, $p = 0.018$, $\eta_p^2 = 0.138$]. Further simple effect analysis showed the IT priming was associated with increased beta synchronization, while ET priming tended to increase beta desynchronization in the left frontal and bilateral parietal lobes. Like the priming stage, there was also no significant difference of theta wave power among the three conditions in the RAT stage. Corresponding EEG results are shown in **Figures 2**, **3**.

DISCUSSION

This study investigated the impact of different forms of zhongyong thinking closely related to Chinese traditional culture on creative problem-solving. Based on previous research, zhongyong thinking was divided into IT and ET in the current study. Priming paradigms were adopted to induce participants' ET or IT. Participants were first presented with a real-world problem situation which needed to be solved with ET or IT. Then participants were asked to complete a RAT. Finally, the performance of participants on the RAT was examined in relation to priming conditions.

Behavioral findings revealed higher accuracy and shorter response time in IT priming than in ET priming, which may be related to different characteristics of different forms of zhongyong thinking. IT not only involves encoding information and retrieving information from long-term memory but also requires participants to integrate information from various sources. In comparison, ET involves less information integration than is typically required within a RAT, such that an individual can solve problems simply based on the retrieval and encoding of information. Additionally, the minds of participants were likely in a heightened integrative state following IT priming, making it easier to link concepts together in the RAT phase, resulting in improved performance. Therefore, results of the current study indicate that IT is more conducive to creative problem solving when compared to ET. These results also indirectly provide evidence that the testing protocol of the current study was effective in manipulating different forms of zhongyong thinking.

In the priming stage, EEG results showed that alpha desynchronization in the IT condition was significantly higher than in the ET condition in the left frontal, left temporal and left parietal lobes. Some studies have found that the phenomenon of alpha desynchronization is observed as a function of increased cognitive load (Stipacek et al., 2003; Fink et al., 2005). As previously mentioned, IT not only involves ET' mainly function – encoding information and retrieving information from long-term memory, but also requires to integrate information from various sources. Thus, IT may require more cognitive resources. It was found that IT was associated with beta synchronization, while ET was related to beta desynchronization in the bilateral parietal lobes. Some researchers have argued that synchronization in beta waves represents attentiveness and a binding mechanism that subserves perceptual and cognitive functions (Von and Sarnthein, 2000). Additionally, Engel and Fries (2010) have also pointed out that tasks involving endogenous top-down processes are often accompanied by increases in beta power. The IT aspect of zhongyong focuses on integrating information from different sources, which may require top-down processes, such as cognitive control and attention (Bhattacharya and Petsche, 2005; Fink and Benedek, 2014; Schwab et al., 2014). Conversely, unlike IT, ET mainly encodes and retrieves information, and lacks an information integration function. As such, beta desynchronization reflects the encoding of large amounts of external information, as well as the encoding and retrieval of long-term memory information, rather than the integration of information (Weiss and Mueller, 2012), which is essentially the function of ET.

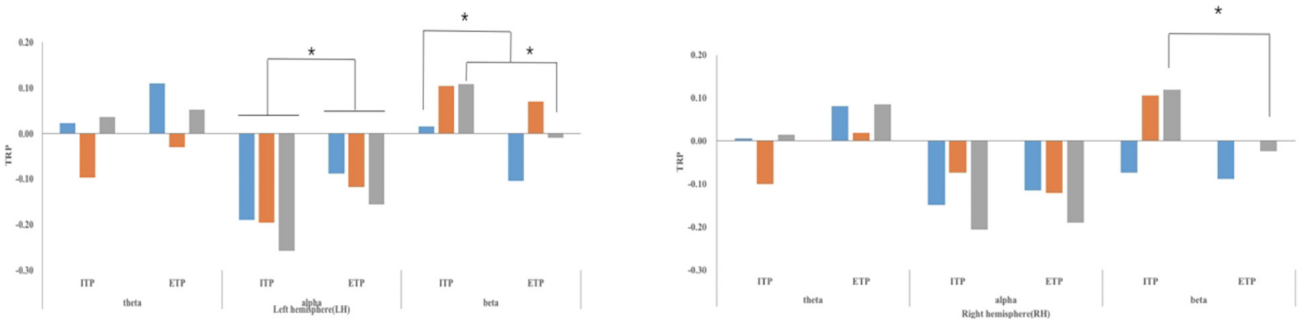

FIGURE 3 | Task-related power of EEG bands (theta, alpha, and beta) in different areas of LH and RH (frontal lobe, temporal lobe, and parietal lobe) in RAT stage. *$p < 0.05$; TRP, task-related power; CIT, condition of integrated thinking; CET, condition of eclectic thinking.

Therefore, IT involves more top-down processes, while ET only involves the retrieving and encoding of information in the priming stage.

In the RAT, EEG results showed that alpha desynchronization in the IT condition was significantly higher than in the ET condition in the left hemisphere. IT engages not only information integration but also the retrieving and encoding information. Thus, it may require more cognitive resources. Some studies have found that the phenomenon of alpha desynchronization is typically observed during performance of conventional cognitive tasks, and an increase of alpha band ERD is observed as a function of increased cognitive load (Stipacek et al., 2003; Fink et al., 2005). This study also found IT priming was associated with increased beta synchronization, while ET priming tended to increase beta desynchronization in the left frontal and bilateral parietal lobes. Many studies have indicated the temporal and frontal lobes are key brain regions for solving semantic creativity problems (Jung-Beeman et al., 2004; Qiu et al., 2010; Zhao et al., 2013; Shen et al., 2017). Further, a significant increase of beta activity over the parietal region is associated with better RAT performance, likely reflecting enhanced attentiveness and binding capacity (Bhattacharya and Petsche, 2005; Razumnikova, 2007). These results may be observed because a RAT mainly examines the abilities of word association and concept integration. IT is involved in top-down processes to integrate information, which is the exact skill necessary to excel on a RAT. In contrast, ET is primarily associated with information retrieval and encoding. While these functions are necessary to solve RAT problems, the top-down processes of information integration that ET lacks are also necessary for the final stages of solving a RAT.

On the whole, results found that EEG activity in the RAT phase was similar to that observed in the priming phase. Especially, IT and ET were found to trigger the same EEG activities. Specifically, priming phase and RAT phase both showed beta synchronization and beta desynchronization, respectively, in the bilateral parietal lobes and IT condition with higher alpha desynchronization than ET condition in the left hemisphere. This suggests that RAT and priming tasks might share the same neural mechanism, both of which are likely based on the top-down processing utilized in IT and the retrieval and encoding of information that is a result of ET. Thus, different forms of thinking that are initiated by priming tasks allowed participants to enter into a corresponding state of preparation in advance, further affecting problem-solving ability, as evidenced by RAT performance, which is consistent with the current behavioral findings.

In summary, participants primed in IT showed better RAT performance than those primed for ET, indicating that IT allows for top-down processing of information integration, differing substantially from ET, which appears to focus more on the retrieval and encoding of information. Simultaneously, priming tasks of zhongyong thinking might share a common neural mechanism activated by the RAT, so participants were in an enhanced state of integrative mind preparation after the IT priming, making it easier to integrate and link information in the RAT phase, and further improving RAT performance.

LIMITATIONS

It is worth mentioning that this study utilized only one creative thinking task. This may limit the generalizability of the findings to other creative tasks, such as divergent thinking. However, it is important to note that the top-down process involved in a RAT may be the same as those necessary for other types of creative tasks. Additionally, the EEG method was adopted in this study to explore the cognitive process of the effect of zhongyong thinking priming on RAT. As we know that the EEG has a low spatial resolution, so future research may consider using fMRI (functional magnetic resonance imaging) instead. Last, getting participants to apply zhongyong while solving problems resulted in subjects completing very few priming problems (two problems in each formal experiment). Therefore, some important data (effective EEG signal) may have drowned out due to fewer overlapping times and high noise during the experiment.

ETHICS STATEMENT

This study is approved by the Ethics Institutional Review Board of Central China Normal University and all study participants provided informed consent. We have read and understood your

journal's policies, and we believe that neither the manuscript nor the study violates any of these.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

Fundamental Research Funds for the Central Universities (CCNU18ZD005), The Open Research Fund of the State Key Laboratory of Cognitive Neuroscience and Learning (China) (CNLZD1604), Self-Determined Research Funds of CCNU from The Colleges' Basic Research and Operation of MOE (CCNU19TD019), and National Natural Science Foundation of China (31471000).

ACKNOWLEDGMENTS

We would like to thank Dr. Chanvi Singh in the University of South Australia for correcting grammatical and spelling errors of the paper. We sincerely appreciate all the members who voluntarily devoted time and interest to our research.

REFERENCES

Agnoli, S., Zanon, M., Mastria, S., Avenanti, A., and Corazza, G. E. (2018). Enhancing creative cognition with a rapid right-parietal neurofeedback procedure. *Neuropsychologia* 118, 99–106. doi: 10.1016/j.neuropsychologia.2018.02.015

Benedek, M., Bergner, S., Könen, T., Fink, A., and Neubauer, A. C. (2011). EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. *Neuropsychologia* 49, 3505–3511. doi: 10.1016/j.neuropsychologia.2011.09.004

Bhattacharya, J., and Petsche, H. (2005). Phase synchrony analysis of EEG during music perception reveals changes in functional connectivity due to musical expertise. *Signal Process.* 85, 2161–2177. doi: 10.1016/j.sigpro.2005.07.007

Choi, I., Nisbett, R. E., and Norenzayan, A. (1999). Causal attribution across cultures: variation and universality. *Psychol. Bull.* 125, 47–63. doi: 10.1037/0033-2909.125.1.47

Csikszentmihalyi, M. (1999). "16 implications of a systems perspective for the study of creativity," in *Handbook of creativity*, ed. R. J. Sternberg (Cambridge, MA: Cambridge University Press), 313–335.

Engel, A. K., and Fries, P. (2010). Beta-band oscillations–signalling the status quo? *Curr. Opin. Neurobiol.* 20, 156–165. doi: 10.1016/j.conb.2010.02.015

Feng, Y. L. (ed.) (1940). *Explaining the Zhongyong Concept*. Beijing: China Radio and Television Press.

Fink, A., and Benedek, M. (2014). EEG alpha power and creative ideation. *Neurosci. Biobehav. Rev.* 44, 111–123. doi: 10.1016/j.neubiorev.2012.12.002

Fink, A., Benedek, M., Grabner, R. H., Staudt, B., and Neubauer, A. C. (2007). Creativity meets neuroscience: experimental tasks for the neuroscientific study of creative thinking. *Methods* 42, 68–76. doi: 10.1016/j.ymeth.2006.12.001

Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., et al. (2009). The creative brain: investigation of brain activity during creative problem solving by means of EEG and FMRI. *Hum. Brain Mapp.* 30, 734–748. doi: 10.1002/hbm.20538

Fink, A., Grabner, R. H., Neuper, C., and Neubauer, A. C. (2005). EEG alpha band dissociation with increasing task demands. *Brain Res. Cogn. Brain Res.* 24, 252–259. doi: 10.1016/j.cogbrainres.2005.02.002

Fink, A., Schwab, D., and Papousek, I. (2011). Sensitivity of EEG upper alpha activity to cognitive and affective creativity interventions. *Int. J. Psychophysiol.* 82, 233–239. doi: 10.1016/j.ijpsycho.2011.09.003

Gong, Z., Liu, C., and Shen, W. (2016). Several thoughts on measuring creativity. *Adv. Psychol. Sci.* 24, 31–45. doi: 10.3724/SP.J.1042.2016.00031

Jauk, E., Benedek, M., and Neubauer, A. C. (2012). Tackling creativity at its roots: evidence for different patterns of EEG α activity related to convergent and divergent modes of task processing. *Int. J. Psychophysiol.* 84, 219–225. doi: 10.1016/j.ijpsycho.2012.02.012

Ji, L., Peng, K., and Nisbett, R. E. (2000). Culture, control, and perception of relationships in the environment. *J. Pers. Soc. Psychol.* 78, 943–955. doi: 10.1037/0022-3514.78.5.943

Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambelliu, S., Greenblatt, R., et al. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biol.* 2:E94. doi: 10.1371/journal.pbio.0020097

Liao, B., and Dong, W. Q. (2015). The study for the relationship among gold-mean thinking, organizational harmony and innovation behavior of knowledge staff. *Sci. Technol. Prog. Policy* 32, 150–154.

Liu, H., Wang, F., and Yang, X. (2015). More dialectical thinking, less creativity? the relationship between dialectical thinking style and creative personality: the case of China. *PLoS One* 10:e0122926. doi: 10.1371/journal.pone.0122926

Mednick, S. A. (1968). The remote associates test. *J. Creat. Behav.* 2, 213–214. doi: 10.1002/j.2162-6057.1968.tb00104.x

Mehta, R., and Zhu, R. J. (2009). Blue or red? Exploring the effect of color on cognitive task performances. *Science* 323, 1226–1229. doi: 10.1126/science.1169144

Mölle, M., Marshall, L., Wolf, B., Fehm, H. L., and Born, J. (1999). EEG complexity and performance measures of creative thinking. *Psychophysiology* 36, 95–104. doi: 10.1017/S0048577299961619

Morris, M. W., and Peng, K. (1994). Culture and cause: American and Chinese attributions for social and physical events. *J. Pers. Soc. Psychol.* 67, 949–971. doi: 10.1037/0022-3514.67.6.949

Nisbett, R. E., and Miyamoto, Y. (2005). The influence of culture: holistic versus analytic perception. *Trends Cogn. Sci.* 9, 467–473. doi: 10.1016/j.tics.2005.08.004

Pang (1980). Evaluating the zhongyong concept. *Soc. Sci. China* 75–100.

Pang (2000). Zhongyong and trichotomization. *J. Lit. Hist. Philos.* 21–27.

Pfurtscheller, G. (1999). "Quantification of ERD and ERS in the time domain," in *Event-Related Desynchronization. Handbook of Electroencephalography and Clinical Neurophysiology*, Vol. 6, eds G. Pfurtscheller and F. H. Lopes da Silva (Amsterdam: Elsevier), 89–105.

Pfurtscheller, G., and Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clin. Neurophysiol.* 110, 1842–1857. doi: 10.1016/S1388-2457(99)00141-8

Qiu, J., Li, H., Jou, J., Liu, J., Luo, Y., Feng, T., et al. (2010). Neural correlates of the "aha" experiences: evidence from an fMRI study of insight problem solving. *Cortex* 46, 397–403. doi: 10.1016/j.cortex.2009.06.006

Razumnikova, O. M. (2007). Creativity related cortex activity in the remote associates task. *Brain Res. Bull.* 73, 96–102. doi: 10.1016/j.brainresbull.2007.02.008

Schwab, D., Benedek, M., Papousek, I., Weiss, E. M., and Fink, A. (2014). The time-course of EEG alpha power changes in creative ideation. *Front. Hum. Neurosci.* 8:310. doi: 10.3389/fnhum.2014.00310

Shen, W., Yuan, Y., Liu, C., and Luo, J. (2017). The roles of the temporal lobe in creative insight: an integrated review. *Think. Reason.* 23, 321–375. doi: 10.1080/13546783.2017.1308885

Shen, W., Yuan, Y., Zhao, Y., Zhang, X., Liu, C., Luo, J., et al. (2018). Defining insight: a study examining implicit theories of insight experience. *Psychol. Aesthet. Creat. Arts* 12, 317–327. doi: 10.1037/aca0000138

Srinivasan, N. (2007). Cognitive neuroscience of creativity: EEG based approaches. *Methods* 42, 109–116. doi: 10.1016/j.ymeth.2006.12.008

Stipacek, A., Grabner, R. H., Neuper, C., Fink, A., and Neubauer, A. C. (2003). Sensitivity of human eeg alpha band desynchronization to different working memory components and increasing levels of memory load. *Neurosci. Lett.* 353, 193–196. doi: 10.1016/j.neulet.2003.09.044

Von, S. A., and Sarnthein, J. (2000). Different frequencies for different scales of cortical integration: from local gamma to long range alpha/theta synchronization. *Int. J. Psychophysiol.* 38, 301–313. doi: 10.1016/S0167-8760(00)00172-0

Weiss, S., and Mueller, H. M. (2012). "Too many betas do not spoil the broth": the role of beta brain oscillations in language processing. *Front. Psychol.* 3:201. doi: 10.3389/fpsyg.2012.00201

Wu, J. H., and Lin, Y. Z. (2005). Development of a zhongyong thinking style scale (in Chinese). *Res. Indig. Psychol.* 24, 247–300.

Yang, Y. Y. (2014). "The moralmeaning and life purpose in daily life: the conceptualization of the C. F. Yang's zhongyong action-deliberation system," in *Chinese Social Psychological Review*, Vol. 8, ed. Y. Y. Yang (Beijing: Social Sciences Academic Press), 256–271.

Yang, Z. F. (2009). A case of attempt to combine the Chinese traditional culture with the social science: the social psychological research of "zhongyong". *J. Renmin Univ. China* 3, 53–60.

Yang, Z. F., and Lin, S. D. (2012). A construct validity study of C. F. Yang's Zhongyong conceptualization. *Soc. Psychol. Res.* 4, 167–186.

Yang, Z. F., Yang, Z. H., and Ding, Y. (2014). "A second validity study of C.F.Yang's Conceptualization of Zhongyong. Chinese social psychology review," in *Chinese Social Psychological Review*, Vol. 7, ed. Y. Y. Yang (Beijing: Social Sciences Academic Press), 18–42.

Yang, Z. F., and Zhao, Z. Y. (1997). "The primary exploration of zhongyong practical thinking style," in *Proceedings of the Fourth International Symposium on Chinese Psychology and Behavior Interdisciplinary (CPBI)*, Taibei, 29–31.

Yao, X., Yang, Q., Dong, N., and Wang, L. (2010). Moderating effect of zhongyong on the relationship between creativity and innovation behavior. *Asian J. Soc. Psychol.* 13, 53–57. doi: 10.1111/j.1467-839X.2010.01300.x

Zhang, G. X., and Gu, X. Y. (2015). Moderation thinking and employees' creativity. *Sci. Res. Manage.* 36, 251–257.

Zhao, Q. B., Zhou, Z. J., Xu, H. B., Chen, S., Xu, F., Fan, W. L., et al. (2013). Dynamic neural network of insight: a functional magnetic resonance imaging study on solving Chinese 'chengyu' riddles. *PLoS One* 8:e59351. doi: 10.1371/journal.pone.0059351

Zhou, L. S. (1994). "Preface," in *Researches of Chinese Traditional Thinking Mode,* eds C. Y. Gao (Jinan: Shandong University Press), 1–6.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 11 February 2019
doi: 10.3389/fpsyg.2019.00273

Boosting Creativity, but Only for Low Creative Connectivity: The Moderating Effect of Priming Stereotypically Inconsistent Information on Creativity

Fangfang Wen[1,2,3], *Bin Zuo*[1,2,3]*, *Zhijie Xie*[1,2] and *Jia Gao*[1,2]

[1] School of Psychology, Central China Normal University, Wuhan, China, [2] Center for Studies of Social Psychology, Central China Normal University, Wuhan, China, [3] Key Laboratory of Adolescent Cyberpsychology and Behavior, Ministry of Education, Wuhan, China

Previous researchers have documented that priming inconsistent stereotypic information boosts creativity. The current study further examined the moderating role of creativity connectivity—which is the degree to which people perceive a social group or professional role to be relevant to creativity—in the priming of information related to the boosting effects of creativity. Study 1 adopted a 2 (stereotypically inconsistent target gender: male vs. female) × 2 [priming types: stereotypically consistent information (SCI) priming vs. stereotypically inconsistent information (SICI) priming] group design in which 89 college students from Wuhan were enrolled to complete a priming paradigm and a poster-advertising-design task. As a result, we found that the activation of inconsistent stereotypic information boosted creativity compared with that of consistent stereotypic information, which replicated previous findings. Study 2 also adopted a 2 (creativity-domain connectivity: high vs. low) × 2 (priming types: SCI priming vs. SICI priming) group design in which 85 college students from Wuhan were enrolled to complete the same tasks as in Study 1. The results of Study 2 indicated that when information with low relevance to creativity such as "a nurse" was primed, creativity was then significantly boosted by inconsistent stereotypic information such as "a male nurse" compared with the stereotypic one such as "a female nurse." Conversely, when information with high relevance to creativity such as "a poet" was primed, there were no significant creativity-boosting effects between inconsistent stereotypic information such as "a dull poet" and the consistent one such as "an eccentric poet." In sum, this study (i) replicated the previous findings in Chinese culture and (ii) further explored the moderating role of creativity connectivity of the inconsistent stereotypic information.

Keywords: individual creativity, stereotypically inconsistent information, creativity connectivity, poster design task, priming paradigm

OPEN ACCESS

Edited by:
Chang Liu,
Nanjing Normal University, China

Reviewed by:
Li Liu,
Beijing Normal University, China
He Xianyou,
South China Normal University, China

***Correspondence:**
Bin Zuo
zuobin@mail.ccnu.edu.cn

Specialty section:
This article was submitted to Cognitive Science, a section of the journal Frontiers in Psychology

Received: *26 September 2018*
Accepted: *28 January 2019*
Published: *11 February 2019*

Citation:
Wen F, Zuo B, Xie Z and Gao J (2019) Boosting Creativity, but Only for Low Creative Connectivity: The Moderating Effect of Priming Stereotypically Inconsistent Information on Creativity. Front. Psychol. 10:273. doi: 10.3389/fpsyg.2019.00273

INTRODUCTION

Creativity, which refers to the ability of individuals to generate novel and useful products (Sternberg, 1999; Gong et al., 2016), is one of the most important topics in the study of psychology. Creativity plays a vital role in individual career success and represents an unconventional way of thinking that is critical to problem solving, individual progress, change, and innovation (Ward et al., 2008; Tyagi et al., 2017). To fully tap the creative potential of individuals, researchers

have explored and validated various factors that may affect creativity, such as individual factors—including personality traits and intelligence (Nusbaum and Silvia, 2011; Simonton, 2014; Barbara et al., 2018; Kenett et al., 2018)—and environmental factors, including family environment and cultural background (Peijia et al., 2006; Lew and Cho, 2013). Thus, most previous studies on creativity have focused on the influence of relatively stable factors.

In recent years, social psychologists have gradually turned their attention to the effect of relatively manipulable cognitive factors on boosting creativity. For example, changing individual cognitive styles can boost creativity; studies have shown that priming one's own multiple social identities can effectively boost creativity (Gaither et al., 2015). Additionally, usage of stereotypes—an important social cognitive style (Song and Zuo, 2016; Zhang et al., 2016) that implies fixed viewpoints and opinions on the characteristics a certain group (Zuo et al., 2006, 2018)—is also receiving increased attention by social psychologists and is emerging as a new way of boosting creativity. Hudson (1968) first attempted to use stereotypic information to boost the creative potential of elementary school students. The study asked participants in the experimental group to imagine themselves as "eccentric poets," while participants in the control group were asked to imagine themselves as "hardworking scientists." The results of this study showed that the experimental group performed better than the control group in a subsequent divergent-thinking task. On this basis, Dumas and Dunbar (2016) used a multi-purpose task to measure the divergent-thinking performance of participants and found that both fluency and originality of the divergent thinking of participants in the group primed with low-creativity stereotypes (e.g., "a stubborn librarian") were lower than that of participants primed with high-creativity stereotypes (e.g., "an eccentric poet"); that is, the effect of primed stereotypic information on creativity was based on the connectivity between stereotypic content and creativity. Later, de Rooij et al. (2017) attempted to manipulate the relationship between the participants' network avatars and their corresponding creativity in a 3D virtual environment. They asked the participants to imagine themselves as the avatar and to generate creative examples of objects characterized by a particular feature, which was used to measure participants' creativity. The results showed that non-creative network avatars (worker stereotypes) reduced creativity, while creative network avatars (artist stereotypes) had no significant effect on creativity. All of the studies above focusing on the effect of stereotypic information on creativity came to a relatively consistent conclusion, which is that priming stereotypes with a strong connection to creativity (e.g., "an eccentric poet," "artists") could improve one's creativity or at least keep creativity constant, while priming stereotypes with little connection to creativity (e.g., "a stubborn librarian," "office workers") would reduce creativity. It can be seen that the creative connectivity of priming information—that is, the degree of association between social groups/professional roles and the perceived creativity of these groups/roles—plays an extremely important moderating role in how stereotypes affect creativity.

In addition to exploring the impact of stereotypically consistent information (abbreviated as SCI, which means information that corresponds to existing stereotypes), recently, the effect of the priming with stereotypically inconsistent information (abbreviated as SICI, which means information that does not correspond to existing stereotypes) on creativity has aroused great interest among social psychologists. For example, Gocłowska et al. (2013) conducted two experiments to investigate this effect. In this paper, Study 1 used an "unintentional plagiarism" task and found that priming with SICI could effectively stimulate participants' cognitive flexibility and reduce their reliance on the availability of knowledge. Study 2 asked participants in the stereotypical condition to come up with five social combinations that "should go together," while participants in the stereotypically inconsistent condition were asked to think of five social combinations that "should not go together." Afterward, the researchers used a poster-design experiment to measure creativity, which required the participants to generate new ideas for a themed night at a college club and display their ideas on posters. The results showed that priming with SICI could boost the performance of the participants in the creative task, even if the priming information was unrelated to any specific target group. For this result, Gocłowska et al. (2013) argued that when SICI was primed, stereotyped or schematized knowledge would no longer be effective due to participants' less frequent reliance on available knowledge. Thus, priming with SICI is beneficial to boost the flexibility and creativity of individual thinking. Based on these results, researchers (Gocłowska et al., 2014) further explored the boundary conditions of the creativity-boosting effect. They found that the boosting effect only existed in individuals with a low personal need for structure (PNS). PNS is defined as "the long-term tendency to create and use abstract mental representations (such as pictures, scripts, attitudes, and stereotypes) that have been simplified by previous experience" (Sun et al., 2016). When exposed to SICI, low PNS promoted participants' divergent thinking, making them perform better on insight problem-solving, but it had no effect on aggregate thinking. Although high PNS did not affect the individuals' aggregate thinking, it inhibited their divergent thinking, making them perform worse when solving insight problems. Later, Damer et al. (2018) found that need for cognition (NFC), which refers to the tendency of a person to participate in and enjoy cognitive activities that require effort, also influenced the effect of SICI on cognitive flexibility. For individuals with low NFC, exposure to SICI increased their cognitive flexibility. Conversely, for individuals with high NFC, SICI was not enough to surprise them and, thus, would instead reduce their cognitive flexibility. Therefore, according to these previous findings, it can be inferred that the effect of SICI on creativity is moderated by multiple variables. However, the existing literature has mostly explored the boundary conditions of the boosting effect of SICI on creativity from the perspective of evaluators' individual differences (such as PNS and NFC), while few studies have examined the possible moderating role of priming information—such as its creativity connectivity—in the creativity-boosting effect of SICI. Therefore, this study will further examine the creativity-boosting effect from this information-priming perspective.

Furthermore, previous studies on the boosting effect of SICI on individual creativity have mostly been carried out in a Western

context, whereas Confucianism—which is dominant in China (Liu, 2018)—advocates a moderation-thinking pattern and an educational system that promotes collectivist culture, which is extremely different from the framework of Western countries. Hence, it is necessary to examine whether the positive effects of SICI on creativity also exist in this Eastern kind of social context. In addition, the moderating role of the creative connectivity of priming information in the creativity-boosting effect is also worth exploring further. Therefore, this study first examined whether the positive effects of SICI on creativity still exists in the context of Chinese culture and then, in Study 2, explored the moderating role of creative connectivity of priming information.

STUDY 1: THE EFFECT OF STEREOTYPICALLY INCONSISTENT INFORMATION ON CREATIVITY

Purposes and Hypotheses

We aimed to use the priming paradigm and the poster paradigm to explore whether the priming of SCI/SICI would have a boosting effect on creativity. The poster paradigm has previously been used to measure creativity by Gocłowska et al. (2013). In this paradigm, participants are asked to think of a party theme for a college club and to display their ideas on posters. Then several raters—blind to the experimental conditions and hypotheses—judge the creativity of ideas and posters. When the inter-rater reliability is acceptable, the average score of the raters is used as the participant's creativity score. In this study, we hypothesized that, compared with SCI priming, SICI priming would boost the creative performance of participants more effectively.

Methods

Participants

The required test volume for calculations using G*Power 3.1 was 89 people (assuming a significance-level α of 0.05, a statistical power ($1 - \beta$) of 0.95, and an effect size of 0.45). A total of 89 students (41 males and 48 females) with an average age of 19.12 years (SD = 1.90) from Wuhan were recruited through advertising in college. All of the participants volunteered to be involved in the study and were compensated with six yuan after completing the experiment. Each subject was randomly assigned to an experimental condition. The results of specific grouping, gender, and age distributions are shown in **Table 1**.

In addition, this study was carried out in accordance with the recommendations of APA ethical guidelines. The protocol was approved by the Ethics Committee of the Research Center for Social Psychology at Central China Normal University. Before the experiment, all subjects gave written informed consent in accordance with the Declaration of Helsinki. The informed consent included a brief description of the study and potential risks. Subjects were also informed of the experiment duration, their right to withdraw from the experiment at any time, the confidentiality and anonymity protection of their data, and the contact information of the lead researcher. Participants indicated their willingness by checking the "I agree" option and then moved on to the experiment. This informed consent procedure was identical in Study 2.

Experimental Design

The experiment adopted a 2 × 2 group design. The independent variables were the information's target gender (male vs. female) and priming type (SCI priming vs. SICI priming), which were both between-subject variables, while the dependent variable was the performance of the participants in the poster design.

Selection of Experimental Materials

First, we chose "a male governor" and "a female nurse" as the targets of the SCI group, and "a female governor" and "a male nurse" as the targets of the SICI group. Then we used a subjective evaluation method to test the validity of the experimental materials. Specifically, we recruited 37 participants (21 males and 16 females) through the QQ group platform; their average age was 20.73 years (SD = 2.16). Participants were asked to complete a questionnaire on the Wenjuanxing questionnaire platform[1], which was used to rate the typicality of the four targets as a male/female. For example, we asked, "To what extent do you think 'a male nurse' is typical among men?" The participants rated them on a seven-point Likert scale (from 1 = "very typical" to 7 = "very atypical"). A high score indicated that the participant thought that the target was atypical and was considered an anti-stereotype, while a low score indicated that the subject thought that the target was typical and was considered a stereotype.

The results of repeated measures ANOVA showed that the mean scores of the two targets in the SICI group (M = 4.76, 4.35) were significantly higher than those of the two targets in the SCI group (M = 2.41, 2.54; $p < 0.001$ for both). Hence, the experimental materials were validated.

[1]In China, The Wenjuanxing questionnaire platform (https://www.wjx.cn/) is widely used for posting online questionnaire and collecting data. We first posted the questionnaire on the platform and after collecting all the data, we downloaded them from the platform.

TABLE 1 | Distribution and descriptions of gender and age in each group (N = 89).

		SCI priming			SICI priming		
Participant gender	**Target gender**	***n***	M_{age}	***SD***	***n***	M_{age}	***SD***
Male	Male	11	20.0	2.49	10	19.9	1.85
	Female	10	20.0	2.36	10	20.7	2.21
Female	Male	13	17.9	0.56	12	18.4	0.79
	Female	10	18.7	1.49	13	18.2	0/99

Experimental Procedure

This experiment was divided into two phases, namely, the priming phase and the creativity-measurement phase. First, participants completed the SCI/SICI priming phase through an adjective description task (Leicht et al., 2014), which required participants to use six adjectives (trying to avoid repetition) to describe a specific target. The target for the SICI priming group to describe was "a male nurse" or "a female governor," while the target for the SCI priming group to describe was "a male governor" or "a female nurse." For example, the instruction was, "Please use six adjectives to describe 'a male nurse'." After the description task, each participant completed a manipulation check to ensure the validity of the independent variable, that is, the priming type. The corresponding manipulation-check question for each condition was the same as in the pre-experiment.

The second phase took place immediately after the manipulation check, during which we used poster design (Gocłowska et al., 2013) for creativity evaluation. All participants were asked to design a poster for a party at a college in 5 min, and were instructed to make the poster as novel and unique as possible. After collecting all the posters, we invited three raters—who were blind to the purpose of the experiment—to evaluate the novelty and creativity of the posters using a five-point Likert scale (from 1 = "very uncreative" to 5 = "very creative"). Then we calculated the inter-rater reliability of the three scorers to ensure the credibility of the evaluation. A higher score indicated better creativity performance.

Results

We tested the validity of the independent-variable manipulation using SPSS 21.0. *Post hoc* multiple comparisons of the one-way ANOVA showed that the mean scores of the two targets in the SICI priming group (M = 5.55, 3.95) were both significantly greater than those of the two targets in the SCI priming group (M = 2.35, 2.08; $p < 0.001$ for both), which indicated that participants in the SICI group thought the targets were more counter-stereotypic than those in SCI group. Hence, our manipulation on priming type was validated.

With regard to the inter-rater reliability of the three raters, we obtained $\alpha = 0.76$, which indicated that the three scorers' evaluations on the posters were reliable; therefore, a mean value could be calculated for further data analysis. We conducted a one-way ANOVA on the novelty scores of the participants' posters. The results showed that the main effect of the priming type was significant [$F(1,85) = 6.74$; $p < 0.05$; η^2 partial = 0.06]. The main effect of the target gender was not significant [$F(1, 85) = 0.08$; $p = 0.78$]. Additionally, the interaction between the priming type and target gender was not significant [$F(1,85) = 2.62$; $p = 0.11$]. Specifically, the creativity scores of participants under the condition of SICI priming (M = 2.76, SD = 0.14) were higher than those of participants under the condition of SCI priming (M = 2.25, SD = 0.14). This result indicates that, in comparison to SCI priming, SICI priming boosts creative performance significantly better, which confirms our research hypothesis. Meanwhile, the gender of the targets did not have a significant effect on the creativity performance of participants. Specifically, there was no significant difference in the creativity scores of the participants when priming with stereotypically inconsistent men (M = 2.94, SD = 0.85) vs. when priming with stereotypically inconsistent women (M = 2.57, SD = 0.96; $p = 0.18$). There was also no significant difference in the creativity scores of the participants when priming with stereotypical males (M = 2.13, SD = 0.71) vs. priming with stereotypical females (M = 2.38, SD = 1.11; $p = 0.38$). The specific results are shown in **Table 2**.

Discussion

Study 1 manipulated the independent variables by asking the participants to write adjectives to describe stereotypically consistent or stereotypically inconsistent individuals, and examined the influence of the priming type on creativity performances. The results confirmed that the priming type can indeed influence the creativity performances of participants; that is, compared to participants who were primed with SCI, participants who were primed with SICI were more likely to think unconventionally and obtained higher scores on the subsequent creativity tests (i.e., poster designs). Further examination about the influence of the gender of the evaluation target on the relationship between the priming type and the creativity score suggested that whether the stereotypically inconsistent target used for priming was male or female did not make a difference, indicating that the positive influence of SICI is not affected by the gender of the evaluation target. In general, the results of Study 1 have confirmed the positive effect of SICI on individual creativity. Next, Study 2 explores the boundary conditions of SICI on creativity-boosting from other perspectives.

STUDY 2: THE MODERATING ROLE OF THE CREATIVE CONNECTIVITY OF SICI

Purposes and Hypotheses

Study 2 further examined whether priming information with different levels of creative connectivity would have different effects on creativity-boosting. Specifically, we examined whether SICI highly connected with creativity or lowly connected with creativity would have a similar effect on creativity performances. In Study 2, our hypothesis was that, relatively speaking, SICI highly connected with creativity would not boost the creativity of participants while SICI lowly connected with creativity would boost the creativity of participants.

TABLE 2 | The results of the one-way ANOVA on the novelty scores of the participants' posters.

Variation source	*df*	*F*	*p*	η^2_P
Priming type	1	6.74*	0.001	0.00
Target gender	1	0.08	0.78	0.07
Priming type × target gender	1	2.62	0.11	0.03

*$p < 0.05$.

Methods

Participants

We recruited a total of 85 students (41 males and 43 females) from Wuhan through advertising in college. All of the participants were volunteered to be involved in the study and were compensated with six yuan after completing the experiment. Their average age was 19.36 years (SD = 1.34), and one of the participants did not write down his or her gender or age. Each subject was randomly assigned to an experimental condition. The specific grouping, gender, and age distribution are shown in **Table 3**. In addition, this study was also carried out in accordance with the recommendations of APA ethical guidelines. The protocol was approved by the Ethics Committee of the Research Center for Social Psychology at Central China Normal University. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The informed consent procedure was identical for Study 1.

Experimental Materials

First, we selected "poet" and "nurse" as targets with different levels of creative connectivity and added stereotypically consistent or stereotypically inconsistent characteristic words to form SCI ("an eccentric poet" and "a female nurse") and SICI ("a dull poet" and "a male nurse"). Then we used subjective evaluation methods to test the validity of the experimental materials. Specifically, we recruited 33 participants (14 males and 19 females) through advertising on campus. Their average age was 21.3 years (SD = 2.88). We asked the participants to rate the typicality of the four targets—"an eccentric poet," "a dull poet," "a male nurse," and "a female nurse"—as poets or a nurses. For example, we asked, "How typical is it for there to be 'a male nurse' among nurses?" Subsequently, the participants rated the targets on a seven-point Likert scale (from 1 = "very typical" to 7 = "very atypical"). A high score meant that the participant believed that the stimulus was atypical and belonged to the stereotypically inconsistent category and a low score meant that the participant thought that the stimulus was typical and belonged to the stereotypical category.

The results of repeated-measures ANOVA showed that the mean scores of the two targets in the SICI group (M = 5.12, 5.06) were significantly higher than those in the SCI group (M = 3.39, 2.45; $p < 0.001$ for both). Hence, the experimental materials were validated.

Experimental Design

We used a 2 (creativity-domain connectivity: high vs. low) × 2 (priming types: SCI priming vs. SICI priming) inter-group design. Within this design, the priming information of the high-connectivity SCI condition was "an eccentric poet," and the low-connectivity SCI condition was "a female nurse," while the high-connectivity SICI condition was "a dull poet," and the low-connectivity SICI condition was "a male nurse." The dependent variable was the creativity performance of the participants in the poster design.

Experimental Procedure

First, we completed the priming phase through an adjective-description task. The target that the participant needed to describe was "an eccentric poet," "a dull poet," "a male nurse," or "a female nurse." Apart from the descriptive targets in the priming phase, the remaining specific processes were the same as in Study 1. Next, the validity of the manipulation of the independent variables was tested; the specific process was the same as in the pre-experiment. Finally, we measured the dependent variable. We also used the poster-design paradigm and scored the collected posters. The specific process was the same as in Study 1.

Results

We tested the validity of the independent-variable manipulation using SPSS 21.0. *Post hoc* multiple comparisons of the one-way ANOVA showed that the mean scores of the two targets in the SICI group (M = 5.48, 4.61) were significantly higher than those of the SCI group (M = 2.65, 3.47; $p < 0.01$ for both). This indicated that the manipulation of the independent variable of priming type was validated.

With regard to inter-rater reliability of the three raters, we obtained $\alpha = 0.75$, which indicated that the evaluations of the three evaluators were reliable; therefore, a mean value was calculated for further data analysis. We conducted a one-way ANOVA on the novelty scores of the participants' posters. The results showed that the main effect of the priming type [$F(1,80) = 0.24$; $p = 0.63$] and the main effect of creativity-domain connectivity [$F(1,80) = 0.03$; $p = 0.87$] were not significant, but the effects of the interaction between the priming type and connectivity were significant [$F(1,80) = 5.23$; $p < 0.05$; η^2 partial = 0.06]. The specific results are shown in **Figure 1**.

TABLE 3 | Distribution and descriptions of gender and age in each group (N = 85)*.

		SCI priming			SICI priming		
Target gender	**Creative connectivity**	***n***	M_{age}	***SD***	***n***	M_{age}	***SD***
Male	High	9	19.9	0.67	11	19.1	1.04
	Low	10	19.1	1.45	11	19.5	1.13
Female	High	10	20.1	1.60	12	20.2	1.47
	Low	10	18.5	1.35	11	18.6	1.03

*In Study 2, age and gender variables were not our independent variables, so we decided to keep the data of the one subject who did not specify gender and age. His or her experimental condition was low-connectivity SICI priming condition. His or her data would be included in the subsequent analysis, while his or her information is not shown in **Table 3**.*

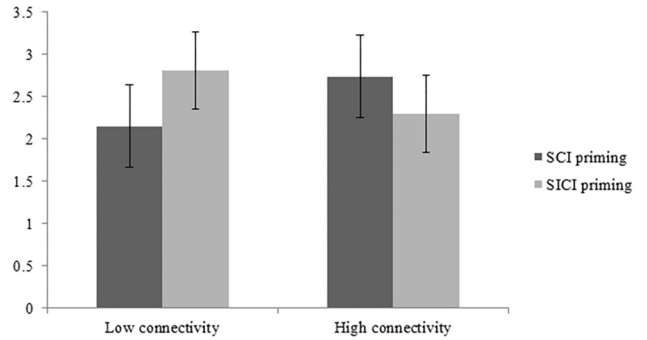

FIGURE 1 | Interaction diagram between the priming type and creativity-domain connectivity.

Since the effects of the interaction between creative connectivity and priming type were significant, we further performed a simple-effect analysis. The results showed that under the high-connectivity conditions, the creativity scores of the participants in the SCI priming group and SICI priming group did not differ significantly [$F(1,39) = 1.64$; $p = 0.21$]. However, under low-connectivity conditions, the creativity scores of the participants in the SCI priming group and SICI priming group differed significantly [$F(1,41) = 4.23$; $p < 0.05$]. Specifically, under low-connectivity conditions, the creativity scores of the SICI priming group ($M = 2.81$, $SD = 1.14$) were significantly higher than those of the SCI priming group ($M = 2.15$, $SD = 0.95$). Furthermore, under the high-connectivity conditions, the creativity scores of the SICI priming group ($M = 2.3$, $SD = 1.03$) did not differ significantly from those of the SCI priming group ($M = 2.74$, $SD = 1.14$). The specific results are shown in **Table 4**.

Discussion

Study 2 explored the moderating mechanism of the relationship between SICI priming and creativity-boosting. Specifically, it examined whether SICI priming affects individual creative performance differently when the creativity connectivity of the priming information is different. The results show that when the priming information has low connectivity to creativity, the priming of SICI is more stimulating to participants' creative performance than the priming of SCI. However, when the priming information is highly connected to creativity, there is no significant difference between the two. Specifically, when the priming information has low connectivity to creativity, such as the information about the nurse, priming with SICI ("a male nurse") boosts participants' creativity more than priming with SCI ("a female nurse"). Furthermore, when the priming information has high connectivity to creativity, such as the information about the poet, priming with SCI ("an eccentric poet") and priming with SICI ("a dull poet") do not affect the creative performance of the participants differently. These results suggest that not all SICI can improve the creativity of participants. Only when the connectivity between priming information and creativity is relatively low will SICI be able to better boost creativity.

TABLE 4 | Further simple-effect analysis.

Variation source	*df*	*F*	*p*	*η2 partial*
Priming type (SCI/SICI)				
Low connectivity	1	4.23*	0.04	0.09
High connectivity	1	1.64	0.21	0.04

*$p < 0.05$.

GENERAL DISCUSSION

From the perspective of social cognition, this study has deepened our understanding of the effect of SICI on creativity-boosting from two different aspects. First, this study has confirmed that priming with SICI is an effective strategy for boosting an individual's creative performance in the poster-design task, which is consistent with the results of previous studies conducted in a Western cultural context (Gocłowska et al., 2013). Besides, our findings proved that even in a Chinese cultural context, the positive effect of SICI can also be extended beyond the field of stereotypes. Finally, this study proposed and confirmed the moderating effect of creativity connectivity, which further supplements the research of Gocłowska et al. (2014) on the relationship between SICI and creativity. This result indicates that creativity is not a stable characteristic of an individual, but rather a flexible product of the interaction between the situation and the individual.

The results of Study 1 suggest that SICI priming can boost an individual's creative performance, and that this effect is unrelated to the gender of the target of the priming information. Whether one primes with SICI of a male or female target, both are able to significantly improve the creative performance of participants. This result is consistent with the results obtained by Gocłowska et al. (2013) using a stereotypically inconsistent linking method. On the other hand, it also shows that, in the context of Eastern culture, SICI can also lead subjects to be less likely to apply stereotypical or schematic knowledge, thus making their cognition more flexible and boosting their creativity performances.

In addition, other studies on the effects of SICI on cognition have also provided indirect evidence for the results of this study. For example, many studies have found that the exposure to SICI can effectively reduce people's stereotypes and prejudices toward specific groups (Lai et al., 2014; Finnegan et al., 2015). Additionally, there have been other researchers who have shown that priming with anti-stereotypes can influence an individual's self-concept, that is, reducing the stereotyping of one's implicit self-concept can make one's explicit self-concept more flexible (Asgari et al., 2010, 2012). All these studies have suggested that priming with SICI can provide an unconventional atmosphere for individuals in a short time, thus affecting their original cognition. In the present study, creativity performance in the poster-design task was enhanced precisely because the previous description task of SICI activated the creative-thinking process of the subjects.

Some of the results in Study 2 provide indirect evidence to corroborate previous studies regarding stereotypes and creativity. According to Dumas and Dunbar (2016), when the priming stimulus has low-creativity connectivity (e.g., "a stubborn librarian"), it is not conducive to individual creativity. Only when the stimulus has high-creativity connectivity (e.g., "an eccentric poet")—or at least does not have low creativity—will it boost individual creativity. Similarly, we found that when the high-creativity-connected SCI ("an eccentric poet") was primed, its boosting effect on creativity was marginally significantly higher than that of priming with low-creativity-connected SCI ("a female nurse"), $p = 0.09$, which is consistent with the results of Dumas and Dunbar (2016). What is more, we further explored the impact of SICI with different creativity correlations on creativity. We found that when the SICI were highly related with creativity—such as "a dull poet," which is anti-stereotyped since information on poets is generally associated with high creativity—it was not conducive to boosting individual creative performance. However, when the SICI had low connectivity to creativity—such as a male nurse, since information about nurses generally has a low connectivity to creativity—it did boost individual creativity.

In general, based on previous research and theories, the present study made some reasonable inferences and further obtained some meaningful conclusions and findings that can extend and supplement previous findings through strict manipulation and control of variables. However, there are still some limitations to our study. First, the participants selected in the two experiments were all college students. We did not consider other social groups, which could have affected the ecological validity of the study. As a special group, college students have stronger cognitive ability and higher intelligence, relative to other social groups. Studies have shown that individual intelligence and creativity have a moderate level of correlation (Nusbaum and Silvia, 2011). Therefore, in future research, it will be necessary to select other social groups—such as teenagers and children—and different occupational groups to test these hypotheses. Second, while Study 2 explored the effect of creative connectivity on creativity-boosting by selecting "an eccentric poet" and "a dull poet," and "a female nurse" and "a male nurse" as high/low creative connectivity stereotypically consistent/inconsistent targets—future research may also adopt other groups to conduct repetitive tests, such as the following: "an innovative artist" and "a somber artist"; "a male engineer" and "a female engineer." Third, although the poets and nurses discussed in this study are two common domains of high/low association with creativity, we still consider that the creativity connectivity may be a continuous variable of varying degrees, while nurse is only a domain of medium relevance. Hence, we suggest that future research could further examine the impact of SICI on creativity performance at different degrees of creativity connection (e.g., high vs. medium vs. low). Finally, further exploration of the duration of the effect of SICI on creativity—that is, whether the positive effect is temporary or chronic—is also an important topic for future research.

Building upon the foundation of previous research, the present study found that SICI has a positive boosting effect on creativity in a Chinese cultural context. Additionally, the present study also explored whether the creative connectivity of priming information has influence on this process. The results show that only when the priming information has low connectivity to creativity does priming with SICI promote the creative performance of participants. In sum, this study replicated previous findings in Chinese culture, and revealed that the creativity boosting effect is affected not only by individual differences but also by priming information itself.

ETHICS STATEMENT

The full name and affiliation of the ethics committed of the present study is the Center for Studies of Social Psychology at Central China Normal University.

AUTHOR CONTRIBUTIONS

FW and BZ conceived and designed the analysis, and wrote the manuscript. ZX and JG collected the data.

FUNDING

This research was supported by National Natural Science Foundation of China (31571147 and 31400903), National Social Science Major Project of China (18ZDA331), and Self determined Research Funds of CCNU from the Colleges' Basic Research and Operation of MOE grants (CCNU18ZDPY12).

REFERENCES

Asgari, S., Dasgupta, N., and Cote, N. G. (2010). When does contact with successful ingroup members change self-stereotypes? A longitudinal study comparing the effect of quantity vs. quality of contact with successful individuals. *Soc. Psychol.* 41, 203–211. doi: 10.1027/1864-9335/a000028

Asgari, S., Dasgupta, N., and Stout, J. G. (2012). When do counterstereotypic ingroup members inspire versus deflate? The effect of successful professional women on young women's leadership self-concept. *Pers. Soc. Psychol. Bull.* 38, 370–383. doi: 10.1177/0146167211431968

Barbara, C., Alessandro, A., and Brendan, D. (2018). The relationships between cognitive reserve and creativity. a study on american aging population. *Front. Psychol.* 9:764. doi: 10.3389/fpsyg.2018.00764

Damer, E., ebb, T. L., and Crisp, R. J. (2018). Diversity may help the uninterested: evidence that exposure to counter-stereotypes promotes cognitive reflection for people low (but not high) in need for cognition. *Group Process. Intergroup Relat.* doi: 10.1177/1368430218811250

de Rooij, A., van der Land, S., and van Erp, S. (2017). "The creative Proteus Effect: How self-similarity, embodiment, and priming of creative stereotypes with avatars influences creative ideation," in *Proceedings of the 2017 ACM Sigchi Conference on Creativity and Cognition*, New York, NY. doi: 10.1145/3059454.3078856

Dumas, D., and Dunbar, K. N. (2016). The creative stereotype effect. *PLoS One* 11:e0142567. doi: 10.1371/journal.pone.0142567

Finnegan, E., Oakhill, J., and Garnham, A. (2015). Counter-stereotypical pictures as a strategy for overcoming spontaneous gender stereotypes. *Front. Psychol.* 6:1291. doi: 10.3389/fpsyg.2015.01291

Gaither, S. E., Remedios, J., Sanchez, D., and Sommers, S. (2015). Thinking outside the box: multiple identity mindsets affect creative problem solving. *Soc. Psychol. Pers. Sci.* 6, 1–8. doi: 10.1177/1948550614568866

Gocłowska, M. A., Baas, M., Crisp, R. J., and De Dreu, C. K. W. (2014). Whether social schema violations help or hurt creativity depends on need for structure. *Pers. Soc. Psychol. Bull.* 40, 959–971. doi: 10.1177/0146167214533132

Gocłowska, M. A., Crisp, R. J., and Labuschagne, K. (2013). Can counter-stereotypes boost flexible thinking? *Group Process. Intergroup Relat.* 16, 217–231. doi: 10.1177/1368430212445076

Gong, Z., Liu, C., and Shen, W. (2016). Several thoughts on measuring creativity. *Adv. Psychol. Sci.* 24, 31–45. doi: 10.3724/SP.J.1042.2016.00031

Hudson, L. (1968). Frames of mind: ability perception and self-perception in the arts and sciences. *Psychosomatics* 11:110.

Kenett, Y. N., Rinat, G., and Miriam, F. (2018). Metaphor comprehension in low and high creative individuals. *Front. Psychol.* 9:482. doi: 10.3389/fpsyg.2018.00482

Lai, C. K., Marini, M., Lehr, S. A., Cerruti, C., Shin, J.-E. L., Joy-Gaba, J. A., et al. (2014). Reducing implicit racial preferences: i. A comparative investigation of 17 interventions. *J. Exp. Psychol. General* 143, 1–21. doi: 10.1037/a0036260

Leicht, C., de Moura, R. G., and Crisp, R. J. (2014). Contesting gender stereotypes stimulates generalized fairness in the selection of leaders. *Leadersh. Q.* 25, 1025–1039. doi: 10.1016/j.leaqua.2014.05.001

Lew, K. H., and Cho, J. (2013). "Relationship among creativity, motivation and creative home environment of young children," in *Proceedings of the 5th International Conference on Advanced Science and Technology*, Washington, DC.

Liu, C. (2018). Psychology of china: why is possible? How to be achieved? *J. Nanjing Normal Univ.*. 4, 5–13.

Nusbaum, E. C., and Silvia, P. J. (2011). Are intelligence and creativity really so different? Fluid intelligence, executive processes, and strategy use in divergent thinking. *Intelligence* 39, 36–45. doi: 10.1016/j.intell.2010.11.002

Peijia, Z., Jeffrey, J. W., Diana, A. G., Jerome, J. T., and Daniel, F. W. (2006). The impact of culture and individualism–collectivism on the creative potential and achievement of americanand chinese adults. *Creat. Res. J.* 18, 355–366. doi: 10.1207/s15326934crj1803_10

Simonton, D. K. (2014). Creative performance, expertise acquisition, individual differences, and developmental antecedents: an integrative research agenda. *Intelligence* 45, 66–73. doi: 10.1016/j.intell.2013.04.007

Song, J., and Zuo, B. (2016). Functional significance of conflicting age and wealth cross-categorization: the dominant role of categories that violate stereotypical expectations. *Front. Psychol.* 7:1624. doi: 10.3389/fpsyg.2016.01624

Sternberg, R. J. (1999). *Handbook of Creativity*. Cambridge: Cambridge University Press.

Sun, S., Zuo, B., Wu, Y., and Wen, F. (2016). Does perspective taking increase or decrease stereotyping? the role of need for cognitive closure. *Pers. Indiv. Diff.* 94, 21–25. doi: 10.1016/j.paid.2016.01.001

Tyagi, V., Hanoch, Y., Hall, S. D., Runco, M., and Denham, S. L. (2017). The risky side of creativity: domain specific risk taking in creative individuals. *Front. Psychol.* 8:145. doi: 10.3389/fpsyg.2017.00145

Ward, T. B., Smith, S. M., and Finke, R. A. (2008). "Creative cognition," in *Handbook of Creativity*, ed. R. J. Sternberg (New York: Cambridge University Press), 189–212.

Zhang, X., Li, Q., Shan, S., and Zuo, B. (2016). The time course from gender categorization to gender stereotype activation. *Soc. Neurosci.* 13, 52–60. doi: 10.1080/17470919.2016.1251965

Zuo, B., Wen, F., Yang, W. U., and Dai, T. (2018). Situational evolution of the relationship between warmth and competence in intergroup evaluation: impact of evaluating intention and behavioral outcomes. *Acta Psychol. Sinica* 50:1180. doi: 10.3724/SP.J.1041.2018.01180

Zuo, B., Zhang, Y., Ju, Z., and Wang, J. (2006). The stereotype content model and its researches. *Adv. Psychol. Sci.* 14, 138–145.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 11 April 2019
doi: 10.3389/fpsyg.2019.00537

Does Exposure to Foreign Culture Influence Creativity? Maybe It's Not Only Due to Concept Expansion

Liu Tan[1,2], *Xiaoqin Wang*[2], *Chanyu Guo*[1,2], *Rongcan Zeng*[1,2], *Ting Zhou*[3] and *Guikang Cao*[1,2*]

[1] Key Laboratory of Cognition and Personality, Ministry of Education, Southwest University, Chongqing, China, [2] Faculty of Psychology, Southwest University, Chongqing, China, [3] Mental Health Education Center, Henan Normal University, Xinxiang, China

Multicultural experience refers to those experiences gained through individuals' contact with other cultures. This study focused on exploring whether knowledge of different cultures can improve creative performance-and also how multicultural experiences influenced this performance through changes in individual's physiological mechanisms. Study 1 explored the influence of different cultural priming on creative story-writing tasks. Eighty-nine Chinese college students were randomly assigned to 4 conditions: sole American culture, dual cultures, sole Chinese culture or control condition, and made to watch 45 min slides with cultural elements—including pictures, music and videos,—and then they were asked to complete the creative story-writing task. The results showed that American culture priming group's score was significantly higher than the control condition with regards to the uniqueness and novelty of the creative story-writing task. Study 2 was aimed at exploring the relationship between physiological arousal levels induced by different cultural and creative performance. We divided the whole experiment into five stages,—including the baseline, picture, listening to music, watching video, and completing creative tasks. Through Biofeedback measurement, we recorded the physiological indexes of participants in different groups in every stage, including skin conductance, thermal, electroencephalographic, and heart rate. The results showed that contacting with foreign cultures would increase individuals' physiological arousal level and brain activity, which contributed to the following creative task.

Keywords: multicultural experience, creativity, physiological awaken, culture shock, cultural priming paradigm

OPEN ACCESS

Edited by:
Chang Liu,
Nanjing Normal University, China

Reviewed by:
Xiaoyang Yang,
Sichuan Normal University, China
Baoguo Shi,
Capital Normal University, China

***Correspondence:**
Guikang Cao
cgk@swu.edu.cn

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *27 September 2018*
Accepted: *25 February 2019*
Published: *11 April 2019*

Citation:
Tan L, Wang X, Guo C, Zeng R, Zhou T and Cao G (2019) Does Exposure to Foreign Culture Influence Creativity? Maybe It's Not Only Due to Concept Expansion. Front. Psychol. 10:537. doi: 10.3389/fpsyg.2019.00537

INTRODUCTION

Creativity, which refers to the generation of useful and appropriate new ideas (Dong et al., 2016), is one of the most important capabilities of the twenty-first century (Fink et al., 2014; Miron-Spektor and Beenen, 2015). There are two common elements in the definition of creativity, namely novelty and applicability (Sternberg et al., 1999; Runco and Jaeger, 2012). The measurements of creativity include the cognitive process of the creativity and creative support, such as the measurement of creative performance through problem solving tasks, remote association task, story-writing task and divergent thinking tasks (Leung, 2008) Creativity depends on many factors including environment, personality, cognition and motivation and so on (Amabile, 1996; Csikszentmihalyi, 1996; Sawyer, 2006; De Dreu, 2010; Chua et al., 2012, 2014). Zha et al. (2006) also proposed that culture could contribute to individual creativity in respect of the definition and evaluation

of creativity. However, whether different cultures have different influence on creativity and the psychological mechanism by which culture influences creativity all remain to be explored.

Recent researches have shown that multicultural experience could enhance creativity (Presbitero, 2016; Falavarjani and Irandust, 2017). Multicultural experience refers to all direct and indirect experiences gained by individuals when they communicate or connect with members or elements of other cultures (Leung, 2008; Aytug et al., 2018). Due to the diversity of cultures, multicultural experience should include not only the experience brought by exposure to cultures of different countries, but also the experience brought by exposure to cultures of different nations and regions. Chang et al. (2017) suggested that multicultural experiences not only provide individuals with opportunities to learn new concepts and knowledge, but often require the establishment of innovative frameworks, which help to solve the incongruity when the idea of new learning is incompatible with individuals' prior knowledge structures (Chang et al., 2017). Studies also have shown that exposure to working groups that include members of multiple cultures or contacting a diverse range of perspectives generated by groups, are positively correlated with the development of creative potential (Guimerà et al., 2005; Kurpis and Hunter, 2016; Sparkman et al., 2016). It may be that this exposure increases tolerance for the mixed views of organizations and teams. Other research shows that individuals who speak two kinds of language have higher levels of creative performance than those who speak one language (Lambert et al., 1973). In addition, previous evidence showed that race diverse groups, such as first or second generation immigrants, were more creative (Simonton, 1999), which was evaluated by multidimensional indexes, such as verbal fluency, flexibility and originality (Chang et al., 2014). Chang et al. (2015) found that the children of parents from two different cultures would have better performance in general fields and special fields mathematics creativity. Tendayi Viki and Williams (2014) found that the bicultural experience in the family is conducive to the creativity of children who belong to mixed race group. In addition, more and more research shows that studying abroad could stimulate individuals' creativity (Hu et al., 2017). Besides, the results found that people who lived abroad could solve the Duncker Candle Problem much more easily than those who did not, while the time spent living abroad significantly predicted creative solutions. However, the time spent on traveling abroad before had no correlation with individual creativity (Galinsky et al., 2006; Falavarjani and Irandust, 2017). Shi et al. (2012) found that the disintegration of multicultural experience general knowledge structure improved the access to knowledge which was difficult to obtain in conventional cases. Yang and Li (2015) suggested that individuals with multicultural experience were more likely to obtain complex construct cultural cognition and improved their cognitive complexity. And research also showed that multicultural experience would enable individuals to adopt the global processing cognitive styles in information processing (Yang and Wan, 2012; Yang, 2014). All of these studies showed that creativity was promoted to a certain extent when an individual was in one or more new cultures, and previous studies have indicated that this was most likely due to the fact that when an individual experienced a multicultural environment, the cognitive process would be changed, which might enhance individuals' creativity.

For individuals without experience abroad, studies also found that the multicultural experience could make the participants tend to the whole processing of information, and properly has the significant positive correlation with creative problem solving (Gaither C. J. et al., 2015). It can also have a positive impact on verbal creative tasks. Furtherly, the scores of novelty of the AUT task and story-writing task of the participants in the American culture priming group were significantly higher than those in the Chinese culture group and the control group, and multiracial participants who were primed with flexible multiracial identities performed significantly better on RAT tasks than non-primed multiracial participants and primed mono-ethnic participants. These studies have shown that even if individuals do not live in a new cultural environment, they could still get multicultural experience by culture priming, and the promotion effect on creativity might still exist, which proved the effectiveness of the cultural initiation paradigm to some extent.

Leung and Chiu (2010) using cultural priming paradigm, found the multicultural experience could help to improve individuals' creativity. According to researchers exposed to different cultures, the individuals' concepts would be expanded, so as to improve the creativity of the individuals. However, Leung only found this phenomenon under dual cultural conditions, and this point of view is obviously not enough to explain all the experimental results. In Leung's study, participants only exposed to Chinese cultural elements were actually stimulated by new cultural elements and gained multicultural experience. However, their creativity was not improved, so the influence of multicultural experience on creativity was not necessarily due to concept expansion. In addition, on account of the difference in mainstream culture and the disparity in national development level, American college students' degree of interest and familiarity with Chinese culture is greatly different from that of Chinese college students' degree of interest and familiarity with American culture, which leads to different results in the influence on creativity. Therefore, we speculate that since this experiment's participants were all college students in the United States, different results would be obtained if the college students in China participated in the experiment. We speculate that since the participants used in this experiment are American college students, if the subjects were replaced by participants from another cultural environment, the results might be different. Because of the difference in mainstream culture, as well as the difference in the two countries level of development, American students' interest and familiarity in Chinese culture may be different than Chinese students', leading to the change on the creative ability also could produce different results. Therefore, we would test this assumption in study 1.

Studies have shown that when individuals are separated from the environment or customs they used to live in, they would feel a sense of physical and emotional maladjustment which was brought by cultural shock caused by the new environment (Junaid and Pertiwi, 2017). Cultural shock refers to the psychological reaction when most people are exposed to

a new culture that they have never experienced before. Different cultural shocks can lead to different psychological responses, such as anxiety, surprise and confusion when people enter the new environment (Kristian, 2013). Cultural shock may have some positive emotions, such as surprise, excitement, careful and good social interaction and adaptation of life changes. These experiences are likely to improve individual physiological activation level.

Clark et al. (1993) pointed out that high creativity individuals has faster synapses activities and more abundant chemical composition of neurons, so that there may be a more complex neural model underlying the information processing of high creativity individuals. He also pointed out that high creativity alpha waves of electrical activity in the brain maintained more durable and input more quickly, therefore, they had better effect on learning and memory. According to Martindale et al.'s (1996) research, higher creative people have stronger intense skin potential responses to tone stimulation than lower creative people did, and the underlying skin response is covariant with cortical activation levels. Previous study about creative individuals showed that the amplitude of the pre-frontal cortex wave was higher in the verbal association and in the imagination task, while the amplitude of the frontal lobe wave was higher in the imagination task (Hudspith et al., 1985). In researches of EEG on divergent thinking and convergent thinking, Jausovec and Jausovec (2000) found that individuals with high creativity have a higher wave power. The investigation of the cortical activity in remote association task, which has three conditions: the classic remote association task, simple associative task and eye-opening rest, showed that the power value of the β2 (20–30 Hz) distant association task's worm 2 (20–30 Hz) band were significantly increased in various brain regions compared with the other two tasks. The power of θ1 (4–6 Hz) increased significantly in the frontal cortex of the brain; and the α wave (8–13 Hz) was significantly increased in the posterior region of the brain Razumnikova (2007). Carlsson et al. (2000) explored the changes of brain blood flow in alternate uses task, and found that the high creativity individuals showed significant activation in both frontal lobes of the brain. Previous studies have shown that when individuals' cognitive activities change, the physiological arousal level might be different with a series of changes. Above results suggested that creativity was closely related to brain activity and physiological activation.

Some theories suggest that creativity has a lot to do with the level of cortical activation in the brain. There are two distinct findings about the relationship between creativity and cortical activation. One opinion suggested that high creativity people have higher cortical activation levels. Individuals who were more creative got higher scores on the word association and anxiety tests than those who were less creative did. Furthermore, there was a positive correlation between basic skin conductance measurements and creativity tests in high creativity individuals (Zhou and Zhang, 2002). Another view claimed that high creativity individuals have lower levels of basic activation. Wyspianski et al. (1963) found that compared with high creativity people, the amplitude of α wave is greater in the low creativity people, which can represent the activation level of cerebral cortex. Another experimental evidence showed that the plasma levels of uric acid in the high creativity individual are low, since the plasma levels in the high creativity individual reflect the physiological activity status, which also indicates that the basic activation level of the high creativity individual is relatively low. Due to these different findings, some researchers proposed the variability of cortical activation level, and the variability of physiological activation was higher in individuals with high creativity. Studies by Martindale and Hasenfus (1978) showed that individuals with high creativity showed more variability in their skin electrocardiogram and EEG α waves. Previous studies have shown that attentional alertness level changes are accompanied by a series of physiological arousal changes (Pfaff, 2008; Smolders and de Kort, 2014). For example, the increasing of the sustained attention and the alertness level had a positive relationship with EEG low theta activity (Oken et al., 2006). Besides, there was a negative correlation between attentional alertness level and Electromyogram (EMG) and maximum fractal length (MFL) of EEG (Arjunan et al., 2009). As we could know from the research reviews above, we could conclude that multicultural experience would change individuals' cognitive process of information processing and changes in cognitive processing were usually accompanied by a series of physiological changes. Since there was a correlation between physiological arousal changes and creativity promotion, study 2 designed to explore the internal mechanism of multicultural experience to promote creativity from the perspective of physiological arousal. Therefore, in current study, we also wanted to explore the relationship between multicultural activation and physiological arousal, and the effect of activation of this physiological state on creativity.

STUDY 1

To explore the influence of different cultural startup conditions (American cultural priming conditions, Chinese cultural priming conditions, American–Chinese fusion culture conditions and control conditions) on the story-writing task.

Methods

Participants

The participants were selected from students of Southwest University, which were randomly assigned to such four groups. This is a between-subjects design with 20 subjects in each condition. In accordance with the Declaration of Helsinki (1991), the experiment was approved by the Academic Committee of the School of Psychology and the local ethics committee of the School of Psychology, Southwest University in China. We had obtained appropriate ethics committee approval for the research reported, and all subjects gave written informed consent before our experiment.

Materials

Prime conditions: American cultural priming conditions, Chinese cultural priming conditions, American–Chinese fusion culture conditions. Each condition was presented to the subjects as a slide show, which included 160 images and was played with

a music background of the corresponding culture for 20 min. After that were 10 min music video and 15 min TV video. Materials under the three cultural conditions involve various aspects, such as home decoration, entertainment program music, furniture, costume, cooking, life, film, art and architecture, landscape literature, and so on. Under the American–Chinese fusion culture conditions, American cultural elements and Chinese cultural elements each account for half, and alternate presented (Zhou et al., 2011).

Creative task: Story-writing task. First of all, let the participants read about the story of the Cowherd and the Weaving Maid (a Chinese legend), and then let them to make up a new versions of the story for Turkish children. They are required to try their best to imagine to rewrite the story, make the story more creative, novelty and organization. They not only need to give participants an overview of the original story, but also the information about Turkey's geographical location, climate, religion, economy, industry, and a narrative of everyday Turkish life. Importantly, these participants were unfamiliar with Turkish culture. Before rewriting the story, the subject was asked to report familiarity with Turkish culture, with a score range 1–7. A score of 1 indicating that he was not at all familiar, and a score of 7 indicating that he was very familiar. Finally, the score was $M = 1.72$, $SD = 0.98$.

Procedures

First of all, the participants were randomly assigned to four kinds of experimental conditions: (1) the American culture condition: the participants only watched the slide showing about American culture (2) the Chinese culture condition: the participants only watched slides showing about Chinese culture (3) the American–Chinese fusion culture conditions: the participants watched a slide showing of Chinese and American culture alternatively (4) control condition: participants did not watch any power point slides. The slide lasted 45 min, including pictures of music video in the corresponding culture, in which the picture stage was about 20 min, the music stage was about 15 min, and the TV video stage was about 10 min, followed by the subjects finishing the story-writing task.

After the experiment, the four undergraduate students in the department of Chinese language and literature were asked to rate the story making task from the two aspects of novelty and uniqueness (scores ranged from 1 to 7). The novel degree of novelty was about the original story, and the uniqueness was relative to the unique degree among all the stories written. The consistency reliability of novelty was 0.898, the consistency reliability of uniqueness was 0.886.

Analysis

SPSS16.0 statistical software was used to test the differences in creative performance under various cultural conditions with one-way ANAVA (**Table 1**).

Results

The results showed that under all the culture priming conditions, the novelty of the story-writing task reached marginal significance [$F_{(3, 76)} = 2.656$, $p = 0.055$, $\eta_p{}^2 = 0.410$], and the novelty score of the story-writing task in the United States was significantly higher than that in the control group ($p = 0.01$), and there was no significant difference between the other groups. In addition, there was a significant difference in the originality of the story-writing task under all the culture priming conditions [$F_{(3, 76)} = 3.437$, $p = 0.021$, $\eta_p{}^2 = 0.348$]. The originality score of American culture groups was significantly higher than that of the control group ($p = 0.002$).

In terms of the total scores of story-writing task under various cultural priming conditions, there were significant differences between the groups [$F_{(3, 76)} = 3.208$, $p = 0.028$, $\eta_p{}^2 = 0.333$]. The score of the American culture group was significantly higher than that of the control group ($p = 0.003$).

Discussion

Base on the experimental results, our study suggested that the multicultural experience did have a significant promoting effect on the creativity of the participants, since the performance in American culture priming group was better than the other groups on the whole. However, the promoting effect depended on: (1) whether the participants did get the multicultural experience. The multicultural experience can be formed only when the participants have a certain understanding of the new culture; (2) prototype features contained in multicultural experience. If the multicultural experience included prototypes that promoted creative work, the multicultural experience would promote creativity.

From the study 1, it could be concluded that the significant difference in the creative task was caused by individuals' multicultural experience. When the participants experienced new culture, they might produce culture shock. According to previous studies mentioned above, we could speculate that this culture shock experienced by individuals could improve their attention alertness level and increase the involvement of individuals. Therefore, we would use the biofeedback technology to verify the speculation as previous studies which have shown that individuals' attention alert changes would be reflected in the physiological arousal level.

STUDY 2

The participants may have different physiological arousal levels when watching the slides of different cultural conditions, which would have influence on the following creative tasks. This study aimed to explore the relationship between multicultural experience and physiological arousal level.

Methods

Participants

There were three conditions in the experiment: American cultural priming conditions, Chinese cultural priming conditions, American–Chinese fusion culture conditions, and the design of the study was a between-subjects design with 16 subjects in each condition. The subjects had not received biofeedback training in the past, had no surgical or hospitalization experience in the past 1 year, and had no neuropsychiatric history. On the day of the experiment, the

TABLE 1 | The total score and dimension score of the story-writing task under the conditions of cultural priming.

Conditions	Novelty			Originality			AUT score		
	M	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
American culture	5.20	0.97	20	4.75	1.16	20	9.95	2.01	20
Fusion culture	4.43	1.38	20	3.93	1.48	20	8.35	2.79	20
Chinese culture	4.45	1.36	20	4.03	1.53	20	8.48	2.78	20
Control group	4.12	1.18	17	3.29	1.34	17	7.41	2.48	17

subjects could not do strenuous exercise and could not overeat, smoke, drink, or take drugs. The subjects kept an empty stomach for half an hour before the experiment, and the female subjects were not in the Menstrual Cycle. In accordance with the Declaration of Helsinki (1991), the experiment was approved by the Academic Committee of the School of Psychology and the local ethics committee of the School of Psychology, Southwest University in China. We had obtained appropriate ethics committee approval for the research reported, and all subjects gave written informed consent before our experiment.

Experimental Materials and Equipments

In order to assess the impact of cultural contents on the participants more objectively, this study adopted the Dutch Spirit 10 biofeedback instrument to collect the physiological indicators of the participants. Physical data, such as skin conductivity (SC), skin temperature (TEMP), electroencephalogram (EEG), blood volume (BVP), electromyography (EMG), and heart rate (HR) were collected. In this experiment, only EEG, SC, TEMP, and HR data were collected. During the experiment, each participant was isolated in a biofeedback laboratory and did not interfere with each other. The subjects could adjust the seat and earphone volume according to the comfort level. During the experiment, the environment was kept quiet.

Creative task: divergent thinking task, in which the subject was asked to write out the alternative uses of a newspaper for 2 min. In study 1, we have proved that experience multicultural could enhance creativity which measurement was story-writing task. As there were so many ways to measure of creativity, so in study 2, we would like to further explore whether we would also conclude the same result when we used other measuring method of the creativity.

Prime materials: priming conditions: American culture, Chinese culture and Chinese-American fusion culture. There are 160 images in the slides and was played with a music background of the corresponding culture for 20 min. After that were 10 min music video and 15 min TV video.

Experimental Procedures

First of all, the participants filled in the informed consent form. The experimenters debugged the biofeedback instrument and installed the electrode. Then explained the biofeedback instrument to the participants to reduce the anxiety and discomfort when use of the instrument. Then, baseline levels were measured. The participants sat in a relaxed state for 5 min, and the participants recorded baseline levels of EEG, SC, TEMP, and HR. The mean of the final 3 min measurement was taken as the baseline level. After 5 min, the subjects were shown slides. The physiological indexes of the subjects were recorded when learned the culture. After that, the subjects completed the divergent thinking task within 2 min, and biofeedback data were collected throughout the process.

Spirit 10 biofeedback instrument to collect physiological indexes of EEG, SC, TEMP, and HR. Firstly, participants were required to clean the skin, and then placed electrodes, galvanic skin electrodes were placed in the left hand index finger and ring finger, electrodes placed on the left hand little finger skin temperature. EEG is formulated according to the international society for EEG 10–20 international EEG recording system (Wei and Luo, 2002). Two channels ExG cables were used to conduct the lead connection of the electrodes. Positive 1 was placed at F4, negative 1 at A2, positive 2 at F3, negative 2 at Al, the grounding electrode was placed at Fz, and the blood volume (heart rate) electrode was placed at the middle finger of the left hand.

Experimental Results and Analysis

Physiological Results

Although we recorded the whole physiological indexes during the experiment, we only selected data of a part of each stage in the analysis, and the last 3 min of each stage were taken for analysis (**Table 2**).

The results showed that as for the index of SC, the main effects of four stages in each conditions were significant [$F_{(2, 45)} = 3.557$, $p = 0.037$, $\eta_p{}^2 = 0.608$, $F_{(3, 135)} = 2.913$, $p = 0.037$, $\eta_p{}^2 = 0.362$] and the interaction effect was also significant [$F_{(6, 135)} = 2.360$, $p = 0.034$, $\eta_p{}^2 = 0.403$]. In the American group, the SC gradually increased when viewing slide, while in the Chinese group, the SC gradually decreased. Furthermore, there was no significant difference among baseline, photograph and music stages, but in the video stage, the results showed significant difference [$F_{(2, 45)} = 3.563$, $p = 0.037$, $\eta_p{}^2 = 0.652$]. The American group was significantly higher than the Chinese group ($p = 0.029$) and the fusion group ($p = 0.022$). Under the American culture condition, the four stages of SC had reached marginal significant difference [$F_{(3, 45)} = 2.556$, $P = 0.067$, $\eta_p{}^2 = 0.601$]. The photograph stage was significantly higher than the video stage ($p = 0.026$). Under the fusion condition, there is no significant difference between the four stages. Under the Chinese culture condition, the four stages also reach marginal significance [$F_{(3, 45)} = 2.486$, $p = 0.073$, $\eta_p{}^2 = 0.577$]. Furthermore, music stage and baseline stage reached marginal significance ($p = 0.078$).

TABLE 2 | In the three experimental conditions, participants watched music video and TV video in the baseline stage.

Indicators	Stages	American group			Fusion group			Chinese group		
		M	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
SC	Baseline	0.65	0.06	16	0.62	0.03	16	0.65	0.08	16
	Photograph	0.62	0.05	16	0.61	0.02	16	0.62	0.04	16
	Music	0.66	0.10	16	0.62	0.02	16	0.62	0.04	16
	Video	0.73	0.22	16	0.62	0.02	16	0.63	0.04	16
	After task	0.74	0.21	16	0.63	0.03	16	0.63	0.04	16
TEMP	Baseline	23.05	0.48	16	23.29	0.13	16	23.23	0.18	16
	Photograph	23.20	0.23	16	23.28	0.14	16	23.23	0.18	16
	Music	23.18	0.23	16	23.27	0.15	16	23.22	0.17	16
	Video	23.19	0.24	16	23.26	0.16	16	23.21	0.17	16
	After task	23.04	0.38	16	23.21	0.35	16	23.05	0.34	16
Left θ	Baseline	36.29	12.90	16	25.94	9.41	16	35.79	14.97	16
	Photograph	35.21	13.33	16	32.80	18.40	16	35.62	13.24	16
	Music	30.35	12.50	16	23.94	9.88	16	36.34	30.08	16
	Video	40.36	38.68	16	31.77	16.02	16	37.35	15.94	16
	After task	39.37	16.73	16	38.29	17.92	16	40.05	12.69	16
Left α	Baseline	16.82	5.84	16	13.26	3.13	16	15.21	4.05	16
	Photograph	13.24	3.36	16	14.01	10.83	16	12.45	2.83	16
	Music	11.99	3.12	16	10.16	2.24	16	13.47	10.22	16
	Video	21.21	16.87	16	13.33	8.00	16	14.46	9.48	16
	After task	16.46	6.72	16	17.89	12.66	16	15.90	4.34	16
Left SMR	Baseline	7.74	1.67	16	8.41	3.27	16	7.18	1.91	16
	Photograph	8.29	2.28	16	9.96	11.83	16	7.05	1.51	16
	Music	7.50	1.84	16	6.62	1.69	16	8.24	7.36	16
	Video	11.02	4.83	16	7.94	2.36	16	8.58	2.50	16
	After task	13.52	9.45	16	10.32	4.08	16	9.51	2.55	16
Left β	Baseline	7.34	1.96	16	7.93	3.32	16	6.44	1.41	16
	Photograph	7.93	2.63	16	8.54	8.28	16	6.28	1.65	16
	Music	7.00	1.83	16	6.30	2.04	16	6.84	4.36	16
	Video	10.12	4.36	16	6.96	2.32	16	7.54	2.25	16
	After task	10.61	5.34	16	9.18	3.42	16	8.18	2.14	16
Left γ	Baseline	12.20	5.06	16	13.34	10.70	16	13.77	8.59	16
	Photograph	14.28	7.45	16	15.46	11.47	16	13.59	7.69	16
	Music	16.44	8.14	16	11.39	4.72	16	12.70	5.97	16
	Video	20.12	30.08	16	14.45	7.86	16	14.66	10.22	16
	After task	17.02	9.10	16	14.18	5.87	16	13.25	6.01	16
Right θ	Baseline	36.82	15.14	16	27.28	9.83	16	42.91	35.42	16
	Photograph	37.59	15.74	16	31.68	13.34	16	36.83	15.37	16
	Music	32.99	16.76	16	32.88	23.54	16	31.11	12.09	16
	Video	36.92	12.71	16	30.37	12.45	16	31.84	12.26	16
	After task	39.91	13.99	16	33.44	10.19	16	41.20	12.54	16
Right α	Baseline	12.40	3.52	16	16.10	18.14	16	11.95	3.28	16
	Photograph	12.25	3.23	16	11.73	2.14	16	13.26	3.29	16
	Music	14.59	7.19	16	12.81	3.72	16	13.49	3.81	16
	Video	21.87	3.05	16	13.32	3.22	16	15.58	4.31	16
	After task	16.41	4.79	16	14.04	4.12	16	16.30	4.21	16
Right SMR	Baseline	15.34	2.63	16	7.75	2.96	16	8.72	2.47	16
	Photograph	9.46	6.33	16	7.95	2.95	16	7.75	3.21	16
	Music	7.94	2.67	16	11.26	1.57	16	6.81	1.60	16
	Video	7.54	1.73	16	7.29	1.05	16	7.94	3.12	16

(Continued)

TABLE 2 | Continued

Indicators	Stages	American group			Fusion group			Chinese group		
		M	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
	After task	16.30	4.21	16	8.77	4.09	16	9.62	3.70	16
Right β	Baseline	7.19	2.19	16	11.57	1.88	16	6.02	1.70	16
	Photograph	8.91	6.32	16	7.24	2.62	16	6.78	2.58	16
	Music	10.75	11.05	16	11.67	16.01	16	7.17	2.48	16
	Video	14.74	2.64	16	7.08	2.91	16	7.53	2.25	16
	After task	8.95	2.05	16	7.87	3.61	16	8.13	2.92	16
Right γ	Baseline	17.46	1.69	16	12.60	7.81	16	19.70	2.33	16
	Photograph	18.92	1.92	16	16.56	1.03	16	18.02	1.18	16
	Music	18.32	1.97	16	18.28	1.65	16	15.84	1.53	16
	Video	19.46	1.99	16	14.75	7.19	16	15.61	8.62	16
	After task	14.44	4.09	16	12.60	6.26	16	16.54	15.10	16
HR	Baseline	81.57	24.25	16	82.34	32.53	16	81.95	26.26	16
	Photograph	76.69	25.08	16	66.97	20.51	16	77.03	21.79	16
	Music	85.13	21.85	16	68.75	22.11	16	78.10	17.07	16
	Video	84.03	19.61	16	70.14	25.21	16	73.57	20.19	16
	After task	84.74	27.98	16	83.71	29.43	16	90.45	29.74	16

In these four stages, the mean and standard deviation of the heart rate of each indicator of the ecg temperature, left alpha, left SMR, right alpha, right alpha, right SMR, right beta, right gamma, were shown in ***Table 2****.*

For each stage of the physiological indexes of three kinds of experimental conditions with one-way ANOVA, the results showed that when considered the left SMR index, At the baseline, photograph and music stages, there was no significant difference between the experimental conditions, but at the video stage, there was significant difference between the three conditions [$F_{(2, 45)} = 3.594$, $p = 0.036$, $\eta_p{}^2 = 0.656$]. The American group is significantly higher than the Chinese group ($p = 0.05$) and fusion group ($p = 0.015$). Similarly, as for the left β index, there was no significant difference between the experimental conditions in the baseline, photograph and music stages, but at the video stage, there was significant difference between the three conditions [$F_{(2, 45)} = 4.590$. $p = 0.015$, $\eta_p{}^2 = 0.775$]. The American group is significantly higher than the Chinese group ($p = 0.025$) and fusion group ($p = 0.007$).

Results of Creative Tasks and Physiological Indexes at the Task Stage

We analyzed the results of divergent thinking task, and the results are as follows: divergent thinking task is scored from three aspects, including fluency, flexibility and novelty. The index of fluency referred to the number of newspaper uses. The index of flexibility is the category of newspaper use. The score of novelty is to calculate the frequency of occurrence of each item. If it is >10%, 0 points will be recorded; if it is between 5 and 10%, 1 point will be recorded; if it is <5%, 2 points will be calculated (Hu and Adey, 2002). By analyzing the data of the creative test, we found that there is no significant difference in the scores of divergent thinking tasks under the three cultural conditions.

We also recorded biofeedback data as the participants completed their creative tests (**Table 2**).

The analysis showed that there was significant difference in the SC index in the creative task stage under various cultural conditions [$F_{(2, 45)} = 4.239$, $p = 0.021$, $\eta_p{}^2 = 0.608$], the American group was significantly higher than the Chinese group ($p = 0.016$) and the fusion group ($p = 0.015$), and there was no difference in other indexes under various cultural conditions.

Discussion

Electrodermal is the excess or resistance of electrical current between two points in the skin, which measures the activity of the sweat glands and reflects changes in the human physiological state. When individuals' mood is nervous or anxious and wakeful, skin surface sweat, skin conductivity and skin electricity would increase. In a relaxed state, people's mood is calm, sweat gland secretion, skin conductivity, and skin electricity would decrease (Zheng, 2003).

EEG is a kind of rhythmic nerve activity, which could also reflect the physiological arousal state of people. When the brain is highly awakened, the frequency is high. Otherwise, the frequency is low. β waves, frequency range for a 12–36 Hz, appeared when experience mental tension and emotional or stimulated. β waves can be divided into three bands: low Beta waves (12–15 Hz), namely the SMR, middle Beta waves (15–18 Hz), and high Beta waves (12–36 Hz). SMR is related with behaviors, such as analysis judgment, problem solving thinking and listening, middle Beta waves associated with intelligence and mental activity, and high Beta waves is concerned with alert and excited state (Zheng, 2003).

According to the results, the American group was significantly higher in the SC, left SMR and left β than the Chinese group and the fusion group when watching the video. The results showed that the physiological arousal level in American group

was relatively high. In addition, the cultural priming conditions in the United States indeed improved the physiological arousal level of the subjects. Finally, arousal level had a significant association with attention. Arousal played an important role in maintaining and changing the excitability of the cerebral cortex and maintaining the state of arousal. It also helped maintaining attention and focusing on consciousness (Xuemin and Xinbao, 2005). This may contribute to the next creative task. In addition, in the video stage, the left-side SMR of the American group was significantly higher than that of the other groups, indicating that the participants showed more analytical problems, thinking, listening and other behaviors when watching video, and their brain activity level was higher. According to Leung and Chiu (2010), researchers believed that multicultural experience promoted creativity because the exposure to multicultural culture expanded individuals' concepts, which enhanced the creative performance of participants. However, the current study considered that conceptual extension was not the only reason why multicultural experience influenced creativity. Confronted with new culture, individuals might be involved in attention switch and the increase of alertness level, which could help individuals to be more engaged in the following creative task and thus improve their creative performance. Previous studies have shown that the improvement of attention alertness level would be accompanied by a series of changes in physiological arousal level. The results of study 2 in this study also confirmed this point and indicated that multicultural experience could increase the individual's attention alertness, which has been reflected in the change of physiological arousal level. Furthermore, previous studies have proved that the increasing of physiological arousal was related to the promotion of creative performance. That was to say, the hypothesis, which suggested that multicultural experience promoted creativity was not only due to the expansion of individual concept, but also the improvement of individual attention alertness level has been indirectly confirmed in study 2. Unfortunately, this study did not produce direct evidence as there was no significant difference in the creative tasks under the three conditions in study 2. We speculated that this was due to a change in creative tasks. In study 1, we used the story-writing task and asked the participants to make up stories for Turkish children. Considering that it was to make up a story for foreign children, in order to make the children understand their stories better, the participants would consider more about cultural differences, so that the promotion of multicultural experience on creative tasks might be more obvious. And the AUT in study 2, although it was a task widely used in the field of creative research, but the task only focus on object uses itself. Essentially, AUT task was a general field of creative task, which was less sensitive to the multicultural experience. Therefore, its promoting effect was weaker, leading to there was no significant difference in creativity performance among three priming conditions. In future studies, we still need to adopt creative tasks which are more related to cultural factors to continue exploring about it. On top of this, it may also be influenced by environmental factors. During the task, the subjects also collected physiological data. As it was a paper-and-pencil test, the electrodes glued on the subjects might have some influence on the writing of the participants, thus affecting the results of the creativity test. In future studies, we should improve on this defect.

GENERAL DISCUSSION

Reasons Why Multicultural Experiences Influence Creativity

In this study, Chinese college students' creative performance was higher after viewing the slides of American cultural elements than after viewing the slides of Chinese cultural elements and the slides without viewing any cultural elements. It may be that exposure to different cultures gives individuals the ability to perceive more of their inner functions through the surface of things. In addition, this experience may expand the perception scope of participants, activate the upper concept in a semantic network, and expand the concept classification category and concept prototype, so that the individual is easy to break through the mind-set and functional fixation (Yang, 2014). Multicultural experience also exist in problem-solving situations, enabling individuals to extract information automatically from different cultures, and integrate it in novel ways to expanding the conceptual categories in the brain by adopting seemingly unrelated concepts (Ward et al., 1997). For example, when participants were activated to experience multi-racial culture in the context of environmental demands, they could quickly transform among multiple races to improve cognitive flexibility (Gaither S. E. et al., 2015), thus promoting the expansion of creative ideas.

However, the creative task (story-writing task and AUT) adopted in this study was only limited to the verbal divergent thinking task related to semantic concepts, and the performance of the creative task under the American culture priming condition was better than other conditions. This was not completely consistent with the findings of Leung and Chiu. We believed that this result first illustrated the promoting effect of multicultural experience on the creativity of Chinese college students. Chinese college students have grown up under the influence of Chinese culture, and their way of thinking and behavior have been deeply branded with Chinese culture. Exposing to American cultural elements different from Chinese culture would prompt them to compare the differences between the two cultures. Compared with Chinese culture, American culture is more attractive and novel for Chinese college students, because American culture is easy to be associated with open and free innovation. Therefore, the value advocated by American culture is more in line with the characteristics of keeping pace with the times of college students, so. Chinese college students are more interested in American culture and have more contact with it, and their comparison of cultural differences will be more profound. For example, when see a picture of a hamburger, they know that it is fast food in the United States, and also have tasted the taste of it, so, when compare it with the Chinese food, they would not only take it from the color shape and taste, but also can from the ways of production and material. Therefore, they are more likely to get new ideas, extension of the concept of food, such as prototype, they would perform better in divergent thinking task.

However, the American college students in Leung and Chiu's study were not familiar with Chinese culture. Therefore, under the condition of single Chinese culture initiation, they were probably unable to understand Chinese culture with the help of their American cultural knowledge because they actually did not know Chinese cultural elements so that it is impossible to expand the concept and form corresponding concept prototype of something. However, for Chinese college students, why did they perform better in the verbal creative task only under the American culture conditions and there was no difference between fusion condition and Chinese culture condition? We believed that Chinese college students are more familiar with American culture than American students are with Chinese culture, and American culture is more novel and attractive to Chinese students than Chinese culture to American students. Mendelsohn (1976) emphasized the importance of attention process in creative performance and thus influences the following creative tasks. He believed that the difference in individual concentration level is the main reason for the difference in creativity level. Studies by Dewing and Battye (1971); Dykes and Mcghie (1976) and Kasof (1997) showed that individuals with low creativity level had narrower attention than those with high creativity level. So the Chinese students under American culture priming condition would actively analysis the differences between these two cultures due to attention resources were attracted to novel and relatively familiar elements of American culture, so that the concept or concept of something is expanded to form a concept prototype that helps to inspire the next verbal creative task to be completed. However, the Chinese college students under the fusion condition contacted between the two kinds of cultural elements alternatively, so they needed to continue switching between the two kinds of culture. On the one hand, it may extend the participants' concepts of something, and on the other hand, it may also limit the scope of participants' idea or concept extension. Therefore, the performance of verbal creative task is limited. In addition, this study participants were college students under the background of Chinese culture, cultural experience is still the dominant Chinese culture, and the Chinese culture elements under the fusion condition may be a ceiling effect. Besides, the priming effect of American cultural elements is less than half that of American cultural groups in terms of time and quantity. Therefore, the diversity of participants' multicultural experience under American cultural conditions may be superior to that of fusion cultural groups so the performance of the creative task is better than that of the fusion culture group.

Multicultural Experiences Affect the Physiological Basis of Creativity

In study 2, the participants' galvanic skin gradually rise under the American culture conditions. This may be caused by exposure to new cultural shocks, indicating that the American cultural priming group caused higher physiological arousal of the subjects, and the activation level of the subjects was relatively high, which may have some influence on the following creative tasks. High activation levels can increase the degree of individual attention. In addition, as for the indexes of left SMR and left β in American culture group is higher than other groups. It suggested that the brain activity levels in the left hemisphere were also higher when the subjects viewed a slide of American culture. Some psychologists have shown that the left hemisphere of the brain is involved in continuous processing of analytical language, while the right hemisphere is involved in the overall processing of visual images. Therefore, it is possible that when the subjects watched the American culture slide, they compared and processed the American culture elements and the Chinese culture elements, which expanded the concept of words and words, thus enhancing the activity of the brain.

Finally, there was no difference between the cultural priming groups in the divergent thinking task, which might be caused by the influence of external environmental factors. When the subject was conducting the experiment, the electrode plate was glued on the left hand, which was a certain obstacle to the completion of paper and pencil test, and thus had an impact on the experimental results.

Deficiencies and Prospects of the Research

In current study we only used photograph, music and video, if we can also provide some information about people how to solve the similar problems in different cultural environment of the material, the multicultural experience obtained at this moment, may not only promote the semantically related creative tasks, such as divergent thinking task, but also help the creative problems like graphical insight problem solving. Of course, it remains to be validated in further research. In addition, the multicultural experience priming conditions used American culture. However, With the increasing economic and cultural exchanges between China and the United States, especially in education of China, American culture is no totally strange for Chinese college students. It remains to be seen whether similar results could emerge if the experimental conditions were changed to a completely unfamiliar culture, or change the participants with less knowledge of American culture. Besides, in the second experiment, creative tasks under the different conditions has no significant difference. It may be because during the paper-pencil tests, the electrodes were glued on the hands of the participants, which had a certain hindering effect on the completion of the task, which should be improved in future experiments.

CONCLUSION

The multicultural experiences have a significant promoting effect on the creativity of the subject, but such promoting effect depends on:(1) whether the subject really obtains the multicultural experience; only when the subject has a certain understanding of the new culture can the multicultural experience be formed; (2) the participants acquired the prototype characteristics contained in the multicultural experience. If the multicultural experience included the prototype that had a promoting effect on the

creative work, the multicultural experience had a promoting effect on the creativity. In addition, the activation of American culture will increase the physiological arousal level of the individual, increase brain activity, and improve the attention level of the participants, thus contributing to the following creative tasks.

AUTHOR CONTRIBUTIONS

LT and GC contributed conception and design of the study. XW performed the statistical analysis and LT wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

REFERENCES

Amabile, T. M. (1996). *Creativity in Ontext*. Boulder, CO: Westview Press.

Arjunan, S. P., Kumar, D. K., and Jung, T.-P. (2009). Changes in decibel scale wavelength properties of EEG with alertness levels while performing sustained attention tasks. *Int. Conf. IEEE Eng. Med. Biol. Soc.* 2009, 6288–6291. doi: 10.1109/IEMBS.2009.5332801

Aytug, Z. G., Rua, T., Brazeal, D. V., Almaraz, J. A., and González, C. B. (2018). A socio-cultural approach to multicultural experience: why interactions matter for creative thinking but exposures don't. *Int. J. Intercult. Relati.* 64, 29–42. doi: 10.1016/j.ijintrel.2018.03.004

Carlsson, I., Wendt, P. E., and Risberg, J. (2000). On the neurobiology of creativity. differences in frontal activity between high and low creative subjects. *Neuropsychologia* 38, 873–885. doi: 10.1016/S0028-3932(99)00128-1

Chang, J.-H., Su, J. C., and Chen, H.-C. (2017). "Rethinking the multicultural experiences–creativity link: the interactive perspective on environmental variability and dispositional plasticity," in *Cambridge Handbook of Creativity and Personality Research*, eds G. Feist, R. Reiter-Palmon, and J. C. Kaufman (New York, NY: Cambridge University Press), 124–139. doi: 10.1017/9781316228036.008

Chang, J. H., Hsu, C. C., Shih, N. H., and Chen, H. C. (2014). Multicultural families and reative children. *J. Cross Cult. Psychol.* 45, 1288–1296. doi: 10.1177/0022022114537556

Chang, J. H., Su, J. S., and Chen, H. C. (2015). Cultural distance between parents' and hilden's creativity: a within-country approach in Taiwan. *Cult. Divers. Ethnic Minor. Psychol.* 21, 477–485. doi: 10.1037/a0037539

Chua, R. Y. J., Morris, M. W., and Mor, S. (2012). Collaborating across cultures: cultural metacognition and affect-based trust in creative collaboration. *Organ. Behav. Hum. Decis. Process.* 118, 116–131. doi: 10.1016/j.obhdp.2012.03.009

Chua, R. Y. J., Roth, Y., and Lemoine, J.-F. (2014). The impact of culture on creativity how cultural tightness and cultural distance affect global innovation crowdsourcing work. *Adm. Sci. Q.* 60:0001839214563595. doi: 10.1177/0001839214563595

Clark, L. A., Mcewen, J. L., Collard, L. M., and Hickok, L. G. (1993). Symptoms and traits of personality disorder: two new methods for their assessment. Psychol. Assess. 5, 81–91. doi: 10.1037/1040-3590.5.1.81

Csikszentmihalyi, M. (1996). *Creativity: Flow and the Psychology of Discovery and Invention*. New York, NY: HarperCollins.

De Dreu, C. K. W. (2010). Human creativity: reflections on the role of culture. *Manage. Organ. Rev.* 6, 437–446. decision processes, 118: 116–131. doi: 10.1111/j.1740-8784.2010.00195.x

Dewing, K., and Battye, G. (1971). Attention deployment and non-verbal fluency. *J. Pers. Sicial Psychol.* 17, 214–218.

Dong, Y., Bartol, K. M., Zhang, Z.-X., and Li, C. (2016). Enhancing employee creativity via individual skill development and team knowledge sharing: influences of dual-focused ransformational leadership. *J. Organ. Behav.* 38, 439–458. doi: 10.1002/job.2134

Dykes, M., and Mcghie, A. (1976). A comparitive study of attentional strategies of schizophrenic and highly creative normal subjects. *Br. J. Psychiatry* 128, 50–56.

Falavarjani, M. F., and Irandust, F. (2017). Does exposure to multicultural experience enhance all individuals' creative problem-solving ability? *Int. J. Soc. Sci. Res.* 5:14. doi: 10.5296/ijssr.v5i2.11173

Fink, A., Koschutnig, K., Hutterer, L., Steiner, E., Benedek, M., Weber, B., et al. (2014). Gray matter density in relation to different facets of verbal creativity. *Brain Struct. Funct.* 219, 1263–1269. doi: 10.1007/s00429-013-0564-0

Gaither, C. J., Roberts, N. S., and Hanula, K. L. (2015). *Visitor Diversity Through the Recreation Manager Lens: Comparing Forest Service Regions 8 (us South) and 5 (California).* General Technical Report - Southern Research Station, USDA Forest Service.

Gaither, S. E., Cohen-Goldberg, A. M., Gidney, C. L., Maddox, K. B., Gidney, C. L., and Gidney, C. L. (2015). Sounding black or white: priming identity and biracial speech. Front. Psychol. 6:457. doi: 10.3389/fpsyg.2015.00457

Galinsky, A. D., Maddux, W. W., and Ku, G. (2006). The view from the other side of the table: getting inside your counterpart's head can increase the value of the deal you walk away with. Here's how to do it. *Negotiation* 9, 1–5.

Guimerà, R., Uzzi, B., Spiro, J., and Amaral, L. A. N. (2005). Team assembly mechanisms determine collaboration network structure and team performance. *Science* 308, 697–702. doi: 10.1126/science.1106340

Hu, S., Gu, J., Liu, H., and Huang, Q. (2017). The moderating role of social media usage in the relationship among multicultural experiences, cultural intelligence, and individual creativity. *Inform. Technol. People* 30, 265–281. doi: 10.1108/itp-04-2016-0099

Hu, W., and Adey, P. A. (2002). Scientific creativity test for secondary school student. *Int. J. Sci. Educ.* 24, 384–403. doi: 10.1080/09500690110098912

Hudspith, M., John, G. R., Nhamburo, P. T., and Littleton, J. M. (1985). Effect of ethanol *in vitro* and *in vivo* on Ca^{2+}-activated metabolism of membrane phospholipids in rat synaptosomal and brain slice preparations. *Alcohol* 2, 133–138. doi: 10.1016/0741-8329(85)90030-8

Jausovec, N., and Jausovec, K. (2000). Eeg activity during the performance of complex mental problems. *Int. J. Psychophysiol.* 36, 73–88. doi: 10.1016/S0167-8760(99)00113-0

Junaid, S., and Pertiwi, I. (2017). Culture shock experienced by main character in Lauren Kate's novel "Torment" by using the psychology of culture shock by Collen Ward. *English Literature J.* 2, 108–125.

Kasof, J. (1997). Creativity and breadth of attention. *Creat. Res. J.* 10, 303–315.

Kristian, G. (2013). *The Bleeding Land.* Hijos Del Trueno.

Kurpis, L. H., and Hunter, J. (2016). Developing students' cultural intelligence through an experiential learning activity a cross-cultural consumer behavior interview. *J. Market. Educ.* 39:0273475316653337. doi: 10.1177/0273475316653337

Lambert, W. E., Tucker, G. R., and d'Anglejan, A. (1973). Cognitive and attitudinal consequences of bilingual schooling: the St. Lambert project through grade five. *J. Educ. Psychol.* 65, 141–159.

Leung, A. K. (2008). Multicultural experience enhances creativity: the when and how. *Am. Psychol.* 63, 169–181. doi: 10.1037/0003-066X.63.3.169

Leung, A. K. Y., and Chiu, C. Y. (2010). Multicultural experience, idea receptiveness, and creativity. *J. Cross Cult. Psychol.* 41, 723–741. doi: 10.1177/0022022110361707

Martindale, C., Anderson, K., Moore, K., and West, A. N. (1996). Creativity, oversensitivity, and rate of habituation. *Pers. Indiv. Differ.* 20, 423–427. doi: 10.1016/0191-8869(95)00193-X

Martindale, C., and Hasenfus, N. (1978). EEG didderences as a function of creativity, stage of the creative process, and effort to be oringinal. *Biol. Psychol.* 6, 157–167.

Mendelsohn, G. A. (1976). Associative and attentional processes in creative performance. *J. Pers.* 44, 341–369.

Miron-Spektor, E., and Beenen, G. (2015). Motivating creativity: the effects of sequential and simultaneous learning and performance achievement goals on product novelty and usefulness. *Organ. Behav. Hum. Decis. Process.* 127, 53–65. doi: 10.1016/j.obhdp.2015.01.001

Oken, B. S., Salinsky, M. C., and Elsas, S. M. (2006). Vigilance, alertness, or sustained attention: physiological basis and measurement. *Clin. Neurophysiol.* 117, 1885–1901. doi: 10.1016/j.clinph.2006.01.017

Pfaff, D. W. (2008). Molecular and biophysical mechanisms of arousal, alertness, and attention. *Ann. N. Y. Acad. Sci.* 1129:xi. doi: 10.1196/annals.1417.034

Presbitero, A. (2016). Culture shock and reverse culture shock: the moderating role of cultural intelligence in international students' adaptation. *Int. J. Intercult. Relat.* 53, 28–38. doi: 10.1016/j.ijintrel.2016.05.004

Razumnikova, O. M. (2007). Creativity related cortex activity in the remote associates task. *Brain Res. Bull.* 73, 96–102. doi: 10.1016/j.brainresbull.2007.02.008

Runco, M. A., and Jaeger, G. J. (2012). The standard definition of creativity. *Creat. Res. J.* 24, 92–96. doi: 10.1080/10400419.2012.650092

Sawyer, K. (2006). *Explaining Creativity: The Science of Human Motivation*. New York, NY: Oxford University Press.

Shi, D., Liu, L., and Ke, Y. (2012). The influence of multicultural experience on creative problem solving. *China Sci. Educ. Innov. Guide* 29, 16–18. doi: 10.3969/j.issn.1673-9795.2012.29.014

Simonton, D. K. (1999). *Origins of Genius: Darwinian Perspectives on Creativity*. New York, NY: Oxford University Press.

Smolders, K. C. H. J., and de Kort, Y. A. W. (2014). Bright light and mental fatigue: effects on alertness, vitality, performance and physiological arousal. *J. Environ. Psychol.* 39, 77–91. doi: 10.1016/j.jenvp.2013.12.010

Sparkman, D. J., Eidelman, S., and Blanchar, J. C. (2016). Multicultural experiences reduce prejudice through personality shifts in openness to experience. *Eur. J. Soc. Psychol.* 46, 840–853. doi: 10.1002/ejsp.2189

Sternberg, R. J., Amabile, T. M., and Lubart, T. I. (1999). *Handbook of Creativity*. New York, NY: Cambridge University Press.

Tendayi Viki, G., and Williams, M. L. J. (2014). The role of identity integration in enhancing creativity among mixed-race individuals. *J. Creat. Behav.* 48, 198–208. doi: 10.1002/jocb.48

Ward, T. B., Smith, S. M., and Vaid, J. (1997). "Conceptual structures and processes in creative thought," in *Creative Thought: An Investigation of Conceptual Structures and Processes*, eds T. B. Ward, S. M. Smith, and J. Vaid (Washington, DC: American Psychological Association), 1–27.

Wei, J., and Luo, Y. (2002). *A Course of Cognitive Event-Related Brain Potentials*. Beijing: Economic Daily Press.

Wyspianski, J. O., Barry, W. F., Dayhaw, L. T. (1963). *Brain Wave Amplitude and Creative Thinking*. Revue de l'Universite d'Ottawa, 260–276.

Xuemin, Z., and Xinbao, W. (2005). Influence of arousal level on tennis. *J. Jiujiang Univ.* 20, 120–122.

Yang, X., and Li, H. (2015). Research review on the value of multicultural experience. *Contemp. Educ. Cult.* 4, 26–32. doi: 10.3969/j.issn.1674-5779.2015.04.005

Yang, Y. (2014). *The Influence of Multicultural Experience on the Way of Information Processing*. Doctoral dissertation.

Yang, Y., and Wan, M. (2012). New progress in creativity research: the influence of multicultural experience on creativity. *Contemp. Educ. Cult.* 4, 86–91. doi: 10.3969/j.issn.1674-5779.2012.05.016

Zha, P., Walczyk, J. J., Griffith-Ross, D. A., and Tobacyk, J. J. (2006). The impact of culture and individualism-collectivism on the creative potential and achievement of American and Chinese adults. *Creat. Res. J.* 18, 355–366. doi: 10.1207/s15326934crj1803_10

Zheng, Y. (2003). *Clinical Practice of Biofeedback*. Beijing: Advanced Education Press.

Zhou, H., and Zhang, Q. (2002). New progress in creative physiological research. *Exploration of Psychol.* 22, 9–13. doi: 10.3969/j.issn.1003-5184.2002.03.002

Zhou, T., Cao, G., and Zhou, S. (2011). *Different Culture Priming Lead to Different Creative Performance*. Chongqing: Scientific Research.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

REVIEW
published: 24 April 2019
doi: 10.3389/fpsyg.2019.00833

QEOSA: A Pedagogical Model That Harnesses Cultural Resources to Foster Creative Problem-Solving

David Yun Dai[1], Huai Cheng[2] and Panpan Yang[1]*

[1]University at Albany, Albany, NY, United States, [2]China Preschool Education Group (Beijing), Beijing, China

The nature of creative thinking is complex and multifaceted, often involving cognitive processes and dispositions modulated by implicit cultural belief systems and ways of thinking. In this article, we build on existing research on the relations of creative thinking and culture, and explore how specific cultural resources can be harnessed to foster creative problem-solving in education. We first review the recent changes in our understanding of creative thinking, from an exclusive focus on cognitive processes to a more inclusive view of creative problem-solving as socially negotiated and culturally modulated, carrying important cultural functions. We then introduce a pedagogical model, QEOSA, to illustrate how cultural resources, particularly culture-specific ways of thinking about the world, can be harnessed to foster creative thinking in education, and what developmental and pedagogical considerations are involved to make it effective. We finally conclude this article by indicating the value of this line of work that integrates psychological, cultural, developmental, and educational principles in fostering the development of a creative mind-set with relevant knowledge, skills, dispositions, and values.

Keywords: problem-solving, indigenous epistemologies, developmental constraints, creative mind-set, pedagogical design

OPEN ACCESS

Edited by:
Haiying Long,
Florida International University,
United States

Reviewed by:
Anna N. N. Hui,
City University of Hong Kong,
Hong Kong
Saskia Jaarsveld,
University of Kaiserslautern,
Germany

****Correspondence:***
David Yun Dai
ydai@albany.edu

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *01 October 2018*
Accepted: *28 March 2019*
Published: *24 April 2019*

Citation:
Dai DY, Cheng H and Yang P (2019) QEOSA: A Pedagogical Model That Harnesses Cultural Resources to Foster Creative Problem-Solving. Front. Psychol. 10:833. doi: 10.3389/fpsyg.2019.00833

FOSTERING CREATIVE THINKING: COGNITIVE CONSIDERATIONS

Creativity is often defined in terms of a psychological process leading to novel and useful ideas and products (Plucker et al., 2004). While distinct cognitive processes and mechanisms are identified (Finke et al., 1992), they are always associated with affective and conative forces that provide the necessary impetus, that is, energy, purpose, and direction for such endeavor (Dai and Sternberg, 2004). In addition, as long as this process involves multiple individuals interacting with one another in such an undertaking, the process is socially engendered and culturally facilitated (Sawyer, 2012). Thus, connecting cognition, creativity, and culture entails the recognition that the creative process is complex and multifaceted.

There has been a bulk of research on creative thinking and creative problem-solving (see Mumford and Gustafson, 1988; Plucker et al., 2004 for reviews). It is difficult to exhaust all possible processes and mechanisms that help define and solve problems in a creative way. There are two prominent issues, however, regarding creative thinking and

problem-solving. One is how to overcome rigidity in thought and exercise cognitive flexibility, particularly when a problem is ill-defined; that is, the nature of the problem as well as the solution paths is not clear (Spiro et al., 1991). In real life, individuals can be easily the victims of mental sets and entrenched views that create tunnel vision and dogmatism (Ambrose et al., 2013). Besides self-serving biases and interests, there are important cognitive sources of rigidity in thinking. We tend to think about issues in terms of conflicts and contradictions, for example, pitting economic development against environmental protection, as if one is also gained at the cost of the other. Cast such thinking in game theory, all games are zero-sum games: if the other side wins, you lose. This is a cognitive trap easy to fall into, even for scientists and scholars; if a claim is true, then an alternative claim is always false (e.g., the perennial nature–nature debate in psychology; see Dai, 2012). In either case, breaking mental sets (Luchins and Luchins, 1970) is essential for finding out better alternative possibilities and solutions, rather than rigidly adhering to a fixed problem representation and solution path (Dai and Cheng, 2017). For example, to overcome conceptual entrapment, we can alternatively view environmental protection as a win-win opportunity for job creation and reindustrialization; or on the nature-nurture issue, we can see nurture sometimes transcends nature, and other times reveals nature, or view both as making up one inseparable functional and developmental system (e.g., Gottlieb, 1998).

In addition to initial problem framing, a subsequent issue is how to seek better solutions by carefully constructing a problem representation that identifies and satisfies relevant goal-related constraints in reaching a solution. Researchers have reached a consensus that creativity involves both divergent and convergent thinking (Treffinger, 1995; Cropley, 2006; Runco, 2010), and that creativity is not just free ideation or association but entailing knowledge of a problem and exercise of strategic thinking about tackling a problem (Mumford and McIntosh, 2017). For that matter, while holding multiple, sometimes competing, perspectives is important, a crucial step moving problem-solving forward is to critically analyze these options and negotiate a viable solution through gathering and integrating information.

In sum, envisioning multiple possibilities while holding a critical perspective is the key to creativity (Baron, 2000; Langer, 2012); we define this way of approaching specific real-world problems as a *creative mind-set*, a concept we will elaborate on in later sections. While novelty of a solution comes from cognitive flexibility that generates alternative perspectives and possibilities, usefulness and appropriateness come from careful evaluation of alternatives that help select more viable and optimal ones. Because creative problem-solving in the real world is often knowledge-rich rather than knowledge-lean (Finke et al., 1992; Ericsson et al., 2006), transfer of learning and problem-solving across situations through analogical mapping or rule-based reasoning becomes a relevant issue as to *how one learns to be creative*. As we shall demonstrate later with QEOSA, a pedagogical model, fostering creative problem-solving through education can be firmly based on such scientific understanding of underlying social-cognitive processes.

FOSTERING CREATIVE THINKING: CULTURAL CONSIDERATIONS

There are many ways of defining culture. For the purpose of this article, we view culture as conventions and norms that regulate thought and action among members of a particular group. In an important way, it is an "invisible hand" behind people's attitudes, thoughts, mind-sets, and behaviors (Triandis, 1990). For example, norms in individualistic cultures encourage self-expression, and norms in collectivist cultures expect conformity and self-control. There is evidence that individuals in loose cultures are more likely to succeed in creative tasks than individuals in tight cultures (Chua et al., 2015), and tight cultures are less receptive to novel ideas deviating from accepted ways of life or thinking (Shane, 1992; Jones and Davis, 2000; Niu and Sternberg, 2001). Furthermore, individualistic cultures value originality, an essential component of creativity (Torrance, 1972), compared with collectivist cultures (Bechtoldt et al., 2010).

Arguments have been advanced, however, against such broad-brushed generalization. In a more nuanced manner, Arieli and Sagiv (2018) showed through a series of experiments that congruence between cultural mind-sets and problem types matters in effective problem-solving. Kharkhurin (2014) suggested that Western ideology highlighting individualism and Eastern ideology stressing the collective or common good may yield qualitatively different views of what constitute creative solutions (see also Niu and Sternberg, 2002). Shi (2008) challenged the view that traditional Chinese culture, a collectivist culture, hinders creativity. He identified essential characteristics, such unity of the person and the universe (天人合一), the value of harmony and "middle way" (贵中尚和), and moral reflection (知耻自省), among others, as important for a creative personality. His view of creativity has a distinct ethical and moral overtone, similar to Kharkhurin's conception of creativity as involving utility values specific to particular cultures. In the same vein, Hennessey (2017) advocated a systems view of creativity with a distinct cultural dimension: creative problem-solving serves a cultural agenda of solving real-world problems of cultural importance. Viewed this way, an emphasis on the person and the universe as forming a unity (in Chinese culture) rather than an antagonistic relationship seems to be more productive in terms of being harmonious with nature for an agricultural economy. There are distinctive culture-specific epistemic beliefs or indigenous epistemologies (Dai, 2015) in terms of what constitute *reliable and viable ways or strategies to comprehend the realities and solve real-world problems*. These belief systems can either operate in an implicit manner, embedded or encrypted in a culture's natural language and social practices (Masuda and Nisbett, 2006; Paletz and Peng, 2009), or be articulated by intellectual leaders as mottos or scripted teachings spread out throughout a culture.

Are these norms, conventions, and belief systems necessarily more or less creative in serving their respective cultures? We differ from some researchers who set out to determine whether specific epistemic beliefs in a culture (e.g., dialectic thinking) can or cannot facilitate creative thinking (e.g., Paletz et al., 2018). We believe that epistemic beliefs serve as heuristics rather than algorithms in problem-solving situations. To fashion our strategies for promoting creativity, we asked what part of Chinese culture helps people break their rigid, dichotomous (i.e., either-or thinking) mind-set when dealing with practical dilemmas or conceptual conflicts, and what kind of epistemic beliefs in Chinese culture facilitates cognitive flexibility and creative ideation. In other words, there are a set of norms, conventions, belief systems that can be made explicit and "harnessed" as cultural resources to foster creative thinking. As a result, we found rich connections between what the psychology literature we reviewed earlier helps us conclude, and what was conveyed from two most influential schools of thought in Chinese history: Confucianism and Taoism.

The Confucian golden mean (中庸), or the value of harmony and "middle way" mentioned earlier, is an ethical rule that helps balance competing social concerns and maximize gains for all concerned parties with competing priorities (i.e., for the common good). In contrast to the tendency in Western cultures for stressing and polarizing differences and conflicts, the principle of golden mean seeks harmony and unity. It is based on the conviction that, rather than destined to be a zero-sum game, optimal solutions can be found for complex social problems with competing and conflicting priorities and claims. In effect, it is similar in spirit to Sternberg's (1999) balance theory of wisdom. The influence of the principle of harmony is even embodied in the ying-yang logo showing the seamless complementarity and perfect harmony of the apparent opposites. Indeed, the logo itself evidences originality and creativity. Pervasive cross-cultural differences in ways of thinking can be found in research. For instance, Peng and Nisbett (1999) compared college students from China and United States and found that American students tend to engage in adversarial dispute resulting in polarized viewpoints, whereas Chinese students are more likely to consider both sides of competing or contradictory arguments as valid to some extent and thus have a tendency to seek the "middle road" (see also Masuda et al., 2018; see Nisbett, 2003 for a general review).

In comparison to Confucians concerned mainly with ethics, Taoists (e.g., Lao Zhi and Zhuang Zhi) took a more epistemological approach; they tried to make people aware of language entrapment and entrenched conceptual schemas that prevent them from thinking freely and adaptively in an ever-changing world. They maintained that breaking language and conceptual barriers is the only way to achieve free thinking, hence creativity (see Feng, 1988). Taoism inherited the essence of the Book of Change in that it views the world as constantly changing, a kind of dynamism based on ying-yang dialectics that defies static description (see Dai, 2015). Again, this idea finds support from the contemporary psychology literature showing the impediments of entrenched perspectives or mind-sets on creative problem-solving (Frensch and Sternberg, 1989; Kameda and Sugimori, 1993; Ohlsson, 2011; Brockner and Rubin, 2012).

A crucial question from a practical point of view is that, if the Chinese conventions and norms in thought and action are implicitly functional in people's everyday life, is it possible to articulate and harness them to foster creative thinking and problem-solving in education, especially in formative years of human development? After all, if creativity is truly "an important vehicle for cultures to advance their purpose" (Hennessey, 2017, p. 343), the process of enculturation should involve cultivation of such potential. This is precisely what we are trying to accomplish with QEOSA, to articulate and formalize an implicit aspect of culture for an educational intervention aiming to develop a creative mind-set capable of envisioning multiple possibilities while holding a critical perspective (Langer, 2012). Our work was inspired by Confucianism in the sense that creative solutions to complex real-world problems entail a balancing act for the common good. It was inspired by Taoism in the sense that, to achieve an optimal solution, one has to break loose the language and conceptual entrapment, particularly the either-or dichotomous mental set. In this way, the Chinese cultural ideas we introduce here, generated more than 2000 years ago, serve as *heuristics* or *norms* to guide thinking and problem-solving. To fully implement this agenda, there are developmental and pedagogical considerations, to which we now turn.

FOSTERING CREATIVE THINKING: DEVELOPMENTAL AND PEDAGOGICAL CONSIDERATIONS

Masuda et al. (2018) explored the developmental ramifications of enculturation in terms of cultural ways of thinking. It is clear that cross-cultural differences in cognitive processes mediated by cultural influences must have a developmental underpinning; that is, they have to do with the use of specific symbolic systems (e.g., language) as well as patterns of social interaction over time in formative years in shaping the way individuals feel and think, namely, enculturation (Peng and Nisbett, 1999). A question can be raised as to whether we can deliberately cultivate a *creative mind-set* in formative years, and what are psychological mechanisms that mediate developmental changes involved. Indeed, to postulate that young children can formulate creative solutions to complex and ill-defined problems almost violates the developmental canon that thinking and reasoning become more sophisticated only when one reaches adulthood (see Grossmann, 2018 for a review of Reigel's and Perry's theories). This is why it is more common to see well-defined problems featured in early childhood education; it was not until recently that the issue of designing a learning environment featuring ill-defined problems and projects was brought to public attention (e.g., Resnick, 2017).

Decades ago, Torrance (1972) analyzed and summarized 133 studies that were designed to examine whether children can be taught to think more creatively. His review indicated that it is possible to teach children to think more creatively. In addition, several case studies demonstrated that creativity

can be cultivated in formative years. Although under the influence of developmental theory (e.g., Piaget, 1950/2001), people tend to see young children as incapable of hypothetical thinking, Craft et al. (2007) showed that creative learning of children aged 3–7 can be enhanced by what she called *possibility thinking*, a process by which children are prompted to switch modes of thinking from "what is" to "what might be" (Craft, 2002). Although analogical transfer of problem-solving is considered difficult even for college students, Brown and her colleagues (e.g., Crisafi and Brown, 1986) showed when structured properly (e.g., ensuring that children noticed structural similarities between two problems), children as young as 2–3 years old are capable of applying a reasoning rule and making analogical transfer in problem situations, which is a basic mechanism for far transfer and creative problem-solving (Mayer, 1992; Lohman, 1993). Ansburg and Dominowski (2000) found that children having creativity training solved 14–24% more problems than a control group. Together, they suggest that creative thinking in formative years can be enhanced by carefully designed activities.

Developmental considerations go beyond just age-appropriateness of specific knowledge, skills, and dispositions we expect children to master in order to exercise creative thinking; they also draw our attention to the nature of creativity from a developmental point of view. Many scholars (e.g., Mumford and Gustafson, 1988; Sternberg and Lubart, 1991; Amabile, 2001; Perkins and Tishman, 2001) argue that intelligence or creativity is not a unitary ability or skill to be developed, but reflects a combination of knowledge, skills, values, and personal dispositions, coupled with an environment conducive to acts of intelligence and creativity. Viewed this way, enculturation of a *creative mind-set* capable of envisioning multiple possibilities while holding a critical or evaluative stance (Langer, 2012) is a long-term developmental proposition that involves the growth of the whole mind, not merely skill sets. According to Vygotsky's (1978) social-cultural theory, such individual development involves an internalization process involving prolonged co-construction of cognitive apparatus with more competent peers or adults (see Moran and John-Steiner, 2003). An important pedagogical implication is that, although a "skill training" approach to enhancing creativity can be useful, in formative years of individual development, a growth-oriented approach to nurturing a creative mind-set through *enculturation* is more viable and effective.

Consistent with the view enhancing creativity through enculturation, Torrance (1972) argued that the most successful method of teaching children to think creatively is to consider their cognitive and emotional functioning, give them sufficient structure and motivation, and provide opportunities to engage, practice, and interact with teachers and other children. These instructional strategies form the core of a pedagogy for fostering children's creative thinking. For example, at the beginning, teachers need to evoke children's knowledge and emotional experiences with a presenting problem, and then motivate children to think creatively and scaffold the creative ideation and action through social interaction such as brainstorming. More recently, metacognitive monitoring of creative work is also emphasized as part of this pedagogy (e.g., Scardamalia and Bereiter, 2006). All these features are incorporated into QEOSA.

More specific to learning to be creative problem solvers is the issue of transfer: how to develop a unique set of knowledge, skills, dispositions, and values, a mind-set that is responsive to a range of problem situations calling upon creative solutions, and capable of generating novel and useful solutions. This was the impetus that drove the development of a pedagogical model, QEOSA (**Figure 1**; Cheng, 2012).

QEOSA AS A PEDAGOGICAL MODEL OF FOSTERING CREATIVITY IN FORMATIVE YEARS

QEOSA, standing for Question, Explore, Optimize, Show, and Act, is a pedagogical model developed in the context of preschool education, aiming to nurture creativity in formative years with children of age 3–6 years (Cheng, 2012). Historically, QEOSA was developed as an alternative to teaching divergent thinking. Divergent thinking focuses on ideational fluency and functional flexibility, elaboration, and originality whereas QEOSA emphasizes finding optimal solutions to real-life dilemmas. A focus on optimal problem-solving represents a distinct quality-over-quantity strategy compared to the divergent thinking paradigm of creativity, which originated with Guilford's (1950) conception of creativity, and the evolution model of creativity: blind variations followed by selective retention (Campbell, 1960; see also Simonton, 2003).

In keeping with the current practice of using authentic occasions for fostering and assessing creativity (Treffinger, 1995; Mumford and McIntosh, 2017), QEOSA uses practical problems accessible to preschool children as the main tool for enhancing and assessing creativity rather than more contrived traditional divergent thinking tasks.

While inspired by the Chinese cultural tradition embodied in Confucianism and Taoism in terms of seeking win-win solutions to social and practical problems and conflicts, and overcoming the conceptual entrapment of either-or dichotomous thinking, QEOSA integrates cognitive, developmental, and pedagogical considerations in informing a viable creativity pedagogy for young children. This way, cultural resources capitalized in QEOSA include but are not limited to culturally inspired ethical rule or epistemic stance; they include other norms (e.g., agency, collaboration, and responsibility) and conventions (e.g., children-initiated questioning, peer critiquing of new ideas) for promoting creative thinking. First, QEOSA structures learning experiences into five phases, with each phase having a distinct set of goals and activities; together, they constitute a steady progression toward a creative solution to some real-world problems. Second, QEOSA is a group-based pedagogy; peer interaction and collaboration as well as teacher-learner (in classroom) and parent–child interaction (at home) are the norm for scaffolding and synergistic play. Questions Pool, Products Collection, and Ideas Tank are built as public records of problem-solving for later productive use in a collective manner. Organized this way, QEOSA stresses the social

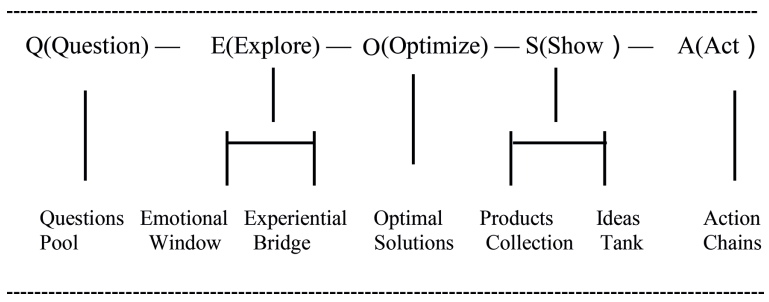

FIGURE 1 | QEOSA: A pedagogy model specifying five phases and seven processes.

(vs. solo) and co-constructed nature of creative problem-solving, which serves the important function of scaffolding optimal problem-solving. Third, to make all steps of problem-solving accessible and visible to young children, all learning activities involve pictures, tangible tools, and manipulatives. In the following section, we delineate each of the five phases of QEOSA in detail, illustrated by a case "Grandpa's Misgivings" used in instruction.

The Questioning Phase

The first phase of QEOSA is to generate a pool of questions raised by young children. For example, the case we introduce here, Grandpa's Misgivings, was initiated by a question asked by one girl, Diandian: "My grandpa always forgot to take medication. What should I do?" This question brought forward a dilemma: her grandpa was troubled with forgetting (he is taking multiple medications with different schedules) but did not want to rely on her parents who had to constantly remind him of taking pills on time. Other children bring their own problems, questions, and observations to share. The teacher organizes a variety of opinions voiced by children and helps them clarify the problems in questions. Then the Questions Pool is created for later use.

The Exploration Phase

In this phase, children are asked to *brainstorm* ideas about the nature of a problem at hand as well as possible solutions. The exploration of various life dilemmas helps build the Experiential Bridge in terms of foregrounding children's experience and factual knowledge (e.g., in the case of Grandpa's Misgivings: illness, treatment, medicine, troubles with taking it on time, the help is not without costs). The next step is to guide children to think about advantages and disadvantages of each solution (e.g., Grandpa is prompted to take medication timely and correctly but the lives of mom and dad are disturbed, and *vice versa*). Two cards are presented to children when children brainstorm ideas of advantages and disadvantages of a solution. If a child identifies advantages of a solution, a happy face card will be given to her or him. Conversely, if a child identifies disadvantages of a solution, a sad face card will be presented. Such visible feedback evokes children's emotions (i.e., opening *Emotional Windows)* and motivates cause-effect analytic thinking. The third step is to scaffold children's ability to synthesize information for finding optimal solutions by providing a cost–benefit analytic scheme. As shown on Q-Pad presented in **Figure 2,** two solutions show both advantages and disadvantages, and children are encouraged to brainstorm ideas of creating a win-win solution, with advantages retained and disadvantages avoided (e.g., Grandpa will be able to take medication in time as well as correctly, while Diandian's parents are free of the labor of constantly reminding her grandpa). The session ends with the teacher's suggestion to children that they should go back home thinking and discussing with their moms and dads about a win-win solution. The sad and happy cards and Q-Pad serve two important pedagogical functions: to make cost–benefit analysis and paths to optimal solutions accessible to young children, to make children's own thinking and reasoning visible to themselves. Related to the issue of design, Q-Pad provides a structure for navigating an ill-defined problem space with identifiable constraints (Welter et al., 2017).

Introducing Q-Pad in early phases of problem-solving distinguishes QEOSA from the traditional approach: QEOSA imposes a structure (i.e., constraints for optimal win-win solutions) before brainstorming. The purpose of imposing structure early is to scaffold an evaluative (or critical) stance early toward solutions better than those involving a trade-off, a distinct *quality-over-quantity* strategy we mentioned earlier. This approach is developmentally appropriate given that young children are still fragile in terms of formulating logical thoughts (Piaget, 1950/2001). Research shows that identifying and satisfying goal-related constraints is central to problem-solving. Creative solutions sometimes rely on releasing assumptions of constraints (Ohlsson, 2011), and other times rely on identifying or setting up new constraints (Stokes, 2001). Optimal problem-solving that QEOSA promotes with dilemma cases involves satisfying multiple constraints so as to create a win-win condition. Medeiros et al. (2014) showed that imposing constraints, when done with the right doses, can improve creative problem-solving.

The Optimization Phase

In this phase, the teacher first reminds children that they are striving for an optimal solution (i.e., seeking a win-win solution). The brainstorming session in the previous phase is followed by a critique session in which children challenge one another about validity and feasibility of the suggested solutions (i.e., whether they truly satisfy the cost–benefit constraints).

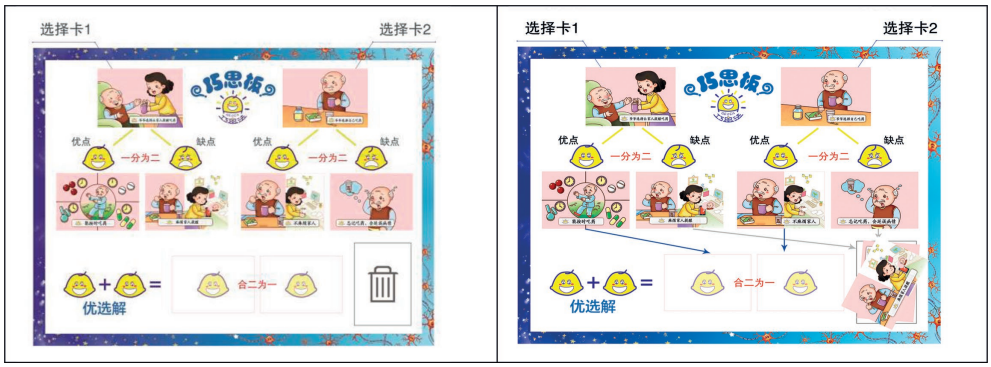

FIGURE 2 | Q-Pad for the case of "Grandpa's Misgivings": The first figure shows constraints for optimal solutions, and the second figure shows an achieved optimal solution.

Then, under the guidance of the teacher, different practical solutions are tried and tested, and children are guided to find tools and resources relevant to specific ideas. For example, in the case of Grandpa's Misgivings, medicine boxes, (fake) medical pills, timer, and recorders become part of an optimal solution (see **Figure 3**). During this optimization process, children have to learn the design rule of combining these tools for a multifunctional design, another aspect of constraint satisfaction. Much "just-in-time" learning and the teacher's scaffolding (but without telling) take place during this phase.

The Show Phase

In this phase, children have to demonstrate, present, and share their ideas of how a dilemma can be solved. Although young children still do not have the skills to engineer their design ideas, they can show their solution by drawing or metaphorically using a seven-piece puzzle (a set of manipulatives for model building). The purpose of showcase children's solutions is to develop children a sense of audience, ownership, and agency, both collectively and individually. Renzulli (2005) pointed out the motivational importance of addressing an audience and making a social impact with creative work, this point is often neglected by creativity researchers. Since the use of QEOSA in young children in China, more than a dozen plays based on real incidences of QEOSA-guided problem-solving have been scripted and performed by participating children on stage in front of classmates and parents as audiences. In the Show phase, some projects were enacted as a theatrical play; so far, a repertoire of 17 plays have been created. And others as the Collection of Products or Ideas Bank are showcased in children's learning fair. The Show phase not only presents occasions that enhance children's sense of agency and accomplishments; it is also a metacognitive moment to show how they managed to get this far.

The Action Phase

In this final phase, the main task is to truly materialize the solution, including searching the market value of a solution. Parents and teachers help children search relevant information as to, for instance, whether the multifunctional medicine box in the case of Grandpa's Misgivings has been produced before. If not, they would help children produce a real multifunctional medicine box as they conceptualized. In this case, children were eventually able to invent a multifunctional medicine box to materialize the optimal solution, capable of automatically prompting Grandpa to take specific medications. These activities form an Action Chain to help improve children's practical skills, but more importantly, enhance a sense of entrepreneurship and achievement. Indeed, so far more than four dozen QEOSA-guided and children-made designs and products have been officially patented in China.

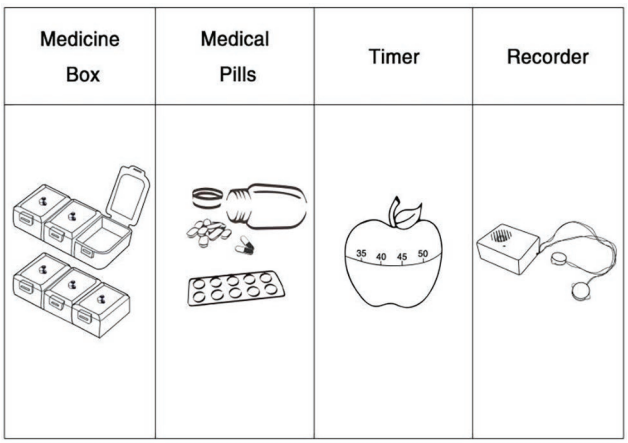

FIGURE 3 | Toy tools used in the case of Grandpa's Misgivings.

HOW QEOSA CONTRIBUTES TO THE DISCOURSE REGARDING BRIDGING CULTURE, COGNITION, AND CREATIVITY

In the previous section, we presented in a nutshell how QEOSA as a pedagogical model was conceptualized and implemented in education for young children. Particularly important to this special issue is the question of how does it contribute to the

current discussion of the role of culture in creative thinking and problem-solving? There are at least three ways in which QEOSA makes culture more prominent in nurturing creativity, with its emphasis on (1) a distinct set of norms and conventions for thought and action embedded in QEOSA, (2) the social and co-constructive nature of developing creative thinking, and (3) the enculturation of a creative mind-set instead of the training of a skill set.

Culture as a Set of Norms and Conventions for Thought and Action Embedded in Pedagogy

While the sequence of Questioning, Exploring, Optimizing, Showing, and Acting resembles current models of creative problem-solving (e.g., Treffinger, 1995; Mumford and McIntosh, 2017), optimal problem-solving engendered by QEOSA carries a distinct set of norms (implicit or explicit) and conventions (i.e., built-in procedures) aiming to shape a creative way of thinking about social and practical problems, dilemmas, and conflicts. Viewed this way, what we consider as influences of Confucianism and Taoism is just part of norm-setting (e.g., the relentless search for a win-win solution, or avoiding either-or conceptual entrapment). More broadly, other values are embedded in QEOSA, such as taking initiative and exercising personal agency, collaboration, and responsibility (be ready to defend one's hypotheses or proposed solutions). In addition, QEOSA also institutes a set of built-in routines (i.e., conventions), such as creating questions and ideas banks for collective use, building *Emotional Windows*, and facilitating *Experiential Bridges* to activate personal experiences and generate new understandings, as well as ensure sustainability of optimal problem-solving. Together, these norms and conventions help create a culture of problem-solving among preschool children, analogous to creating a community of learners and inquirers (Brown, 1994), for knowledge building and creative knowledge work (Scardamalia and Bereiter, 2006).

Historically, creativity has been viewed as having a fixed set of underlying cognitive processes regardless of cultural experience. This view is challenged (Hennessey, 2017). A pedagogy capable of enhancing creative thinking is one that is capable of preparing and positioning a mind to solve real-world problems. From this perspective, even a Western conception of divergent thinking as quintessential for creativity, starting with Guilford (1950), reflects a cultural norm characteristic of an individualist culture.

Social and Co-constructive Nature of Developing Creative Thinking

A developmental corollary of the above argument is that the process of developing creative problem-solving has to involve enculturation that is social in nature; thinking and reasoning, such as maintaining a critical stance, finding multiple possibilities, and seeking win-win solutions, must be co-constructed and scaffolded in formative years. The exercise of optimal problem-solving under QEOSA helps children not only solve complex problems creatively, but also come to appreciate the complexities of the real world and untapped possibilities for the common good. Indeed, the social and intellectual aspects of individual development are intricately connected. As shown in our introduction to QEOSA, almost in every step of the way, children are constantly working with the help of more competent peers and adults. In exploration as well as optimization phases, ideas are generated and improved in such a manner that no individual alone can claim full credit for the outcomes. This approach is in sharp contrast to trait or cognitivist conceptions of the genesis of creativity.

Enculturation of a Creative Mind-Set Instead of the Training of a Skill Set

Mind-set, a term popularized by Dweck (2006), implies a specific way of thinking about important aspects of the world and self. If the norms and conventions involved in a culture of problem-solving embedded in QEOSA provide a structure in support of the development of a creative mind-set (seeking multiple possibilities while holding a critical stance; Langer, 2012), the co-constructing and scaffolding of problem representation and optimal solution finding provides a social-cultural meditational process that helps shape such a creative mind-set over time, the way children learn to relate to and think about the world and themselves in a way conducive to creative contributions.

Such a mind-set surely includes cognitive skills, but it goes beyond divergent and convergent thinking to encompass world knowledge, epistemic stance regarding how the world operates, and how we should approach real-world problems and issues (e.g., how to avoid conceptual entrapment). It should also involve a sense of personal agency for making a difference, whether it involves significant others (e.g., in the case of Grandpa's Misgivings) or the human race (e.g., the issue of global warming). A corollary of the argument for developing a mind-set rather than merely cognitive skills deemed essential for creativity is that an exclusive cognitive approach to creativity, devoid of experiential, affective, knowledge, and social bases, is untenable (see Dai and Sternberg, 2004, for a critique of cognitivism). From a developmental and pedagogical point of view, this point becomes even more important in formative years (i.e., childhood).

CONCLUSION

Historically, creativity research has made many turns in focus, from person, to process, to product, and more recently, to place (or press; see Dai, 2013). Lubart (2017) even coined seven Cs in mapping out all the components involved. This article represents our attempt to make a case for the importance of culture in creative thinking and problem-solving, with a focus on how various lines of research, psychometric, cognitive, developmental, and psychosocial, can be integrated in fashioning a pedagogy of creative problem-solving and the enculturation of a creative mind-set. QEOSA is just a small step in this direction. The enculturation hypothesis advanced in this article is predicated on the notion of transferability

of such a creative mind-set. Empirical effort has been made along this line. Much research is warranted to advance this line of inquiry for the sake of individuals as well as the vitality of society.

AUTHOR CONTRIBUTIONS

DD conceptualized the paper. HC provided pedagogical materials and research data. PY assisted in reviewing literature and writing.

REFERENCES

Amabile, T. M. (2001). Beyond talent: John Irving and the passionate craft of creativity. *Am. Psychol.* 56, 333–336. doi: 10.1037/0003-066X.56.4.333

Ambrose, D., Sternberg, R. J., and Sriraman, B. (Eds.) (2013). *Confronting dogmatism in gifted education*. (New York: Routledge).

Ansburg, P. I., and Dominowski, R. I. (2000). Promoting insightful problem solving. *J. Creat. Behav.* 34, 30–60. doi: 10.1002/j.2162-6057.2000.tb01201.x

Arieli, S., and Sagiv, L. (2018). Culture and problem-solving: congruency between the cultural mindset of individualism versus collectivism and problem type. *J. Exp. Psychol. Gen.* 147, 789–814. doi: 10.1037/xge0000444

Baron, J. (2000). *Thinking and deciding*. 3rd edn. (New York: Cambridge University Press).

Bechtoldt, M. N., De Dreu, C. K., Nijstad, B. A., and Choi, H. S. (2010). Motivated information processing, social tuning, and group creativity. *J. Pers. Soc. Psychol.* 99:622. doi: 10.1037/a0019386

Brockner, J., and Rubin, J. Z. (2012). *Entrapment in escalating conflicts: A social psychological analysis*. (New York: Springer).

Brown, A. L. (1994). The advance of learning. *Educ. Res.* 23, 4–12.

Campbell, D. N. (1960). Blind variation and selective retention in creative thought as in other knowledge processes. *Psychol. Bull.* 2, 380–400.

Cheng, H. (2012). "Developing preschool children's innovation education, and laying the foundation for making China a scientific and technological powerhouse: methodology for the theory and practice of the development of children's creativity (in Chinese)" in *Scientific development and the methodological support*. eds. X.-T. Wu, and Y. Zhou (Beijing: Higher Education Press), 145–160.

Chua, R. Y., Roth, Y., and Lemoine, J. F. (2015). The impact of culture on creativity: how cultural tightness and cultural distance affect global innovation crowdsourcing work. *Adm. Sci. Q.* 60, 189–227. doi: 10.1177/0001839214563595

Craft, A. (2002). "Little c creativity" in *Creativity and early years education: A life wide foundation*. ed. A. Craft (London: A&C Black).

Craft, A., Cremin, T., Burnard, P., and Chappell, K. (2007). "Developing creative learning through possibility thinking with children aged 3–7" in *Creative learning 3-11 and how we document it*. eds. A. Craft, T. Cremin, and P. Burnard (London: Trentham). Retrieved from: http://oro.open.ac.uk/12952/2/

Crisafi, M. A., and Brown, A. L. (1986). Analogical transfer in very young children: combining two separately learned solutions to reach a goal. *Child Dev.* 57, 953–968. doi: 10.1111/j.1467-8624.1986.tb00258.x

Cropley, A. (2006). In praise of convergent thinking. *Creat. Res. J.* 18, 391–404. doi: 10.1207/s15326934crj1803_13

Dai, D. Y. (2012). "The nature-nurture debate regarding high potential: beyond dichotomous thinking" in *Confronting dogmatism in gifted education*. eds. D. Ambrose, R. J. Sternberg, and B. Sriraman (New York: Routledge), 41–54.

Dai, D. Y. (2013). "How advances in gifted education contribute to innovation education, and vice versa" in *International handbook on innovation education*. ed. L. Shavinina (New York: Routledge), 52–67.

Dai, D. Y. (2015). "Indigenous Chinese epistemologies as a source of creativity" in *Creativity, culture, and development*. eds. A.-G. Tan, and C. Perleth (New York: Springer), 29–44.

Dai, D. Y., and Cheng, H. (2017). How to overcome the one-track mind: teaching for wisdom and creativity. *Roeper Rev.* 39, 174–177. doi: 10.1080/02783193.2017.1318659

Dai, D. Y., and Sternberg, R. J. (2004). *Motivation, emotion, and cognition: Integrative perspectives on intellectual functioning and development*. (Mahwah, NJ: Lawrence Erlbaum).

Dweck, C. S. (2006). *Mindset: The new psychology of success*. (New York: Ballantine).

Ericsson, K. A., Charness, N., Feltovich, P. J., and Hoffman, R. R. (2006). *The Cambridge handbook of expertise and expert performance*. (New York: Cambridge University Press).

Feng, Y.-L. (1988). *A history of Chinese philosophy*, vol. 1. (Princeton: Princeton University Press).

Finke, R. A., Ward, T. B., and Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*. (Cambridge, MA: The MIT Press).

Frensch, P. A., and Sternberg, R. J. (1989). Expertise and intelligent thinking: when is it worse to know better. *Adv. Psychol. Hum. Intell.* 5, 157–188.

Gottlieb, G. (1998). Normally occurring environmental and behavioral influences on gene activity: from central dogma to probabilistic epigenesis. *Psychol. Rev.* 105, 792–802. doi: 10.1037/0033-295X.105.4.792-802

Grossmann, I. (2018). "Dialecticism across the lifespan: Toward a deeper understanding of the ontogenetic and cultural factors influencing dialectical thinking and emotional experience" in *The psychological and cultural foundations of East Asian cognition*. eds. J. Spencer-Rodgers, and K. Peng (New York: Oxford University Press), 135–180.

Guilford, J. P. (1950). Creativity. *Am. Psychol.* 5, 444–454. doi: 10.1037/h0063487

Hennessey, B. A. (2017). Taking a systems view of creativity: on the right path toward understanding. *J. Creat. Behav.* 51, 341–344. doi: 10.1002/jocb.196

Jones, G. K., and Davis, H. J. (2000). National culture and innovation: implications for locating global R&D operations. *Manag. Int. Rev.* 40, 11–39.

Kameda, T., and Sugimori, S. (1993). Psychological entrapment in group decision making: an assigned decision rule and a groupthink phenomenon. *J. Pers. Soc. Psychol.* 65, 282–292. doi: 10.1037/0022-3514.65.2.282

Kharkhurin, A. V. (2014). Creativity. 4in1: four-criterion construct of creativity. *Creat. Res. J.* 26, 338–352. doi: 10.1080/10400419.2014.929424

Langer, J. A. (2012). "The interplay of creative and critical thinking in instruction" in *Design research on learning and thinking in educational settings: Enhancing intellectual growth and functioning*. ed. D. Y. Dai (New York: Routledge), 65–82.

Lohman, D. F. (1993). Teaching and testing to develop fluid abilities. *Educ. Res.* 22, 12–23.

Lubart, T. L. (2017). The 7 C's of creativity. *J. Creat. Behav.* 51, 293–296. doi: 10.1002/jocb.190

Luchins, A. S., and Luchins, E. H. (1970). *Wertheimer's seminar revisited: Problem solving and thinking*, vol. 1. (Albany, NY: State University of New York Press).

Masuda, T., Li, L. M. Y., and Russell, M. J. (2018). "Judging the world dialectically versus non-dialectically: Cultural variations in online decision-making processes" in *The psychological and cultural foundations of East Asian cognition*. eds. J. Spencer-Rodgers, and K. Peng (New York: Oxford University Press), 213–242.

Masuda, T., and Nisbett, R. (2006). Culture and point of view. *Cogn. Sci.* 30, 381–399. doi: 10.1207/s15516709cog0000_63

Mayer, R. E. (1992). *Thinking, provblem solving, and cognition*. 2nd edn. (New York: Freeman).

Medeiros, K. E., Partlow, P. J., and Mumford, M. D. (2014). Not too much, not too little: The influence of constraints on creative problem solving. *Psychol. Aesthet. Creat. Arts* 8, 198–210. doi: 10.1037/a0036210

Moran, S., and John-Steiner, V. (2003). "Creativity in the making: Vygotsky's contemporary contribution to the dialectic of development and creativity" in *Creativity and development*. eds. R. K. Sawyer, V. John-Steiner, S. Moran, R. J. Sternberg, D. H. Feldman, J. Nakamura, and M. Csikszentmihayi (Oxford, England: Oxford University Press), 61–90.

Mumford, M. D., and Gustafson, S. B. (1988). Creativity syndrome: integration application, and innovation. *Psychol. Bull.* 103:27. doi: 10.1037/0033-2909.103.1.27

Mumford, M. D., and McIntosh, T. (2017). Creative thinking processes: the past and the future. *J. Creat. Behav.* 51, 317–322. doi: 10.1002/jocb.197

Nisbett, R. E. (2003). *The geography of thought: How Asians and Westerners think differently, and why*. (London: Nicholas Brearley Publishing).

Niu, W., and Sternberg, R. J. (2001). Cultural influences on artistic creativity and its evaluation. *Int. J. Psychol.* 36, 225–241. doi: 10.1080/00207590143000036

Niu, W., and Sternberg, R. J. (2002). Contemporary studies on concept of creativity: the East and the West. *J. Creat. Behav.* 36, 269–288. doi: 10.1002/j.2162-6057.2002.tb01069.x

Ohlsson, S. (2011). *Deep learning: How the mind overrides experience*. (Cambridge, UK: Cambridge University Press).

Paletz, S. B. F., Bogue, K., Miron-Spektor, E., and Spencer-Rodgers, J. (2018). "Dialectical thinking and creativity from many perspectives: contradiction and tension" in *The psychological and cultural foundations of East Asian cognition*. eds. J. Spencer-Rodgers, and K. Peng (New York: Oxford University Press), 267–308.

Paletz, S. F., and Peng, K. (2009). Problem finding and contradiction: examining the relationship between naive dialectical thinking, ethnicity, and creativity. *Creat. Res. J.* 21, 139–151. doi: 10.1080/10400410902858683

Peng, K., and Nisbett, R. E. (1999). Culture, dialectics, and reasoning about contradiction. *Am. Psychol.* 54:741. doi: 10.1037/0003-066X.54.9.741

Perkins, D. N., and Tishman, S. (2001). "Dispositional aspect of intelligence" in *Intelligence and personality: Bridging the gap in theory and measurement*. eds. S. Messick, and J. M. Collis (Mahwah, NJ: Erlbaum), 233–257.

Piaget, J. (1950/2001). *The psychology of intelligence*. (London: Routledge).

Plucker, J. A., Beghetto, R. A., and Dow, G. T. (2004). Why isn't creativity more important to educational psychologists? Potentials, pitfalls, and future directions in creativity research. *Educ. Psychol.* 39, 83–96. doi: 10.1207/s15326985ep3902_1

Renzulli, R. S. (2005). "The three-ring conception of giftedness: A developmental model for promoting creative productivity" in *Conceptions of giftedness*. eds. R. J. Sternberg, and J. E. Davidson. 2nd ed (Cambridge, England: Cambridge University Press), 98–119.

Resnick, M. (2017). *Lifelong kindergarten: Cultivating creativity through projects, passion, peers, and play*. (Cambridge, MA: MIT Press).

Runco, M. (2010). "Education based on a parsimonious theory of creativity" in *Nurturing creativity in the classroom*. eds. R. A. Beghetto, and J. C. Kaufman (Cambridge, UK: Cambridge University Press), 235–251.

Sawyer, R. K. (2012). *Explaining creativity: The science of human innovation*. 2nd edn. (Oxford, UK: Oxford University Press).

Scardamalia, M., and Bereiter, C. (2006). "Knowledge building: theory, pedagogy, and technology" in *The Cambridge handbook of the learning sciences*. ed. R. K. Sawyer (Cambridge, UK: Cambridge University Press), 97–115.

Shane, S. A. (1992). Why do some societies invent more than others? *J. Bus. Ventur.* 7, 29–46.

Shi, Z. Y. (2008). Does traditional Chinese culture impede fostering creative people? *J. Chin. Soc. Educ.* 8, 1–6.

Simonton, D. K. (2003). Scientific creativity as constrained stochastic behavior: the integration of product, person, and process perspectives. *Psychol. Bull.* 129, 475–494. doi: 10.1037/0033-2909.129.4.475

Spiro, R. J., Feltovich, P. L., Jackson, M. J., and Coulson, R. L. (1991). Cognitive flexibility, constriuctivism, and hypoertext: random access instruction for advanced knowledge acquisition in ill-structured domains. *Educ. Technol.* 31, 24–33.

Sternberg, R. J. (1999). A propulsion model of types of creative contributions. *Rev. Gen. Psychol.* 3, 83–100. doi: 10.1037/1089-2680.3.2.83

Sternberg, R. J., and Lubart, T. I. (1991). An investment theory of creativity and its development. *Hum. Dev.* 34, 79–86.

Stokes, P. (2001). Variability, constraints, and creativity: Shedding light on Claude Monet. *Am. Psychol.* 56, 355–359. doi: 10.1037/0003-066X.56.4.355

Torrance, E. P. (1972). Can we teach children to think creatively? *J. Creat. Behav.* 6, 114–143. doi: 10.1136/gut.13.8.627

Treffinger, D. J. (1995). Creative problem solving: Overview and educational implications. *Educ. Psychol. Rev.* 7, 301–312.

Triandis, H. C. (1990). "Cross-cultural studies of individualism and collectivism" in *Nebraska symposium on motivation: Cross-cultural perspective: Studies of behavior across cultures*. ed. J. J. Berman, vol. 37 (Lisse: Swets and Zeitlinger), 41–133.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. (Cambridge, MA: Harvard University Press).

Welter, M., Jaarsveld, S., and Lachmann, T. (2017). Problem space matters: development of creativity and intelligence in primary school children. *Creat. Res. J.* 29, 1–8. doi: 10.1080/10400419.2017.1302769

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 24 April 2019
doi: 10.3389/fpsyg.2019.00927

The Effect of Working Memory Updating Ability on Spatial Insight Problem Solving: Evidence From Behavior and Eye Movement Studies

Qiang Xing[1], Zheyi Lu[1] and Jing Hu[2]*

[1]Department of Psychology, School of Education, Guangzhou University, Guangzhou, China, [2]Guangzhou Sport University, Guangzhou, China

It still remains uncertain whether working memory updating ability influences spatial insight problem solving and whether working memory updating ability plays a role in the representation restructuring phase. The current study explored the correlation of working memory updating ability and spatial insight problem solving by behavior and eye movement experiments, and the results showed that high working memory updating ability individuals spend significant shorter time to solve spatial insight problem than low working memory updating ability individuals. For participants with high or low working memory updating ability, the underlying mechanism of spatial insight problem solving is sudden rather than incremental, which demonstrated that the working memory updating ability did not influence the representation restructuring phase. Working memory updating ability influences spatial problem solving, and it works critically in the problem space search phase, while the restructuring phase is sudden and immediate, which is not influenced by working memory updating ability. The representation restructuring tends to be spontaneous.

Keywords: working memory updating, problem solving, insight, representation restructuring, eye movement

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Lihong Liu,
Guangdong University of Foreign Studies, China
Miriam Gade,
Medical School Berlin, Germany

****Correspondence:***
Qiang Xing
xingqiang@gzhu.edu.cn

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *15 December 2018*
Accepted: *08 April 2019*
Published: *24 April 2019*

Citation:
Xing Q, Lu Z and Hu J (2019) The Effect of Working Memory Updating Ability on Spatial Insight Problem Solving: Evidence From Behavior and Eye Movement Studies. Front. Psychol. 10:927. doi: 10.3389/fpsyg.2019.00927

INTRODUCTION

Creative thinking plays an important role in human society, facilitating individual and social development. Creative thinking is ubiquitous in current society, production, transportation, and entertainment, especially in the field of education. Researchers attempt to identify factors that influence creative thinking (Chirico et al., 2018) and ways to improve creative thinking (Nurdyani et al., 2018). Insight is an important cognitive process in creative thinking. Bowden and Jung-Beeman (2007) argued that insight is a phenomenon accompanied by an "aha" experience in which participants suddenly and intuitively understand complex perceptual situations or capture the intrinsic property of things.

Ash and Wiley (2006) indicated that the process of insight problem solving consists of three main phases: the initial representation phase, the faulty problem space search phase, and the post-impasse problem representation restructuring phase. In the initial representation phase, the problem solver would inappropriately represent the problem. The faulty problem space search phase may lead to the form of impasse. In post-impasse problem representation

restructuring phase, the solver would overcome the impasse and restructure the problem representation and then get the problem successfully solved. The non-insight problem (analytical problem) can be solved through the search for problem representation, but the solution of insight problem needs to be restructured into an appropriate representation after the faulty problem space searching, only in this way can the insight problem be solved. Fleck and Weisberg (2004) hold the view that restructuring occurs in a few small, incremental, reportable steps that change the initial representation after a problem-solving failure, during which consciousness and cognitive resources should be involved. By contrast, some studies proposed that restructuring contains subconscious changes in the representation of problems, which is an unreportable and sudden process. It is tended to be spontaneous (Jung-Beeman et al., 2004; Öllinger et al., 2006). Overall, problem representation restructuring is essential to cognitive mechanism underlying insight problem solving, but whether the consciousness involved in representation restructuring phase remains debate.

In the process of insight problem solving, executive function, emotional state, time pressure, expected reward, and embodied guidance (Xing et al., 2018) would have an impact on it. Gilhooly and Fioratou (2009) investigated the individual differences in executive function in insight and non-insight problem solving and found that the achievement of insight problem solving is only related to the working memory subcomponent of executive function, and the span of working memory could well predict the achievement of insight and non-insight problem solving. On the other hand, the insight and non-insight problem solving are irrelevant with the inhibition and transformation, that is, the process of insight problem solving does not seem to need the participation of inhibition and transformation. Executive functions are generally considered to include three sub-components: responses inhibition, transformation of mental sets, and working memory updating (WMU; Huizinga et al., 2006; Zhou, 2013). In addition, WMU ability is closely correlated to fluid intelligence and advanced cognitive abilities (Chen and Li, 2007; Engle, 2010). Chein and Weisberg (2014) compared the differences of individuals with different working memory capacities and attentional abilities in solving insight problem and found that individuals' differences in working memory capacity and attention ability can significantly predict the score of insight problem solving. The process of insight problem solving required working memory and attention resources, and the updating ability is used to maintain multiple representation and quickly update the representation in a short-term information storage and processing system when the specific stimuli occur. WMU ability shows the individual's working memory capacity and information updating ability and mainly involves the cognitive resources and conscious process (Collette and Linden, 2002; Zhou, 2013). Furthermore, quantities of studies have found that WMU ability has a significant predictive effect on insight problem solving (Jung-Beeman et al., 2004; Chein and Weisberg, 2014; Xing et al., 2017).

Verbal insight problem has been proved to be correlated with executive function, and the results suggested that executive function influences searching within the problem space but not the problem representation restructuring phase (Xing et al., 2017). The two key processes in representation restructuring are constraint relaxation and chunk decomposition (Luo and Niki, 2003; Luo et al., 2004; Zhang et al., 2019). In this case, the representation restructuring phase in spatial insight problem is similar to that in verbal insight problem. Classic spatial insight problem includes the nine-dot problem, the mathematic arithmetic problem, and tumor-laser radiation problem. The nine-dot problem requires problem solvers to draw four connected straight lines to connect all of nine dots, and the pen used for drawing is not allowed to be lifted from the paper (Chein et al., 2010). Chein et al. (2010) found that higher spatial working memory capacity was related to faster solution of nine-dot problem. The matchstick arithmetic problem requires problem solvers to move one or more matchstick to ensure the equation make sense (Öllinger et al., 2006). Recent study proposed that tight chunk in matchstick arithmetic problem is more difficult to restructure representation than loose chunk (Zhang et al., 2019). Problem solvers in tumor-laser radiation problem simulate to use laser power to kill tumor and avoid doing harm to healthy tissue (Duncker, 1945). Xing et al. (2018) used eye movement technique to reveal the impact of embodied guidance on insight by tumor-laser radiation problem. Although spatial and verbal insight problems both emphasize the impasse and representation restructuring as important features of insight, the existing findings revealed differences in the psychological and neural mechanisms of spatial and verbal insight problem (Gilhooly et al., 2011; Cushen and Wiley, 2012). Therefore, it is necessary to explore the impact of WMU ability on spatial insight problem solving and its underlying mechanism, as well as investigate the WMU ability affect which specific phase in the course of spatial insight problem solving.

Previous works investigated the neurocognitive mechanisms of insight problem solving using fMRI (Shen et al., 2016, 2017) and ERP (Zhang et al., 2019) technologies. Eye movement technique, more suitable to investigate the underlying mechanism of spatial insight problem, is also increasingly used (Hegarty and Just, 1993; Grant and Spivey, 2003; Xing et al., 2018). Previous study found that attention is closely related to eye movement (Deubel and Schneider, 1996), and eye gaze is a good indicator of attentional flexibility, which well predicts change in cognitive activity (Kruschke et al., 2005; Rehder and Hoffman, 2005; Blair et al., 2009). Therefore, in the research of spatial insight problem solving, the involving of eye movement technique can help intuitively observe the change of individual's attention resources in the process of spatial insight problem solving and understand its underlying mechanism.

The present study consists of two experiments. Experiment 1 initially explored the correlation between WMU ability and spatial insight problem solving. Experiment 2 used eye movement technique to directly explore the attention resources change and its underlying mechanism in the process of spatial insight problem solving.

EXPERIMENT 1

Method

Participants

Fifty-seven undergraduate volunteers participated in the experiment (20 males; aged from 17 to 24; mean 18.15 ± 3.1 years), right-handed, having normal or corrected-to-normal vision. All the participants did not encounter the Triangle of Circles or similar problems before, and they signed the informed consent before the experiment and got course credit after. Our sample size was determined using G*power 3.1 (Faul et al., 2009). We assumed that the current study would yield a comparatively large effect size (d = 0.8, power = 0.8, α = 0.05), in this case the total sample size should be 42 participants, 21 participants, respectively, in one group.

Apparatus

The working memory updating task was programmed using the E-prime 2.0 program. The display resolution of the screen is 1,024 × 768. The spatial insight problem was presented on a paper, and participants should draw the answer on a sheet.

Procedure

Working Memory Updating Task

Matrix updating task designed by Chen and Li (2005) is used as working memory updating task, which could well predict WMU ability (Chen and Li, 2007; Ecker et al., 2010). At first, a 4 × 4 matrix with 16 cells is presented in the center of computer screen. And there are three different color dots (red, yellow, and green), respectively, in one of the cells. The initial locations of these three dots are lasting for 4,000 ms. Afterward, some color arrows (red, yellow, and green) are presented in the center of the matrix successively. These arrows with different directions (left, right, up, or down) are available for 1,500 ms followed by a blank for 500 ms. These color arrows indicated that the dot sharing the same color should move one cell according to the direction of the arrow. There are three series of the number of arrows, respectively, 3, 4, and 5, so arrows of each color are presented once or twice in each trial. The number of arrows varied randomly in each trial, so that participants have no idea about their termination. After all the arrows are presented in one trial, a note is presented on the screen: "Now it's time to answer." Only in this time, participants could write three words (red, yellow, and green) to indicate the current locations of dots in 4 × 4 matrix with 16 cells printed on an answer sheet. It should be emphasized that participants were required not to take any notes or keep track of dots using pencil before answering, and they could only update the location of dots mentally. After participants finish answering, they can press the space bar to continue to the next trial. Participants would practice three trials (3, 4, and 5 arrows, respectively) to be familiar with the experiment procedure. In the formal experiment, there are four trials in each series of the number of arrows, 12 trials in total. Each correct answer (correct location of color dot) is rated 1 point, thus 3 points with all correct answers in one trial. The score is recorded from 0 to 36. Getting higher scores means stronger working memory updating ability.

Spatial Insight Problem Task

The "Triangle of Circles" is used to be the materials of the spatial insight problem solving, which is adopted from Cushen and Wiley (2012). As shown in **Figure 1A**, 10 circles are set up as a perfect triangle pointing toward the top of the page. And the participants are required to move only three circles to reform a perfect triangle pointing toward the bottom of the page, as shown in **Figure 1B**.

Before the experiment, participants read the requirement of the spatial insight problem, and it is ensured that they understand it. In the formal experiment, participants would be provided 30 s to think and try to figure out the solution. Then, they are given 10 s to draw out three to-be-moved circles and the after-moving positions (**Figure 2** shows an example of one participant's answer). If they do not get the right answer, they would be provided another 30 s to think about the problem and 10 s to answer it. This pattern was repeated as mentioned above until the participants get the right answer or until 10 min running out counting from the first answering.

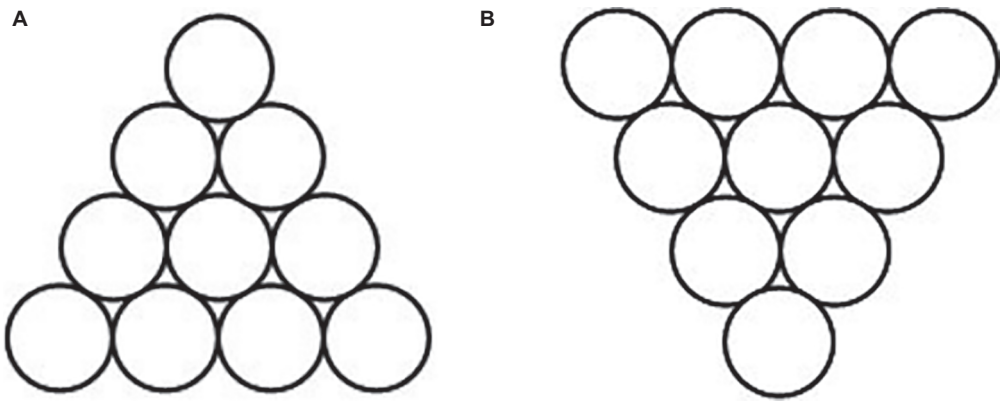

FIGURE 1 | Sample of "Triangle of Circles" problem. Initial state of insight problem **(A)** and target state of insight problem **(B)**.

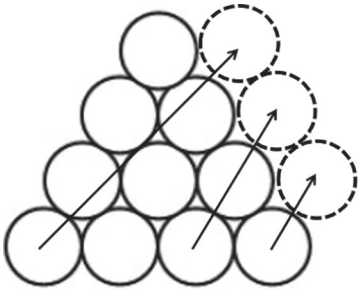

FIGURE 2 | An example of one participant's answer.

Two parts should be considered to successfully solve the problem of "Triangle of Circles," the circles to be moved and the positions after moving. The key circles are the ones on each vertex of the triangle, while the two key positions are on the left and right side of the second row counting from the top, respectively, and the third one is right above the middle of the fourth row. Only find out all right circles and positions can the participants get the correct answer. Each key circle or position is assessed 1 point, with 6 points in total. Each assessment was according to the participants' answer of to-be-moved circles and after-moving positions. Take one answer shown in **Figure 2** as an example, two key circles and one key position are correct, so this answer got 3 points. In the course of problem solving, each answer would be assessed and only the final correct answer got total 6 points.

The order of two tasks was counterbalanced across the participants.

Results and Analysis

Analysis of Time of Spatial Insight Problem Solving

The average score of WMU ability is 24.42 ± 7.02 (M ± SD). Participants with score above the average were divided into high working memory updating ability group (high-level group in short), while participants with score below the average were divided into low working memory updating ability group (low-level group in short; Li et al., 2007; Xing et al., 2017), leaving 28 participants in high-level group and 29 in low-level group.

Forty-one of 57 participants successfully solved the insightful problem, with 21 of them in high-level group and 20 low-level group. The average time of solution for high-level group is 136.71 ± 57.40 (M ± SD) s, while 234.00 ± 151.29 (M ± SD) s for low-level group. Independent sample T test is applied to compare the time of solution of both groups. The result showed that the solution time of high-level group is significantly shorter than that of low-level group (t = −2.78, p = 0.008, Cohen's d = −0.85).

Analysis of Representation Pattern Score of Spatial Insight Problem

According to the researches by Cushen and Wiley (2012), each answering assessment can be seen as their problem representation pattern, in order to obtain an online measure of representational change. Therefore, before the participants successfully reached insight (get 6 points), their representational state of concessive answering can be regarded as search or exploration in the faulty problem space. The length of the search process is represented by their solution time. To analyze the restructuring process of insight problem solving, we compared the scores of the participants' last four answers, which may represent representation pattern.

For 41 participants who successfully solved the problem, their last four assessments were chosen into the analysis, that is, the forth answer prior to the solution (d4), the third answer prior to the solution (d3), the second answer prior to the solution (d2) and the solution (d1, d1 = 6). Those who solved the problem within four times of answering were excluded in data analysis. As a result, 40 sets of data are effective. The average scores of d4, d3, d2, d1 of these 40 participants are shown in **Figure 3A**.

A repeated measures ANOVA was conducted on four sets of d score, and $F(3,117) = 246.49$, $p < 0.001$, $\eta_p^2 = 0.86$. The results showed that there is no significant difference between d3 and d4, while the difference of other sets of scores reached significance. The score gap (represent representational change) of d1–d2 (d12) is significantly more than d2–d3 (d23) or d3–d4 (d34). This means that the gap between final correct representation pattern and the prior one is much larger than the other two periods. The detailed data were shown in **Figure 3B**.

For the analysis of different score of d4, d3, d2, d1 for both high- and low-level group together, it showed that there is no significant difference in d3, d2, and d1 for two groups, with marginal significance in d4, p = 0.06. We analyzed mean score gap in high- and low-level group, respectively. For low-level group, there is one difference between d3 and d4, but significant difference existed between the other two comparisons. For high-level group, there is marginal significance between d3 and d4, p = 0.08, with significant difference existing between the other two comparisons. The different representation pattern of high- and low-level group was shown in **Figure 4**.

Discussion

The solution time of high WMU ability group is significantly shorter than that of low WMU ability group. In other words, the participants in high-level group figured out the solution more quickly. According to three phases of insight problem solving (Ash and Wiley, 2006), it is indicated that participants with high WMU ability would form the correct problem representation more quickly. In the general analysis of representation pattern of insight problem, the comparison of score gap among four sets of d score (assessment of answer representing representation pattern) indicated that there is no significant rise of the solver's representation level before breaking the impasse (d1). In addition, the following analysis of the score gap of d score showed that the score gap of d12 (d1–d2) is significantly larger than that of d23 (d2–d3) or d34 (d3–d4). Therefore, it can be inferred that the process between the impasse (d4, d3, d2) and the impasse overcoming (d1, representation restructuring phase) is not an incremental

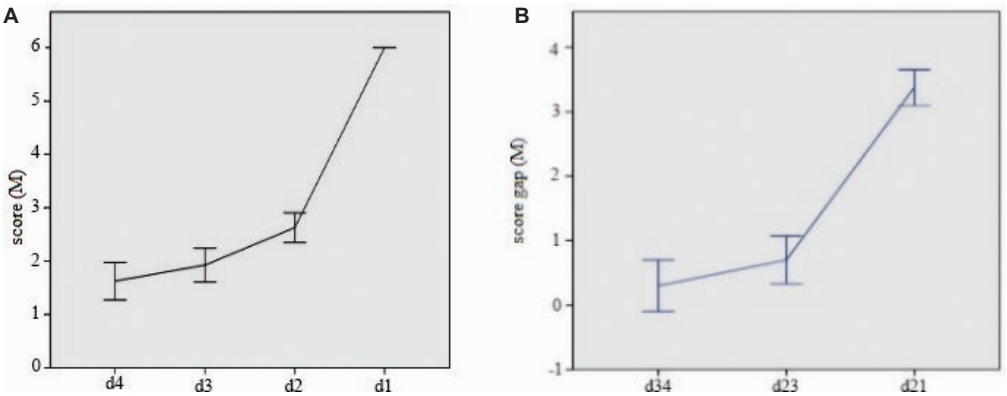

FIGURE 3 | Mean score of last four answers **(A)** and mean score gap between two answers **(B)**. Error bars represent 1 SEM.

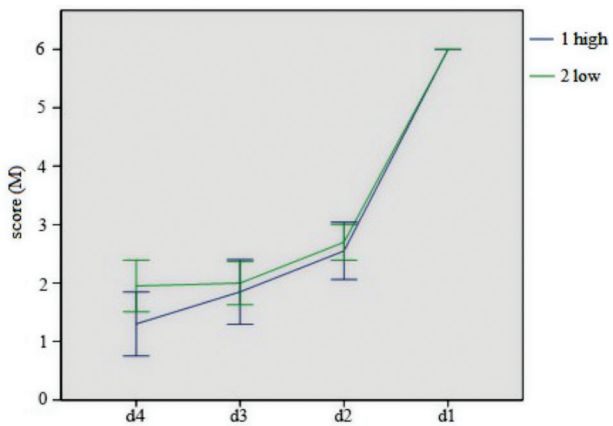

FIGURE 4 | The different mean score of high- and low-level group in last four answers. Error bars represent 1 SEM.

and gradual one but a sudden and immediate one. Furthermore, WMU ability has no influence on the tendency of this sudden and immediate process in spatial insight problem solving. In other words, this process involves little working memory, which further indicated that the process of overcoming the impasse and representation restructuring is tended to be spontaneous.

According to the analysis of representation pattern in insightful problem for both high- and low-level groups, there is no difference for the score in d1, d2, and d3. However, there is marginal difference in score of representation pattern in d4 (early problem space search phase). And the representation pattern of low-level group is similar to that of the general group, but there is significant difference between each two of four sets of scores (one marginally significant). Therefore, in the problem space search phase, participants with low WMU ability are inclined to adopt analytical search mode, while participants with high WMU ability tended to adopt divergent search mode. Hence, in the early phase of problem space search, the problem representation of participants with high WMU ability is far away from the target state but they can reach the target state quickly.

We believe that the influence of individual cognitive resources on insight problem space search mode is more reflected in the distribution of resources and the cooperation between different functions. That is, the divergent resource allocation of high-level groups enables attention and cognitive resources to better update and restructure the problem representation, then to search for the correct problem representation. Eye movement technique can intuitively observe the change of attention recourses, so we used it to directly explore the attention resource change and to underlie the mechanism in the process of spatial insight problem solving in Experiment 2.

EXPERIMENT 2

Method

Participants

Sixty-two undergraduate volunteers participated in the experiment (25 males; aged from 18 to 26; mean 20.15 ± 2.51 years), right-handed, having normal or corrected-to-normal vision. All the participants did not encounter Triangle of Circles or similar problem before, and they signed the informed consent before the experiment and got course credit after.

Apparatus

The working memory updating task and spatial insight problem task were programmed using the E-prime 2.0 program. The display resolution of the screen is 1,024 × 768. Eye movement data were recorded by EYELINK II with a sampling rate of 250 HZ. The movement of right eye was recorded.

Procedure

The procedure of working memory updating task is the same as Experiment 1. The procedure of spatial insight problem task is similar to Experiment 1 with the difference that the insight problem in Experiment 1 is presented by paper and answered by drawing, while the problem in Experiment 2 is

presented by computer screen and answered verbally. In order to ensure that participants could consider the insight problem continuously, if they do not come up with an answer during the answering phase, there is no need to answer. On the other hand, if the insight happens during the observation phase, participants can immediately press the space bar to enter the answering phase, during which they could answer the question verbally. Eye movements in both two phases were recorded. We set the position of the three key circles and the target position as the Area of Interest (AOI), which is represented by square boxes. The AOI 4, 5, and 6 are key circles, and the AOI 1, 2, and 3 are key positions, as shown in **Figure 5**.

Results and Analysis

Analysis of Time of Spatial Insight Problem Solving

The data of 11 participants who did not successfully answer the spatial insight problem were excluded, remaining 51 subjects in the analysis. For WMU ability, the participants above the average score 21.96 ± 6.87 (M ± SD) were rated as group with high WMU ability (high-level group for short), while the participants below the average score were rated as group with low WMU ability (low-level group for short), leaving 26 participants in the high-level group and 25 in the low-level group.

The average solution time of the high-level group was 150.77 ± 61.25 (M ± SD) s, and the average solution time of the low-level group was 232.00 ± 114.31 (M ± SD) s. Independent sample *T* test was conducted on the time of spatial insight problem between high- and low-level groups. The results showed that the problem-solving time of high-level group was significantly shorter than that of low-level group, $t(49) = -3.18$, $p = 0.003$, Cohen's $d = -0.88$.

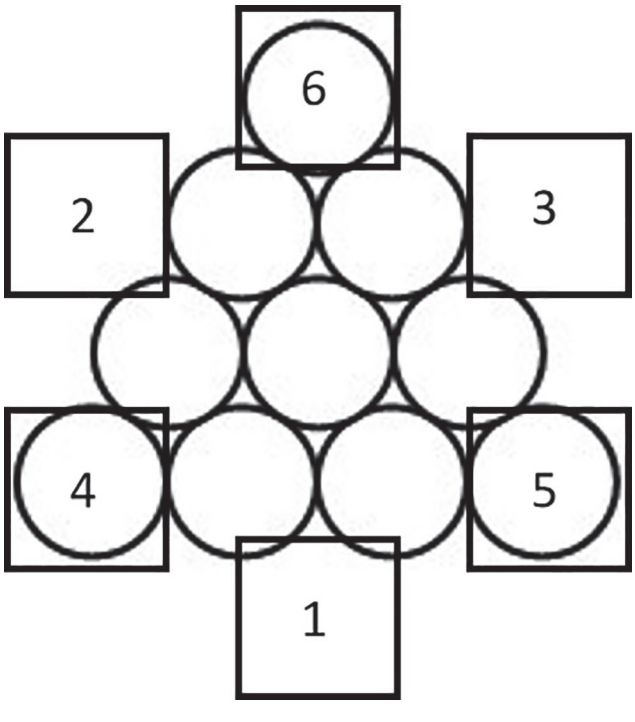

FIGURE 5 | The distribution of AOIs.

Analysis of Eye Movement Data

Thirty-second observation phase and 10-s answering phase are together regarded as one block. Since the number of blocks required to solve the spatial insight problem in the high-level group was 3.78 ± 1.53 (M ± SD) blocks, the eye movement data in last three blocks of each participant (three blocks count downward from the last block) were chosen for analysis. To help clarity, the last block was the block in which participants successfully solve the problem, and the data in the last block was also included into analysis. Nine participants in the high-level group completed the spatial insight problem task within two blocks, so these data were excluded from final analysis, leaving 25 participants in low-level group while 17 in high-level group. We set Block 3 referring to the last but two blocks, Block 2 referring to the last but one block, Block 1 referring to the last block in which participants successfully solved the spatial insight problem.

Fixation refers to eyes keeping comparatively static during eye movement, and the number of fixations could effectively reflect the processing cognitive load of the certain stimuli, with larger cognitive load accompanying with larger number of fixations (Yan et al., 2013). Owing that AOIs we settled only occupied some parts of the Triangle of Circles, fixation ratio in AOIs was selected as an indicator of eye movement, which refers to the proportion of the number of fixations in AOIs and the number of fixations falling on the entire stimulus. A 2 (WMU ability) × 3 (block) repeated measures ANOVA was conducted on the fixation ration in AOIs, with WMU ability being between-subject variable and block within-subject variable. The results showed that the main effect of block was significant, $F(2,80) = 7.62$, $p = 0.001$, $\eta_p^2 = 0.16$, but the main effect of WMU ability was not significant, $F(1,40) = 0.046$, $p = 0.83$, $\eta_p^2 = 0.001$. There is no significant interaction, $F(2,80) = 0.052$, $p = 0.95$, $\eta_p^2 = 0.001$. Further analysis found that the difference between Block 3 and Block 1 was significant, $p = 0.004$; the difference between Block 2 and Block 1 was significant, $p < 0.001$; the difference between Block 3 and Block 2 is not significant, $p = 0.50$.

The information in AOIs is critical to spatial insight problem solving. Among them, the AOIs 4, 5, and 6 are key circles, and the AOIs 1, 2, and 3 are key positions. To verify the successful solution of spatial insight problem depends which types of information, a 2 (type of AOIs) × 3 (block) repeated measures ANOVA was conducted on the fixation ration, with type of AOIs and block being within-subject variables. The results showed that the main effect of block is marginally significant, $F(2,82) = 2.77$, $p = 0.068$, $\eta_p^2 = 0.063$, but the main effect of type of AOIs is not significant, $F(1,41) = 0.225$, $p = 0.64$, $\eta_p^2 = 0.005$. The interaction was either not significant, $F(2,82) = 1.38$, $p = 0.26$, $\eta_p^2 = 0.032$. Further analysis found that the difference between Block 3 and Block 1 was significant, $p = 0.03$; the difference between Block 2 and Block 1 was significant, $p = 0.019$; the difference between Block 3 and Block 2 is not significant, $p = 0.61$. See **Table 1** and **Figure 6** for the detailed fixation ratio in each block.

TABLE 1 | Descriptive statistics of fixation ratio in AOIs (M ± SD).

AOIs	Block 3	Block 2	Block 1
Overall	0.37 ± 0.03	0.33 ± 0.03	0.50 ± 0.03
Key circles	0.18 ± 0.02	0.17 ± 0.02	0.23 ± 0.02
Key positions	0.19 ± 0.02	0.16 ± 0.02	0.24 ± 0.02

Note: Block 3 refers to the last but two blocks; Block 2 refers to the last but one block; Block 1 refers to the last block.

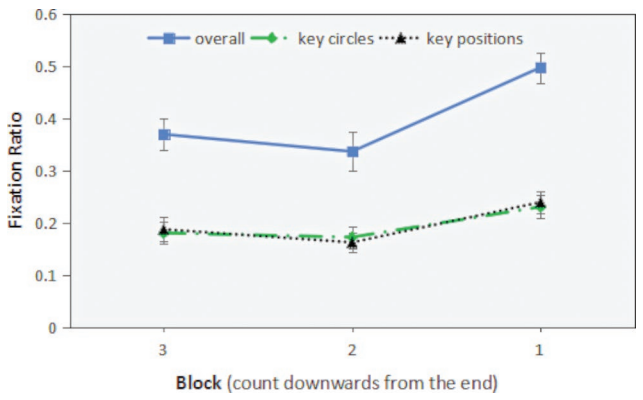

FIGURE 6 | The fixation ration in AOIs in last three blocks. Error bars represent 1 SEM.

Discussion

The last block in which participants successfully solve the spatial insight problem is regarded as insight phase, while other blocks are regarded as non-insight phase. In the process of spatial insight problem solving, the fixation ration in AOIs of insight phase is significantly higher than that of non-insight phase, indicating that more attention resources are allocated to the key circles and key positions when the participants reached insight. Moreover, there is no significant difference between the fixation ration of key circles and key positions, indicating that it is necessary to focus on these two key pieces of information instead of one single piece of information to achieve insight. In the previous problem space search phase, the participants did not pay enough attention to the key circles and key positions, or just focused on some parts of them, so that the participants form the incorrect problem representation and were stuck in impasse. The eye movement reflects the change of attentional and cognitive recourses to a certain extent (Godijn and Pratt, 2002). When the participants attempted to solve the spatial insight problem, they would try to move the circles to other positions. In the process, the participants needed to remember the previous-moving circles, the after-moving positions, and the reconstructed shape of the stimulus, after that participants should judge whether the new shape of circles is the perfect triangle pointing to the bottom. Each step in this process is closely related to the WMU ability. Participants with high WMU ability may remember the previously wrong representation of information, so they found key information and reached insight faster than those with low WMU ability. They may repeat the same misrepresentation of the problem, leading to spend longer time to solve the spatial insight problem.

From the whole course of spatial insight problem solving, the fixation ration in AOIs of the last block is significantly higher than that of its previous block, while there is no significant difference in the fixation ratio in AOIs between the last but two blocks and the last but one block. The changing pattern of the fixation ration in AOIs in Experiment 2 is similar to that of representation pattern in Experiment 1. The results showed that the underlying mechanism of insight problem solving is sudden rather than incremental, although there is difference in the length of time to solve the insight problem, which provides some evidence for that representation restructuring phase is a spontaneous process.

GENERAL DISCUSSION

The current study is an expansion and supplement of Cushen and Wiley (2012) to make it clearer to understand the psychological process of insight problem solving. First, Cushen and Wiley (2012) defined the participants' problem representation by rating the importance of each problem item. And in current experiment, the participants were not required to rate the circles but to directly offer their immediate answers, which represent more specific representation. Second, the time limit for the participants to think is reduced from 1 min to 30 s, which makes it clearer to understand the process of the problem representation restructuring. Third, even if the participants found out the key circles, they might still fail to solve the problem for not getting the key positions. Therefore, scores are given according to both key circles and key positions in Experiment 1, and AOIs are settled for both key circles and key positions in Experiment 2. Finally, to investigate the problem representation, participants were asked to draw the answer on the answer sheet in Experiment 1 every 30 s, which may interfere with their thinking course. It is different from the solution to the insight problem in real life, which should be smooth and continuous. So, Experiment 2 improved the design to avoid this interfering influence.

Quantities of studies were conducted to explore whether the underlying mechanism of insight problem solving is conscious, cognitive recourses needed or spontaneous, automatic, and implicit. Murphy (2005) investigated the correlation between the insight problem solving task and the graphical fluency task (measurement of the inhibition of dominant responses and the transformation of the basic response) and found that there is inhibition and transformation involving in the solution of the insight problem.

However, some researchers indicated that restructuring is an all-or-none and unreportable problem-solving process in insight problem solving (Metcalfe and Wiebe, 1987; Ash and Wiley, 2006; Ash et al., 2009). Fleck (2008) compared four insight and non-insight problems (analytic problems) and found the correlation between working memory span and non-insight problem solving, as well as the correlation between insight problem solving and short-term information storage (without attentional control), which supports the spontaneous theory of restructuring in insight. It also revealed that in insight problem

solving, control processing accounts for a small proportion and automatic processing accounts for a large proportion. Lavric and Forstmeier (2000) also drew similar conclusions that dual processing tasks (simultaneous computing tasks) having less interference with insight problem solving. Ash and Wiley (2006) compared the different size of the faulty initial search space and found that higher capacity to control attention help navigate the initial space. This result also explains the effect of automatic processing on restructuring for that small search spaces only need to be restructured, while large search spaces need to be searched and restructured. Shanker (1995) proposed that unconsciousness does not have a rigorous filter like consciousness. In the course of solving creative problems, problem solvers unconsciously pick out clues irrelevant or new to the problem and link them, which explain the facilitate role of unconscious thinking in insight problem solving to some extent.

The Representational-Change Theory (Ohlsson, 1992; Knoblich et al., 1999) asserts that insight only occurs when the problem solvers stuck in impasse, which is the result of the current problem representation acts as the memory predictor of the incorrect initial problem representation. Individuals only change the current problem representation and form a new memory predictor, then extract the relevant information from the memory can overcome the impasse, and then partial or complete insight may occur. Later, Knoblich et al. (2001) perfected this theory, arguing that the initial representation of problems established by problem solvers enables unimportant knowledge be activated, creating obstacles to problem solving. Only by restructuring the representation of this problem and changing the state of knowledge activation, they can solve the insight problem successfully. And Knoblich et al. (2001) also pointed out that representation restructuring mainly relies on two mechanisms, constraint relaxation and chunk decomposition. Among them, the entire constraint is the most difficult to relax, because in this case, it is necessary to transform the representation of the whole problem; and the partial restriction is much easier, because the partial constraint only affects part of the problem representation. The same is true for chunk decomposition, which is easier to break down for loose chunks than tight chunks (Zhang et al., 2019). Knoblich et al. (2001) also verified the theoretical hypothesis of constraint relaxation and chunk decomposition by solving the matchstick arithmetic problem. After problem solvers see the stimulus and get the negative feedback in the insight condition, they need to break his previous guessing rules and generate new connection between the answer and the puzzle as well as correct representation, in which process more attention recourses and working memory are needed. Individuals with low WMU ability have formed an incorrect problem representation, so they spend more time in impasse than individuals with high WMU ability.

Analysis of representation pattern in Experiment 1 found that search mode of individuals with low WMU ability in problem search space is similar to that in analytical problem solving, which is analytical search mode, while individuals with high WMU ability adopt the divergent search mode. Compared with analytical search mode, the divergent search mode enjoys higher requirements in terms of cognitive resources, state of consciousness, attention span, and divergent thinking. WMU ability mainly shows the individual's working memory capacity and information updating ability (Collette and Linden, 2002) and involves the participation of cognitive resources and conscious process. The negative correlation between WMU ability and the time of spatial insight problem solving in both Experiments 1 and 2 showed that WMU ability plays an important role in the problem space search phase. It is believed that there are quantities of cognitive resources participating and investing in the initial representation phase and problem space search phase in the course of spatial insight problem solving.

In addition, Experiment 1 found significant difference of representation pattern between representation restructuring phase and impasse; Experiment 2 found significant difference of fixation ratio in AOIs between insight phase and non-insight phase. Both two experiments proved that the restructuring process of insight is sudden and immediate. The representation restructuring phase is not affected by the ability of working memory updating, which leads to that the representation restructuring may be a spontaneous processing.

In conclusion, the current study found that insight basically conforms to the Representational-Change Theory. According to the interpret of different phases in the course of insight problem solving (Ash and Wiley, 2006), the previous two phases (initial problem representation phase and problem space search phase) are more involved of conscious processing, and the last phase (representation restructuring process) is more inclined to be a spontaneous process. The current study also provided some evidence for that the solution of insight problem is a dual thinking processing.

There are several limitations in this research, which could be further improved and investigated in the future. (1) The test of the individual's WMU ability only used Matrix Updating task, and the evaluation and prediction of the WMU ability can be conducted in a more integrated and comprehensive method (Ecker et al., 2010; von Bastian et al., 2015). Furthermore, the division of high and low WMU ability group could be upper and lower quarter or third (Gelman and Park, 2009), to make the comparison more precisely. (2) The current study chose classic spatial insight problem, but previous studies have found that the size of problem space would influence insight problem solving (Ash and Wiley, 2006), so we consider further investigating the effect of WMU ability on different size of problem space. (3) The exact moment of insight is difficult to define. Some conservative participants may rethink the problem again after insight to verify their answer. In future, we can combine eye movement and ERPs technology to explore the solution of insight in a more precise time course.

CONCLUSION

1. The ability of working memory updating affects the solution of spatial insight problem solving, and individuals with high WMU ability spend significant shorter time on spatial

problem solving than individuals with low WMU ability. The influence occurs in the problem space search phase.
2. The representational score and fixation ratio in AOIs of insight phase is significantly higher than that of non-insight phase, indicating the representation restructuring phase of spatial insight is a sudden and spontaneous process and is not affected by the ability of WMU.
3. There is no significant difference in the fixation ratio in AOIs of the key circles and key positions, indicating that the solution to the spatial insight problem solving needs to pay attention to both types of key information.

ETHICS STATEMENT

The study reported in the manuscript entitled "The Effect of Working Memory Updating Ability on Spatial Insight Problem Solving: Evidence from Behavior and Eye Movement Studies" has been approved by the Institutional Review Board at Guangzhou University.

AUTHOR CONTRIBUTIONS

QX designed the study, ZL and JH assisted with data collection. All authors wrote the manuscript and analyzed and interpreted the data.

FUNDING

This work was supported by the National Natural Science Foundation of China (31571144).

REFERENCES

Ash, I. K., Cushen, P. J., and Wiley, J. (2009). Obstacles in investigating the role of restructuring in insightful problem solving. *J. Probl. Solv.* 2, 6–41. doi: 10.7771/1932-6246.1056

Ash, I. K., and Wiley, J. (2006). The nature of restructuring in insight: an individual-differences approach. *Psychon. Bull. Rev.* 13, 66–73. doi: 10.3758/BF03193814

Blair, M. R., Watson, M. R., and Meier, K. M. (2009). Errors, efficiency, and the interplay between attention and category learning. *Cognition* 112, 330–336. doi: 10.1016/j.cognition.2009.04.008

Bowden, E. M., and Jung-Beeman, M. (2007). Methods for investigating the neural components of insight. *Methods* 42, 87–99. doi: 10.1016/j.ymeth.2006.11.007

Chein, J. M., and Weisberg, R. W. (2014). Working memory and insight in verbal problems: analysis of compound remote associates. *Mem. Cogn.* 42, 67–83. doi: 10.3758/s13421-013-0343-4

Chein, J. M., Weisberg, R. W., Streeter, N. L., and Kwok, S. (2010). Working memory and insight in the nine-dot problem. *Mem. Cogn.* 38, 883–892. doi: 10.3758/MC.38.7.883

Chen, T., and Li, D. (2005). The diversity of executive functions in normal adults: a latent variable analysis. *Acta Psychol. Sin.* 37, 210–217. doi: 10.1111/j.1744-7909.2005.00136.x

Chen, T., and Li, D. (2007). The roles of working memory updating and processing speed in mediating age-related differences in fluid intelligence. *Aging Neuropsychol. Cogn.* 14, 631–646. doi: 10.1080/13825580600987660

Chirico, A., Glaveanu, V. P., Cipresso, P., Riva, G., and Gaggioli, A. (2018). Awe enhances creative thinking: an experimental study. *Creat. Res. J.* 30, 123–131. doi: 10.1080/10400419.2018.1446491

Collette, F., and Linden, M. V. D. (2002). Brain imaging of the central executive component of working memory. *Neurosci. Biobehav. Rev.* 26, 105–125. doi: 10.1016/S0149-7634(01)00063-X

Cushen, P. J., and Wiley, J. (2012). Cues to solution, restructuring patterns, and reports of insight in creative problem solving. *Conscious. Cogn.* 21, 1166–1175. doi: 10.1016/j.concog.2012.03.013

Deubel, H., and Schneider, W. X. (1996). Saccade target selection and object recognition: evidence for a common attentional mechanism. *Vis. Res.* 36, 1827–1837. doi: 10.1016/0042-6989(95)00294-4

Duncker, K. (1945). On problem solving. *Psychol. Monogr.* 58, 1–113. doi: 10.1037/h0093599

Ecker, U. K. H., Lewandowsky, S., Oberauer, K., and Chee, A. E. H. (2010). The components of working memory updating: an experimental decomposition and individual differences. *J. Exp. Psychol. Learn. Mem. Cogn.* 36, 170–189. doi: 10.1037/a0017891

Engle, R. W. (2010). Role of Working-Memory Capacity in Cognitive Control. *Curr. Anthropol.* 51, S17–S26. doi: 10.1086/650572

Faul, F., Erdfelder, E., Buchner, A., and Lang, A. G. (2009). Statistical power analyses using G * Power 3.1: tests for correlation and regression analyses. *Behav. Res. Methods* 41, 1149–1160. doi: 10.3758/BRM.41.4.1149

Fleck, J. I. (2008). Working memory demands in insight versus analytic problem solving. *Eur. J. Cogn. Psychol.* 20, 139–176. doi: 10.1080/09541440601016954

Fleck, J. I., and Weisberg, R. W. (2004). The use of verbal protocols as data: an analysis of insight in the candle problem. *Mem. Cogn.* 32, 990–1006. doi: 10.3758/BF03196876

Gelman, A., and Park, D. (2009). Splitting a predictor at the upper quarter or third and the lower quarter or third. *Am. Stat.* 63, 1–8. doi: 10.1198/tast.2009.0001

Gilhooly, K. J., and Fioratou, E. (2009). Executive functions in insight versus non-insight problem solving: an individual differences approach. *Think. Reason.* 15, 355–376. doi: 10.1080/13546780903178615

Gilhooly, K. J., Fioratou, E., and Henretty, N. (2011). Verbalization and problem solving: insight and spatial factors. *Br. J. Psychol.* 101, 81–93. doi: 10.1348/000712609X422656

Godijn, R., and Pratt, J. (2002). Endogenous saccades are preceded by shifts of visual attention: evidence from cross-saccadic priming effects. *Acta Psychol.* 110, 83–102. doi: 10.1016/S0001-6918(01)00071-3

Grant, E. R., and Spivey, M. J. (2003). Eye movements and problem solving: guiding attention guides thought. *Psychol. Sci.* 14, 462–466. doi: 10.1111/1467-9280.02454

Hegarty, M., and Just, M. A. (1993). Constructing mental models of machines from text and diagrams. *J. Mem. Lang.* 32, 717–742. doi: 10.1006/jmla.1993.1036

Huizinga, M., Dolan, C. V., and van der Molen, M. W. (2006). Age-related change in executive function: developmental trends and a latent variable analysis. *Neuropsychologia* 44, 2017–2036. doi: 10.1016/j.neuropsychologia.2006.01.010

Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., et al. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biol.* 2:E97. doi: 10.1371/journal.pbio.0020097

Knoblich, G., Ohlsson, S., Haider, H., and Rhenius, D. (1999). Constraint relaxation and chunk decomposition in insight problem solving. *J. Exp. Psychol. Learn. Mem. Cogn.* 25, 1534–1555. doi: 10.1037/0278-7393.25.6.1534

Knoblich, G., Ohlsson, S., and Raney, G. E. (2001). An eye movement study of insight problem solving. *Mem. Cogn.* 29, 1000–1009. doi: 10.3758/BF03195762

Kruschke, J. K., Kappenman, E. S., and Hetrick, W. P. (2005). Eye gaze and individual differences consistent with learned attention in associative blocking and highlighting. *J. Exp. Psychol. Learn. Mem. Cogn.* 31, 830–845. doi: 10.1037/0278-7393.31.5.830

Lavric, A., and Forstmeier, S. G. (2000). Differences in working memory involvement in analytical and creative tasks: an ERP study. *Neuroreport* 11, 1613–1618. doi: 10.1097/00001756-200006050-00004

Li, M., Bai, X., and Yan, G. (2007). The Eye-movement of experiment of mental rotation for the high or low level of executive function of the college students. *Psychol. Explor.* 27, 55–60. doi: 10.3969/j.issn.1003-5184.2007.03.012

Luo, J., Kazuhisa, N., and Steven, P. (2004). Neural correlates of the 'Aha! reaction'. *Neuroreport* 15, 2013–2017. doi: 10.1097/00001756-200409150-00004

Luo, J., and Niki, K. (2003). Function of hippocampus in "insight" of problem solving. *Hippocampus* 13, 316–323. doi: 10.1002/hipo.10069

Metcalfe, J., and Wiebe, D. (1987). Intuition in insight and noninsight problem solving. *Mem. Cogn.* 15, 238–246. doi: 10.3758/BF03197722

Murphy, P. (2005). Differentiating insight from non-insight problems. *Think. Reason.* 11, 279–302. doi: 10.1080/13546780442000187

Nurdyani, F., Slamet, I., and Sujadi, I. (2018). Creative thinking level of students with high capability in relations and functions by problem-based learning. *J. Phys. Conf. Ser.* 983:012102. doi: 10.1088/1742-6596/983/1/012102

Ohlsson, S. (1992). "Information processing explanations of insight and related phenomena" in *Advances in the psychology of thinking*. eds. M. T. Keane, and K. J. Gilhooly (London: Harvester-Wheatsheaf).

Öllinger, M., Jones, G., and Knoblich, G. (2006). Heuristics and representational change in two-move matchstick arithmetic tasks. *Adv. Cogn. Psychol.* 2, 239–253. doi: 10.2478/v10053-008-0059-3

Rehder, B., and Hoffman, A. B. (2005). Eyetracking and selective attention in category learning. *Cogn. Psychol.* 51, 1–41. doi: 10.1016/j.cogpsych.2004.11.001

Shanker, S. G. (1995). The nature of insight. *Mind. Mach.* 5, 561–581. doi: 10.1007/BF00974986

Shen, W., Yuan, Y., Liu, C., and Luo, J. (2017). The roles of the temporal lobe in creative insight: an integrated review. *Think. Reason.* 23, 1–55. doi: 10.1080/13546783.2017.1308885

Shen, W., Yuan, Y., Liu, C., Zhang, X., Luo, J., and Gong, Z. (2016). Is creative insight task-specific? A coordinate-based meta-analysis of neuroimaging studies on insightful problem solving. *Int. J. Psychophysiol.* 110, 81–90. doi: 10.1016/j.ijpsycho.2016.10.001

von Bastian, C. C., Souza, A. S., and Gade, M. (2015). No evidence for bilingual cognitive advantages: a test of four hypotheses. *J. Exp. Psychol. Gen.* 145, 246–258. doi: 10.1037/xge0000120

Xing, Q., Rong, C., Lu, Z., Yao, Y., Zhang, Z., and Zhao, X. (2018). The effect of the embodied guidance in the insight problem solving: an eye movement study. *Front. Psychol.* 9:2257. doi: 10.3389/fpsyg.2018.02257

Xing, Q., Sun, H., Zhan, D., Hu, J., and Liu, K. (2017). The effect of executive function on verbal insight problem solving: behavioral and ERPs studies. *Acta Psychol. Sin.* 49, 909–919. doi: 10.3724/SP.J.1041.2017.00909

Yan, G., Xiong, J., Zang, C., Yu, L., Cui, L., and Bai, X. (2013). Review of eye-movement measures in reading research. *Adv. Psychol. Sci.* 21, 589–605. doi: 10.3724/SP.J.1042.2013.00589

Zhang, Z., Luo, Y., Wang, C., Warren, C. M., Xia, Q., Xing, Q., et al. (2019). Identification and transformation difficulty in problem solving: electrophysiological evidence from chunk decomposition. *Biol. Psychol.* 143, 10–21. doi: 10.1016/j.biopsycho.2019.02.004

Zhou, Y. (2013). The effects of emotional states on executive functioning. *Adv. Psychol. Sci.* 21, 1186–1199. doi: 10.3724/SP.J.1042.2013.01186

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

BRIEF RESEARCH REPORT
published: 26 April 2019
doi: 10.3389/fpsyg.2019.00926

Visual and Linguistic Stimuli in the Remote Associates Test: A Cross-Cultural Investigation

Teemu Toivainen[1], Ana-Maria Olteteanu[2], Vlada Repeykova[3], Maxim Likhanov[4] and Yulia Kovas[1,3,4]*

[1] Department of Psychology, Goldsmiths, University of London, London, United Kingdom, [2] The International Centre for Research in Human Development, Tomsk State University, Tomsk, Russia, [3] Tomsk State University, Tomsk, Russia, [4] Sirius Educational Centre, Sochi, Russia

The Remote Associates Test (RAT) is a measure of associative ability, which is often regarded as essential for creative thinking. The most commonly used version of the test is the compound RAT. However, many RAT items do not translate directly in different languages. Additionally, a linguistic measure cannot be used to measure visual associative ability. A visual measure for associative ability that is similar to the RAT would be a useful tool for cross-cultural investigations of creativity. The present study investigated the relationship between the linguistic and a newly developed visual version of RAT in Russian and Finnish native speakers (for both samples $n = 67$). Both linguistic and visual measures showed good internal reliabilities in both samples (Cronbach's $\alpha = 0.73–0.84$). The mean score in the visual task was slightly higher for the Finnish sample. The correlation between the two measures was stronger in the Russian sample ($r = 0.56$) compared to the Finnish sample ($r = 0.28$). These results are discussed in relation to linguistic and cultural differences between the samples.

Keywords: Remote Associates Test, creativity, measurement, cross-cultural, visual stimuli

OPEN ACCESS

Edited by:
Linden John Ball, University of Central Lancashire, United Kingdom

Reviewed by:
Margaret Webb, The University of Melbourne, Australia
Emma Threadgold, University of Central Lancashire, United Kingdom

***Correspondence:**
Ana-Maria Olteteanu
ana-maria.olteteanu@fu-berlin.de; amoodu@informatik.uni-bremen.de

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *14 December 2018*
Accepted: *08 April 2019*
Published: *26 April 2019*

Citation:
Toivainen T, Olteteanu A-M, Repeykova V, Likhanov M and Kovas Y (2019) Visual and Linguistic Stimuli in the Remote Associates Test: A Cross-Cultural Investigation. Front. Psychol. 10:926. doi: 10.3389/fpsyg.2019.00926

INTRODUCTION

The Remote Associates Test (RAT) is a widely used measure in creativity research. The RAT was developed by Mednick (1962) to empirically test his associative theory of creativity. According to the theory, creative individuals are better at making remote associations in comparison to non-creative (Mednick, 1962). The originally proposed version of the RAT is to find a solution word for three stimuli words. According to Mednick (1962), the solution word can be associated with the stimuli by semantic association (e.g., chicken and egg), synonymy (e.g., chicken and coward) or formation of a compound word (e.g., spring chicken). The most commonly used version of the RAT is the compound Remote Associates Test (cRAT; Bowden and Jung-Beeman, 2003). In the cRAT the stimuli words form a compound word with the solution word. For example, for stimuli words "*cake*," "*swiss*," and "*cottage*," a potential answer is "*cheese*," because it creates compound words that have new meanings: "*cheesecake*," "*swiss cheese*," and "*cottage cheese*." Traditionally, the cRAT has appealed to researchers as each item is held to have only one correct response, making scoring easy as well as taking limited space and time to administer (Bowden and Jung-Beeman, 2003; Lee et al., 2014). However, new computational approaches have shown that many cRAT stimuli words have more than one correct answer (Olteteanu and Falomir, 2015).

The cRAT has been used in several languages and has provided normative data for example in English (Bowden and Jung-Beeman, 2003), Dutch (Chermahini et al., 2012), and Japanese (Terai et al., 2013). Due to the language specific rules on forming

compound words, the translation of the test items is often difficult if not impossible. Also, due to high demands of vocabulary in the cRAT, native speakers have been shown to have an advantage compared to second language speakers (Estrada et al., 1994). Additionally, some researchers have argued that the cRAT is limited as a measure of remote associational ability due to its overreliance on linguistic rules (Worthen and Clark, 1971).

Another variation of linguistic RAT is the functional RAT (fRAT; Worthen and Clark, 1971). As in the cRAT, participants are asked to come up with words that are associated with the three stimuli words. However, instead of creating compound words, the response word is connected to the stimuli with semantic associations. For example, for stimuli "*bait*," "*pond*," and "*tuna*," the answer word can be "*fish*" (bait is used to catch fish, fish live in ponds and tuna is a type of fish). In the fRAT, it is likely that there are also other potential words that may connect the stimuli words semantically. A set of functional items has been created computationally (Olteteanu et al., 2018). Additionally, a recent extension of the fRAT is the visual Remote Associates Test (vRAT). In the vRAT, participants are asked to identify a concept that is semantically linked with three presented images (Olteteanu et al., 2015).

The vRAT has many advantages. Firstly, the use of visual stimuli in the vRAT overcomes limitations of language specificity for linguistic measures. The use of the vRAT instead of linguistic versions of the test may reduce the advantage of native speakers over second-language participants. Secondly, the use of vRAT in combination with linguistic RAT measures, can address questions relating to domain-specificity in creativity research. Mednick (1962) argued that his measure is domain-general but other researchers have proposed that the cRAT in particular is a domain-specific measure that taps into verbal abilities linked to a general intelligence factor (Kaufman et al., 2008).

The present study provides further information on the validity of different versions of the RAT as a measure of associative ability by investigating the relationship between visual and linguistic RAT measures in two samples of Russian and Finnish native speakers. A correlation of 0.37 between the cRAT and vRAT has been reported in an English speaking sample (n = 38; Olteteanu and Zunjani, 2019). The present study addressed the following questions:

(1) Is there a relation between the linguistic and visual RAT performance in Finnish?
(2) Is there a relation between the linguistic and visual RAT performance in Russian?
(3) Are these relations similar in the Russian and Finnish samples?

In addition, the study investigated potential difference in the vRAT between the Russian and Finnish samples. A mean difference in the visual task could be an indication of culture/language-specificity. For example, certain images could be more relevant in some cultures than in others.

METHODS

Sample

The participants were members of general public, recruited via social media. Both Russian and Finnish samples had 67 participants (age range 18 to 69; see the **Supplementary Material** for details). The Russian sample included 17 males and 50 females, the Finnish sample 7 males and 60 females. *A priori* power analysis showed that a sample of 52 participants would be required to detect an effect of 0.37 (Olteteanu and Zunjani, 2019) with 80% power at significance level of 0.05.

Measures

Same visual items were used for both samples (vRAT). The test included 46 items. For the development of visual items, see Olteteanu et al. (2015) for further details.

Translation of the English cRAT items (Bowden and Jung-Beeman, 2003) to Russian and Finnish was unsuccessful due to changes in the meanings of the words. Therefore, some Russian and all Finnish linguistic RAT (lingRAT) items were created for this study. Linguistic items and test forms (cRAT, fRAT) differed between the samples. In the Finnish sample, all 47 linguistic items were in the compound form (cRAT). In the Russian sample, 48 items were both in compound (cRAT) and functional (fRAT) forms. The use of different lingRAT stimulus sets was aimed to provide insights on the form of linguistic stimuli (compound vs. functional) in relation to the vRAT.

The study utilized 36 previously used Russian lingRAT items (Druzhinin, 1999). Twelve additional items, both compound and functional, were created by the research team. The items were tested by a group of native Russian speakers to make sure the items were commonly known (procedure similar to Chermahini et al., 2012). The lingRAT items were created in Finnish by the research team (procedure similar to Chermahini et al., 2012). However, no piloting was done prior to the present study. Examples of the measures (in English, Russian, and Finnish) are presented in **Table 1**. All Russian and Finnish lingRAT items are presented in the **Supplementary Material**.

In all tasks, participants were asked to provide an answer word that is connected to stimuli. Also, participants were shown two practice items with example answers. No time limits for the tasks were set to replicate the procedure of the initial study (Olteteanu et al., 2015). In all tasks, participants could skip the items they did not have an answer for.

In addition to the responses (accuracy), reaction times (RT) were recorded for all items (see **Supplementary Material**). RTs longer than 400,000 ms (6 min and 40 s) were coded as outliers and imputed with the new series mean method in SPSS. The cut-off point was chosen to exclude extreme outliers at this pilot stage of the project. This will be redefined in the following studies, in which, with the additional data, we can make more informed decisions regarding the cut-off for the reaction times.

Scoring

All responses (lingRAT and vRAT) were checked and scored by native Russian and Finnish speakers. This was to make sure

TABLE 1 | Example items of cRAT, fRAT, and vRAT.

Test	The form of Stimuli	Task	Language	Stimulus 1	Stimulus 2	Stimulus 3	Example response
Compound lingRAT (cRAT)	Word	What word can form compound words with the three stimuli words?	English	Cake	Cottage	Swiss	Cheese
			Russian	Кино (a cinema)	Экзаменационный (an exam)	Проездной (a travel)	Билет (ticket; paper)
			Finnish	Kirja (a book)	Tori (a marketplace)	Tiede (science)	Kauppa (shop)
Functional lingRAT (fRAT)	Word	What word is associated with the three stimuli words?	English	Bait	Pond	Tuna	Fish
			Russian	Холодная (cold)	Зеленая (green)	Мутная (muddy)	Вода (water)
vRAT	Image	What co-occurs with the three stimuli images?	English				Hand

lingRAT, linguistic RAT; vRAT, visual RAT; cRAT, compound RAT; fRAT, functional RAT.

that all correct answers were identified, since some of the items could have more than one correct answer. Correct answers were assigned 1 point, incorrect answers scored 0. The summed total was used as an Accuracy score for each participant.

RESULTS

Descriptive statistics and frequency distributions showed that all measures (RAT scores and RTs) were normally distributed. **Table 2** presents descriptive statistics, internal reliabilities (Cronbach's alpha), within sample correlations and the total mean time for the four measures (Russian vRAT, Russian lingRAT, Finnish vRAT, and Finnish lingRAT).

The correlation between the lingRAT and vRAT in the Russian sample was $r(65) = 0.56$, $p < 0.001$, and $n = 67$, and in the Finnish sample it was $r(65) = 0.28$, $p = 0.02$, and $n = 67$. The difference between sample-specific correlations was statistically significant (Fisher's r-to-z transformation $z = 1.95$ and $p = 0.03$). Additionally, there was a significant mean difference in vRAT [$t(132) = -3.78$ and $p < 0.001$] between the Russian and Finnish samples. The total reaction times (sum of RTs for each item) were positively correlated between lingRAT and vRAT total scores for both Russian [$r(65) = 0.47$ and $p < 0.001$] and Finnish [$r(65) = 0.46$ and $p < 0.001$] samples. The difference in correlations was non-significant (Fisher's r-to-z transformation $z = -0.07$).

DISCUSSION

The present study was the first to explore the relationship of linguistic and visual stimuli in the RAT in Russian and Finnish samples. Correlations between accuracy scores in the linguistic (cRAT + fRAT) and visual (vRAT) tasks differed between the samples: correlation was moderate in the Russian sample and weak in the Finnish sample. For the RT measure, a very similar moderate correlation was found in both samples.

The difference in the lingRAT stimuli sets may influence the accuracy correlation between the lingRAT and vRAT. Finnish items were all compound words whereas Russian items were a combination of both compound and functional items (30 functional items). In the vRAT, all items were the same for both groups. Since the vRAT is based on semantic associations (same as linguistic fRAT items), the higher correlation in the Russian sample may reflect that the similar strategy could be used to solve items in lingRAT and vRAT. Conversely, the lower correlation in the Finnish sample could be due to differences in measures. Whereas the vRAT tapped into semantic associations, performance in the Finnish lingRAT (all compound items) was more related to linguistic ability to form compound words than it was in the Russian sample.

Alternatively, the difference between the correlations may also indicate language-specific features of how compound words are created. Due to different linguistic rules in Russian and Finnish, it may be that language specific grammatical constraints direct the selection of the words that can be used to form compound words. For example, if in Russian fRAT items a stimulus word is an adjective, it will have the appropriate grammatical gender in congruence with the solution word. Potentially this will also constrain the search space for the correct solution word.

Overall, the two samples performed very similarly in the visual RAT. The frequency distributions were largely overlapping with similar ranges. However, there was a small mean difference in the vRAT between the samples. Future research is needed to explore

TABLE 2 | Mean accuracy means (standard deviations); internal reliabilities (Alpha); skewness and kurtosis values; mean accuracy correlations; total mean times; and total mean time correlations for the vRAT and lingRAT in Russian and Finnish samples.

		M (SD)	Alpha	Skewness	Kurtosis	Accuracy correlation	M total time (in minutes)	Total time correlation
Russian	vRAT	24.6 (6.8)	0.79	−0.61	1.30	0.56**	14.40 (5.8)	0.47**
	lingRAT	26.6 (6.9)	0.83	−0.76	0.71		18.83 (8.3)	
Finnish	vRAT	29.2 (7.1)	0.84	−1.99	5.57	0.28*	14.07 (6.49)	0.46**
	lingRAT	21.6 (5.3)	0.73	0.37	0.45		29.25 (13.6)	

$^{**}p < 0.01$ and $^{*}p < 0.05$. $n = 134$; $n_{russian} = 67$, $n_{finnish} = 67$.

whether this difference stems from methodological limitations or some culture/language specificity. The observed difference may reflect culture-specificity of certain items, when some concepts (images) may be more familiar in certain cultures. For example, a picture of Poseidon is recognizable only to participants with knowledge on Greek mythology.

Different proportions of linguistic test items was also a limitation in the study. In our future work we will address this by creating comparable stimulus sets to investigate the relationships of lingRAT (cRAT, fRAT) and vRAT within the samples. Additionally, we will also investigate the psychometric properties of the linguistic and visual items in more detail. Future studies should also employ the same stimuli, both in linguistic or visual form, to explore their role in associative processing. Eventually, future studies will help to further develop a valid vRAT measure that can be used in cross-cultural studies.

The findings of the present study show promise in the use of a vRAT across populations with different native languages. They also show that linguistic and cultural specificity may influence RAT performance. Using linguistic and visual remote association tests in cross-cultural context will lead to better understanding of the cognitive processes underlying creativity.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of Goldsmiths' (University of London) Ethics Committee' with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Goldsmiths' (University of London) Ethics Committee.

AUTHOR CONTRIBUTIONS

TT and AMO designed the study and wrote the manuscript. TT, AMO, VR, and ML created the test items. AMO and YK supervised all aspects of the study. All authors reviewed the manuscript.

FUNDING

TT was supported by the Economic and Social Research Council (Grant No. ES/J500124/1). AMO acknowledges the support of the German Research Foundation (DFG) for the Creative Cognitive Systems project OL 518/1-1 (CreaCogs). This research was supported by The Tomsk State University Competitiveness Improvement Programme grant (№ 8.1.11.2018).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00926/full#supplementary-material

REFERENCES

Bowden, E. M., and Jung-Beeman, M. (2003). Normative data for 144 compound remote associate problems. *Behav. Res. Methods Instr. Comput.* 35, 634–639. doi: 10.3758/bf03195543

Chermahini, S. A., Hickendorff, M., and Hommel, B. (2012). Development and validity of a dutch version of the remote associates task: an item-response theory approach. *Think. Skills Creat.* 7, 177–186. doi: 10.1016/j.tsc.2012.02.003

Druzhinin, V. N. (1999). *Psychology of General Abilities*. Russia: Piter Publishing House.

Estrada, C. A., Isen, A. M., and Young, M. J. (1994). Positive affect improves creative problem solving and influences reported source of practice satisfaction in physicians. *Motiv. Emot.* 18, 285–299. doi: 10.1007/bf02856470

Kaufman, J. C., Plucker, J. A., and Baer, J. (2008). *Essentials of Creativity Assessment*, Vol. 53. Hoboken, NJ: John Wiley & Sons.

Lee, C. S., Huggins, A. C., and Therriault, D. J. (2014). A measure of creativity or intelligence? Examining internal and external structure validity evidence of the remote associates test. *Psychol. Aesthet. Creat. Arts* 8:446. doi: 10.1037/a0036773

Mednick, S. (1962). The associative basis of the creative process. *Psychol. Rev.* 69, 220–232. doi: 10.1037/h0048850

Olteteanu, A., and Falomir, Z. (2015). comRAT-C: a computational compound remote associate test solver based on language data and its comparison to human performance. *Pattern Recogn. Lett.* 67, 81–90. doi: 10.1016/j.patrec.2015.05.015

Olteteanu, A., Gautam, B., and Falomir, Z. (2015). "Towards a visual remote associates test and its computational solver," in *Proceedings of the International Workshop on Artificial Intelligence and Cognition AIC 2015*, (Turin). doi: 10.1016/j.patrec.2015.05.015

Olteteanu, A., Susanne, S., and Mikkel, S. (2018). Computationally resurrecting the functional remote associates test using cognitive word associates and principles from a computational solver. *Knowl. Based Syst.* 168, 1–120.

Olteteanu, A.-M., and Zunjani, F. H. (2019). A visual remote associates test and its validation. *ResearchGate* [Preprint]. doi: 10.13140/RG.2.2.18614.14407

Terai, H., Miwa, K., and Asami, K. (2013). Development and evaluation of the Japanese remote associates test. *Shinrigaku kenkyu* 84, 419–428. doi: 10.4992/jjpsy.84.419

Worthen, B. R., and Clark, P. M. (1971). Toward an improved measure of remote associational ability. *J. Educ. Meas.* 8, 113–123. doi: 10.1111/j.1745-3984.1971.tb00914.x

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

REVIEW
published: 28 May 2019
doi: 10.3389/fpsyg.2019.01219

How Does Culture Shape Creativity? A Mini-Review

Yong Shao[1†], Chenchen Zhang[2†], Jing Zhou[3], Ting Gu[4] and Yuan Yuan[5]*

[1]College of Economics and Management, Guangxi Normal University, Guilin, China, [2]School of Art, Nanjing University, Nanjing, China, [3]Department of Art Design, Changzhou Art Vocational College of Jiangsu Province, Changzhou, China, [4]Department of Information Media, The City Vocational College of Jiangsu, Suzhou, China, [5]School of Rehabilitation Science, Jiangsu Provincial Key Laboratory of Special Children's Impairment and Intervention, Nanjing Normal University of Special Education, Nanjing, China

OPEN ACCESS

Edited by:
Haiying Long,
Florida International University,
United States

Reviewed by:
Caroline Di Bernardi Luft,
Queen Mary University of London,
United Kingdom
Dan Zhang,
Tsinghua University, China

***Correspondence:**
Yuan Yuan
appsyche@163.com

[†]Co-first authors

Specialty section:
This article was submitted to Cognitive Science, a section of the journal Frontiers in Psychology

Received: 31 October 2018
Accepted: 08 May 2019
Published: 28 May 2019

Citation:
Shao Y, Zhang C, Zhou J, Gu T and Yuan Y (2019) How Does Culture Shape Creativity? A Mini-Review. Front. Psychol. 10:1219. doi: 10.3389/fpsyg.2019.01219

The purpose of this study was to examine how culture shapes creativity by reviewing empirical findings across diverse studies. The impact of culture on creativity is typically manifested in three ways: (1) people from different cultures or settings have distinct implicit and/or explicit conceptions of creativity; (2) individuals from different cultures, particularly those from individualist and collectivist cultures, show differences in preferred creative processes and creative processing modes (e.g., usefulness seems more important than novelty in the East, whereas novelty seems equally important as usefulness, if not more so, in the West) when they are engaged in creative endeavors; (3) creativity may be assessed using different measures based on culture-related contents or materials, and findings are accurate only when culturally appropriate or culturally fair measures are used. Potential implications and future directions are also proposed.

Keywords: culture, creativity, conceptualization, thinking pattern, creative process

INTRODUCTION

Creativity, a key engineer for facilitating social harmony, sustainable human development, technological invention and scientific revolution, is manifested in human activities at different levels, from everyday life to advanced technological industries. To date, there is no consensus-based definition of creativity; however, according to a standard definition, creativity is often perceived as the ability to produce something new/novel and appropriate/useful. At present, unprecedented significance is being attributed to creativity due to the implementation of policy-based, innovation-oriented national development strategies and increasingly pressing global issues, such as global warming and terrorism. Perhaps for these reasons, the study and application of creativity have received considerable attention in the past 10 years, and many critical findings regarding creativity have been revealed through a variety of research methods and approaches. Although these findings play an increasingly important role in understanding and developing creativity, they are largely isolated and fragmented because of

the various approaches and methods used. Creativity, as a key product of human culture and a tool for enriching culture, has an extremely intimate but complex relationship with culture. To obtain a comprehensive understanding of the nature of creativity, this work attempted to integrate available studies from a cultural and cross-cultural research perspective. In a sense, creativity is inherent to culture. Simply speaking, if culture is the "background," then creativity is the "object" that is likely to become a new "background" for emerging and forthcoming "creativity (objects)." Nobody can live well and be creative without the involvement of culture. Accordingly, the present study attempted to identify how culture molds creativity from a (cross-)cultural psychology perspective.

Creativity is deeply rooted in all cultures, but its definition and attributes vary across cultures. According to the literature, the dichotomy of "the West" and "the East" is one of the most influential approaches in characterizing (potential cultural) differences in understanding and defining creativity. "The East" commonly refers to Asian countries, especially East Asian countries such as China and other countries influenced by its culture, such as Japan or Korea; they possess general similarities in social and cultural aspects that differ from those of "Western" countries. The mentioned countries are often considered to largely represent "collectivist cultures" (i.e., cultures that emphasize that collective interests should override individuals' interests and that fitting in with the collective is more important than being unique) and share a similar tradition that traces its origin from Asian thought, such as Taoism, Buddhism, and Confucianism. In contrast, "the West," although usually considered to reflect "individualist cultures" (i.e., those that value the individual's goals and interests over the group's collective interests and goals; Xie and Paik, 2019), usually refers to the US, Western Europe, Canada, Australia, and New Zealand, which are closely linked to ancient Greece and the ideas of Christianity, Judaism, and rationality (Weiner, 2000; see Dubina and Ramos, 2016). The plausibility of such clustering of the East and the West has been substantially supported by several large-scale studies, such as the World Value Survey (Inglehart et al., 1998) and the GLOBE project survey (House et al., 2004; see Xie and Paik, 2019).

In a review of previous studies, we found that some pioneering studies have probed the link between culture and creativity from various perspectives. These studies included two fascinating approaches: a comparison of cross-cultural creativity between aboriginals from different cultural backgrounds and the investigation of the effects of multicultural experiences, such as studying abroad, and cultural priming on creativity. Leung and Chiu (2010), for example, asked European American undergraduates to complete a creative writing task (followed 5–7 days later by a creative analogies construction task) immediately after exposure to visual materials that mirrored either American or Chinese cultures or a hybrid culture created by the fusion of American and Chinese cultures. The researchers not only empirically documented a robust facilitative role of multicultural experience in both immediate and delayed creative performance but also found that this effect was primarily mediated by the generation of uncommon and unconventional ideas and by enhancing receptiveness to ideas that are natively rooted in foreign cultures and modulated by individuals' need for cognitive closure and existential terror. Similarly, through five studies using a multimethod approach, Maddux and Galinsky (2009) empirically revealed the positive association between time spent living abroad (not traveling abroad) and creativity, demonstrating that foreign living experiences and the experience of adapting to a foreign culture temporarily boosted creativity in individuals who had lived abroad. Although considerable studies of this kind have reliably replicated the effects of exposure to foreign culture on facilitating creativity, they require integration and a more comprehensive perspective. Two recent theoretical studies (Shen and Yuan, 2015; Huang et al., 2018) attempted to integrate these "isolated findings"; however, they mainly focused on the influence of different aspects of culture (i.e., cultural values/norms and activities, multicultural learning, or cultural artifacts/products) or multicultural experiences on creativity (as an entity), without evaluating the effect of culture on different aspects of creativity. Nonetheless, creativity as a multifaceted and complex construct naturally involves distinct representation across different levels, from conceptual analysis to experimental manipulation and practical assessment. In fact, an increasing number of studies have been criticized for utilizing a "Western" (or American) framework to conceptualize and measure creativity (Glăveanu, 2010). Therefore, to deepen the understanding of the relationship between culture and creativity, particularly the role of culture in modifying and nurturing creativity, the major roles of culture in conceptualizing, manipulating, and measuring creativity were carefully identified.

The remainder of this research is organized as follows. Section "Culture Underwrites the Definitions of Creativity" mainly illustrates the role of culture in conceptualizing or defining creativity. Next, we present recent findings on the influence of culture on the creative process, followed by the effect of culture on assessing creativity or developing creativity measures. Finally, the study concludes with some proposed directions for future studies.

CULTURE UNDERWRITES THE DEFINITIONS OF CREATIVITY

Creativity is bound to culture. To systemically or scientifically investigate a new construct, the first order of business is to establish a definition of the construct. Without exception, a key to scientifically demystifying the construct of creativity is to conceptualize or define creativity. Although defining creativity is easy, establishing a consensual definition of creativity is not. Previous studies have acknowledged that a collection of creativity conceptions proposed by earlier psychologists has been compiled into a book (see Treffinger, 1996), indicating that there have been considerable attempts and efforts to explicitly define creativity. For example, working from the perspective of intersubjectivity, Glăveanu (2010, p. 157) conceived of creativity as a complex phenomenon leading to

"the generation of new and valuable artifacts by working with 'culturally impregnated' materials within an intersubjective space." However, the standard definition of creativity argues that creativity requires both originality (also called novelty, newness, or uniqueness) and effectiveness (also called utility, usefulness, appropriateness, value, or meaningfulness) (Runco and Jaeger, 2012, p. 92). In contrast to considering creativity as an intrapersonal cognitive process or performance or as an individual's personality or abilities (Williams and Yang, 1999, p. 378), creativity is assumed to be a complex, multivariate construct or phenomenon that refers to the "interplay between ability and process by which an individual or group produces a perceptible outcome or product that is both novel and useful as defined within some social context" (Plucker et al., 2004, p. 90). Perhaps because so many different definitions of creativity are available and because of the lack of universal agreement regarding such definitions, individuals across cultures conceptualize creativity differently and sometimes use context- or culture-specific theories of creativity as general theories or definitions (Lee et al., 2015). A review of the existing literature found that some definitions of creativity concerned the nature of dynamic thought processes and the intellectual capability used to produce insights or creative solutions to problems; some primarily focused on the personal characteristics (personality or traits) and cognitive abilities of individuals; and still others targeted the products or outcomes of creative attempts (Martins and Terblanche, 2003). Importantly, some variability is found in explicit conceptions of creativity across cultures or countries. Typically, these suggest that Western cultures attach more importance to process- and product-based creativity and highlight the pragmatic, problem-solving outcome of creativity and that Eastern cultures have great interest in creative spirits and person-based creativity, treating creativity as a form of revelation or rediscovery (Westwood and Low, 2003) and emphasizing the role of creativity in facilitating personal fulfillment and enlightenment or the self-expression of an inner essence or ultimate reality (Lubart, 1999; Glăveanu, 2010).

Numerous conceptual constructs in psychology can be studied and depicted as explicit (based on domain experts and/or theories) or implicit (derived from laypersons' or individuals' belief systems). Creativity is no exception. In contrast to explicit theories, which rely heavily on experts' data-driven theories regarding creativity, implicit theories of creativity preexist in people's minds and only need to be discovered (Shen et al., 2018b). Implicit theories are regarded as having great practical and theoretical importance for formulating common cultural views on creativity and understanding how individuals perceive their own beliefs regarding creativity (Rudowicz, 2003; Shen et al., 2018b). Consistent with the numerous studies that have attempted to determine the explicit concepts of creativity, substantial evidence has demonstrated that implicit conceptions of creativity show some variability across cultures. According to Rudowicz (2003), the majority of studies concerning implicit theories of creativity have either focused on creative individuals (the traits or personality characteristics that typify a creative individual) or the conceptualization of creativity (what laypeople perceive creativity to be). For example, Sternberg (1985) reported that the implicit conception of creativity overlaps with but also distinctively differs from the conceptions of intelligence and wisdom. In Western studies, descriptions such as "curious," "imaginative," "independent," "inventive," "original," "wide interests," "nonconformist," "individualistic," "confident," "assertive," "daring," "artistic," "open-minded," "intelligent," "capable," and "sense of humor" were frequently named as implicit personality characteristics that describe a creative individual (Runco and Bahleda, 1987; Rudowicz, 2003; Runco, 2014; Luescher et al., 2019). Using Chinese undergraduates as participants, Rudowicz and Yue (2000) demonstrated that Chinese college students from Beijing, Guangzhou, Taipei, and Hong Kong all named "originality," "innovativeness," "thinking," "observational skills," "flexibility," "willingness to try," "self-confidence," and "imagination" as core characteristics of a creative person, with some regional differences (except in the Taipei sample) that attributed "wisdom," "assertiveness," and "individualism" to creativity. Additionally, Rudowicz and Yue (2002) surveyed 489 Chinese students and required them to name the most creative Chinese people in history and in modern times. Their results showed that Chinese youths' perceptions of creative individuals focused more on an individual's social influence or their potential or realized contributions to society through their creativity. Furthermore, Rudowicz (2003) noted that characteristics related to "artistic" and "sense of humor" were missing or almost nonexistent in Chinese perceptions of creativity and that "inspires people," "makes contributions to society," and "is appreciated by others" were uniquely Chinese views of creativity that were not reported among Westerners' implicit conceptions of creativity. Overall, to Westerners, creativity implies a break with tradition and a move beyond what exists, whereas to Easterners, creativity suggests the reinterpretation or rediscovery of tradition. Relatedly, in the West, creativity is valued primarily for solving particular problems through insight or achieving personal success, whereas in the East, the value of creativity primarily lies in the social and moral contributions an individual can make to society (Rudowicz and Yue, 2000; Niu and Sternberg, 2006).

Taken together, although mounting studies have investigated the potential influence of culture or multiculturism on creativity (Leung et al., 2008; Leung and Chiu, 2010; Shen and Yuan, 2015; Chua, 2018), including conceptualizing creativity and showing the rich connotations and cultural variability of creativity, the majority of these studies focused on experts' data-driven definitions of creativity and laypersons' perceptions of creativity to identify explicit and implicit conceptions of creativity. Western notions of creativity primarily focus on creative processes and products at the explicit level and on achieving personal success and solving difficult problems at the implicit level, whereas the Eastern world strongly emphasizes the spirit of creativity and personal characteristics, either traits or abilities, at the explicit level and individuals' moral and social contributions to society at the implicit level.

CULTURE UNDERWRITES CREATIVE PROCESSES

As a complex and multistage process, creativity is not integral to an entire process and may involve various subcomponents or subprocesses. In other words, creativity is a consequence of human thought that involves a variety of creative processes and operates on a set of existing representations, concepts, objects, symbols, rules, or notions. As mentioned above, creativity does not seem to appear in a vacuum or to be isolated from various materials. The materials that are involved in or processed during creativity include representations, concepts, objects, symbols, rules, or notions, which are actually derived from individual and group context-related experiences or cultures and undoubtedly involve elements that are more or less cultural. Nevertheless, the cultural effect of the materials processed during different stages or processes of creativity is not the point of interest in this study; rather, the point of special interest is the effect of culture on creative processes or stages across diverse contexts or cultures. However, this approach does not suggest that the processes underlying creativity in different cultures are completely distinct, without any standard or normative processes or stages; rather, it means that researchers from different cultures are inclined to study different creative processes or processing modes and assign different degrees of importance to the same aspect of the creative process.

Creativity embraces both novelty and usefulness. These concepts correspond to two critical processes of creativity: the generative process of acquiring and accessing information and knowledge and recombining them to produce new ideas and the exploratory process of searching one's knowledge for novel and potentially useful combinations of ideas and judging the viability of potential solutions (Chua et al., 2015). Substantial evidence indicates that in Western or individualistic cultures (Xie and Paik, 2019, p. 7), greater importance is assigned to the novelty processing mode underlying creativity and to flexible, inferential processing, which is beneficial to generating more novel solutions; in contrast, Eastern or collectivist cultures attribute more significance to the processing mode of appropriateness or usefulness underlying creativity and value cautious, persistent processing, which is conductive to more useful solutions (Nijstad et al., 2010; Adair and Xiong, 2018). In fact, the emphasis on novel or "groundbreaking" outcomes fits better with the Western or individualist belief system, which is based on the ideals of individuality, freedom, and democracy. In contrast, the focus on usefulness reflects a strong reliance on tradition, and Eastern or collectivist societies, which are firmly grounded in the ideals of interdependence, cooperation, collectivity, and authoritarianism, have evolved a distinct perspective on the inherent meaning of uniqueness, originality, and/or novelty (Rudowicz, 2003; Kaufman and Lan, 2012).

Similarly, different degrees of significance have been attributed to radical creativity or innovation and incremental creativity or innovation. A gradual or incremental pattern dominates creativity in the East, while a pattern of radical creativity is the dominant pattern of creativity in the West (Shen et al., 2018b). Specifically, some studies have shown that in East Asian cultures, particularly in Chinese culture, there is both a strong desire for creativity and great fear and rejection of radical creativity (Paletz and Peng, 2008; Shen et al., 2018b). In two recent studies (Jarman, 2014; Shen et al., 2018b) that examined the psychological processes underlying creative insight, particularly insight experiences, researchers observed that small radical insights or radical restructuring (which, according to the Chinese, only occurs when solving brainteasers; see Luo and Knoblich, 2007) is different from the robustness of more radical forms of creativity (e.g., radical insight, restructuring or creativity) valued by Westerners (Jarman, 2014). Essentially, the cultural difference in preferred creativity processing patterns or creative processes is rooted in belief system differences between the East and the West. Specifically, in Eastern areas, creativity is characterized as an ongoing process involving "a circular movement in the sense of successive reconfiguration of an initial totality"; in contrast, in the West, creativity is considered "a linear movement towards a new point" and "an insightful production achieved by individuals engaged in a working process with a finite beginning and end" (Lubart, 1999, p. 341). There is a unique dialecticism called Chinese naïve dialecticism that is mainly derived from East Asian philosophical and religious traditions, such as Confucianism, Taoism, and Buddhism; as such, it deals with apparent contradictions by retaining the fundamental elements of opposing perspectives as a state of tension or conflict in which contradictions do not necessarily have to be resolved and opposites can coexist (Paletz and Peng, 2009; Shen et al., 2018b). Under such belief systems, almost all things that Westerners believe are radical are regarded by Chinese as incremental.

The four-stage approach of Wallas (1926), derived from Helmholtz's ideas on the thought process involved in creative ideas (Rhodes, 1961; Sadler-Smith, 2015), is a heuristic working model that illustrates key cognitive processes of creativity; it states that the creative process can be divided into the stages of preparation, incubation, illumination, and verification (Shen et al., 2018a). Although Wallas' four-stage model of creativity, the most widely cited framework for creativity in the West, has been used to describe the key processes underlying creativity in some contemporary Eastern studies on creative cognition, such as creative thinking and insight, cultural variation in the four stages of the creative process also exists; for example, relatively, the Western process model follows a cognitive problem-solving approach (a product-oriented definition of creativity; e.g., Dubina and Ramos, 2016), whereas the Eastern creative process highlights the emotional, personal, and intrapsychic aspects of creativity. Lubart (1999) cited two alternative models, contrasting Eastern processes of creativity with the Western four-stage model of creativity which were introduced in Maduro (1976) and Chu (1970). The four-stage model based on the Yoga Sutras (from Maduro, 1976) emphasizes self-will and the ceaseless effort, internal identification, personal insights, and social communication of personal realizations; these aspects are

individually considered similar to the four stages of Wallas' creative model (preparation, incubation, illumination, and verification) (Shen et al., 2018a). Different from the Western depiction of the creative process, mediation or mindfulness is also regarded as a key facilitator and sometimes as integral to the Eastern process of creativity. In addition, from a three-stage perspective, Chiu and Kwan (2010) assessed how culture impacts the creative process of authoring, editing, and accepting and revealed that existing knowledge of the established norms of one culture and cultural elements are not only reference points for determining the originality or uniqueness of new ideas but also serve as important sources of inspiration. Specifically, the cultural norms and elements in which an individual is located build perceptual and conceptual sets that may also result in mental impasses and impede the fluency of the problem-solving process. In contrast, exposure to a foreign culture could help expand the conceptual boundaries established in the individual's culture, providing inspiration to break free from his/her culture's limiting sets and initiating the creative reappropriation/synthesis of diverse ideas. One powerful avenue for creativity is the combination of disparate ideas from as diverse categories (a culture can be considered a category) as possible. Individuals exposed to different cultures have a great likelihood of generating novel or new things through combining different elements from the experienced cultures, which would be perceived as novel by individuals who have experience with only one or some of those cultures. Culture is believed to indirectly facilitate or impair the fluency of the creative process of idea authoring (i.e., authoring creative ideas) through moderating variables or intervening factors, such as the process of selecting, editing, and marketing new ideas (i.e., how ideas are edited and marketed) and the process of accepting or tolerating creative or novel ideas (e.g., the acceptability of novel ideas).

In summary, the role of culture in underwriting creative processes is primarily that culture both provides the fundamental materials and inputs that are processed in creativity and modifies the specific processes of creativity directly and/or indirectly. Cultural knowledge, such as awareness of cultural norms, simplifies, facilitates, or modifies some processes of creativity and provides reference points for these processes. In addition, culture may lead to different preferences in the selection and application of models of creative processes among different cultures and to different attributions of importance to the same creative process across cultures.

CULTURE UNDERWRITES THE ASSESSMENT OF CREATIVITY

Through the use of creativity measures and assessment tools, creativity can be studied qualitatively and/or quantitatively. Most previous studies have shown that Westerners scored higher than their Eastern counterparts on various creativity measures or tests (for details, see the Singaporean bestseller *Why Asians Are Less Creative than Westerners*; Ng, 2001), resulting in an enduring controversy regarding whether Eastern or Asian populations lack creativity or are inferior in terms of creativity. However, an increasing number of studies demonstrate that although Western students perform better on many measures of divergent thinking and creative performance, this superiority is not consistent across all types of creativity measures (e.g., convergent thinking measures) and does not always appear for all dimensions of creativity assessment (e.g., originality, fluency, and flexibility; see Xie and Paik, 2019). For instance, Saad et al. (2015) reported that more ideas (assessed by two divergent thinking problems) were generated by Canadians (representing individualist culture), while Taiwanese (representing a collectivist culture) showed greater originality in their generated ideas. In a review based on 29 published papers, Xie and Paik (2019) reported mixed findings regarding the effect of individualist vs. collectivist cultures (West vs. East) on creativity, as assessed with a variety of creativity measures.

Given the complexity of conceptualizing creativity and the variation in creative processes across contexts and cultures, it is difficult to believe that assessing creativity is a simple thing. This difficulty in assessing creativity mirrors the diversity of cultures or contexts in which creativity is rooted and is reflected in the variation in creativity measures (for instance, see Cropley, 2000) and approaches to assessing creativity. As early as 1989, Torrance and Goff (1989), in an increasingly substantial body of evidence, listed more than 255 creativity assessment tools; the current number of creativity measures may be substantially higher. Overall, the four P's of creativity – person, product, process and press – seems to be a more profitable framework for measuring creativity. Of the instruments developed to assess creativity, some attempt to evaluate the cognitive processes involved in creativity, such as creative insight; some are concerned with product-based creativity or creative performance/achievements; some focus on personal characteristics or personality traits; and others examine the impact of the environment (Feldhusen and Goh, 1995).

Culture is a key factor that influences cross-cultural assessment and determines individuals' or groups' creativity in diverse settings. In contrast with previous assertions that Western populations have higher scores on creativity tests compared with Asian or Chinese populations (Lubart, 1999; Kharkhurin and Samadpour Motalleebi, 2008), recent studies have revealed that individuals from tight cultures, as opposed to those from loose cultures, feel more confident and experience greater creative self-efficiency when they attempt creative tasks or measures within their own cultures (see Chua et al., 2015). More importantly, an increasingly substantial body of evidence reliably shows that Asian and Chinese populations exhibit greater creativity on some creative performance or thinking measures (e.g., Zhou et al., 1995; Xie and Paik, 2019). For example, by presenting six creative problems to Chinese and American college students, Chen et al. (2004) examined the potential influence of the folk tales (cultural compositions) that the participants had heard during their childhood on creative or insight-based problem-solving. They observed that more than 70% of Chinese

undergraduate students were able to solve the Statue Problem, which is procedurally similar to the folk tales they heard during childhood; in contrast, fewer than 10% of their American counterparts solved this problem because they had not heard the relevant folk tales. The opposite performance pattern was observed for solving the Cave Problem, which was similar to stories the American students had heard during childhood but bore no similarity to any tale the Chinese students had heard before. This effect might be considered a familiarity effect (cultural customs) rather than truly superior creativity. However, another longitudinal study by Zhou et al. (1995) provides stronger evidence; in that study, a three-wave (longitudinal) China-German comparison of children's creative performance (assessed individually using figural divergent thinking test, verbal alternative uses test, and technical problem-solving task) was conducted, and better figural creativity performance was found for Chinese elementary students than for their German counterparts (irrespective of grades), while the opposite trend was found for verbal convergent thinking performance. After reviewing 29 papers, Xie and Paik (2019) found no consistent findings regarding the relative strength of Westerners in creativity and innovation.

Findings of this type suggest that culturally appropriate measures are important for accurately assessing creativity and that culture may influence the precise assessment of creativity. The same issue also appears in the Torrance Tests of Creative Thinking (TTCT). For example, Lubart (1999) noted that the images and objects that are used to construct test questions or brief paper-and-pencil creativity tasks such as those on the TTCT may be culturally bound (e.g., Jellen and Urban, 1989; Rudowicz et al., 1995). Perhaps for these reasons, the seven-piece puzzle (tangram; e.g., Domino, 1980; Siew and Chong, 2014) and the Chinese ring puzzle (puzzle ring; see Hamel and Elshout, 2000) were developed by the Chinese to measure creativity and/or intelligence; in contrast, tasks involving Roman numerals (see Knoblich et al., 2001) and English letters (e.g., anagrams; see Bowden, 1997) were developed by Westerners to assess creativity in the West. Nevertheless, some issues persist due to the use of language or verbal forms to assess creativity across different cultures. A growing number of studies show that language learning can influence individuals' creativity and that language, as an integral aspect of culture, may influence the generation of creativity (expressed in verbal forms). In a study of Hong Kong children that used the Chinese version of the TTCT as a creativity measurement tool, Rudowicz et al. (1995) found that "stimuli, in the form of pictures, presented in the verbal forms seem to relate to stories that are more familiar to American and European children than to Asian children" (p. 424; see also Lubart, 1999). In addition, most creativity measures are developed in the West, especially in the United States; thus, Westerners may be more familiar with them than Easterners are, which would account for the better performance among Westerners. Simply speaking, familiarity with the materials, especially verbal expressions or symbols, that are used to construct test questions and culture-related misinterpretations of the task (which result from the existence of different norms or conventions) will both influence the accuracy of creativity assessments.

In addition to objective measures of creativity, many techniques are relative (sample- or population-based) measures of creativity, including divergent thinking tests and consensual assessment techniques. As an example, in the evaluation of originality or uniqueness in divergent thinking tests, such as the consensual assessment method, cultural differences in widespread knowledge and social norms mean that a response that is considered highly original or unique in one culture will not necessarily be considered highly unique in other cultures or contexts. As mentioned in Jones and Shea (1974), "statistical frequency-based measures of originality that lump together the responses of different cultural groups tend to inflate the originality score of responses common in one group and to diffuse culture-specific originality" (Lubart, 1999, p. 347). Additionally, the cultural background of the raters influences their ratings, a finding that has been better illustrated for differences in creativity or originality according to ethnicity (e.g., Kaufman et al., 2004; Kaufman, 2006) and gender (Gralewski and Karwowski, 2013), in which individuals of different genders or ethnicities could be considered members of different (sub)cultures.

The influence of culture on the assessment of creativity is typically manifested in two points below. On the one hand, culture exerts great impacts on the construction of creativity measurement instruments due to the cultural characteristics of the materials constructed as test questions or items. On the other hand, culture influences the expression or output of individuals' creative ideas due to cultural familiarity or performance bias resulting from the application of culturally inappropriate creativity measures. Additionally, culture plays important roles in the subjective or relative ratings of subjective creativity and in some dimensions of creativity tests, especially population- or sample-based originality ratings.

CONCLUDING REMARKS

Creativity is complex and culture-sensitive. In this review, cross-cultural differences in conceptualizing, processing, and measuring creativity were discussed and summarized by contrasting Eastern and Western cultures. Our research provides substantial evidence supporting the profound role of culture in defining and assessing creativity and underwriting creative processes. Consistent with our finding, Lubart (1999) argued that culture might influence creativity, and this influence might manifest as people from different contexts or cultures having distinct implicit and/or explicit concepts of creativity and people from various contexts or cultures adopting or preferring to use different psychological processes, such as tingeing, in their creative endeavors. Because the definition and assessment of creativity are highly dependent on culture, most of the observed differences in actual creativity could be the result of cultural differences. Future studies should take greater efforts to carefully examine the influence of

culture on the "consensus components or operations" of creativity or the standard processes or criteria of creativity. In addition to the fact that culture, including language and environment, may nurture creativity, culture may also exert a robust role in the assessment of creativity. Future studies could empirically investigate the roles of culture, including but not limited to multicultural experiences and language learning, that have emerged in the past 10 years in underwriting the conceptualization, processing, and assessment of creativity. Additionally, other studies could take greater efforts to demystify the cross-cultural neural underpinning of creativity using high-density brain potentials or neuroimaging measures, given that two recent studies have started to explore the neural correlates of cross-cultural differences in creativity (Ivancovsky et al., 2018, 2019).

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

The work is approved by the Philosophy and Social Science fund of Jiangsu Higher Education Institutions (2017SJB0649), the Natural Science Foundation of Jiangsu Province (BK20181029), the Natural Science Foundation of the Higher Education Institutions of Jiangsu Province (17KJB190002), and the introduced talents' start-up funds of Nanjing Normal University of Special Education.

REFERENCES

Adair, W. L., and Xiong, T. X. (2018). How Chinese and Caucasian Canadians conceptualize creativity: the mediating role of uncertainty avoidance. *J. Cross-Cult. Psychol.* 49, 223–238. doi: 10.1177/0022022117713153

Bowden, E. M. (1997). The effect of reportable and unreportable hints on anagram solution and the aha! Experience. *Conscious. Cogn.* 6, 545–573. doi: 10.1006/ccog.1997.0325

Chen, Z., Mo, L., and Honomichl, R. (2004). Having the memory of an elephant: long-term retrieval and the use of analogues in problem solving. *J. Exp. Psychol. Gen.* 133, 415–433. doi: 10.1037/0096-3445.133.3.415

Chiu, C. Y., and Kwan, L. Y. (2010). Culture and creativity: a process model. *Manag. Organ. Rev.* 6, 447–461. doi: 10.1111/j.1740-8784.2010.00194.x

Chu, Y. K. (1970). "Oriental views on creativity" in *Psi factors in creativity*. eds. A. Angoff and B. Shapiro (New York: Parapsychology Foundation). 35–50.

Chua, R. Y. (2018). Innovating at cultural crossroads: how multicultural social networks promote idea flow and creativity. *J. Manag.* 44, 1119–1146. doi: 10.1177/0149206315601183

Chua, R. Y., Roth, Y., and Lemoine, J. F. (2015). The impact of culture on creativity: how cultural tightness and cultural distance affect global innovation crowdsourcing work. *Adm. Sci. Q.* 60, 189–227. doi: 10.1177/0001839214563595

Cropley, A. J. (2000). Defining and measuring creativity: are creativity tests worth using? *Roeper Rev.* 23, 72–79. doi: 10.1080/02783190009554069

Domino, G. (1980). Chinese tangrams as a technique to assess creativity. *J. Creat. Behav.* 14, 204–213. doi: 10.1002/j.2162-6057.1980.tb00244.x

Dubina, I. N., and Ramos, S. J. (2016). "Creativity through a cultural lens: the dichotomy of "the west" and "the east"" in *Creativity, innovation, and entrepreneurship across cultures, innovation, technology, and knowledge management*. eds. I. N. Dubina, and E. G. Carayannis (New York: Springer), 29–34.

Feldhusen, J. F., and Goh, B. E. (1995). Assessing and accessing creativity: an integrative review of theory, research, and development. *Creat. Res. J.* 8, 231–247. doi: 10.1207/s15326934crj0803_3

Glăveanu, V. P. (2010). Principles for a cultural psychology of creativity. *Cult. Psychol.* 16, 147–163. doi: 10.1177/1354067X10361394

Gralewski, J., and Karwowski, M. (2013). Polite girls and creative boys? Students' gender moderates accuracy of teachers' ratings of creativity. *J. Creat. Behav.* 47, 290–304. doi: 10.1002/jocb.36

Hamel, R., and Elshout, J. J. (2000). On the development of knowledge during problem solving. *Eur. J. Cogn. Psychol.* 12, 289–322. doi: 10.1080/09541440050114534

House, R. J., Hanges, P. J., Javidan, M., Dorfman, P. W., Gupta, V., and GLOBE associates (2004). Leadership, Culture and Organizations: The GLOBE Study of 62 Nations. (Thousand Oaks, CA: Sage).

Huang, L. J. Q., Liu, H. Y., An, L., Liu, Y. N., Zhang, S., and Jin, C. Y. (2018). Multicultural experience fosters creativity. *Adv. Psychol. Sci.* 26, 1511–1520. doi: 10.3724/SP.J.1042.2018.01511

Inglehart, R., Basanez, M., and Moreno, A. (1998). Human Values and Beliefs: A Cross-cultural Sourcebook. (Ann Arbor, MI: University of Michigan Press).

Ivancovsky, T., Kleinmintz, O., Lee, J., Kurman, J., and Shamay-Tsoory, S. G. (2018). The neural underpinnings of cross-cultural differences in creativity. *Hum. Brain Mapp.* 39, 4493–4508. doi: 10.1002/hbm.24288

Ivancovsky, T., Kurman, J., Morio, H., and Shamay-Tsoory, S. (2019). Transcranial direct current stimulation (tDCS) targeting the left inferior frontal gyrus: effects on creativity across cultures. *Soc. Neurosci.* 14, 277–285. doi: 10.1080/17470919.2018.1464505

Jarman, M. S. (2014). Quantifying the qualitative: measuring the insight experience. *Creat. Res. J.* 26, 276–288. doi: 10.1080/10400419.2014.929405

Jellen, H. G., and Urban, K. K. (1989). Assessing creative potential world-wide: the first cross-cultural application of the test for creative thinking—drawing production (TCT-DP). *Gift. Educ. Int.* 6, 78–86.

Jones, J., and Shea, J. (1974). Some problems in the comparison of divergent thinking scores across cultures. *Aust. Psychol.* 9, 47–51. doi: 10.1080/00050067408256524

Kaufman, J. C. (2006). Self-reported differences in creativity by ethnicity and gender. *Appl. Cognit. Psychol.* 20, 1065–1082. doi: 10.1002/acp.1255

Kaufman, J. C., Baer, J., and Gentile, C. A. (2004). Differences in gender and ethnicity as measured by ratings of three writing tasks. *J. Creat. Behav.* 38, 56–69. doi: 10.1002/j.2162-6057.2004.tb01231.x

Kaufman, J. C., and Lan, L. (2012). East-west cultural bias and creativity: we are alike and we are different. *Gifted Talented Int.* 27, 115–118. doi: 10.1080/15332276.2012.11673616

Kharkhurin, A. V., and Samadpour Motalleebi, S. N. (2008). The impact of culture on the creative potential of American, Russian, and Iranian college students. *Creat. Res. J.* 20, 404–411. doi: 10.1080/10400410802391835

Knoblich, G., Ohlsson, S., and Raney, G. E. (2001). An eye movement study of insight problem solving. *Mem. Cogn.* 29, 1000–1009. doi: 10.3758/BF03195762

Lee, H., Kim, J., Ryu, Y., and Song, S. (2015). Do people use their implicit theories of creativity as general theories? *J. Creat. Behav.* 49, 77–93. doi: 10.1002/jocb.55

Leung, A. K. Y., and Chiu, C. Y. (2010). Multicultural experience, idea receptiveness, and creativity. *J. Cross-Cult. Psychol.* 41, 723–741. doi: 10.1177/0022022110361707

Leung, A. K. Y., Maddux, W. W., Galinsky, A. D., and Chiu, C. Y. (2008). Multicultural experience enhances creativity: the when and how. *Am. Psychol.* 63, 169–181. doi: 10.1037/0003-066X.63.3.169

Lubart, T. I. (1999). "Creativity across cultures" in *Creativity research handbook*. ed. R. J. Sternberg (Cambridge, England: Cambridge University Press), 339–350.

Luescher, R., Barthelmess, P. Y. Z., Kim, S. Y., Richter, U. H., and Mittag, M. (2019). Conceptualizing creativity: general and cultural biases in Gough's creative personality scale. *J. Creat. Behav.* 53, 30–43. doi: 10.1002/jocb.160

Luo, J., and Knoblich, G. (2007). Studying insight problem solving with neuroscientific methods. *Methods* 42, 77–86. doi: 10.1016/j.ymeth.2006.12.005

Maddux, W. W., and Galinsky, A. D. (2009). Cultural borders and mental barriers: the relationship between living abroad and creativity. *J. Pers. Soc. Psychol.* 96, 1047–1057. doi: 10.1037/a0014861

Maduro, R. (1976). *Artistic creativity in a Brahmin painter community*. (Berkeley, CA:Research Monograph 14, Center for South and Southeast Asia Studies).

Martins, E. C., and Terblanche, F. (2003). Building organisational culture that stimulates creativity and innovation. *Eur. J. Innov. Manag.* 6, 64–74. doi: 10.1108/14601060310456337

Ng, A. K. (2001). *Why Asians are less creative than westerners.* (Singapore: Prentice Hall).

Nijstad, B. A., De Dreu, C. K., Rietzschel, E. F., and Baas, M. (2010). The dual pathway to creativity model: creative ideation as a function of flexibility and persistence. *Eur. Rev. Soc. Psychol.* 21, 34–77. doi: 10.1080/10463281003765323

Niu, W., and Sternberg, R. J. (2006). The philosophical roots of Western and Eastern conceptions of creativity. *J. Theor. Philos. Psychol.* 26, 18–38. doi: 10.1037/h0091265

Paletz, S. B., and Peng, K. (2008). Implicit theories of creativity across cultures: novelty and appropriateness in two product domains. *J. Cross-Cult. Psychol.* 39, 286–302. doi: 10.1177/0022022108315112

Paletz, S. B., and Peng, K. (2009). Problem finding and contradiction: examining the relationship between naive dialectical thinking, ethnicity, and creativity. *Creat. Res. J.* 21, 139–151. doi: 10.1080/10400410902858683

Plucker, J. A., Beghetto, R. A., and Dow, G. T. (2004). Why isn't creativity more important to educational psychologists? Potentials, pitfalls, and future directions in creativity research. *Educ. Psychol.* 39, 83–96. doi: 10.1207/s15326985ep3902_1

Rhodes, M. (1961). An analysis of creativity. *Phi Delta Kappan* 42, 305–310.

Rudowicz, E. (2003). Creativity and culture: a two way interaction. *Scand. J. Educ. Res.* 47, 273–290. doi: 10.1080/00313830308602

Rudowicz, E., Lok, D., and Kitto, J. (1995). Use of the Torrance tests of creative thinking in an exploratory study of creativity in Hong Kong primary school children: a cross-cultural comparison. *Int. J. Psychol.* 30, 417–430. doi: 10.1080/00207599508246577

Rudowicz, E., and Yue, X. D. (2000). Concepts of creativity: similarities and differences among mainland, Hong Kong and Taiwanese Chinese. *J. Creat. Behav.* 34, 175–192. doi: 10.1002/j.2162-6057.2000.tb01210.x

Rudowicz, E., and Yue, X. D. (2002). Compatibility of Chinese and creative personalities. *Creat. Res. J.* 14, 387–394. doi: 10.1207/S15326934CRJ1434_9

Runco, M. A. (2014). "Big C, little c" creativity as a false dichotomy: reality is not categorical. *Creat. Res. J.* 26, 131–132. doi: 10.1080/10400419.2014.873676

Runco, M. A., and Bahleda, M. D. (1987). Birth-order and divergent thinking. *J. Genet. Psychol.* 148, 119–125. doi: 10.1080/00221325.1987.9914542

Runco, M. A., and Jaeger, G. J. (2012). The standard definition of creativity. *Creat. Res. J.* 24, 92–96. doi: 10.1080/10400419.2012.650092

Saad, G., Cleveland, M., and Ho, L. (2015). Individualism–collectivism and the quantity versus quality dimensions of individual and group creative performance. *J. Bus. Res.* 68, 578–586. doi: 10.1016/j.jbusres.2014.09.004

Sadler-Smith, E. (2015). Wallas' four-stage model of the creative process: more than meets the eye? *Creat. Res. J.* 27, 342–352. doi: 10.1080/10400419.2015.1087277

Shen, W., Tong, Y., Yuan, Y., Zhan, H., Liu, C., Luo, J., et al. (2018a). Feeling the insight: uncovering somatic markers of the "aha" experience. *Appl. Psychophysiol. Biofeedback* 43, 13–21. doi: 10.1007/s10484-017-9381-1

Shen, W. B., and Yuan, Y. (2015). Sociocultural basis underlying creative thinking. *Adv. Psychol. Sci.* 23, 1169–1180. doi: 10.3724/SP.J.1042.2015.01169

Shen, W., Yuan, Y., Zhao, Y., Zhang, X., Liu, C., Luo, J., et al. (2018b). Defining insight: a study examining implicit theories of insight experience. *Psychol. Aesthet. Creat. Arts* 12, 317–327. doi: 10.1037/aca0000138

Siew, N. M., and Chong, C. L. (2014). Fostering students' creativity through Van Hiele's 5 phase-based tangram activities. *J. Educ. Learn.* 3, 66–80. doi: 10.5539/jel.v3n2p66

Sternberg, R. J. (1985). Implicit theories of intelligence, creativity, and wisdom. *J. Pers. Soc. Psychol.* 49, 607–627. doi: 10.1037/0022-3514.49.3.607

Torrance, E. P., and Goff, K. (1989). A quiet revolution. *J. Creat. Behav.* 23, 136–145. doi: 10.1002/j.2162-6057.1989.tb00683.x

Treffinger, D. J. (1996). *Creativity, creative thinking, and critical thinking: In search of definitions.* (Sarasota, FL: Center for Creative Learning).

Wallas, G. (1926). *The art of thought.* (London: Watts).

Weiner, R. P. (2000). *Creativity and beyond: Cultures, values, and change.* (Albany, NY: State University of New York Press).

Westwood, R., and Low, D. R. (2003). The multicultural muse: culture, creativity and innovation. *Int. J. Cross-cult. Manag.* 3, 235–259. doi: 10.1177/14705958030032006

Williams, W. M., and Yang, L. T. (1999). "Organizational creativity" in *The Handbook of Creativity*, ed. R. J. Sternberg (Cambridge: Cambridge University Press), 373.

Xie, G., and Paik, Y. (2019). Cultural differences in creativity and innovation: are Asian employees truly less creative than western employees? *Asia Pac. Bus. Rev.* 25, 123–147. doi: 10.1080/13602381.2018.1535380

Zhou, L., Zha, Z. X., and Shi, J. N. (1995). A comparison study on Chinese and Germany grade 5 and 7 students' figural creative thinking performance. *Psychol. Dev. Educ.* 11, 19–23.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 04 July 2019
doi: 10.3389/fpsyg.2019.01459

Exposure to Ideas, Evaluation Apprehension, and Incubation Intervals in Collaborative Idea Generation

Xiang Zhou[1,2], Hong-Kun Zhai[1], Bibi Delidabieke[1], Hui Zeng[2,3], Yu-Xin Cui[1] and Xue Cao[1]*

[1]Department of Social Psychology, Nankai University, Tianjin, China, [2]Department of International Business, School of Economics, Nankai University, Tianjin, China, [3]Collaborative Innovation Center for China Economy, Tianjin, China

This study focused on the social factors and cognitive processes that influence collaborative idea generation, using the research paradigm of group idea generation, evaluation apprehension, and incubation. Specifically, it aimed to explore the impact of exposure to others' ideas, evaluation apprehension, and incubation intervals on collaborative idea generation through three experiments. The results showed that in the process of generating ideas in a group, exposure to others' ideas and evaluation apprehension can lead to productivity deficits in the number and categories of ideas, without affecting the novelty of ideas. Further, exposure to others' ideas and evaluation apprehension had an interaction effect on the number of ideas. As compared with the situation without exposure to others' idea, in that with exposure to others' idea, evaluation apprehension had a weaker impact on the productivity of the number of ideas. Furthermore, incubation intervals were beneficial in reducing the negative effect of exposure to others' ideas and in improving collaborative idea generation productivity.

Keywords: exposure to ideas, evaluation apprehension, incubation intervals, idea generation, productivity deficits, group creativity

OPEN ACCESS

Edited by:
Linden John Ball, University of Central Lancashire, United Kingdom

Reviewed by:
Ut Na Sio, The Education University of Hong Kong, Hong Kong
Bo Thomas Christensen, Copenhagen Business School, Denmark

***Correspondence:**
Hui Zeng
zenghui@nankai.edu.cn

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *10 October 2018*
Accepted: *07 June 2019*
Published: *04 July 2019*

Citation:
Zhou X, Zhai H-K, Delidabieke B, Zeng H, Cui Y-X and Cao X (2019) Exposure to Ideas, Evaluation Apprehension, and Incubation Intervals in Collaborative Idea Generation. Front. Psychol. 10:1459. doi: 10.3389/fpsyg.2019.01459

INTRODUCTION

Collaborative idea generation is a common phenomenon in organizations (Markman, 2016). According to this concept, when the group is regarded as a unit, members of the group will effectively gather the innovative resources and information they have mastered, and achieve deep collaboration and innovation within and between groups, through extensive interaction between members and resources (Sawyer and Dezutter, 2009; Hennessey and Amabile, 2010; Chen and Yang, 2012). The contemporary group creativity theories focus on the cognitive, social, and motivational factors that influence group performance on creativity. High-level group creativity requires an effective interactive process (Alper et al., 2007), optimal group composition (Zhang et al., 2016), positive group experience, and convenient backgrounds that support innovation and psychological security.

As the initial phase in group creativity, the quality and quantity of idea generation have a significant impact on later phases such as the selection and execution phases. Several studies have focused on the cognitive and social factors influencing performance on collaborative idea generation. In addition, researchers have also focused on developing strategies to promote

productivity in idea generation. For instance, researchers have found that computer-supported electronic brainstorming and brain-writing can eliminate the negative effects of social inhibition on collaborative idea generation performance, alternating between face-to-face and electronic conference is an ideal choice for promoting collaborative idea generation (Paulus and Kenworthy, 2017). Korde and Paulus (2017) proposed that the hybrid brainstorming of individual and group innovation is an effective model for facilitating collaborative idea generation. After comparing the performance of interactive and nominal teams in collaborative learning groups using a task involving the generation of innovative ideas, Zhou et al. (2018) recommended promoting collective intelligence through strategic choices and rule setting in group activities, such as in collaborative learning.

The present study focused on the social factors and cognitive processes that influence collaborative idea generation, using the research paradigm of group idea generation, inducing evaluation apprehension and delayed incubation. It aimed to explore the impact of exposure to ideas, evaluation apprehension, and incubation intervals on group creativity through a series of experiments.

Productivity Deficits in a Collaborative Idea Generation Task

Reporting that, when groups work together on idea generation tasks, they are less effective at creating ideas as compared to individuals, McGrath (1984) stated that "Individuals who work separately generate more creative and more ideas than working in groups, even after deleting the redundant part of their ideas." Paulus et al. (1995) discovered that there is a "productivity deficit" in collaborative idea generation, and follow-up studies further explored the causes of such deficits.

The causes for productivity deficits may be rooted in the cognitive mechanism involved, including production blocking (Diehl and Stroebe, 1987), excessive demand for cognitive resources and working memory (Nijstad et al., 2003), fixation (Smith and Blankenship, 1989, 1991), and effects of part-list cueing inhibition and output interference (Rundus, 1973; Raaijmakers and Shiffrin, 1981). Diehl and Stroebe (1987, 1991) found evidence of production blocking in brainstorming. The main cause of production blocking is that multiple group members could not speak at the same time. Specifically, in their experiment, the "non-blocking" group allowed its members to speak at any time, and they reported that the nominal and "non-blocking" group generated more ideas than did the exposed group, and there was no difference between the nominal and "non-blocking" groups. Paulus and Yang (2000) found that the use of improved brainstorming, which allows group members to process fewer ideas each time, can increase productivity. These findings suggest that cognitive overload or long delays between idea generation and convergence can reduce productivity when a group is in the process of generating ideas (Nagasundaram and Dennis, 1993; Hinsz et al., 1997; Nijstad et al., 2003).

Evaluation of ideas and concerns about social activities may also lead to a decline in group performance. The social comparison process may lead individuals in the group to develop low-performance standards, leading to poor performance (Paulus et al., 2002). Further, the social comparison would cause social loafing. Since the responsibility in the process of completing group tasks is decentralized, if a group member feels that his/her contribution is not noticeable and that other group members are performing their duties, this member may be prone to slackening, and thus, he/she would make fewer contributions. Besides, in the process of collaborative problem-solving or collaborative ideation, individuals often face evaluation apprehension (Diehl and Stroebe, 1987) and exposure to other group members' ideas (Kohn and Smith, 2010), which may also affect the quality of ideation.

Evaluation Apprehension and Exposure to Ideas

Evaluation apprehension occurs when "the fear of negative evaluations from other group members or external members prevents participants who are working in groups from presenting their more original ideas" (Diehl and Stroebe, 1987). That is, because people may worry about negative evaluations from group members, they will generate fewer ideas when working together. Evaluation apprehension has negative effects on group idea generation. Collaros and Anderson (1969) set up three experimental conditions. In the high-evaluation apprehension group, four group members were informed separately that the other three members were experts; in the low-evaluation apprehension group, four group members were informed separately that one member of their group was an expert; and the members in the control group did not receive any information about their group members. The results revealed that the control group members produced the largest number of ideas, and the group which was informed that all other group members were experts produced the fewest. A post-experimental survey showed that the more a person thinks that he/she is surrounded by experts, the more threats he/she perceives, which in turn prevents him/her from providing more ideas. Camacho and Paulus (1995) examined the presence of individual differences in evaluation apprehension. Using the Interactive Anxiety Scale, they divided participants into low and high anxiety groups. The group type (real and nominal groups) interacted with the degree of interaction anxiety (low and high). Additionally, they found that, in real groups, low interaction anxiety level significantly increased the number of ideas generated. In addition, high-anxiety participants expressed hesitation in expressing their own ideas during the idea generation task. Thus, it was concluded that evaluation apprehension can lead to group productivity deficits and that it is better to choose a group of members with low interaction anxiety to avoid decrease in productivity.

Being exposed to other group members' ideas also influences the collaborative idea generation. However, researchers hold different opinions about whether it has negative or positive effects. Fink et al. (2012) investigated the effects of exposure to others' ideas on the originality of generated ideas using functional magnetic resonance imaging (fMRI). Their results suggested that being exposed to common or moderately creative ideas was effective in improving creativity. In contrast, Smith and Linsey (2011) purported that seeing or hearing other members' ideas in a group would prevent individuals

from contributing their own ideas. Though being exposed to others' ideas would inspire individuals, there is also a disadvantage. Specifically, after hearing other group members' ideas, individuals may tend to focus on or limit their ideas to similar categories. Consistent with Smith's opinions, the present study assumed that being exposed to others' ideas may reduce collaborative idea generation productivity.

Though many pieces of research have examined the impact of evaluation apprehension and exposure to ideas on collaborative creativity, fewer studies have focused on the interaction between these variables. The theory of social impact (Latané, 1981) states that the strength of some social powers, such as evaluation, is negatively relevant to the number of individuals addressed as the target of the social force (Henchy and Glass, 1969). Therefore, we could suppose that, as compared with participants who cannot see other group members' ideas, those who can see others' ideas will be clearly aware of the existence of others, leading to a reduction in the level of evaluation apprehension. McGrath (2015) found that compared with individuals, pairwise group structuring significantly reduced evaluation apprehension within idea generation groups. Given the above evidences, exposure to others' ideas could reduce the negative impact of evaluation apprehension on group idea generation.

Reduce Productivity Deficits: Incubation Effects

Incubation effects is an important branch of creativity research. The discussion on incubation effects stems from an interesting phenomenon. When facing an extremely difficult problem that we cannot solve immediately, we tend to put it on the shelf for a moment. Amazingly, we can solve the problem when we return to it after a break. The concept of incubation emerged in the 1920s, as a method or procedure of leaving the problem aside to solve it.

One of the most frequently and widely used paradigms in incubation studies is the delayed incubation paradigm (Gilhooly et al., 2012). In this paradigm, the experimental group is asked to perform "the aiming task (Stage 1)—incubation phase (interference task or relaxation)—the aiming task (Stage 2)," while the control group solves the problem in a single continuous phase. Paulus et al. (2006) set three experimental conditions to examine the effects of rest on individual brain-writing. A group of participants engaged in a 15-min idea generation task, a 6-min relaxation, and a 15-min idea generation task. Another group of participants engaged in a 10-min idea generation task, a 3-min relaxation, a 10-min idea generation task, a 3-min relaxation, and a 10-min idea generation task. Participants in the no-rest condition engaged in a 36-min idea generation task. On comparing group performances in the last 10 min in three conditions, researchers found that participants in the rest conditions produced more ideas than did those in the no-rest condition. However, there was no difference between the two experimental groups with rest intervals. In addition, Lu et al. (2017) found that in creativity tasks that require divergent or convergent thinking, constant interference task could increase creativity by reducing cognitive fixation. Though adopting the same paradigm, previous studies focused on various aspects of the incubation period, such as the target problems, the types of the interpolated tasks and the span of the incubation period (Sio and Ormerod, 2009).

Smith and Blankenship (1991) proposed the selective forgetting hypothesis to account for incubation effects, suggesting that an incubation period provides time for forgetting the thoughts that are not helpful or even detrimental to the problem-solving, and in turn, problem solvers will be less sensitive to these irrelevant concepts. Thus, they can have a fresh perspective toward the current problem and generate new solutions on it (Segal, 2004). As a result, if an individual is stuck on a fixed path while solving a specific problem and cannot generate more ideas, incubation intervals may help improve the situation, reduce productivity deficits, and facilitate problem-solving (Penney et al., 2011).

This study intended to investigate the independent and interaction impacts of evaluation apprehension and exposure to ideas on collaborative idea generation. Evaluation apprehension and exposure to other people's ideas are both important factors that affect creativity. Both stem from the other people's perceptions and are related to the dual processing mechanism of emotion and cognition. Subsequently, we attempted to identify out whether incubation intervals can increase productivity in collaborative idea generation, and if so, how different incubation intervals affect collaborative idea generation. In addition, dyads are sufficiently small groups to provide cognitive stimulation (such as exposure to others' ideas) while not raising the fear of evaluation from group members to impairing level (Brown et al., 1998; Nijstad and Stroebe, 2006). Therefore, all the groups in this study were in the form of dyads in order to exclude the irrelevant variables.

EXPERIMENT 1

Experiment 1 explored the impact of evaluation apprehension and exposure to others' perspectives on creative idea output in groups. We aimed to examine the main effect of evaluation apprehension and exposure to others' ideas, and accordingly proposed the following hypotheses:

> Hypothesis 1: Compared with the groups in the exposed condition, those in the non-exposed condition would perform better on a collaborative idea generation task.

> Hypothesis 2: Compared to the condition with evaluation apprehension, groups would perform better on a collaborative idea generation task in the condition without evaluation apprehension.

In addition, we purported Hypothesis 3 based on the social impact theory mentioned above.

> Hypothesis 3: There is an interactive effect between evaluation apprehension and exposure to group members' ideas on group idea generation task performance, and this exposure will weaken the negative impact of evaluation apprehensions.

Method

Participants

We recruited participants on the communication platform of universities, 178 college students were recruited for this experiment. A total of 89 men and 89 women are recruited and formed 89 groups, each group had one man and one woman. Participants' age ranged from 19 to 23 years. All the groups were divided into one of four experimental conditions randomly. Excluding participants whose answer was blank or did not fit the subject, valid data were collected from 80 dyads. None of the participants had participated in any similar experiment in the past, and they were paid after the present experiment.

Design and Procedure

The experiment employed a 2 (exposure to ideas: exposed vs. non-exposed) × 2 (evaluation apprehension: present vs. absent) design. Participants were randomly assigned to one of the following four experimental conditions: exposed-evaluation apprehension-present group, exposed-evaluation apprehension-absent group, non-exposed-evaluation apprehension-present group, non-exposed-evaluation apprehension-absent group.

In the exposed group, participant dyads were instructed to complete an idea generation task by submitting ideas together to experimenters *via* WeChat. Participants within dyads could see group member's ideas but they were not allowed to communicate with each other. In the non-exposed group, each participant completed the idea generation task by submitting ideas individually to experimenters *via* WeChat. They could not see others' opinions or communicate with them. Before the experiment, the exposed and non-exposed groups were informed that they would generate ideas with another person in a dyad.

In the evaluation apprehension condition, participants were informed that other participants would evaluate their ideas at the end of the experiment. In the evaluation apprehension absent condition, they were informed that the quality of their ideas would not be judged.

Before the commencement of the experiment, participants received explanations to introduce the experiment and the task (a topic of idea generation) using the following text: "Please list methods that can improve the university you study in." In the next 20 min, participants sent their ideas to the experimenter *via* WeChat. They did not receive communication or feedback from the experimenter during the task. In the exposed group, participants could see the ideas provided by their group members.

Task and Measure

The topic of idea generation was "Please list methods that can improve the university you study in." Similar topics have been used in other studies on creativity (Marsh et al., 1997; Paulus et al., 2006; Putman and Paulus, 2009; Baruah and Paulus, 2011). WeChat was used as the tool for experiment operation and idea submission.

As for measures, based on the encoding indexes proposed by Kohn and Smith (2010), experimenters drew a revised set of encoding indexes that included 30 categories. For instance, "course" may include "more diverse curriculum settings"; "diet" may include "regular check-ups in the school cafeteria." Two scorers were invited to divide the 2,159 items generated by 160 participants into 30 categories (see **Appendix**). Scorers were trained before the rating phase to ensure that they understood the meaning of and criteria for each category adequately. In the rare condition that participants reported more than two ideas for one item, experimenters would divide and classify this item appropriately (e.g., "train teachers" and "install an air conditioner in the dormitory" would be respectively be encoded to "teacher" and "dormitory" categories). Because the coding results are nominal variables, we introduced category agreement (CA) and intercoder reliability coefficient to calculate the inter-rater reliability. CA refers to the proportion of the consistent ideas. And the intercoder reliability coefficient (R) = (n − 1) × CA/(1 + n × CA). In experiment 1, CA = 0.68, R = 0.81. When the two coders were divided on the classification, they were asked to discuss the issue until reaching an agreement. Repeated or unserious ideas were excluded from the data analysis.

When creating the non-exposed group, experimenters randomly assigned data from two participants in the nominal group to one set and arranged these ideas chronologically. The novelty level of ideas was determined using the following formula: novelty score of Category X = (total number of ideas/number of ideas falling into Category X)/(total number of ideas/100) (Kohn and Smith, 2010). As a result, the fewer the number of ideas in a category, the higher was its novelty score.

Results and Discussion

We conducted a two-way analysis of variance (ANOVA) on the number, category, and novelty of ideas generated by participants from different evaluation apprehension and exposed conditions.

When it came to the number of ideas, there was a main effect of evaluation apprehension [$F(1, 76) = 55.876$, $p < 0.001$, $\eta^2 = 0.424$, $1 - \beta = 0.98$], with the evaluation apprehension-absent group ($M = 32.95$, SD = 8.17) producing more ideas than evaluation apprehension-present group ($M = 21.03$, SD = 6.76). The main effect of idea exposure was not significant [$F(1, 76) = 1.774$, $p > 0.1$]. There was a significant interaction between evaluation apprehension and idea exposure [$F(1, 76) = 6.525$, $p = 0.013$, $\eta^2 = 0.079$, $1 - \beta = 0.47$]. The simple effect analysis revealed that non-exposed groups ($M = 36.05$, SD = 4.54) generated more ideas than exposed groups ($M = 29.85$, SD = 9.68) under the evaluation apprehension-absent condition. But under the evaluation apprehension-present condition, the number of ideas generated by non-exposed groups ($M = 20.05$, SD = 4.16) and exposed groups ($M = 22.00$, SD = 8.49) were almost the same (see **Figure 1**).

Regarding idea categories, the main effect of evaluation apprehension was significant [$F(1, 76) = 30.886$, $p < 0.001$, $\eta^2 = 0.289$, $1 - \beta = 0.94$], with the evaluation apprehension-absent group ($M = 15.05$, SD = 3.20) generating more categories

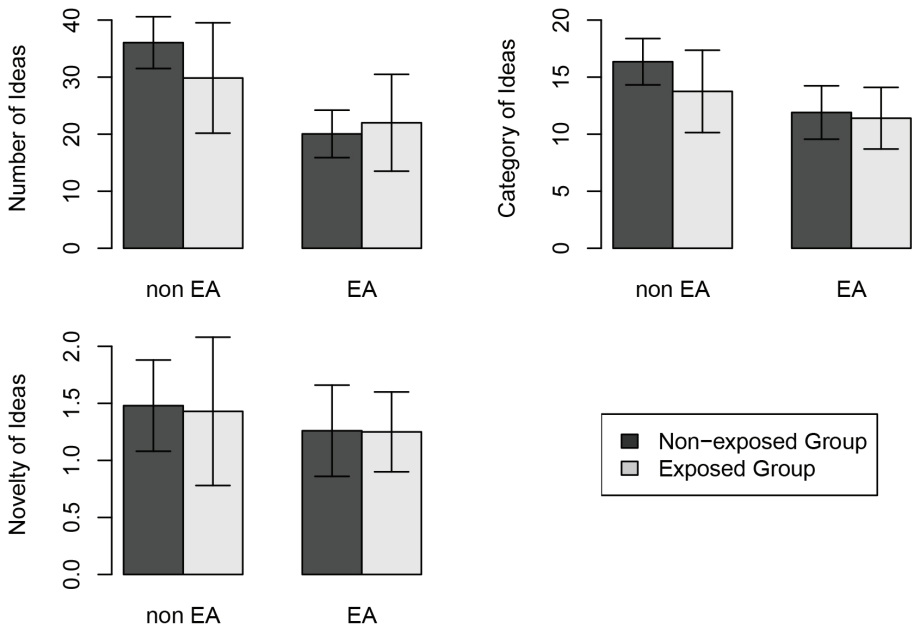

FIGURE 1 | Group idea generation under four conditions (the error bars refer to standard error).

of ideas than evaluation apprehension-present group (M = 11.65, SD = 2.53). The main effect of exposure to other's ideas on categories was also significant [$F(1, 76) = 6.419$, $p = 0.013$, $\eta^2 = 0.078$, $1 - \beta = 0.47$], with the non-exposed group (M = 14.13, SD = 3.12) generating more categories of ideas than exposed group (M = 12.58, SD = 3.37). Whereas, the interaction between evaluation apprehension and exposure to ideas was not significant [$F(1, 76) = 2.946$, $p > 0.05$].

As for the novelty of ideas, both the main effects of evaluation apprehension [$F(1, 76) = 3.566$, $p > 0.05$] and exposure to ideas [$F(1, 76) = 0.091$, $p > 0.1$] and their interaction effect [$F(1, 76) = 0.035$, $p > 0.1$] were not significant.

As shown above, exposure to others' ideas significantly weakened the idea category diversity, which partly supported Hypothesis 1. Possibly, participants were influenced by the ideas expressed by other group members, which may have led to the occurrence of fixation. Specifically, participants may have paid too much attention to others' ideas, which would have in turn limited their views to a small number of categories, leading to the deficit in their productivity in terms of categories of ideas generated during collaborative idea generation.

It was also observed that participants under evaluation apprehension condition generated fewer ideas and explored fewer categories as compared to participants under evaluation apprehension absent condition, suggesting that participants' expression of ideas was hindered by the presence of evaluation apprehension. In the evaluation apprehension condition, participants tended to adopt a more conservative strategy for idea generation. That is, they may have avoided broadening the categories of ideas or putting forward more original ideas to avoid receiving a negative evaluation. Hypothesis 2 was supported.

The results also revealed that there was a significant interaction between evaluation apprehension and idea exposure on the number of ideas, which partly supports Hypothesis 3. Specifically, in the absence of evaluation apprehension, the exposed group performed more poorly as compared to the non-exposed group in terms of the number of ideas. However, in the presence of evaluation apprehension, the difference between the exposed group and the non-exposed group was not significant anymore. It suggested that the idea generation task performance of exposed and non-exposed groups both decreased under apprehension condition, but the degree of decline in the non-exposed group's performance was higher than in the exposed group. This result indicates that, as compared with the non-exposed condition, when the exposure of ideas was present, evaluation apprehension had a less negative influence on productivity in terms of the quantity of collaborative idea generation. This finding supported Hypothesis 3.

EXPERIMENT 2

Based on Experiment 1, Experiment 2 explored methods to eliminate the negative effect of exposure to others' ideas on idea generation. As shown in previous research, in creative problem-solving and memory retrieval, incubation intervals could be used to relieve fixation (Browne and Cruse, 1988; Smith and Blankenship, 1989). Relaxation or interference tasks (Lu et al., 2017) during the process of idea generation could promote individual or group behavior in an idea generation meeting. Therefore, Experiment 2 tried to provide two experimental settings (relaxation and interference task) to explore whether incubation can reduce the negative impact of exposure to others' ideas, thus improving collaborative creativity.

Method

Participants

A total of 98 school students were recruited from different universities across the country. None of the participants had participated in Experiment 1 or any similar experiment before. Participants were paid after the experiment. They were divided into 49 dyads, each dyad containing one male and one female. Because one dyad did not understand the rules clearly, data collected from the remaining 48 dyads were used for the analysis.

Design and Procedure

Participants were randomly divided into the following three groups: exposed-immediate group, exposed-relaxation group, and exposed-task group. Each group had 16 dyads. The procedure was similar to that of Experiment 1. Participants in the above three exposed groups were asked to complete the idea generation task by submitting ideas together to experimenters *via* WeChat. They could see group members' ideas, but they could not communicate with each other. In the exposed-immediate group, participants were required to conduct the idea generation task for 20 continuous minutes without a break. In the exposed-relaxation group, participants were required to stop the idea generation task after 10 min and to relax and not conduct any other activities. In the exposed group, participants were given a break to complete other cognitive tasks after a 10-min idea generation task. After 5 min, participants were required to continue conducting the idea generation task, and they could not submit any ideas that had been generated before. After 10 min, the second idea generation task ended.

Task and Measure

Like in Experiment 1, the topic of idea generation was "List ways to improve your present university." WeChat was used as a tool for experiment operation and idea submission. Experimenters collected ideas from participants in the first and last 10 min of the experiment and classified them into 30 categories using the method employed in Experiment 1 (CA = 0.65, R = 0.79). Finally, they calculated the number of categories and originality of ideas generated by each dyad.

The interference tasks used in this experiment were 10 graphics and logical reasoning questions extracted from the Civil Servant Test Bank (assessment method of the civil servant in China). In order to avoid the extra negative emotion that might come with interference tasks, the questions would not be scored, and the correct answer would be provided after each question was completed. The interference tasks were just used to let the subject break from the original task temporarily.

Results and Discussion

In order to test the differences of idea generation performance under different conditions, three ANOVAs were respectively conducted in the first 10 min, the last 10 min and the total 20 min of the process. Since the present study was conducted to test three independent hypotheses on the same data set, the negative interval in this study was set as $\alpha/3$ *via* Bonferroni correction.

TABLE 1 | *Post hoc* multiple comparisons of ideas generated in last 10 min (Experiment 2).

Time	*I*	*J*	MD	*p*
Number	Immediate	Relax	–3.50	0.028
		Task	–4.81	0.003
	Relax	Task	–1.31	0.398
Category	Immediate	Relax	–2.31	0.026
		Task	–2.75	0.009
	Relax	Task	–0.44	0.664

An ANOVA on the number, category, and novelty of ideas generated by participants in different groups showed that, in the first 10 min and the total 20 min, there were no significant differences in the number, category, and novelty of ideas generated by the dyads.

In contrast, in the last 10 min, the number of ideas generated by the dyads in the three conditions were significantly different, [$F(2, 45) = 5.243$, $p < 0.05/3$, $\eta^2 = 0.189$, $1 - \beta = 0.807$], and the difference among three conditions on the categories of ideas was marginally significant, [$F(2, 45) = 4.350$, $p < 0.1/3$, $\eta^2 = 0.162$, $1 - \beta = 0.725$]. However, the difference in the novelty of ideas generated by participants among the different groups was not significant [$F(2, 45) = 1.693$, $p > 0.1$]. Furthermore, *post hoc* multiple comparisons showed that the dyads in the two kinds of incubation conditions generated significantly more ideas and their ideas had more categories than did those in the immediate condition (see **Table 1**). On applying the Bonferroni correction, the cutoff for the significance level was 0.017, and the difference in the quantity of ideas (mean difference (MD) = 4.81, p = 0.003) and categories (MD = 2.75, p = 0.009) between the exposed-task and exposed-immediate groups was still significant, while that in the difference in the number of ideas (MD = 3.50, p = 0.028) and categories (MD = 2.31, p = 0.026) between the exposed-relaxation and exposed-immediate groups was not significant anymore.

The results indicated that both kinds of incubation interventions reduced the negative effects of exposure to others' ideas on the group's creative productivity. Additionally, it was suggested that relaxing and interference task during the incubation interval could promote idea generation by having participants temporarily take their attention away from the present task, thus reducing their cognitive fixation.

EXPERIMENT 3

Experiment 1 and 2 did not control the contents and number of examples that participants could see. Therefore, the member in exposed groups could see the other group member's opinions. This kind of experimental setting possesses certain ecological validity. However, because the process of idea generation was not controlled by the experimenter, it was necessary to conduct a more rigorous experiment to verify the results of Experiment 1 and 2, including the negative effects of the process of generating innovative ideas, and the effect of incubation on these negative effects. Therefore, Experiment 3 controlled the examples of the ideas presented to participants, to further verify whether

the two incubation methods (relaxation and interference task) could weaken the negative effects of exposure to other people's opinions during collaborative idea generation.

Method

Participants

A total of 111 school students were recruited from different universities across the country. There were 34 men and 77 women, with age ranging from 18 to 26 years. None of the participants had participated in Experiment 1 or 2, or any similar experiment before. Participants were paid after the experiment. After excluding invalid data, the final effective sample size was 104.

Design and Procedure

Participants were randomly divided into the following four groups: non-exposed group (control group), exposed-immediate group, exposed-relaxation group, exposed-task group. Each group comprised of 26 participants. Participants were asked to complete idea generation tasks individually *via* WeChat with the experimenter. In three exposed groups, participants received ideas from the experimenters in the first, third, fifth, and seventh minute of the process of idea generation. Additionally, they were informed that the examples were from their group member. In fact, the examples came from the four most frequently appearing categories in Experiment 1. Each example presented one category, along with three other alternatives. If the idea had been put forward by the participant him/herself, alternative ideas were used. Participants in the non-exposed (control) group did not receive any ideas from the experimenter.

The manipulation of incubation was similar to that used in Experiment 2. In the control and exposed-immediate groups, participants performed the idea generation task for 20 continuous minutes, without breaks. In the exposed-relaxation group, participants were required to stop the idea generation task after 10 min, and to relax and not conduct any other activities. In the exposed-task group, after a 10-min idea generation task, participants were given a break to complete other cognitive tasks. After 5 min, participants in the two incubation conditions were required to continue conducting the original idea generation task, and they could not submit any ideas that had been generated before. After 10 min, the second idea generation task ended.

Task and Measure

As in Experiment 1 and 2, the topic of idea generation was "List ways to improve your present university." WeChat was used as a tool for experiment operation and idea submission. Experimenters collected ideas from participants in the first and last 10 min of the experiment and classified them into 30 categories using the method employed in Experiment 1 and 2 (CA = 0.72, R = 0.83). Finally, they calculated the number of categories and originality of ideas generated by each participant.

Results and Discussion

In order to test the differences of idea generation performance under different conditions, three ANOVAs were respectively conducted in the first 10 min, the last 10 min, and the total 20 min of the process. Since the present study was conducted to test three independent hypotheses on the same data set, the negative interval in this study was set as $\alpha/3$ *via* Bonferroni correction.

An ANOVA on the number, category, and novelty of ideas generated by the participants in the different groups showed that, in the first 10 min, there were no significant differences in the number [$F(3,100) = 0.597$, $p > 0.1$], category [$F(3, 100) = 0.859$, $p > 0.1$] and novelty [$F(3, 100) = 1.326$, $p > 0.1$] of ideas generated by participants.

In the last 10 min (see **Table 2**), the number [$F(3, 100) = 5.06$, $p < 0.01/3$, $\eta^2 = 0.132$, $1 - \beta = 0.909$] of ideas generated by participants in the last 10 min differed significantly across the four conditions. Furthermore, *post hoc* multiple comparisons (with Bonferroni correction, the cutoff for the significance level was 0.008) showed that participants in the exposed-immediate group generated fewer ideas as compared to the number of ideas generated by participants in the exposed-relaxation group (MD = −2.483, $p < 0.001$), exposed-task group (MD = −1.751, $p = 0.010$, marginal significant) and non-exposed group (MD = −1.789, $p = 0.009$, marginal significant), while the difference in the number of ideas among exposed-relaxation group, exposed-task group, and non-exposed group was not significant.

As for idea categories, the results of ANOVA revealed that it differed significantly across the three conditions [$F(3, 100) = 4.55$, $p < 0.05/3$, $\eta^2 = 0.120$, $1 - \beta = 0.874$]. *Post hoc* multiple comparisons showed that participants in the exposed-immediate group explored fewer idea categories as compared to the category of ideas generated by participants in the other conditions. After Bonferroni correction, only the difference between exposed-immediate group and exposed-relaxation group was still significant (MD = 1.680, $p < 0.001$).

Besides, the difference in the novelty of ideas generated by participants among the four groups was not significant [$F(3, 100) = 2.43$, $p > 0.1$].

An inter-group ANOVA on the number, category, and novelty of ideas in the total 20 min showed that there was a marginally significant difference in the number of ideas generated among four conditions [$F(3, 100) = 3.283$, $p < 0.1/3$, $\eta^2 = 0.090$, $1 - \beta = 0.736$]. Furthermore, *post hoc* multiple comparisons

TABLE 2 | *Post hoc* multiple comparisons of ideas generated in last 10 min (Experiment 3).

	I	*J*	MD	*p*
Number	Non-exposed	Exposed-immediate	1.79	0.009
		Exposed-relax	–0.69	0.292
		Exposed-task	0.04	0.954
	Exposed-immediate	Exposed-relax	–2.48	0.000
		Exposed-task	–1.75	0.010
	Exposed-relax	Exposed-task	0.73	0.266
Category	Non-exposed	Exposed-immediate	1.10	0.020
		Exposed-relax	–0.58	0.209
		Exposed-task	0.12	0.803
	Exposed-immediate	Exposed-relax	–1.68	0.000
		Exposed-task	–0.99	0.036
	Exposed-relax	Exposed-task	0.69	0.132

TABLE 3 | *Post hoc* multiple comparisons of ideas generated in total 20 min (Experiment 3).

	I	*J*	MD	*p*
Number	Non-exposed	Exposed-immediate	1.61	0.136
		Exposed-relax	–1.60	0.131
		Exposed-task	–0.77	0.470
	Exposed-immediate	Exposed-relax	–3.21	0.003
		Exposed-task	–2.38	0.029
	Exposed-relax	Exposed-task	0.83	0.431

showed that, after Bonferroni correction, participants in the exposed-relaxation condition generated significantly more ideas than did those in the exposed-immediate group (MD = 3.210, p = 0.003). The results of ANOVA are listed in **Table 3**.

DISCUSSION

One of the goals of this paper is to further explore the comprehensive impact of opinion exposure and evaluation apprehension on the creation of collaborative ideas. The result of Experiment 1supported the main effect and the interaction effect of exposure to others' ideas and evaluation apprehension in group idea generation. We also tried to explore whether two different incubation methods (relax/task conversion) had a significant effect on reducing the negative impact of exposure on group creativity and thus improving idea generation productivity.

Impact of Evaluation Apprehension and Exposure to Others' Ideas

Experiment 1 revealed that exposed groups generated fewer ideas than did non-exposed groups, and their ideas included fewer categories. This result may have appeared because, in the process of social interaction in the cooperative innovation group, if members saw the ideas of other members, they would focus too much attention on others' ideas, thus limiting their scope of thinking and reducing the output of innovative ideas.

In this study, to elicit evaluation apprehension among participants, the experimenter's instructions prompted participants to conduct external evaluations. The main effects of this manipulation were significant. Further, in the presence of evaluation apprehension, the number and categories of ideas generated by the non-exposed and exposed groups decreased. This finding is consistent with those of previous research, and it evidences the presence of the negative impact of evaluation apprehension on the group's innovative idea generation. It is worth mentioning that the evaluation apprehension and exposure to others' ideas had an interaction effect on the number of categories of ideas generated. This phenomenon can be explained using the social impact theory mentioned earlier in this manuscript. When the evaluation expectation is conducted in exposed groups, the presentation of other members' answers clearly conveys their existence, thus virtually sharing the pressure of this evaluation. This, in turn, weakens the negative impact of the evaluation apprehension. Therefore, compared with non-exposed groups, the reduction in innovation productivity was less severe in the presence of evaluation apprehension in exposed groups.

Role of Incubation Interval

Experiment 2 explored possible measures to reduce the negative effects of exposure and to improve groups' creative output by introducing two different incubation methods. By controlling the exposure to ideas received by participants and simulating a collaborative situation in the creative generation task, Experiment 3 conducted a more rigorous experiment to verify the results of Experiment 1 and 2.

The results of Experiment 2 showed that both incubation methods increased the number and categories of ideas generated by dyads in the last 10 min, supporting the positive effect of incubation in collaborative idea generation. The difference between the two methods was not significant, which means that putting the problem aside and relaxing or performing other tasks both promoted the generation of innovative ideas. This result could be explained by selective forgetting hypothesis (Smith and Blankenship, 1991). Participants' attention would be temporarily diverted when led to a break or interference task, contributing to forgetting the irrelevant or redundant ideas from the previous task. Thus, participants may generate ideas from different perspectives after the incubation period.

In Experiment 3, there was no significant difference in the number, category, and novelty of ideas generated by the exposure and control groups in the first 10 min among four conditions. This may indicate that participants' ideas were not affected by exposure to others' ideas immediately. Despite this, its role in the inhibition of innovative idea generation appeared as the experimental time increased, especially in the last 10 min. A comparison of the performance of the four groups of participants in the last 10 min revealed that the control, exposure-relaxation, and exposure-task groups produced more ideas than the exposure-immediate group, and their ideas included more categories, suggesting the number and types of ideas produced were affected negatively by exposure to others' ideas, and this effect was more likely to manifest later in the task. On the other hand, the present study found that the incubation interval had a positive impact on the number and type of ideas generated by participants, which is consistent with the results of Experiment 2 and findings of previous studies (Penaloza and Calvillo, 2012).

The number and types of ideas generated by the two incubation groups were higher than those of the exposure-immediate group in the total 20 min, but not significantly. This may be due to the fact that the experiment was used for thinking and suggesting that the experiment was only 20 min long, and cannot reflect enough utility. Subsequent research can consider increasing the length of time to continue to explore the effects of incubation.

CONCLUSION

In our daily life, collaborative idea generation is a widely used working technique, which is often applied to the conceptual

design group (Sutton and Hargadon, 1996), the research team and various other forms of collaborative groups. However, the productivity loss caused by collaborative idea generation is also an ongoing concern of researchers. Based on the results of this study, we speculate that when individuals work in a group, they will: (1) pay too much attention to evaluation when surrounded by people, resulting in evaluation apprehension and (2) tend to conform to other group members, as well as fixate their ideas on the existing ideas of others. Both of the points above will limit individuals' creativity and reduce the number and categories of ideas. This kind of influence will finally result in productivity deficits, which means that when people work together, they will generate fewer ideas than work alone. Furthermore, this study also tended to explore effective strategies to weaken the negative effects. According to the results of Experiment 2 and Experiment 3, we draw support from previous studies that relaxation and interference task in the incubation interval significantly diminish the negative effects of exposure to other people's ideas.

In summary, this study focused on the social factors and cognitive processes that influence collaborative idea generation using the research paradigm of group creativity generation, evaluation of concern induction, and incubation paradigm. Additionally, this study explored the impact of perspective exposure, evaluation apprehensions, and incubation intervals on cooperative innovation productivity through three experiments. The results showed that the second half of the group's idea generation with exposure and evaluation apprehension led to a reduction in the number and type of ideas generated by the groups. Further, these factors had an interaction effect on the number of creative ideas generated. Compared to that in participants with no exposure, in the case of exposure, the impact of evaluation apprehension on the quantitative productivity of cooperative innovation ideas was weak. The addition of incubation intervals helped to increase innovation productivity, suggesting that relax and task transitions are beneficial for reducing the negative impact of exposure on idea generation.

LIMITATIONS AND PROSPECTS

Although this study explored the role of exposure to others' opinions, evaluation apprehensions, and incubation intervals on the generation of group innovation ideas, it had some limitations. For instance, the example ideas presented to participants in Experiment 3 were the most typical types of ideas that emerged in the idea generation task in Experiment 1. Therefore, future researchers can further explore the impact of presentation of typical and atypical, or novel and non-innovative examples. Thus, the scalability of idea presentation can be strengthened further. In addition, novelty score was not significantly different on different levels of idea exposure nor evaluation apprehension. The probable explanation may be that the scoring rule was not fully appropriate. And in future studies, we could consider changing the scoring rules. Furthermore, this study used two-person groups. Future research can further explore incubation effects on groups of different sizes and explore the effects of length of incubation interval, length of thinking in the task, and arrangement of incubation intervals, to generate more creative strategies to improve subsequent productivity of collaborative idea generation groups. The impact of the arrangement of activities during the incubation period is also worth exploring. For example, the task form and complexity of the interpolation task are areas worth exploring.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the ethical review work guidelines of the Institutional Review Board of Psychology of the Nankai University with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Institutional Review Board of Psychology of the Nankai University.

AUTHOR CONTRIBUTIONS

XZ, H-KZ, BD, Y-XC, and HZ developed the research idea together. Under the supervision of XZ, BD, H-KZ, and Y-XC collected and analyzed the data for Experiment 1, 2 and 3. XZ, BD, and XC drafted the manuscript. HZ, H-KZ, and Y-XC provided critical revisions.

FUNDING

This research was supported by the Key Program of the Tianjin Philosophy and Social Science Research Project of China (TJJX16-001), Key Program of the National Natural Science Foundation of China (71532005), Special Task Project of Humanities and Social Sciences Research of Chinese Ministry of Education on Engineering Science and Technology Talent Cultivation Research (19JDGC003), Major Social Science Project of Tianjin Municipal Education Commission of China (2018JWZD41), and National Social Science Foundation of China (12BSH053).

REFERENCES

Alper, S., Tjosvold, D., and Law, K. S. (2007). Interdependence and controversy in group decision making: antecedents to effective self-managing teams. *Organ. Behav. Hum. Decis. Process.* 74, 33–52. doi: 10.1006/obhd.1998.2748

Baruah, J., and Paulus, P. B. (2011). Category assignment and relatedness in the group ideation process. *J. Exp. Soc. Psychol.* 47, 1070–1077. doi: 10.1016/j.jesp.2011.04.007

Brown, V., Tumeo, M., Larey, T. S., and Paulus, P. B. (1998). Modeling cognitive interactions during group brainstorming. *Small Group Res.* 29, 495–526.

Browne, B. A., and Cruse, D. F. (1988). The incubation effect: illusion or illumination? *Hum. Perform.* 1, 177–185.

Camacho, L. M., and Paulus, P. B. (1995). The role of social anxiousness in group brainstorming. *J. Pers. Soc. Psychol.* 68, 1071–1080. doi: 10.1037/0022-3514.68.6.1071

Chen, J., and Yang, Y. J. (2012). Theoretical basis and content for collaborative innovation. *Stud. Sci. Sci.* 2, 161–164. http://www.cnki.com.cn/Article/CJFDTotal-KXYJ201202002.htm

Collaros, P. A., and Anderson, L. R. (1969). Effect of perceived expertness upon creativity of members of brainstorming groups. *J. Appl. Psychol.* 53, 159–163. doi: 10.1037/h0027034

Diehl, M., and Stroebe, W. (1987). Productivity loss in brainstorming groups: toward the solution of a riddle. *J. Pers. Soc. Psychol.* 53, 497–509. doi: 10.1037/0022-3514.53.3.497

Diehl, M., and Stroebe, W. (1991). Productivity loss in idea-generating groups: tracking down the blocking effect. *J. Pers. Soc. Psychol.* 61, 392–403. doi: 10.1037/0022-3514.61.3.392

Fink, A., Koschutnig, K., Benedek, M., Reishofer, G., Ischebeck, A., Weiss, E. M., et al. (2012). Stimulating creativity *via* the exposure to other people's ideas. *Hum. Brain Mapp.* 33, 2603–2610. doi: 10.1002/hbm.21387

Gilhooly, K. J., Georgiou, G. J., Garrison, J., Reston, J. D., and Sirota, M. (2012). Don't wait to incubate: immediate versus delayed incubation in divergent thinking. *Mem. Cogn.* 40, 966–975. doi: 10.3758/s13421-012-0199-z

Henchy, T., and Glass, D. C. (1969). Evaluation apprehension and the social facilitation of dominant and subordinate responses. *J. Pers. Soc. Psychol.* 10, 446–454.

Hennessey, B. A., and Amabile, T. M. (2010). Creativity. *Annu. Rev. Psychol.* 61, 569–598. doi: 10.1146/annurev.psych.093008.100416

Hinsz, V. B., Tindale, R. S., and Vollrath, D. A. (1997). The emerging conceptualization of groups as information processors. *Psychol. Bull.* 121, 43–64. doi: 10.1037/0033-2909.121.1.43

Kohn, N. W., and Smith, S. M. (2010). Collaborative fixation: effects of others' ideas on brainstorming. *Appl. Cogn. Psychol.* 25, 359–371. doi: 10.1002/acp.1699

Korde, R., and Paulus, P. B. (2017). Alternating individual and group idea generation: finding the elusive synergy. *J. Exp. Soc. Psychol.* 70, 177–190. doi: 10.1016/j.jesp.2016.11.002

Latané, B. (1981). The psychology of social impact. *Amer. Psychologist* 36, 343–356.

Lu, J. G., Akinola, M., and Mason, M. F. (2017). "Switching on" creativity: task switching can increase creativity by reducing cognitive fixation. *Organ. Behav. Hum. Decis. Process.* 139, 63–75. doi: 10.1016/j.obhdp.2017.01.005

Markman, A. B. (ed.) (2016). *Open innovation: Academic and practical perspectives on the journey from idea to market*. (New York: Oxford University Press).

Marsh, R. L., Landau, J. D., and Hicks, J. L. (1997). Contributions of inadequate source monitoring to unconscious plagiarism during idea generation. *J. Exp. Psychol. Learn. Mem. Cogn.* 23, 886–897.

McGrath, J. E. (1984). *Groups: Interaction and performance*. (Englewood Cliffs, NJ: Prentice-Hall).

McGrath, L. (2015). When pairing reduces scaring: the effect of dyadic ideation on evaluation apprehension. *Int. J. Innov. Manag.* 19, 1550039-1–1550039-35. doi: 10.1142/S1363919615500395

Nagasundaram, M., and Dennis, A. R. (1993). When a group is not a group: the cognitive foundation of group idea generation. *Small Group Res.* 24, 463–489.

Nijstad, B. A., Stroebe, W., and Lodewijkx, H. F. (2003). Production blocking and idea generation: does blocking interfere with cognitive processes? *J. Exp. Soc. Psychol.* 39, 531–548. doi: 10.1016/S0022-1031(03)00040-4

Nijstad, B. A., and Stroebe, W. (2006). How the group affects the mind: A cognitive model of idea generation in groups. *Pers. Soc. Psychol. Rev.* 10, 186–213.

Paulus, P. B., and Kenworthy, J. B. (2017). "Group and intergroup creativity" in *The Oxford handbook of group and organizational learning*. eds. L. Argote and J. M. Levine. Oxford University Press. doi: 10.1093/oxfordhb/9780190263362.013.34

Paulus, P. B., Larey, T. S., and Ortega, A. H. (1995). Performance and perceptions of brainstormers in an organizational setting. *Basic Appl. Soc. Psychol.* 17, 249–265. doi: 10.1207/s15324834basp1701&2_15

Paulus, P. B., Nakui, T., Putman, V. L., and Brown, V. R. (2006). Effects of task instructions and brief breaks on brainstorming. *Group Dyn. Theory Res. Pract.* 10, 206–219. doi: 10.1037/1089-2699.10.3.206

Paulus, P. B., Putman, V. L., Dugosh, K. L., Dzindolet, M. T., and Coskun, H. (2002). Social and cognitive influences in group brainstorming: predicting production gains and losses. *Eur. Rev. Soc. Psychol.* 12, 299–325. doi: 10.1080/14792772143000094

Paulus, P. B., and Yang, H. C. (2000). Idea generation in groups: a basis for creativity in organizations. *Organ. Behav. Hum. Decis. Process.* 82, 76–87. doi: 10.1006/obhd.2000.2888

Penaloza, A. A., and Calvillo, D. P. (2012). Incubation provides relief from artificial fixation in problem solving. *Creat. Res. J.* 24, 338–344. doi: 10.1080/10400419.2012.730329

Penney, C. G., Godsell, A., Scott, A., and Balsom, R. (2011). Problem variables that promote incubation effects. *J. Creat. Behav.* 38, 35–55. doi: 10.1002/j.2162-6057.2004.tb01230.x

Putman, V. L., and Paulus, P. B. (2009). Brainstorming, brainstorming rules and decision making. *J. Creat. Behav.* 43, 29–40. doi: 10.1002/j.2162-6057.2009.tb01304.x

Raaijmakers, J. G., and Shiffrin, R. M. (1981). Search of associative memory. *Psychol. Rev.* 88, 93–134. doi: 10.1037/0033-295X.88.2.93

Rundus, D. (1973). Negative effects of using list items as recall cues. *J. Verbal Learn. Verbal Behav.* 12, 43–50. doi: 10.1016/S0022-5371(73)80059-3

Sawyer, R. K., and Dezutter, S. (2009). Distributed creativity: how collective creations emerge from collaboration. *Psychol. Aesthet. Creat. Arts* 3, 81–92. doi: 10.1037/a0013282

Segal, E. (2004). Incubation in insight problem solving. *Creat. Res. J.* 16, 141–149. doi: 10.1207/s15326934crj1601_13

Sio, U. N., and Ormerod, T. C. (2009). Does incubation enhance problem solving? A meta-analytic review. *Psychol. Bull.* 135, 94–120. doi: 10.1037/a0014212

Smith, S. M., and Blankenship, S. E. (1989). Incubation effects. *Bull. Psychon. Soc.* 27, 311–314. doi: 10.3758/BF03334612

Smith, S. M., and Blankenship, S. E. (1991). Incubation and the persistence of fixation in problem solving. *Am. J. Psychol.* 104, 61–87.

Smith, S. M., and Linsey, J. (2011). A three-pronged approach for overcoming design fixation. *J. Creat. Behav.* 45, 83–91. doi: 10.1002/j.2162-6057.2011.tb01087.x

Sutton, R. I., and Hargadon, A. (1996). Brainstorming groups in context: effectiveness in a product design firm. *Admin. Sci. Quart.* 41, 685–718.

Zhang, J. H., Liu, X., Ren, F. F., Sun, X. W., and Yu, Q. (2016). The effects of group diversity and organizational support on group creativity. *Acta Psychol. Sin.* 48, 1551–1560. doi: 10.3724/SP.J.1041.2016.01551

Zhou, X., Zhang, Z. Y., and Zeng, H. (2018). Collective intelligence and influencing factors in long term cooperative learning group. *Stud. Psychol. Behav.* 16, 231–237. doi: 10.3969/j.issn.1672-0628.2018.02.013

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDIX: THE CATEGORY LIST OF IDEA GENERATION

Expansion
Investment
Publicity
Culture
Discipline construction
Admission
Course
Teacher
Employment
Academic
Practice
Exchange
Environment
Equipment
Dormitory
Information
Safety
Cost
Administration
Advice
Classroom
Library
Traffic
Food
Service
Energy
Activity
Health
Sports
Network

frontiers in Psychology

ORIGINAL RESEARCH
published: 08 August 2019
doi: 10.3389/fpsyg.2019.01517

Acute Stress Shapes Creative Cognition in Trait Anxiety

Haijun Duan[1], Xuewei Wang[1], Zijuan Wang[1,2], Wenlong Xue[1], Yuecui Kan[1], Weiping Hu[1,3]* and Fengqing Zhang[4]*

[1]MOE Key Laboratory of Modern Teaching Technology, Shaanxi Normal University, Xi'an, China, [2]Jinyuan International School, Shaanxi Normal University, Xi'an, China, [3]Collaborative Innovation Center of Assessment Towards Basic Education Quality, Beijing Normal University, Beijing, China, [4]Department of Psychology, Drexel University, Philadelphia, PA, United States

This study examined the cognitive mechanism underlying acute stress in creative cognition among individuals with high and low trait anxiety. Specifically, cognitive inhibition was assessed using the flanker task during acute stress. Fifty-two participants (26 with high trait anxiety, 26 with low trait anxiety, with a mean age of 18.94 years) underwent stress induction *via* the Trier Social Stress Test (TSST). They all completed the Alternative Uses Test (AUT) and the Remote Associates Test (RAT) before and after the TSST. Biochemical markers (salivary cortisol and salivary alpha amylase) were recorded at regular intervals. The results showed that cognitive inhibition was influenced by trait anxiety and acute stress. In low-trait anxious individuals after experiencing acute stress, there was a lack of cognitive inhibition and they performed better in AUT (fluency), compared to before experiencing acute stress, whereas high-trait anxious individuals showed a decreased interference effect and reduced performance in AUT (fluency, flexibility, and originality). In the RAT, there were shorter response times and increased accuracy after acute stress in both high- and low-trait anxiety groups. Thus, we suggest that cognitive control, which modulates changes in acute stress, influences creative cognition. These findings provide evidence that inhibition control mediates the effect of stress on the creativity of individuals with different trait anxiety.

Keywords: acute stress, creative cognition, Trier social stress test, alternative uses test, remote associates test

OPEN ACCESS

Edited by:
Wangbing Shen,
Hohai University, China

Reviewed by:
Nick Berggren,
Birkbeck, University of London, United Kingdom
Xiaoyang Yang,
Sichuan Normal University, China
Xiang Zhou,
Nankai University, China

****Correspondence:***
Haijun Duan
duanhj@126.com
Weiping Hu
weipinghu@163.com

Specialty section:
This article was submitted to Cognition, a section of the journal Frontiers in Psychology

Received: *28 September 2018*
Accepted: *17 June 2019*
Published: *08 August 2019*

Citation:
Duan H, Wang X, Wang Z, Xue W, Kan Y, Hu W and Zhang F (2019) Acute Stress Shapes Creative Cognition in Trait Anxiety. Front. Psychol. 10:1517. doi: 10.3389/fpsyg.2019.01517

INTRODUCTION

Creativity has long been of great interest in a wide range of fields. People have the ability to exert cognitive control over creativity (Beaty et al., 2014; Kenett et al., 2018). According to controlled-attention theory, creative production depends on individuals' ability to exert control over their attention and cognition (Gilhooly et al., 2007; Beaty et al., 2016). Individuals high in creative thinking tend to be able to dynamically change their level of control according to the current task requirements (Gilhooly et al., 2007; Radel et al., 2010; Benedek et al., 2012). However, our ability to control creativity is not always consistent, especially in the face of suddenly occurring situations.

Stress is an unavoidable feature of modern life. Stress activates the sympathetic nervous system (SNS) and hypothalamus-pituitary adrenal (HPA) axis. In human saliva, the activity of the SNS and HPA can be measured by salivary alpha amylase (sAA) and salivary cortisol (sC),

respectively (Kirschbaum and Hellhammer, 1989; Foley and Kirschbaum, 2010). It is vital that individuals have the ability to exert cognitive control in the face of stress—not doing so may cause stress to impair functioning (Erskine et al., 2007), causing serious distress and mental impairment (McNally, 2006; Qureshi et al., 2011; Cisler and Olatunji, 2012).

Previous literature has presented inconsistent results regarding the association between stress and creativity. Some have found that stress leads to a decrease in creativity (Beversdorf et al., 1999; Probst et al., 2007; Byron et al., 2010; Lovelace and Hunter, 2013; Duan et al., 2019; Wang et al., 2019), while others found that it increased creativity (Baas et al., 2008; Ohly and Fritz, 2010). Still others found a U-shaped relationship between stress and creativity (Suedfeld and Vernon, 1965; Baer and Oldham, 2006; Yeh et al., 2015). Meanwhile, trait anxiety was usually considered as a stress-vulnerability factor (Eysenck and Derakshan, 2011; Berggren and Derakshan, 2013; Ward et al., 2017; Weger and Sandi, 2018).

Trait anxiety has been defined as the tendency of individuals to experience frequent and high-intensity anxiety and worry in the face of stressful situations (Spielberger, 1979). Hence, studies could focus on highly anxious individuals, who are more prone to anxiety in stressful situations. Additionally, these past studies did not explore the cognitive mechanisms underlying how stress affects creativity. As mentioned above, completing creative activities and facing stress both require cognitive control. Thus, the core mechanism underlying creative generation under stress may be an executive control process, including the ability to inhibit the influence of irrelevant information caused by stress. However, this fascinating possibility remains to be addressed.

According to the Attentional Control Theory (ACT; Eysenck et al., 2007), anxiety activates the stimulus-driven system and reduces the goal-driven system (the crux of the ACT is that we have two attentional systems: top-down, goal-driven processing and bottom-up, stimulus-driven processing). Individuals with high trait anxiety (HTA) appear to be more affected by stimulus-driven processing and find it difficult to suppress threatening stimuli from entering attention. Indeed, in the face of threat stimuli, individuals with HTA show more pronounced cognitive deficits, including weakened dorsolateral prefrontal cortex (DLPFC) activity (Clarke et al., 2014; Greening and Mitchell, 2015). Hence, individuals with HTA appear to show both behavioral alterations and cognitive deficits. Further research has revealed that anxiety affects the processing efficiency of executive functioning (shifting, updating and inhibition) when faced with threatening information (e.g., stress; Navarro et al., 2012; Edwards et al., 2015; Goette et al., 2015; Fogelman et al., 2016; Fonzo and Etkin, 2017). Thus, anxiety is related to a diminished ability to inhibit threat (Cisler and Koster, 2010).

A group of researchers suggested that acute stress may affect core executive functions (Hermans et al., 2014; Shields et al., 2016; Gu et al., 2018), particularly inhibition control (Shields et al., 2016). However, there are scant empirical studies examining the effect of acute stress on inhibition control in individuals with HTA and low trait anxiety (LTA). Some indirect evidence from studies on cortisol and individual differences in anxiety implied that anxiety-related personality traits modulate cognitive control processes under stress (Edwards et al., 2017). On the one hand, Grillon et al. (2017) asked participants to perform inhibition tasks while under threat of an electric shock, and found that increased anxiety promoted inhibition control. Individuals needed to allocate only a small amount of attentional resources to fully process the task-related information (Chajut and Algom, 2003). They explained the results using attention approach theory, positing that HTA individuals may have more limited attentional resources than LTA individuals, and thus their available attentional resources may become exhausted quickly under stressful conditions. On the other hand, according to the ACT (Eysenck et al., 2007), HTA individuals could display worse inhibition control under stress (Cisler and Koster, 2010; Navarro et al., 2012; Edwards et al., 2015; Goette et al., 2015; Fogelman et al., 2016; Fonzo and Etkin, 2017).

The relationship between cognitive inhibition and creativity has been explored in relation to creativity. Researchers hold that there are two types of creative thinking: convergent and divergent thinking. Convergent thinking involves deriving a single correct solution, while divergent thinking involves thinking of as many potential solutions as possible. For convergent thinking, high inhibitory control is necessary to prevent irrelevant ideas from entering into working memory and helping individuals focus on identifying solutions that meet the required standards (Zhou et al., 2019). However, for divergent thinking, low inhibition (involving automatic association and a lack of filtering of seemingly irrelevant information) may actually facilitate generation of creative ideas (Chrysikou et al., 2014; Barr et al., 2015; Radel et al., 2015; Beaty et al., 2016; Hao et al., 2016; Kenett et al., 2018).

The present study drew on previous research topics involving the complex interaction between cognitive control, stress, and creativity, with a particular focus on individual differences in trait anxiety. To date, no study has considered all four of these variables together. The present study examined the relationships among trait anxiety, acute stress, and inhibitory control using a version of the flanker task. Trait anxiety was operationalized using the Chinese version of the trait anxiety portion of the State–Trait Anxiety Inventory (STAI; Spielberger et al., 1983; Shek, 1993). Acute stress was induced using the Trier Social Stress Test (TSST) (Kirschbaum et al., 1993; Kudielka et al., 2007). This procedure allowed us to investigate whether trait anxiety under stress affects individuals' ability to exert inhibitory control to influence creative performance outcomes. To summarize, we explore the difference in creativity between HTA and LTA individuals who underwent a stressful situation, and determined if inhibitory control mediated the effect of acute stress on creativity. To this end, two hypotheses were formulated: (1) if acute stress impairs inhibitory control processes, HTA individuals will present better divergent thinking performance and worse convergent thinking performance; (2) if acute stress does not impair inhibitory control processes, HTA individuals will present worse divergent thinking performance and better convergent thinking performance.

MATERIALS AND METHODS

Subjects

Initially, 713 undergraduate students from Shaanxi Normal University (pre-test) completed the Chinese version of the STAI. Based on their scores, we chose individuals for the HTA group (upper 27th percentile of the distribution) and LTA group (lower 27th percentile). In the present study, we invited 52 individuals, including 26 HTA individuals (M_{age} = 18.46 years, SD = 0.89) and 26 LTA individuals (M_{age} = 19.42 years, SD = 1.31), to participate. An independent-samples *t*-test revealed that the HTA group had higher trait anxiety scores (M = 55.42, SD = 5.85) than did the LTA group (M = 35.58, SD = 8.04) at pre-test, $t(50) = -9.976$, $p < 0.001$. We applied the following criteria when selecting these participants. We excluded those with a body mass index (BMI) below 18 or exceeding 27 kg/m^2; those engaged in drug use; those who regularly consumed coffee or alcohol; and those with chronic or acute illnesses. Furthermore, participants were advised to refrain from physical exercise and consumption of food and drinks, except water, 3 h before the test sessions began (Kuhlmann et al., 2005; Kudielka et al., 2009). Female participants were not menstruating. The experiment was conducted from 2:00 pm to 5:00 pm owing to the circadian rhythms (Izawa et al., 2010). The study conformed to the principles of the Declaration of Helsinki (World Medical Association, 2013) and was approved by the Academic Committee of the Ministry of Education of Key Laboratory of Modern Teaching Technology, Shaanxi Normal University in China. All participants provided written informed consent after the procedures were fully explained, and were paid for their participation in the study.

Experiment Procedure

To control for individual differences, this study used a mixed design, with time of measurement (pre-test, post-test) as a within-subjects factor (McHugh et al., 2010) and group (HTA, LTA) as the between-subjects factor. The dependent variable of this experiment was performance on two creative thinking tasks: the Remote Association Test (RAT) and the Alternative Uses Test (AUT). The indicators selected for the RAT were response time and accuracy, and those for the AUT were fluency, flexibility, and originality. The overall procedure was as follows: the first salivary sample (S1) was collected on participants' arrival at the laboratory. Subsequently, they completed a questionnaire on their demographic information, followed by the STAI. The subjects were allowed to relax for 15 min before the second salivary sample (S2). Participants in the HTA and LTA groups then completed the pre-test tasks (flanker and creative tasks) for 15 min, and the TSST for 10 min. After the TSST, the third salivary sample (S3) was taken. Then, all participants performed the post-test tasks (flanker and creative tasks). The order of the creative tasks was counterbalanced across participants. The AUT and RAT were administered *via* a computer using the E-Prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, Pennsylvania, USA) (see **Figure 1**).

Stress Task

According to the procedure of the TSST (Kirschbaum et al., 1993; Kudielka et al., 2007), participants were asked to create a 5-min interview speech for applying to college, which they would deliver to a panel of college counselors. They were given 3 min for preparation. The panel consisted of two experimenters. If a participant's speech did not reach the full 5 min, they had to answer questions given by the experimenters until the full 5 min had passed. Finally, participants were asked to orally report answers to arithmetic problems (they had to subtract increments of 17 from 2023) as quickly and as accurately as possible for 5 min. When they made an error, the experimenter interrupted and instructed the participant to start over at 2023. The entire stress task was recorded with a digital video camera. Experimenters maintained a cold and reserved manner throughout.

Flanker Task

The flanker task measures individuals' ability to selectively attend to a target and ignore distractors (Eriksen and Eriksen, 1974). According to Friedman and Miyake (2004), inhibitory control has at least two components: inhibition of the dominant response and prevention of distracting interference. Compared to other inhibition tasks, the flanker task is considered to best reflect an individual's ability to engage in inhibition control (Redick and Engle, 2006; Shields et al., 2016). In the flanker task, a central arrow (1.48° × 0.82°) was flanked by two distractor arrows, which were kept at a distance of 0.16°. The distractor arrows were pointed either in the same (i.e., congruent trial) or opposite directions (i.e., incongruent trial) as the central target arrow. A fixation cross was displayed for 1,200 ms. After presenting a black screen for 500–1,000 ms, the arrow flanker task was presented for 1,500 ms or until a response was obtained. After presenting a black screen for 1,000 ms, the next flanker task began. Overall, participants completed 100 flanker trials. The flanker-interference effect (Eriksen and Eriksen, 1974) was defined as the difference in reaction times under the incompatible and compatible conditions (a greater difference indicates more interference).

Creative Task

The AUT was selected to measure divergent thinking. Participants were given 2 min per object to verbalize as many uses as they could. Two lists of objects were used for each experimental session (pre-test: bucket, shoe, newspaper; post-test: umbrella, can, paperclip) (Radel et al., 2015). The order of the lists was randomized. According to Guilford (1950), the test is scored in terms of fluency, flexibility, and originality. The fluency score was calculated as the number of responses; the flexibility score as the number of categories of responses; and originality as the frequency of occurrence of a given response among the participants. A response frequency percentage of less than 1% was given a score of 2; a frequency between 1 and 5% was given a score of 1; and a frequency of more than 5% was given a score of 0 (Radel et al., 2015). Two experienced creative field coders rated participants' responses. They had satisfactory inter-rater reliability (Cronbach's alphas: 1 for fluency, 1 for originality, 0.872 for flexibility).

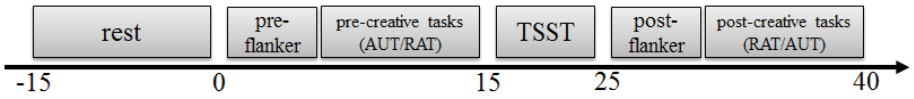

FIGURE 1 | Schematic illustration of the procedure. Saliva from the participants was collected at five time points (–15, 0, 15, 25, and 40 min in relation to the onset of the stressful task). After a rest phase, participants performed Flanker task and creative tasks (AUT and RAT) before and after the TSST.

For convergent thinking, we used the updated Chinese Compound RAT, compiled by Xu et al. (2015) (cf. Bowden and Jung-Beeman, 2003). Each problem in this test consists of three words chosen from the Modern Chinese Frequency Dictionary (1986). High-frequency words (mean frequency: 4,981.6 per million) were used to ensure that participants would understand them. Based on a preliminary test, 135 items were selected. From these, we selected 40 items for which the solution rates ranged from 40 to 65%. Twenty items were used for the pre-test and 20 for the post-test. This selection of Chinese Compound RAT problems had satisfactory internal consistency (Cronbach's α = 0.897) and criterion validity. The solution rate was 66%, and the average response time was 3.79 s. The experiment was compiled using the E-prime program. Five items were used in a practice experiment. At the beginning of each trial, a 500-ms fixation is displayed at the center of the screen. Participants must press the space bar and immediately enter the RAT item in the next screen; then, they must think of an answer and say it aloud immediately after pressing the space bar. The screen automatically records the answer spoken by the participant and presents the correct answer. Finally, participants are asked to judge the answer displayed on the screen. If the correct answer is consistent with the answer spoken, they should press Q; if not, they should press P. If after 15 s, the participant is still not able to determine the answer, the program skips to the next question. A random interval of 100–500 ms is presented between two items.

Physiological Measures

The participants deposited salivary samples at −15, 0, 15 min (T2), 25 min (T3), and 40 min (T4) after the stress task. To control for stress induced by lab environment in subjects, the lower of the two samples between the first sample and the second sample was chosen as the baseline (T1) (McHugh et al., 2010). Saliva was collected using Salivettes® (Sarstedt 51.1534.500, Germany). All saliva samples were stored at −22°C and then thawed and centrifuged at 3000 rpm. The cortisol concentration and salivary alpha amylase were determined by enzyme immunoassay (Jianglai, China).

RESULTS

The physiological data, flanker task, and creativity scores were analyzed using univariate analysis of variance (ANOVA) with group (HTA, LTA) as the between-subjects factor and time (measurement time points) as within-subject factor. The ANOVA tested for the main effects of trait anxiety and presence/absence of stressor and their interaction. The Greenhouse-Geisser correction for non-sphericity was performed wherever appropriate. Bonferroni corrections were used to control for multiple comparisons. Partial-eta^2 (η_p^2) is reported as a measure of effect size. Descriptive statistics and correlation analysis were conducted using SPSS.

Physiological Results

For salivary cortisol, a repeated measurement ANOVA with the within-subject factor of time (T1, T2, T3, and T4) and between-subject factor of group (HTA and LTA) was computed with the salivary cortisol data to examine the effect of stress on salivary cortisol with high- and low-trait anxiety individual. ANOVA revealed a significant main effect of time, $F(3,150) = 123.55$, $p < 0.001$, $\eta_p^2 = 0.712$, and a significant main effect of group, $F(1,50) = 7.75$, $p < 0.001$, $\eta_p^2 = 0.134$. The HTA group ($M = 7.45$, SD = 2.23) was lower than the LTA ($M = 8.36$, SD = 1.77) group in salivary cortisol. The results also revealed a time × group interaction, $F(3,48) = 6.88$, $p < 0.001$, $\eta_p^2 = 0.301$. Bonferroni-corrected simple-effects tests at each time point revealed that the two groups showed significantly lower cortisol at T1 than at each of the subsequent times, ($p < 0.001$). Otherwise, compared with group difference in every time, the HTA group was significantly lower than the LTA group at T1 ($p < 0.001$) and T2 ($p < 0.05$) (see **Figure 2**).

For salivary alpha amylase, a repeated measurement ANOVA with the within-subject factor of time (T1, T2, T3, and T4) and the between-subject factor of group (HTA and LTA) was computed for the salivary alpha amylase data to examine the effect of stress on salivary alpha amylase with high- and low-trait anxiety individuals. ANOVA revealed a significant main effect of time, $F(3,150) = 114.16$, $p < 0.001$, $\eta_p^2 = 0.695$, and a significant main effect of group, $F(1,50) = 63.50$, $p < 0.001$, $\eta_p^2 = 0.599$. The HTA group ($M = 133.34$, SD = 42.77) was lower than the LTA group ($M = 164.27$, SD = 26.61) in salivary alpha amylase. The results also revealed a time × group interaction, $F(3,150) = 22.568$, $p < 0.001$, $\eta_p^2 = 0.311$. Bonferroni-corrected simple-effects tests at each time point revealed that the two groups showed significantly lower cortisol at T1 than at each of the subsequent times ($p < 0.001$). Furthermore, compared with group difference in every time, the HTA group was significantly lower than the LTA group at T1, T2, and T3 ($p < 0.001$) (see **Figure 3**).

Flanker Interference Effect Results

Descriptions of mean response times and error rates in the flanker task in the pre-test and post-test for the LTA and HTA groups are shown in **Table 1**. When analyzing the response

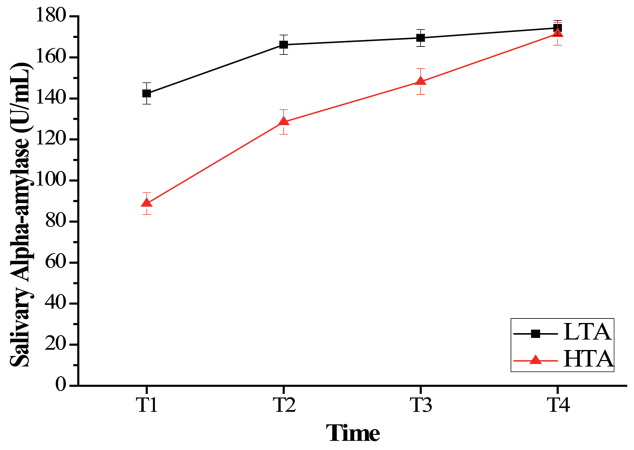

FIGURE 2 | Mean salivary cortisol (nmol/L) as a function of time (minutes following intervention onset) for the stress. Error bars represent standard errors of the means.

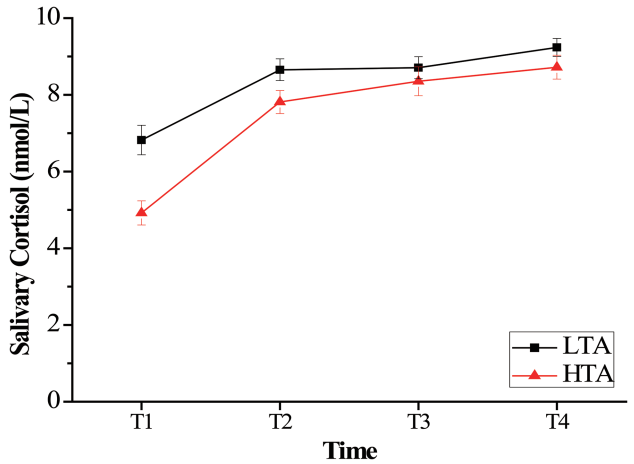

FIGURE 3 | Mean salivary alpha amylase (U/ml) as a function of time (minutes following intervention onset) for the stress. Error bars represent standard errors of the means.

times and error rate, extreme values of three standard deviations were excluded. Repeated measures ANOVAs with the within-subject factor measurement (pre-test and post-test) and the between-subject factor of group (HTA and LTA) were computed for the interference effect on response time and error rate. For interference effect in RTs, ANOVA yielded a significant interaction effect of group and measurement, $F(1,50) = 20.38$, $p < 0.001$, $\eta_p^2 = 0.290$. However, the main effect on group and measurement was insignificant ($p > 0.05$). Bonferroni-corrected simple-effects tests revealed that the HTA group ($M = 81.13$, SD = 40.21) was significantly slower than the LTA group ($M = 54.19$, SD = 32.25) in pre-test, $p = 0.010$. Nevertheless, the HTA group ($M = 53.41$, SD = 32.24) was significantly faster than the LTA group ($M = 88.49$, SD = 43.35) in post-test, $p = 0.002$. The HTA group pre-test ($M = 81.13$, SD = 40.21) was significantly slower than post-test ($M = 53.41$, SD = 32.24), $p = 0.006$, while the LTA group's pre-test ($M = 54.19$, SD = 32.25) was significantly faster than the post-test ($M = 88.49$, SD = 43.35), $p = 0.001$ (see **Table 1**).

For the interference effect in error rate, ANOVA only yielded a significant main effect of measurement (pre-test and post-test); $F(1,50) = 5.65$, $p = 0.021$, $\eta_p^2 = 0.102$. Post-test ($M = 0.020$, SD = 0.013) showed significantly lower score than the pre-test ($M = 0.079$, SD = 0.036), while the main effect on group and the interaction effect between group and measurement were insignificant ($p > 0.05$) (see **Figure 4**).

Creativity Results

Repeated measures ANOVAs for the within-subject factor measurement (pre-test and post-test) and between-subject factor of group (HTA and LTA) was computed for the AUT (fluency, flexibility, and originality) and RAT (response time and accuracy) to examine the effect of stress on creativity with high- and low-trait anxiety individuals.

For *fluency* of AUT, the results only revealed a significant time × group interaction, $F(1,50) = 16.29$, $p < 0.001$, $\eta_p^2 = 0.245$. Bonferroni-corrected simple-effects tests revealed that the HTA group ($M = 20.69$, SD = 8.13) showed significantly more fluency than the LTA group ($M = 13.69$, SD = 4.86) only in post-test, $p < 0.001$. Interestingly, compared with group difference in pre- and post-test, the HTA group's ($M = 13.69$, SD = 4.86) pre-test result was significantly lower than that of the post-test ($M = 16.89$, SD = 5.78), $p = 0.005$, whereas the LTA group scored significantly higher in pre-test ($M = 20.692$, SD = 8.13) than post-test ($M = 17.65$, SD = 6.56), $p = 0.008$. For AUT *flexibility*, the results revealed a significant time × group interaction, $F(1,50) = 17.70$, $p < 0.001$, $\eta_p^2 = 0.261$. Bonferroni-corrected simple-effects tests revealed that the HTA group ($M = 9.50$, SD = 3.05) showed significantly lower flexibility than the LTA group ($M = 13.88$, SD = 4.43) in the post-test, $p < 0.001$. Compared with group difference in pre- and post-test, HTA group's pre-test score ($M = 11.65$, SD = 3.87) was significantly larger than that of their post-test ($M = 9.50$, SD = 3.05), $p = 0.006$, whereas the LTA group scored ($M = 11.62$, SD = 5.12) significantly lower in pre-test than post-test ($M = 13.89$, SD = 4.43), $p = 0.004$. For AUT *originality*, the results also revealed a significant time × group interaction, $F(1,50) = 6.36$, $p = 0.015$, $\eta_p^2 = 0.113$. Bonferroni-corrected simple-effects tests revealed that the HTA group ($M = 10.88$, SD = 5.55) showed significantly less originality than the LTA group ($M = 18.46$, SD = 10.39) in post-test, $p = 0.002$. Compared with group difference in pre- and post-test, HTA group's score in pre-test ($M = 14.04$, SD = 7.61) was significantly higher than in post-test ($M = 10.88$, SD = 5.55), $p = 0.025$ (see **Figure 5**).

For the accuracy of the RAT, there was a significant main effect of time (pre-test and post-test), $F(1,50) = 7.02$, $p = 0.011$, $\eta_p^2 = 0.123$. The pre-test accuracy score ($M = 51.54$, SD = 14.30) was significantly lower than the post-test accuracy score ($M = 57.60$, SD = 15.03). The results showed a significant group effect, $F(1,50) = 11.11$, $p = 0.002$, $\eta_p^2 = 0.182$. The HTA group scored ($M = 49.42$, SD = 14.27) significantly higher than the LTA group ($M = 59.71$, SD = 13.84). There was no

TABLE 1 | Mean and standard deviations of response time (ms) and error rate (%) for flanker tasks pre and post stress for the LTA and HTA.

		Congruence		Incongruence		Interference effect	
		Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
RT	LTA	504.99 (80.86)	466.13 (87.54)	559.18 (78.87)	554.63 (101.61)	54.19 (32.25)	88.49 (43.35)
	HTA	574.16 (111.34)	558.23 (103.08)	655.29 (112.16)	611.65 (107.31)	81.13 (40.21)	53.41 (32.24)
ER	LTA	0.0054 (0.0190)	0.0054 (0.0190)	0.0788 (0.1384)	0.0300 (0.0763)	0.0735 (0.1429)	0.0246 (0.0782)
	HTA	0.0296 (0.0450)	0.0162 (0.0301)	0.1150 (0.2243)	0.0323 (0.0494)	0.0854 (0.2320)	0.0162 (0.0636)

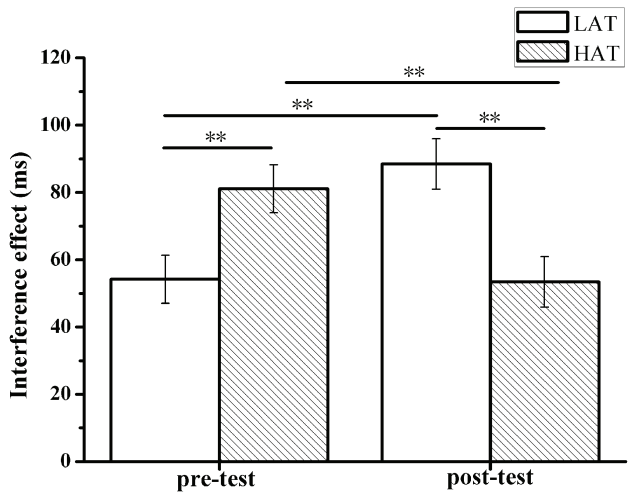

FIGURE 4 | Interference effects (i.e., incongruent-congruent) on response time (a) pre- and post-TSST, for the HTA and LTA groups. Error bars represent standard errors of the means. $^{**}p < 0.01$.

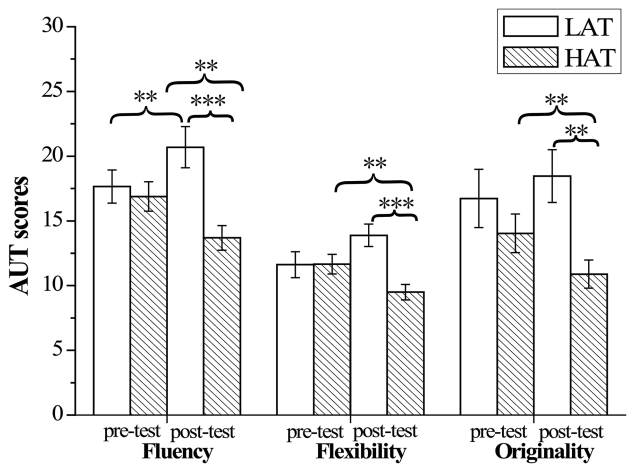

FIGURE 5 | Mean and standard deviation for Alternative Uses Test scores for the HTA and LTA groups. Error bars represent standard errors of the means. $^{**}p < 0.01$, $^{***}p < 0.001$.

interaction effect between measurement and group. For the RAT response time, the results showed a main effect of time (pretest and posttest), $F(1,50) = 5.00$, $p = 0.030$, $\eta_p^2 = 0.091$. The pre-test score ($M = 6174.26$, SD = 1513.66) was significantly lower than the post-test score ($M = 5610.49$, SD = 1435.86) (see **Figure 6**).

To further verify whether there was a mediating mechanism in the process of stress affecting creativity using the bootstrapping method using PROCESS (Hayes, 2013) among flanker performances (model 4) (Preacher and Hayes, 2008). The 95% bias-corrected confidence interval (CI) was examined based on 1,000 bootstrap samples. The area under the curve with respect to increase (AUCi) was calculated using the trapezoidal method for HTA and LTA groups. Pruessner et al. (2003) pointed out that the method represented time-related changes and overall intensity of said changes in salivary cortisol and salivary alpha amylase levels. We performed *z*-transformed AUCi in sC and sAA data because of the individual differences in biological markers (sC and sAA), which were considered independent variables (sAAAUCi; sCAUCi). The changes in creative task performances were considered dependent variables (fluency, flexibility, and originality of the AUT; response time and accuracy of the RAT) and changes in flanker task performances were considered mediator variables (reaction time (FRT) and error rate interference effect (FEI) of flanker); meanwhile, the baseline of flanker and creative task performances were considered control variables. **Table 2** presents the correlations among all variables.

Results only showed that cognitive inhibition (reaction time interference effect of flanker) mediated the effect of stress (AUCi for sAA) on creativity (fluency of AUT), with an estimate of 0.59 and a 95% bootstrap CI of 0.0061–1.4137 (see **Table 3**, **Figure 7**). Based on this result, we claimed that cognitive inhibition was related to pre-post creativity performance (divergent thinking) in both HTA and LTA groups. Furthermore, this result supported the above results that the increase in inhibition control was associated with significantly decreased divergent thinking performance of the HTA group, while decrease in inhibition control was associated with significantly increased divergent thinking performance of the LTA group.

DISCUSSION

The present study examined the mechanism underlying the effect of acute stress on creative thinking, and to what extent this mechanism is influenced by individual differences in trait anxiety. We found higher levels of salivary cortisol and salivary alpha amylase after the TSST, indicating that participants experienced robust activation of the HPA and SNS.

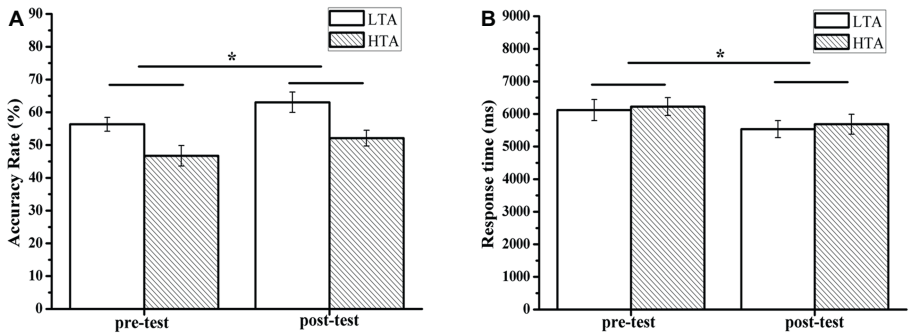

FIGURE 6 | Mean accuracy **(A)** and response time **(B)** for the Remote Associates Test or for the HTA and LTA groups. Error bars represent standard errors of the means. *$p < 0.05$.

TABLE 2 | Correlation coefficients between biological, Flanker and creative performance.

Variables	1	2	3	4	5	6	7	8	9
1. sCAUCi	–	0.312*	–0.111	–0.282*	–0.178	0.016	0.108	0.031	–0.192
2. sAAAUCi		–	–0.521**	–0.480**	–0.433**	–0.153	–0.037	–0.238	–0.234
3. Fluency			–	0.755**	0.668**	–0.032	0.249	0.165	0.234
4. Flexibility				–	0.741**	0.103	0.115	0.299**	0.115
5. Originality					–	0.073	0.069	0.182	0.039
6. RT						–	–0.295*	0.225	–0.048
7. ACC							–	0.102	0.025
8. FRT								–	–0.078
9. FEI									–

*$p < 0.05$; **$p < 0.01$.

TABLE 3 | Mediation results presented based on 1,000 bootstrap resamples.

	Direct effect *c´*	Path *a*	Path *b*	Indirect effect
FRT	–0.94	11.61*	0.05*	0.59 (0.0061–1.4137)†

*Adjusted coefficients with 95% confidence intervals. †Indicates a 95% confidence interval that does not include 0. FRT represents the reaction time interference effect for Flanker task. *$p < 0.05$.*

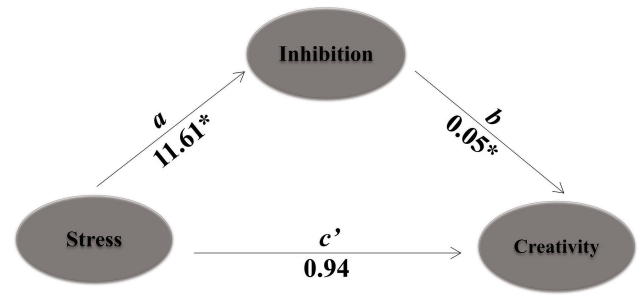

FIGURE 7 | Mediation analyses of cognitive inhibition on the relationship between stress and creativity. Learning stress served as independent variable. Path *a* is the effect of stress on the proposed mediator, while path *b* represents the effect of the mediator on creativity. Path *c'* shows stress's direct effect on creativity. Stress using the indictor of sAAAUCi; inhibition, FRT; creativity, fluency. Result presented here is based on 1,000 bootstrap samples. *$p < 0.05$.

These results were in keeping with previous research, indicating that these two effects are likely due to different neural mechanisms, including the slowly increasing and persistent sC responses during HPA activation and the sAA responses during SNS system activation (Kirschbaum and Hellhammer, 1989; Foley and Kirschbaum, 2010). It is understandable that cognitive tasks (Flanker and creative task) also induced the increase in biological indicators in that cognitive stressors could produce subjective and objective stress effects (MacLeod, 1991; Renaud and Blondin, 1997). In present study, it is important to note that individuals were exposed to robust and reliable stress situation whatever the stress was induced by stress task or by the creative task itself.

One interesting finding was that the HTA group had lower salivary cortisol and salivary alpha amylase than the LTA group. This was consistent with earlier observations, which showed that HTA individuals (who have a relatively low baseline compared with the LTA group) often experience stress in daily social life. This was in line with another study showing that individuals with social anxiety disorder had a decreased cortisol baseline to stress (Elzinga et al., 2010). One possible explanation was that HTA individuals might initially present increased adrenocortical activity, leading to activation of chronicity compensatory mechanisms, gradually resulting in the attenuation in cortisol (Steudte et al., 2011). The repeated exposure to stress then results in habituation reactions,

thereby reducing the individual HPA axis response level (Schommer et al., 2003; Shirotsuki et al., 2009). LTA individuals (who have a relatively high baseline compared with the LTA group), on the other hand, might be more effective in responding to environmental threats owing to their higher cortisol secretion (Villada et al., 2016).

As for the RT interference effect, compared with the LTA group, the HTA group showed worse inhibition control ability before stress, but significantly better inhibition control after. This was consistent with the ACT, which explains that HTA reduces inhibitory control compared with LTA (Eysenck et al., 2007). More importantly, under a stress manipulation, we saw a reduction in interference, whereas LTA individuals showed an increase due to induced anxiety. Combined with the theory of social promotion (Baron, 1986), individuals under stress could narrow the scope of attention and pay closer attention to the target information without distractors because these individuals had no remaining resources to deal with irrelevant information (Chajut and Algom, 2003).

For creative thinking performance, the mediation analysis showed that the increase in inhibition control was associated with significantly decreased divergent thinking performance in the HTA group, while a decrease in inhibition control was associated with significantly increased divergent thinking performance in the LTA group. These results partially supported the hypothesis and were consistent with previous observations, which indicated that anxiety traits modulate biological responses related to cognitive control and representation of cognitive improvement in individuals with HTA under stress (Sehlmeyer et al., 2010). However, the mediation analysis indicated no significant effects of inhibition control on convergent thinking.

According to the ACT, HTA might not decrease effectivity under certain conditions, thereby enabling HTA individuals to recruit additional processing resources to match those of LTA individuals (Eysenck and Derakshan, 2011; Berggren and Derakshan, 2013; Ward et al., 2017). In our study, HTA enhanced top-down processing and thereby hampered divergent thinking. For LTA, the decreased influence of bottom-up automatic processes was more helpful in associating remote ideas during the divergent thinking task (Chrysikou et al., 2014; Barr et al., 2015; Beaty et al., 2016; Hao et al., 2016; Kenett et al., 2018). The finding indicated that the trait anxiety moderates the effect of inhibition control on creativity under stress. The effect of inhibition on creativity also differed with the type of creativity. In other words, a low-inhibition state would enable individuals to obtain potentially useful information in a semantic network through a free association for divergent thinking; however, such a state would cause more distraction, hampering convergent thinking (Eysenck, 1995; Radel et al., 2015).

However, it was surprising that the HTA and LTA groups did not significantly differ in their RAT performance. Our study revealed that there was a shorter response time and a higher accuracy rate after stress in both trait anxiety groups. In the RAT, which is a measure of convergent thinking, stress induction was associated with higher accuracy and shorter reaction times. One possible explanation is that acute stress could increase individual dopamine levels (Robbins and Arnsten, 2009), which might help to facilitate creative problem-solving, such as the RAT (Cristofori et al., 2018). Besides, the problem solution for RAT could involve analytical strategies and insight strategies (Kounios and Beeman, 2014). In negative affect state, people are inclined to use analytical strategies and perform higher accuracy in high negative affect compared to relatively low negative emotions (Shen et al., 2019). Stress is usually accompanied by a relatively higher negative affect which prompts individuals to apply more analytical strategies to facilitate convergent thinking.

FUTURE DIRECTIONS

Creative cognition involves recruitment of working memory (Chuderski and Jastrzębski, 2017, 2018), inhibition (Radel et al., 2015; Teng et al., 2018), and cognitive flexibility (Müller et al., 2016). Our findings indicated that acute stress impaired inhibitory control in LTA individuals but increased inhibitory control in HTA individuals. However, the mechanism underlying the effect of stress was no doubt very complex. Numerous studies showed that activation of the HPA axis was considered to have a significant impact on executive function (working memory, inhibition, and cognitive flexibility). Increased cortisol also could impair working memory (Shields et al., 2015), reduce cognitive inhibition, and increase response inhibition (Shields et al., 2016). In terms of cognitive flexibility, the general conclusion was that stress impaired cognitive flexibility (Alexander et al., 2007; Shields et al., 2016). Recent research has shown that HPA axis activation reduces switching flexibility but increases individual flexibility (Goldfarb et al., 2017). To better understand the role of cognitive control in creative thinking, we need a deeper understanding of the relationship between executive control components and acute stress.

We also found individual differences in creativity under stress. Future research should focus next on individuals with high and low creativity (Beaty et al., 2018), which would enable the assessment of brain functional connectivity as a predictor of individual creative ability under acute stress.

CONCLUSION

The results showed that cognitive inhibition was influenced by trait anxiety and acute stress. Compared to before experiencing acute stress, there was a lack of cognitive inhibition in LTA individuals and they performed better on the AUT (fluency) after acute stress. HTA individuals, on the other hand, showed a decreased interference effect and reduced performance in the AUT (fluency, flexibility, and originality). In the RAT, there were shorter response times and increased accuracy after acute stress in both trait anxiety groups.

Thus, the findings suggest that cognitive control, which is modulated by changes in acute stress, influences creative cognition. The findings also indicated that acute stress can

be influenced by anxiety, thus highlighting the crucial relation between creative cognition, acute stress, and individual differences.

AUTHOR CONTRIBUTIONS

HD and WH designed the experiments. XW and ZW carried out the experiments. FZ analyzed the experimental results. WX and YK assisted with performing the experiments. HD wrote the manuscript.

FUNDING

This research was supported by the Humanity and Social Science Youth Foundation of Ministry of Education of China grant (16YJC190004), National Natural Science Foundation of China grant (31871118, 31700976), Fundamental Research Funds for the Central Universities (GK201902011, GK201901006), Key project for Collaborative Innovation Center of Assessment Towards Basic Education Quality at Beijing Normal University (2018-05-009-BZPK01), and Social Science Foundation of Shaanxi Province (13N151).

REFERENCES

Alexander, J. K., Hillier, A., Smith, R. M., Tivarus, M. E., and Beversdorf, D. Q. (2007). Beta-adrenergic modulation of cognitive flexibility during stress. *J. Cogn. Neurosci.* 19, 468–478. doi: 10.1162/jocn.2007.19.3.468

Baas, M., De Dreu, C. K., and Nijstad, B. A. (2008). A meta-analysis of 25 years of mood-creativity research: hedonic tone, activation, or regulatory focus? *Psychol. Bull.* 134:779. doi: 10.1037/a0012815

Baer, M., and Oldham, G. R. (2006). The curvilinear relation between experienced creative time pressure and creativity: moderating effects of openness to experience and support for creativity. *J. Appl. Psychol.* 91:963. doi: 10.1037/0021-9010.91.4.963

Baron, R. S. (1986). Distraction–conflict theory: progress and problems. *Adv. Exp. Soc. Psychol.* 19, 1–40.

Barr, N., Pennycook, G., Stolz, J. A., and Fugelsang, J. A. (2015). Reasoned connections: a dual-process perspective on creative thought. *Think. Reason.* 21, 61–75. doi: 10.1080/13546783.2014.895915

Beaty, R. E., Benedek, M., Silvia, P. J., and Schacter, D. L. (2016). Creative cognition and brain network dynamics. *Trends Cogn. Sci.* 20, 87–95. doi: 10.1016/j.tics.2015.10.004

Beaty, R. E., Kenett, Y. N., Christensen, A. P., Rosenberg, M. D., Benedek, M., Chen, Q., et al. (2018). Robust prediction of individual creative ability from brain functional connectivity. *Proc. Natl. Acad. Sci. USA* 115, 1087–1092. doi: 10.1073/pnas.1713532115

Beaty, R. E., Silvia, P. J., Nusbaum, E. C., Jauk, E., and Benedek, M. (2014). The roles of associative and executive processes in creative cognition. *Mem. Cogn.* 42, 1186–1197. doi: 10.3758/s13421-014-0428-8

Benedek, M., Franz, F., Heene, M., and Neubauer, A. C. (2012). Differential effects of cognitive inhibition and intelligence on creativity. *Pers. Individ. Dif.* 53, 480–485. doi: 10.1016/j.paid.2012.04.014

Berggren, N., and Derakshan, N. (2013). Attentional control deficits in trait anxiety: why you see them and why you don't. *Biol. Psychol.* 92, 440–446. doi: 10.1016/j.biopsycho.2012.03.007

Beversdorf, D. Q., Hughes, J. D., Steinberg, B. A., Lewis, L. D., and Heilman, K. M. (1999). Noradrenergic modulation of cognitive flexibility in problem solving. *Neuroreport* 10, 2763–2767. doi: 10.1097/00001756-199909090-00012

Bowden, E. M., and Jung-Beeman, M. (2003). Normative data for 144 compound remote associate problems. *Behav. Res. Methods Instrum. Comput.* 35:634. doi: 10.3758/BF03195543

Byron, K., Khazanchi, S., and Nazarian, D. (2010). The relationship between stressors and creativity: a meta-analysis examining competing theoretical models. *J. Appl. Psychol.* 95:201. doi: 10.1037/a0017868

Chajut, E., and Algom, D. (2003). Selective attention improves under stress: implications for theories of social cognition. *J. Pers. Soc. Psychol.* 85, 231–248. doi: 10.1037/0022-3514.85.2.231

Chrysikou, E. G., Weber, M. J., and Thompson-Schill, S. L. (2014). A matched filter hypothesis for cognitive control. *Neuropsychologia* 62, 341–355. doi: 10.1016/j.neuropsychologia.2013.10.021

Chuderski, A., and Jastrzębski, J. (2017). Working memory facilitates insight instead of hindering it: comment on decaro, van stockum, and wieth (2016). *J. Exp. Psychol. Learn. Mem. Cogn.* 43, 1993–2004. doi: 10.1037/xlm0000409

Chuderski, A., and Jastrzębski, J. (2018). Much ado about aha!: insight problem solving is strongly related to working memory capacity and reasoning ability. *J. Exp. Psychol. Gen.* 147:257. doi: 10.1037/xge0000378

Cisler, J. M., and Koster, E. H. W. (2010). Mechanisms of attentional biases towards threat in the anxiety disorders: an integrative review. *Clin. Psychol. Rev.* 30:203. doi: 10.1016/j.cpr.2009.11.003

Cisler, J. M., and Olatunji, B. O. (2012). Emotion regulation and anxiety disorders. *Curr. Psychiatry Rep.* 14, 182–187. doi: 10.1007/s11920-012-0262-2

Clarke, P. J., Browning, M., Hammond, G., Notebaert, L., and MacLeod, C. (2014). The causal role of the dorsolateral prefrontal cortex in the modification of attentional bias: evidence from transcranial direct current stimulation. *Biol. Psychiatry* 76, 946–952. doi: 10.1016/j.biopsych.2014.03.003

Cristofori, I., Salvi, C., Beeman, M., and Grafman, J. (2018). The effects of expected reward on creative problem solving. *Cogn. Affect. Behav. Neurosci.* 18, 925–931. doi: 10.3758/s13415-018-0613-5

Duan, H., Wang, X., Hu, W., and Kounios, J. (2019). Effects of acute stress on divergent and convergent problem-solving. *Think Reason.* 1–19. doi: 10.1080/13546783.2019.1572539

Edwards, E. J., Edwards, M. S., and Lyvers, M. (2015). Cognitive trait anxiety, situational stress and mental effort predict shifting efficiency: implications for attentional control theory. *Emotion* 15, 350–359. doi: 10.1037/emo0000051

Edwards, M. S., Edwards, E. J., and Lyvers, M. (2017). Cognitive trait anxiety, stress and effort interact to predict inhibitory control. *Cognit. Emot.* 31, 671–686. doi: 10.1080/02699931.2016.1152232

Elzinga, B. M., Spinhoven, P., Berretty, E. D., de Jong, P., and Roelofs, K. (2010). The role of childhood abuse in HPA-axis reactivity in social anxiety disorder: a pilot study. *Biol. Psychol.* 83, 1–6. doi: 10.1016/j.biopsycho.2009.09.006

Eriksen, B. A., and Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Percept. Psychophys.* 16, 143–149. doi: 10.3758/BF03203267

Erskine, J. A., Kvavilashvili, L., and Kornbrot, D. E. (2007). The predictors of thought suppression in young and old adults: effects of rumination, anxiety, and other variables. *Pers. Individ. Dif.* 42, 1047–1057. doi: 10.1016/j.paid.2006.09.016

Eysenck, H. J. (1995). *Genius: The natural history of creativity (Vol. 12)*. Cambridge University Press.

Eysenck, M. W., and Derakshan, N. (2011). New perspectives in attentional control theory. *Pers. Individ. Dif.* 50, 955–960. doi: 10.1016/j.paid.2010.08.019

Eysenck, M. W., Derakshan, N., Santos, R., and Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion* 7, 336–353. doi: 10.1037/1528-3542.7.2.336

Fogelman, N., Mikhailik, A., Mueller-Alcazar, A., Bernard, K., and Canli, T. (2016). Stressing over anxiety: a novel interaction of 5-HTTPLR genotype and anxiety-related phenotypes in older adults. *Psychoneuroendocrinology* 71, 36–42. doi: 10.1016/j.psyneuen.2016.05.012

Foley, P., and Kirschbaum, C. (2010). Human hypothalamus-pituitary-adrenal axis responses to acute psychosocial stress in laboratory settings. *Neurosci. Biobehav. Rev.* 35, 91–96. doi: 10.1016/j.neubiorev.2010.01.010

Fonzo, G. A., and Etkin, A. (2017). Affective neuroimaging in generalized anxiety disorder: an integrated review. *Dialogues Clin. Neurosci.* 19, 169–179.

Friedman, N. P., and Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *J. Exp. Psychol. Gen.* 133:101. doi: 10.1037/0096-3445.133.1.101

Gilhooly, K. J., Fioratou, E., Anthony, S. H., and Wynn, V. (2007). Divergent thinking: strategies and executive involvement in generating novel uses for

familiar objects. *Br. J. Psychol.* 98, 611–625. doi: 10.1111/j.2044-8295.2007.tb00467.x

Goette, L., Bendahan, S., Thoresen, J., Hollis, F., and Sandi, C. (2015). Stress pulls us apart: anxiety leads to differences in competitive confidence under stress. *Psychoneuroendocrinology* 54, 115–123. doi: 10.1016/j.psyneuen.2015.01.019

Goldfarb, E. V., Froböse, M. I., Cools, R., and Phelps, E. A. (2017). Stress and cognitive flexibility: cortisol increases are associated with enhanced updating but impaired switching. *J. Cogn. Neurosci.* 29, 14–24. doi: 10.1162/jocn_a_01029

Greening, S. G., and Mitchell, D. G. (2015). A network of amygdala connections predict individual differences in trait anxiety. *Hum. Brain Mapp.* 36, 4819–4830. doi: 10.1002/hbm.22952

Grillon, C., Robinson, O. J., Oconnell, K., Davis, A., Alvarez, G., Pine, D. S., et al. (2017). Clinical anxiety promotes excessive response inhibition. *Psychol. Med.* 47, 1–11. doi: 10.1017/S0033291716002555

Gu, S., Gao, M., Yan, Y., Wang, F., Tang, Y., and Huang, J. H. (2018). The neural mechanism underlying cognitive and emotional processes in creativity. *Front. Psychol.* 9. doi: 10.3389/fpsyg.2018.01924

Guilford, J. P. (1950). Creativity research: past, present and future. *Am. Psychol.* 5, 444–454. doi: 10.1037/h0063487

Hao, N., Ku, Y., Liu, M., Hu, Y., Bodner, M., Grabner, R. H., et al. (2016). Reflection enhances creativity: beneficial effects of idea evaluation on idea generation. *Brain Cogn.* 103, 30–37. doi: 10.1016/j.bandc.2016.01.005

Hayes, A. F. (2013). Introduction to mediation, moderation, and conditional process analysis: a regression-based approach. *Ethn. Health* 51, 335–337. doi: 10.1080/13557858.2017.1315056

Hermans, E. J., Henckens, M. J., Joëls, M., and Fernández, G. (2014). Dynamic adaptation of large-scale brain networks in response to acute stressors. *Trends Neurosci.* 37, 304–314. doi: 10.1016/j.tins.2014.03.006

Izawa, S., Sugaya, N., Yamamoto, R., Ogawa, N., and Nomura, S. (2010). The cortisol awakening response and autonomic nervous system activity during nocturnal and early morning periods. *Neuro Endocrinol. Lett.* 31:685.

Kenett, Y. N., Medaglia, J. D., Beaty, R. E., Chen, Q., Betzel, R. F., Thompson-Schill, S. L., et al. (2018). Driving the brain towards creativity and intelligence: a network control theory analysis. *Neuropsychologia*. doi: 10.1016/j.neuropsychologia.2018.01.001

Kirschbaum, C., and Hellhammer, D. H. (1989). Salivary cortisol in psychobiological research: an overview. *Neuropsychobiology* 22, 150–169. doi: 10.1159/000118611

Kirschbaum, C., Pirke, K. M., and Hellhammer, D. H. (1993). The 'Trier Social Stress Test'–a tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology* 28, 76–81. doi: 10.1159/000119004

Kounios, J., and Beeman, M. (2014). The cognitive neuroscience of insight. *Annu. Rev. Psychol.* 65, 71–93. doi: 10.1146/annurev-psych-010213-115154

Kudielka, B. M., Hellhammer, D. H., Kirschbaum, C., Harmon-Jones, E., and Winkielman, P. (2007). Ten years of research with the Trier Social Stress Test—revisited. *Soc. Neurosci.* 56:83.

Kudielka, B. M., Hellhammer, D. H., and Wüst, S. (2009). Why do we respond so differently? Reviewing determinants of human salivary cortisol responses to challenge. *Psychoneuroendocrinology* 34, 2–18. doi: 10.1016/j.psyneuen.2008.10.004

Kuhlmann, S., Kirschbaum, C., and Wolf, O. T. (2005). Effects of oral cortisol treatment in healthy young women on memory retrieval of negative and neutral words. *Neurobiol. Learn. Mem.* 83, 158–162. doi: 10.1016/j.nlm.2004.09.001

Lovelace, J. B., and Hunter, S. T. (2013). Charismatic, ideological, and pragmatic leaders' influence on subordinate creative performance across the creative process. *Creat. Res. J.* 25, 59–74. doi: 10.1080/10400419.2013.752228

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: an integrative review. *Psychol. Bull.* 109, 163–203. doi: 10.1037/0033-2909.109.2.163

McHugh, R. K., Behar, E., Gutner, C. A., Geem, D., and Otto, M. W. (2010). Cortisol, stress, and attentional bias toward threat. *Anxiety Stress Coping* 23, 529–545. doi: 10.1080/10615801003596969

McNally, R. J. (2006). Cognitive abnormalities in post-traumatic stress disorder. *Trends Cogn. Sci.* 10, 271–277. doi: 10.1016/j.tics.2006.04.007

Modern Chinese Frequency Dictionary (1986). Institute of Language Teaching and Research. Beijing: Beijing Language Institute Press.

Müller, B. C., Gerasimova, A., and Ritter, S. M. (2016). Concentrative meditation influences creativity by increasing cognitive flexibility. *Psychol. Aesthet. Creat. Arts* 10, 278–286. doi: 10.1037/a0040335

Navarro, M., Miyamoto, N., van der Kamp, J., Morya, E., Ranvaud, R., and Savelsbergh, G. J. (2012). The effects of high pressure on the point of no return in simulated penalty kicks. *J. Sport Exerc. Psychol.* 34, 83–101. doi: 10.1123/jsep.34.1.83

Ohly, S., and Fritz, C. (2010). Work characteristics, challenge appraisal, creativity, and proactive behavior: a multi-level study. *J. Organ. Behav.* 31, 543–565. doi: 10.1002/job.633

Preacher, K. J., and Hayes, A. F. (2008). "Contemporary approaches to assessing mediation in communication research" in *The Sage source book of advanced data analysis methods for communication research*. 13–54.

Probst, T. M., Stewart, S. M., Gruys, M. L., and Tierney, B. W. (2007). Productivity, counterproductivity and creativity: the ups and downs of job insecurity. *J. Occup. Organ. Psychol.* 80, 479–497. doi: 10.1348/096317906X159103

Pruessner, J. C., Kirschbaum, C., Meinlschmid, G., and Hellhammer, D. H. (2003). Two formulas for computation of the area under the curve represent measures of total hormone concentration versus time-dependent change. *Psychoneuroendocrinology* 28, 916–931. doi: 10.1016/S0306-4530(02)00108-7

Qureshi, S. U., Long, M. E., Bradshaw, M. R., Pyne, J. M., Magruder, K. M., Kimbrell, T., et al. (2011). Does PTSD impair cognition beyond the effect of trauma? *J. Neuropsychiatry Clin. Neurosci.* 23, 16–28. doi: 10.1176/jnp.23.1.jnp16

Radel, R., Davranche, K., Fournier, M., and Dietrich, A. (2015). The role of (dis) inhibition in creativity: decreased inhibition improves idea generation. *Cognition* 134, 110–120. doi: 10.1016/j.cognition.2014.09.001

Radel, R., Sarrazin, P., Legrain, P., and Wild, T. C. (2010). Social contagion of motivation between teacher and student: analyzing underlying processes. *J. Educ. Psychol.* 102, 577–587. doi: 10.1037/a0019051

Redick, T. S., and Engle, R. W. (2006). Working memory capacity and attention network test performance. *Appl. Cogn. Psychol.* 20, 713–721. doi: 10.1002/acp.1224

Renaud, P., and Blondin, J. (1997). The stress of Stroop performance: physiological and emotional responses to color-word interference, task pacing, and pacing speed. *Int. J. Psychophysiol.* 27, 87–97. doi: 10.1016/S0167-8760(97)00049-4

Robbins, T. W., and Arnsten, A. F. (2009). The neuropsychopharmacology of fronto-executive function: monoaminergic modulation. *Annu. Rev. Neurosci.* 32, 267–287. doi: 10.1146/annurev.neuro.051508.135535

Schommer, N. C., Hellhammer, D. H., and Kirschbaum, C. (2003). Dissociation between reactivity of the hypothalamus-pituitary-adrenal axis and the sympathetic-adrenal-medullary system to repeated psychosocial stress. *Psychosom. Med.* 65, 450–460. doi: 10.1097/01.PSY.0000035721.12441.17

Sehlmeyer, C., Konrad, C., Zwitserlood, P., Arolt, V., Falkenstein, M., and Beste, C. (2010). Erp indices for response inhibition are related to anxiety-related personality traits. *Neuropsychologia* 48, 2488–2495. doi: 10.1016/j.neuropsychologia.2010.04.022

Shek, D. T. (1993). The Chinese version of the State-Trait Anxiety Inventory: its relationship to different measures of psychological well-being. *J. Clin. Psychol.* 49, 349–358. doi: 10.1002/1097-4679(199305)49:3<349::AID-JCLP2270490308>3.0.CO;2-J

Shen, W., Zhao, Y., Hommel, B., Yuan, Y., Zhang, Y., Liu, Z., et al. (2019). The impact of spontaneous and induced mood states on problem solving and memory. *Think. Skills Creat* 32, 66–71. doi: 10.1016/j.tsc.2019.03.002

Shields, G. S., Bonner, J. C., and Moons, W. G. (2015). Does cortisol influence core executive functions? A meta-analysis of acute cortisol administration effects on working memory, inhibition, and set-shifting. *Psychoneuroendocrinology* 58, 91–103. doi: 10.1016/j.psyneuen.2015.04.017

Shields, G. S., Sazma, M. A., and Yonelinas, A. P. (2016). The effects of acute stress on core executive functions: a meta-analysis and comparison with cortisol. *Neurosci. Biobehav. Rev.* 68, 651–668. doi: 10.1016/j.neubiorev.2016.06.038

Shirotsuki, K., Izawa, S., Sugaya, N., Yamada, K. C., Ogawa, N., Ouchi, Y., et al. (2009). Salivary cortisol and DHEA reactivity to psychosocial stress in socially anxious males. *Int. J. Psychophysiol.* 72, 198–203. doi: 10.1016/j.ijpsycho.2008.12.010

Spielberger, C. D. (1979). *Understanding stress and anxiety*. New York, NY: Harper & Rowe.

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., and Jacobs, G. A. (1983). *Manual for the State-Trait anxiety inventory*. Palo Alto, CA: Consulting Psychologists Press.

Steudte, S., Stalder, T., Dettenborn, L., Klumbies, E., Foley, P., Beesdo-Baum, K., et al. (2011). Decreased hair cortisol concentrations in generalised anxiety disorder. *Psychiatry Res.* 186, 310–314. doi: 10.1016/j.psychres.2010.09.002

Suedfeld, P., and Vernon, J. (1965). Stress and verbal originality in sensory deprivation. *Psychol. Rec.* 15, 567–570. doi: 10.1007/BF03393631

Teng, J., Shen, W., and Hao, N. (2018). The role of cognitive control in divergent thinking. *Adv. Psychol. Sci.* 26, 411–422. doi: 10.3724/SP.J.1042.2018.00411

Villada, C., Hidalgo, V., Almela, M., and Salvador, A. (2016). Individual differences in the psychobiological response to psychosocial stress (Trier Social Stress Test): the relevance of trait anxiety and coping styles. *Stress. Health* 32, 90–99. doi: 10.1002/smi.2582

Ward, R. T., Smith, S. L., Kraus, B. T., Allen, A. V., Moses, M. A., and Simondack, S. L. (2017). Alpha band frequency differences between low-trait and high-trait anxious individuals. *Neuroreport* 29, 79–83. doi: 10.1097/WNR.0000000000000915

Wang, X., Duan, H., Kan, Y., Wang, B., Qi, S., and Hu, W. (2019). The creative thinking cognitive process influenced by acute stress in humans: an electroencephalography study. *Stress* 22, 472–481. doi: 10.1080/10253890.2019.1604665

Weger, M., and Sandi, C. (2018). High anxiety trait: a vulnerable phenotype for stress-induced depression. *Neurosci. Biobehav. Rev.* 87:27. doi: 10.1016/j.neubiorev.2018.01.012

World Medical Association (WMA) (2013). World Medical Association Declaration of Helsinki. *Ethical Principles for Medical Research Involving Human Subjects*. Available from: www.wma.net/en/30publications/10policies/b3.htm

Xu, S., Duan, H., Qi, S., Gao, J., and Hu, W. (2015). Development of Chinese compound remote association test. *Paper presented at the meeting of the 18th national conference of Chinese Psychological Association*; Tianjin, China.

Yeh, Y. C., Lai, G. J., Lin, C. F., Lin, C. W., and Sun, H. C. (2015). How stress influences creativity in game-based situations: analysis of stress hormones, negative emotions, and working memory. *Comput. Educ.* 81, 143–153. doi: 10.1016/j.compedu.2014.09.011

Zhou, Z., Hu, L., Sun, C., Li, M., Guo, F., and Zhao, Q. (2019). The effect of Zhongyong thinking on remote association thinking: an EEG study. *Front. Psychol.* 10. doi: 10.3389/fpsyg.2019.00207

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Advantages of publishing in Frontiers

OPEN ACCESS
Articles are free to read for greatest visibility and readership

FAST PUBLICATION
Around 90 days from submission to decision

HIGH QUALITY PEER-REVIEW
Rigorous, collaborative, and constructive peer-review

TRANSPARENT PEER-REVIEW
Editors and reviewers acknowledged by name on published articles

Frontiers
Avenue du Tribunal-Fédéral 34
1005 Lausanne | Switzerland

Visit us: www.frontiersin.org
Contact us: info@frontiersin.org | +41 21 510 17 00

REPRODUCIBILITY OF RESEARCH
Support open data and methods to enhance research reproducibility

DIGITAL PUBLISHING
Articles designed for optimal readership across devices

FOLLOW US
@frontiersin

IMPACT METRICS
Advanced article metrics track visibility across digital media

EXTENSIVE PROMOTION
Marketing and promotion of impactful research

LOOP RESEARCH NETWORK
Our network increases your article's readership