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Self-construals moderate associations between trait creativity and social brain network

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A R T I C L E I N F O

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A B S T R A C T

Creativity is an adaptive way of thinking and plays a key role in problem solving. Recent brain imaging studies focused on structural and functional characteristics of the brain that are correlated with creativity. But whether and how the association between creativity and the brain is moderated by individuals' cultural traits remains unclear. We integrated functional magnetic resonance imaging (fMRI) and questionnaire measures (Williams creativity aptitude test) of trait creativity and self-construal (e.g., interdependence) in male adults to examine whether trait creativity is associated with neural activities underlying social cognition and whether and how the association is moderated by individuals' self-construals. We found that interdependence moderates the association between trait creativity and neural activities in the left superior temporal sulcus, right anterior insular, right temporal-parietal junction and right precentral gyrus engaged in reflection of one's own social attributes. Interdependence also moderates the association between trait creativity and neural activities in the left superior temporal sulcus and right posterior insular involved in reflection of a friend's social attributes. The link of trait creativity and the functional connectivity between the medial prefrontal cortex and postcentral gyri during reflection of a friend's social attributes is also moderated by interdependence. Participants with high and low creativity traits can be dissociated in a three-dimension space defined by integration of interdependence and the brain activity underlying reflection of one's own and the friend's attributes. Our findings suggest that trait creativity is imprinted on the social brain and the link between trait creativity and the neural activities underlying the processing of self and others is moderated by a cultural trait.

1. Introduction

Creativity is a set of complicated mental processes or personalities that give rise to novel ideas/products and help people to solve problems (Hennessey and Amabile, 2010). Given that creativity as either an ability or trait is critical for people to adapt to environments, there have been increasing interests in understanding the neural correlates of creativity in brain imaging literatures. Recent studies have examined characteristics of anatomical structures or functional activity of the human brain that are associated with creativity. These studies have identified several neural networks that are possibly linked to creativity. The semantic network consisting of the left inferior frontal gyrus and temporal regions supports cognitive processes including language production, semantic representation and integration that are necessary for creative performance (Li et al., 2015; Shah et al., 2013; Zhu et al., 2013). The memory retrieval network in the parietal cortices may mediate generation of creative new ideas that are relied on efficient memory retrieval and flexible integration of existing knowledge (Benedek et al., 2013; Fink et al., 2012). The default mode network including the medial prefrontal cortex and precuneus may support internally-focused attention for maintenance of large sets of information during task-specific creative processes and resting states (Aziz-Zadeh et al., 2013; Chen et al., 2015; Mayseless et al., 2015; Takeuchi et al., 2012; Villarreal et al., 2013). The motor-related regions consisting of the precentral gyrus, supplementary motor area and premotor cortex are also associated with creation by providing motor planning or motor control (Aziz-Zadeh et al., 2013; Villarreal et al., 2013; Zhu et al., 2016). Creativity in the aforementioned studies was assessed either

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using questionnaires to estimate individuals' creative potentials (e.g., divergent feeling) (Claxton et al., 2005; Li et al., 2015; Liu et al., 2011; Zhu et al., 2016) or by measuring individuals' creative performances in ongoing cognitive tasks (e.g., divergent thinking) (Aziz-Zadeh et al., 2013; Chen et al., 2015; Mayseless et al., 2015; Villarreal et al., 2013; Zhu et al., 2013).

The findings of these studies provide evidence for co-variations of cortical structures and functions with creative potentials or performances. However, almost all the previous studies focused on the association between neural activities underlying basic cognitive/motor processes and creativity traits/performances. There has been little research concerning the link of brain activity involved in social cognition and creativity. Moreover, little is known about whether and how the association between creativity and brain activities is moderated by individuals' cultural traits. It is crucial to conduct empirical research to address these issues because it has long been recognized that both ongoing cognitive performances and chronic affective traits are critical components of creativity (Williams, 1980).

Behavioral research has shown that experiences of social interaction significantly influence creative performance such that individuals who received support from both work (supervisors/coworkers) and nonwork (family/friends) sources exhibited better creative performance (Madjar et al., 2002). Edmondson and Mogelof (2006) proposed that psychological safety — an environment condition about relationship in which people believe that others will respond positively to themselves when they speak up about concerns, report mistakes, or propose new ideas — is also important for creativity. This assertion implies that creativity may be modulated by how an individual thinks about the self and others in a specific sociocultural environment. At the neural level, one may further hypothesize that the association between trait creativity and neural representations of self and others can be moderated by individuals' cultural traits.

A possible cultural trait that may moderate the association between creativity and neural representations of self and others is self-construal, which is strongly influenced by sociocultural environments. Independent self-construals that emphasize the uniqueness of the self and one's own intentions in behavior dominate the Western, individualistic societies, whereas interdependent self-construals, which view the self as inherently connected with others and take others' opinions into consideration when making decisions on one's own behavior, are popular in the East Asian, collectivistic societies (Markus and Kitayama, 1991; Oyserman et al., 2002). Independent and interdependent self-construals as cultural traits have been shown to affect multiple cognitive/affective and neural processes (Han et al., 2013; Oyserman et al., 2014; Han and Ma, 2015) and thus may also influence the relationships between creativity and the brain. Goncalo and Staw (2006) reported that groups dominated with individualistic cultural traits were more creative than those dominated with collectivistic cultural traits when being asked to generate ideas about how to solve a particular problem. Wiekens and Stapel (2008) also found that, relative to those with interdependent self-construals, individuals' with independent self-construals showed more creative responses in figural and word tasks, suggesting that individualistic culture encourages creation of original ideas possibly by emphasizing uniqueness of the self and less conforming to others. However, collectivistic culture or interdependent self-construals may encourage harmonious relationships with others that also influence creativity (Hannover, 2006). Consistent with this assertion, Bechtoldt et al. (2010) found that people showed increased group creativity when group members showed high pro-social motivation (i.e., collectivistic orientation) rather than pro-self motivation (i.e., individualistic orientation), possibly because collectivistic cultural orientation increased joint outcomes and acceptance by others made individuals less hesitant to spontaneously express their ideas and perceived less personal criticism.

The behavioral findings suggest that creativity is characterized by other-oriented motivation for those with high interdependent (or low independent) self-construals whereas creativity is characterized by self-oriented motivation for those with low interdependent (or high independent) self-construals. The behavioral findings allow us to hypothesize that self-construals moderate the association between trait creativity and brain activities involved in representation of oneself and others. We tested this hypothesis by scanning healthy adults using fMRI in a social role judgment task that required participants to reflect on social attributes of oneself, a close other (e.g., a friend) and a celebrity (Kelley et al., 2002; Ma et al., 2014; Northoff and Bermpohl, 2004; Zhu et al., 2007). This design allowed us to identify brain activities involved in representation of attributes of the self and a close other. We estimated participants' self-construals using Self-Construal Scales (Singelis, 1994) and their trait creativity using the Williams creativity aptitude test (WCAT, Williams, 1980). WCAT is a self-reported questionnaire measuring individuals' divergent feelings, which is described as non-cognitive facets of creativity related to the motivation dimensions in creativity along with personality characteristics (Cropley, 2003). The measurement of WCAT depends on self-report and thus essentially reflects creative self-perceptions. The present study used the WCAT questionnaire (Williams, 1980; Lin and Wang, 1999) to assess individuals' affective component of creativity (i.e., self-reported divergent feelings in daily life). Using hierarchical regression analyses we then examined whether individuals' trait creativity is associated with neural activities underlying representations of the self and whether such associations are moderated by self-construals. We also tested whether individuals with high and low creativity can be identified by integration of self-construals and brain activities underlying self/others representations.

2. Methods

2.1. Participants

Thirty seven male adults (mean age = 22.9 yrs, SD = 2.73 yrs) participated in this study as paid volunteers. All were right-handed and had normal or corrected-to-normal vision. All reported no history of psychiatric disorder and medication/drug/alcohol abuse. Informed consent was obtained prior to participation. This study was approved by the ethics committee of School of Psychological and Cognitive Sciences, Peking University. Because previous research has suggested gender difference both in self-construals (e.g., Cross and Madson, 1997; Guimond et al., 2006) and in self-reported creativity trait or performance (e.g., Baer and Kaufman, 2008; Abraham, 2016), the present study tested only male participants to avoid gender effects on potential associations between brain activity and creativity.

2.2. Stimuli and procedure

We used 144 words of social roles (student, athlete, Chinese, etc.) and randomly selected 48 of them replicated once so that to create a word list of 192 social roles. These 192 words were classified into 2 lists for 2 functional scans. A block design was used in the current work. Each scan consisted of 8 blocks of 12 trials presented in a random order with 8 s interval between two neighboring blocks (Fig. 1). On each trial, a word describing a social role was presented at the center of the screen below a cue word (i.e., Self, a friend's name, a celebrity's name, or Font) for 2250 ms followed by a fixation with a duration of 750 ms. Participants had to judge (yes/no) whether a social role can describe self (or a friend, or Liu Xiang (a well-known Chinese athlete)) by pressing one of two buttons in 2 blocks. They also judged the Font (bold- vs. light-faced character) of a word describing a social role in 2 blocks. Friend- and celebrity-judgments were employed to control for familiarity and general person processing. Font-judgments were used to control general perceptual and semantic processing engaged in the judgment tasks.

Trait creativity was assessed using WCAT developed by Williams (1980). WCAT consists of 50 items with Imagination, Curiosity,

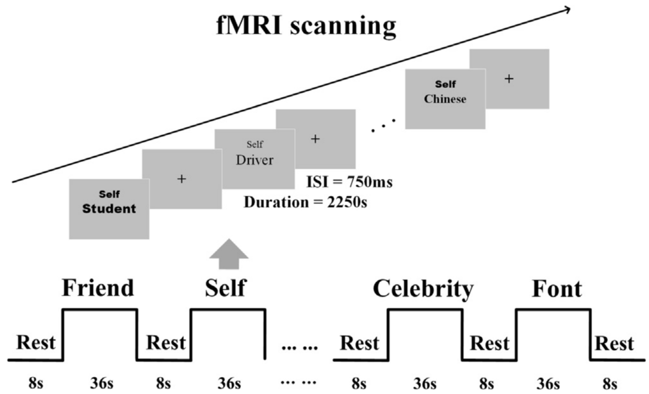

Fig. 1. Illustration of the experimental procedure. A block design was employed in which Self, Friend, Celebrity and Font judgments were conducted in different blocks of trials. Participants were asked to judge whether the social roles presented can describe the self, a friend, a celebrity or the font of the words.

Challenge and Risk-taking four subscales. Subjects were asked to rate the extent to which they agree or disagree with each item on a three-point Likert scales ranging from strongly disagree to strongly agree. We used the Chinese version of the scale developed by Lin and Wang (1999) with good internal consistency (.765–.877) and test–retest reliability (.489–.810). The Cronbach alpha coefficient in this study was .812. The criterion validity of the WCAT was .261~.545 when using figural Torrance Tests of Creative Thinking (TTCT) as a standard (Lin and Wang, 1999). The WCAT was widely used as a reliable measurement of trait creativity (Claxton et al., 2005; Li et al., 2015; Liu et al., 2011). The higher the total score of WCAT, the higher creative potential (Li et al., 2015). Tan et al. (2015) have reported that individuals who showed more insights in problem solving rated themselves higher in WCAT.

Self-construals were measured using the Self-Construal Scale (Singelis, 1994), which consists of 24-items that assess independent and interdependent self-construals on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). Interdependence was defined by the difference between the sum score of the 12 interdependent self-construal items and the sum score of the 12 independent self-construal items. Higher difference scores indicate greater interdependent cultural values (Ma et al., 2014).

2.3. Imaging data acquisition and analysis

Brain images were acquired using a 3.0 T GE Signa MR750 scanner (GE Healthcare; Waukesha, WI) with a standard head coil. Functional images were acquired by using T2-weighted, gradient-echo, echo-planar imaging (EPI) sequences sensitive to BOLD contrast ($64 \times 64 \times 32$ matrix with $3.75 \times 3.75 \times 5\,mm^3$ spatial resolution, repetition time = 2000 ms, echo time = 30 ms, flip angle = 90°, field of view = 24×24 cm). A high-resolution T1-weighted structural image ($512 \times 512 \times 180$ matrix with a spatial resolution of $.47 \times .47 \times 1.0\,mm^3$, repetition time = 8.204 ms, echo time = 3.22 ms, flip angle = 12°) was acquired before the functional scans.

Functional images were preprocessed using SPM8 software (the Wellcome Trust Centre for Neuroimaging, London, UK). Head movements were corrected within each run and six movement parameters (translation; x, y, z and rotation; pitch, roll, yaw) were extracted for further analysis in the statistical model. The anatomical image was coregistered with the mean realigned functional image and then was normalized to the standard Montreal Neurological Institute (MNI) template. The functional images were resampled to $3 \times 3 \times 3\,mm^3$ voxels, normalized to the MNI space using the parameters of anatomical normalization and then spatially smoothed using an isotropic of 8 mm full-width half-maximum (FWHM) Gaussian kernel.

Fixed effect analyses were first conducted by applying a general linear model (GLM) to fMRI data. All five conditions (Self, Friend, Celebrity, Font and rest) were included in the model. The design matrix also included the realignment parameters to account for any residual movement-related effect. A box-car function was used to convolve with the canonical hemodynamic response in each condition. Regardless of creativity and self-construal, whole-brain random effect analyses were conducted on the contrast images of self- vs. celebrity-judgment (contrast vector: self 1, celebrity −1) and friend- vs. celebrity-judgment (contrast vector: friend 1, celebrity −1). Then, we used the contrast images (Self vs. Celebrity, Friend vs. Celebrity) as dependent variables and conducted regression analyses with subjects' Creativity (sum score of WCAT), Interdependence (interdependent minus independent scores) and the interaction between Creativity and Interdependence (product of the centered scores in WCAT and Self-Construal Scale) as regressors, as illustrated below:

$$Y = \beta_1 Creativity + \beta_2 Interdependence + \beta_3 Creativity{*}Interdependence + \beta_0$$

This regression analysis aimed to identify the brain regions correlated with individuals' trait creativity, interdependence and the interaction between interdependence and creativity during self- and friend-related processing. Brain activations were defined using a threshold of $p < .05$ (FDR corrected with single voxel threshold of $p < .001$). Then, the contrast values (self vs. celebrity and friend vs. celebrity) of the brain regions were extracted using MarsBaR (http://marsbar.sourceforge.net). To further check the moderation role of self-construal and for visualization purposes, the moderation effect of self-construal on the association between creativity and self/friend vs. celebrity neural activity was shown with the use of a split of high and low interdependence (6 is the cutoff score and resulted in 20 subjects in low interdependence group and 17 subjects in high interdependence group). Correlation coefficients between creativity and neural activity during self- vs. celebrity-judgment and friend- vs. celebrity-judgment were calculated in high and low interdependent group respectively. Fisher-z transformation was used to check the correlations in different groups were significantly different. Since the brain regions that showed significant interactions between interdependence and creativity were identified in the whole brain analyses after FDR correction, the significance of the correlation coefficients for each brain region was shown only for visualization purpose and thus was not corrected for multiple comparisons.

We also conducted generalized psychophysiological interaction analyses (gPPI) (McLaren et al., 2012) to check brain regions that showed functional connectivity with the seed regions. The coordinates of the peak voxels from the contrast of self- vs. celebrity-judgments and friend- vs. celebrity-judgments in one-sample *t*-tests across all participants were used to define the seed regions for gPPI analyses. The region of interest was defined as a sphere with 5-mm-radius centered at the peak voxel of a cluster. The time courses of each ROI (medial prefrontal cortex (MPFC), x/y/z = −9/53/1, defined in the contrast of self- vs. celebrity-judgments; MPFC (x/y/z = −6/56/−2) and precuneus (x/y/z = −6/−58/43) defined in the contrast of friend- vs. celebrity-judgments) were then extracted and the psychophysiological interaction regressors were calculated as the product of the brain activity of this region and a vector of the psychological variables. The psychophysiological interaction regressors reflected the interaction between psychological variables (self- vs. celebrity-judgments or friend- vs. celebrity-judgments) and the activation time course of the seed regions. The contrast images reflecting the effects of the psychophysiological interaction between the seed regions and other brain areas were subsequently subjected to regression analyses with creativity, interdependence and the product of them (similar to the regression equation above, Y is the functional connectivity with seed regions). The results of regression analysis identified brain regions in which the functional connectivity with the seed regions during self- vs. celebrity-judgments or friend- vs. celebrity-judgments were associated with creativity and modulated by self-construal.

After finding that trait creativity was characterized by specific neural responses to self- and friend-processing (vs. celebrity-processing) and the moderation role of interdependence self-construal, we attempted to use the neural indices (brain activity and functional connectivity) combined with self-construal to predict individuals' creativity. Top 27% subjects (10 subjects whose sum WCAT scores were higher than 113) and bottom 27% subjects (10 subjects whose sum WCAT scores were lower than 100) were selected as high and low creative group. A Fisher's discriminant function was conducted to examine whether the neural indices coding self/friend (vs. celebrity) combined with self-construal could predict individuals' trait creativity. Discriminant analysis was conducted with a featured vector $x = (x_s, x_f, x_{fc}, x_i)$ for each subject that was determined by four values. x_s and x_f denotes the brain activity showed interaction between self-construal and creativity during self- vs. celebrity-judgments and friend- vs. celebrity-judgments respectively. x_{fc} is the increased functional connectivity in friend-judgment compared with celebrity judgment where showed interaction between self-construal and creativity during friend- vs. celebrity-judgments. x_i is the Interdependence score of Self-Construal Scale. We found four brain regions that were sensitive to the interaction of self-construal and creativity during self- vs. celebrity-judgments and that these activities in these regions were correlated with each other ($rs(37) = .495\sim.703$; $p < .005$). To reduce multicollinerity, we averaged the contrast values in these regions weighted with their cluster size to obtain a neural index of self-processing, which is used as x_s in discriminant analysis. Similarly, the two regions sensitive to the interaction of self-construal and creativity during friend- vs. celebrity-judgments and the two regions showed increased functional connectivity with the seed region in friend-judgment vs. celebrity-judgment were also correlated with each other ($rs(37) = .378–.762$; $ps < .021$) and were averaged weighted with their cluster size which is used as x_f and x_{fc} in discriminant analysis. Since self-construal modulates the association between creativity and self-other neural activity, we considered the moderation effect by multiplying the neural indices by the score of Interdependence, i.e., $x_s x_i$, $x_f x_i$ and $x_{fc} x_i$. A quadratic discriminant function was defined as $g(x) = w_s x_s x_i + w_f x_f x_i + w_{fc} x_{fc} x_i + w_0$. w_s and w_f are the weights of the brain activity induced by self- and friend-judgments respectively, w_{fc} is the weight of the increased functional connectivity with the seed region in friend-processing (compared with celebrity-processing) and w_0 is the bias. Because creativity and self-construal didn't simply correlate with the brain activity during self- or friend-judgments, we didn't include x_s, x_f, x_{fc}, x_i and quadratic terms (x_s^2, x_f^2, x_{fc}^2, x_i^2) in the quadratic discriminant function. The brain activity, functional connectivity and interdependence scores used in the equation were all normalized. The optimal weights and bias of the discriminant function were calculated using the Fisher's discriminant function (Duda and Hart, 1973; Cawley and Talbot, 2003). We employed the leave-one-out cross-validation, i.e., one case was left out of the training set and then used as a test set. The discriminant function was then used to classify the "leave-out" individual subject into high creative group or low creative group. Repeating this procedure for all the cases in the data set estimated the generalization accuracy of the method. The accuracy of such classification analysis helps to validate that neural responses during self- and other-processing and individuals' self-construals could predict creativity since the classification analysis reduced any bias produced by precategorization of participants in terms of creativity (Cawley and Talbot, 2003).

3. Results

3.1. Behavioral results

We calculated participants' reaction times (RTs) during self-, friend-, celebrity- and font-judgment as behavioral indices for self-, friend-, celebrity- and font-related processing. A repeated measure analysis of variance (ANOVA) of the reaction times (RTs) with Target (self, friend, celebrity, font) as a within-subject variable showed significant main effect of Target ($F(3, 108) = 111.884$, $p < .001$). The RTs in ascending sequence were Font, Self, Friend and Celebrity. However, the RTs were correlated neither with individuals' trait creativity nor with interdependence self-construal ($ps > .1$). The mean accuracy of font-judgments was high (94.99%). We also calculated the correlation between scores of interdependence and trait creativity but did not find significant results ($r(37) = .118$, $p = .488$).

3.2. fMRI results

Whole-brain analyses of all participants revealed that, relative to celebrity-judgments, self-judgments significantly activated MPFC (x/y/z = −9/53/1, z = 6.43; k = 1053) (Table 1). Friend-judgments also significantly activated MPFC (x/y/z = −6/56/−2, z = 5.74; k = 1109) and precuneus (x/y/z = −6/−58/43, z = 4.45; k = 353) compared with celebrity-judgments. Using these regions as seeds, we then conducted gPPI analyses and found that the MPFC activated during self-judgments showed enhanced functional connection with the calcarine sulcus whereas the MPFC activated during friend-judgments failed to show enhanced connection with any other brain regions (Table 1).

Then, we separately used contrast images of self vs. celebrity and

Table 1
Activations shown in different contrasts and regressions.

Region	MNI Coordinates			Cluster Size	Peak Z
	x	y	z		
Brain activity					
Self- vs. Celebrity-judgments					
MPFC	−9	53	1	1053	6.43
Friend- vs. Celebrity-judgments					
MPFC	−6	56	−2	1109	5.74
Precuneus	−6	−58	43	353	4.45
Modulation effect of Interdependence					
Self- vs. Celebrity-judgments					
Left STS	−39	−10	−11	268	4.51
Right TPJ/PI	51	−28	13	538	4.79
Right AI	33	11	4	128	4.30
Right postcentral gyrus	36	−25	67	148	3.80
Friend- vs. Celebrity-judgments					
Left STS	−51	5	−20	362	4.48
Right PI	39	−22	7	395	4.11
Functional connectivity					
Self- vs. Celebrity-judgments					
Calcarine sulcus	6	−64	10	281	4.72
Friend- vs. Celebrity-judgments					
–					
Modulation effect of Interdependence					
Self- vs. Celebrity-judgments					
Left postcentral gyrus	−60	−10	46	239	4.34
Right postcentral gyrus	54	−10	55	295	4.35
Friend- vs. Celebrity-judgments					
–					

$p < .05$ FDR corrected with single voxel threshold of $p < .001$.
MPFC: medial prefrontal cortex; STS: superior temporal sulcus; TPJ: temporal parietal junction; AI: anterior insular. PI: posterior insular.

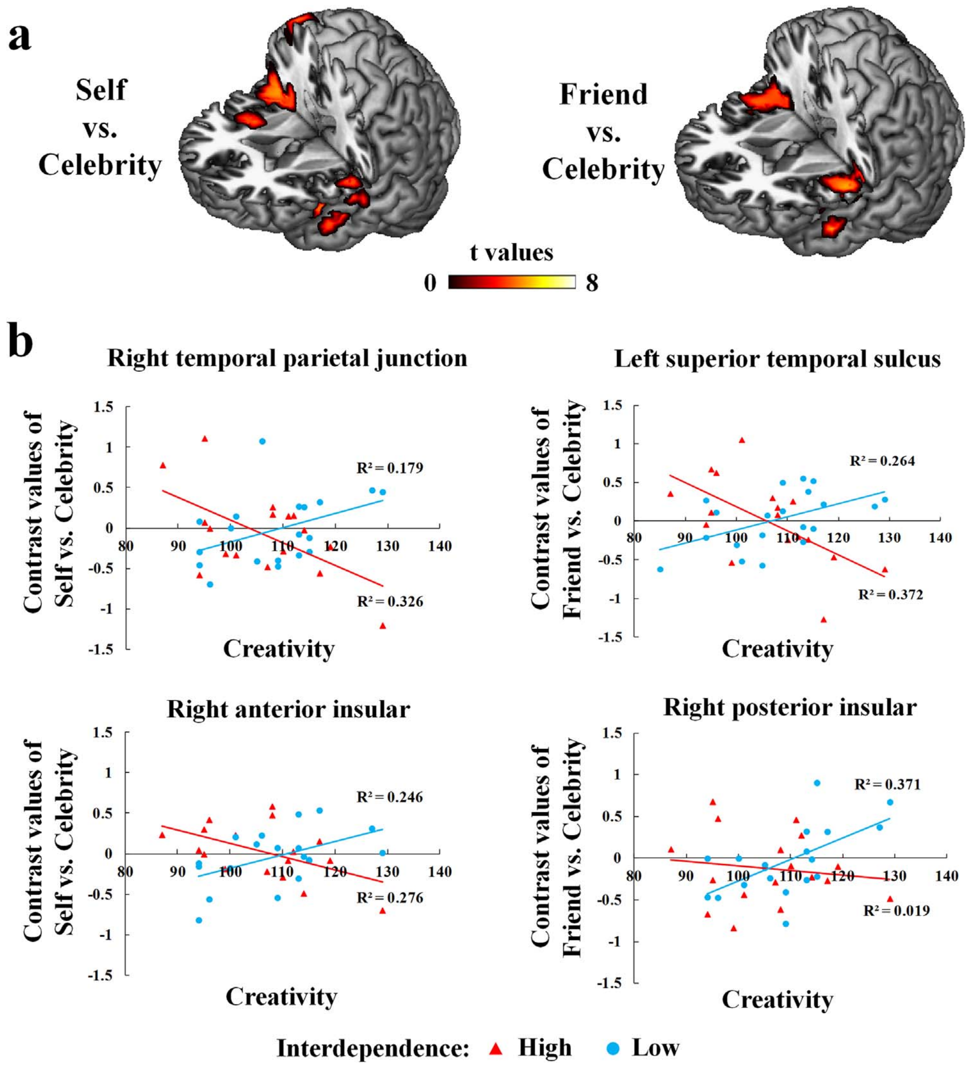

Fig. 2. Moderation effects of the self-construal (i.e., interdependence) on the link between trait creativity and neural activities. (a) Brain regions showed significant interaction between self-construal and trait creativity in self- vs. celebrity-judgment and friend- vs. celebrity-judgment. (b) Pattern of the self-construal moderation on the link between creativity and brain activity in different regions. In each region, red dots represent subjects with high interdependence and blue dots represent subjects with low interdependence.

friend vs. celebrity as a dependent variable and conducted whole brain regression analyses to search for brain activity associated with individuals' scores of trait creativity, interdependence and the interaction of creativity × interdependence. Results showed that there was no brain region in which activities in response to self-judgments significantly correlated with trait creativity or interdependence. However, activities during self-judgments (vs. celebrity-judgments) in several brain regions were significantly correlated with the interaction of interdependence and trait creativity, including the left superior temporal sulcus (STS) (x/y/z = −39/−10/−11, z = 4.51; k = 268), the right temporal-parietal junction (TPJ)/posterior insular(PI) (x/y/z = 51/−28/13, z = 4.79; k = 538), the right anterior insular (AI) (x/y/z = 33/11/4, z = 4.30; k = 129) and the right precentral gyrus (x/y/z = 36/−25/67, z = 3.80; k = 148). The brain activity in the left STS (x/y/z = −51/5/−20, z = 4.48; k = 362) and the right PI (x/y/z = 39/−22/7, z = 4.11; k = 395) activated during friend-judgments was significantly correlated with the interaction of creativity × interdependence (Fig. 2a, Table 1). We conducted similar analyses of the contrast images of celebrity- vs. font-judgments but did not find significant results. These results provide evidence that self-construals moderated the association between trait creativity and the neural activities underlying self- and friend-referential processing.

To further illustrate the moderation effects, we divided subjects into high and low interdependence groups and extracted contrast values (self vs. celebrity and friend vs. celebrity) in these brain regions. Fig. 2b shows the correlations between individuals' trait creativity and neural activities in each group. To rule out the possibility that an outlier dominates the correlation results, we excluded one participant in low interdependence group whose brain activities in the left STS and right TPJ during self- vs. celebrity-judgment and in the right PI during friend- vs. celebrity-judgment were deviated from the mean activity of all subjects with 3 standard deviations. As can be seen in Fig. 2b, individuals with high interdependent self-construal showed negative correlations between trait creativity and neural responses to self- or friend-judgments (vs. celebrity-judgments) in the left STS, TPJ and insular (rs = −.136 to .610, ps = .603-.009), whereas individuals with low interdependent self-construal showed positive correlations between trait creativity and neural responses to self- or friend-judgment (vs. celebrity-judgment) in the same brain regions (rs = .464–.635, ps = .046-.003). Fisher-z transformation further confirmed significant differences in the patterns of correlations between the two subject groups (ps < .01) (Table 2).

We further tested whether self-construals moderate the association between trait creativity and increased functional connectivity between brain regions activated during self- or friend-judgments (compared with celebrity-judgments). The MPFC (x/y/z = −9/53/1) revealed in the

Table 2
Correlations between sum scores of WCAT and brain activities during self- and friend-processing and the increased functional connectivity during friend processing vs. celebrity-processing in high and low interdependence groups (r(N)).

	High	Low	Fisher(z)
Brain activity			
Left STS (Self vs. Celebrity)	−.386(17)	.513(19)*	−2.66**
Right TPJ (Self vs. Celebrity)	−.571(17)*	.464(19)*	−3.14**
Right AI (Self vs. Celebrity)	−.525(17)*	.635(20)**	−3.69**
Right postcentral gyrus (Self vs. Celebrity)	−.401(17)	.513(20)**	−2.75**
Left STS (Friend vs. Celebrity)	−.610(17)**	.514(20)*	−3.54**
Right PI (Friend vs. Celebrity)	−.136(17)	.609(19)**	−2.31*
Functional connectivity			
Left postcentral gyrus (Friend vs. Celebrity)	.668(16)**	−.005(20)	2.20*
Right postcentral gyrus (Friend vs. Celebrity)	.787(16)**	−.113(20)	3.20**

STS: superior temporal sulcus; TPJ: temporal parietal junction; AI: anterior insular; PI: posterior insular.
** $p < .01$.
* $p < .05$.

contrast of self- vs. celebrity-judgments and the MPFC (x/y/z = −6/56/−2) and precuneus (x/y/z = −6/−58/43) revealed in the contrast of friend- vs. celebrity-judgments were used as the seed regions for the gPPI analyses. The functional connectivity between the seed regions and other brain regions were subject to whole brain regression analyses (with creativity, interdependence, and their interaction as regressors) to identify functional connectivity that was sensitive to the interaction of creativity × interdependence. The analyses only confirmed that the increased functional connectivity between the MPFC and bilateral postcentral gyrus (left: x/y/z = −60/−10/46, z = 4.34; k = 239; right: left: x/y/z = 54/−10/55, z = 4.35; k = 295) during friend-judgments (vs. celebrity-judgments) were significantly correlated with the interaction of creativity × interdependence (Fig. 3, Table 1). By removing one outlier we also confirmed that the increased functional connectivity was positively correlated with trait creativity (rs = .668 and .787 for the left and right postcentral gyrus respectively, ps < .001) in those who scored high in interdependent self-construals, whereas no such correlations were observed for those who scored low in interdependent self-construals (rs = −.0005, −.113, ps > .1). The differences in the patterns of correlations between the two subject groups were also confirmed using fisher-z transformation (ps < .01) (Fig. 3, Table 2).

Finally, we conducted a discriminant analysis to further test whether trait creativity can be predictable by integrating brain activity, functional connectivity during self- and friend-judgments and interdependent self-construals. A Fisher's discriminant function was conducted with three neural indices (weighted averaged neural activities in

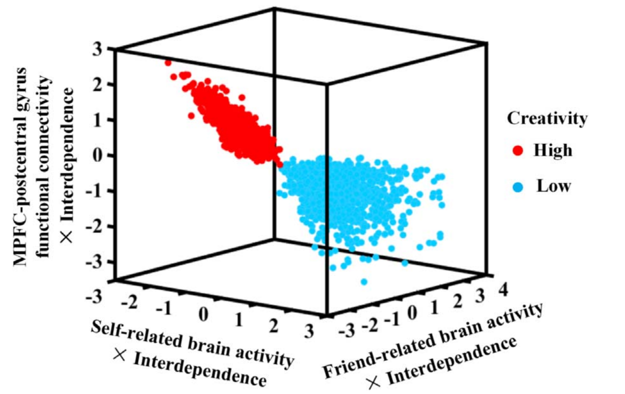

Fig. 4. Illustration of the results of the discriminant analysis. High and low creativity groups can be clearly dissociated in a three-dimensional space defined by the brain activity and functional connectivity related to self- and friend-judgments combined with self-construals.

the left STS, right TPJ/PI, right AI and right postcentral gyrus during self- vs. celebrity judgments; weighted averaged neural activities in the left STS and right PI during friend- vs. celebrity judgments; weighted averaged functional connectivity between MPFC and bilateral postcentral gyri during friend- vs. celebrity judgments) combined with interdependence self-construal as independent variables to test if the patterns of neural activity and functional connectivity underlying self- and friend-judgments and individuals' self-construal characterized a participant's trait creativity. The leave-one-out cross-validation indicated that 75.0% of cross-validated subjects were correctly classified, higher than chance level (50%). Fig. 4 illustrates the results of the bootstrapping analysis (Davison and Hinkley, 1997). The distribution of high and low creativity participants is shown in a three-dimension space defined by the brain activity underlying self-judgments, friend-processing and functional connectivity underlying friend-judgments multiply by individuals' interdependence. High and low creativity groups are clearly separated into two clusters in the three-dimensional space.

4. Discussions

The current work tested the hypothesis that self-construals (i.e., interdependence) moderate the associations between trait creativity and the brain activities of the social brain network engaged in reflection of social attributes of oneself and a close other. We first showed that reflection of one's own social attributes and those of a friend similarly activated the MPFC. This replicated the previous findings of MPFC activations in responses to reflection of personality traits of the self (Kelley et al., 2002; Ma and Han, 2011), one's mother (Zhu et al., 2007;

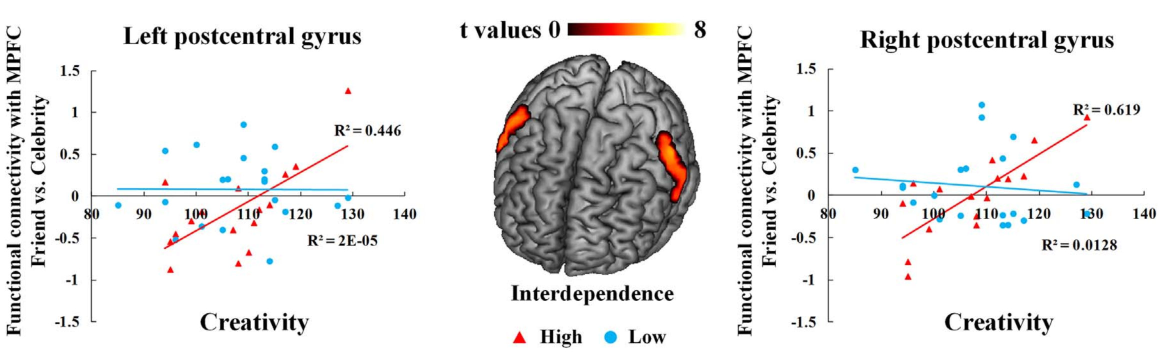

Fig. 3. Moderation effects of the self-construal (i.e., interdependence) on the link between trait creativity and the functional connectivity. MPFC in friend- vs. celebrity processing was used as the seed region, and the postcentral gyrus shown here are the regions showed increased functional connectivity with MPFC during friend-processing compared with celebrity-processing and the functional connectivity was sensitive to the interaction between self-construal and creativity. The pattern of the moderation effects was also shown. Red dots are subjects with high interdependence and blue dots are subjects with low interdependence.

Wang et al., 2012), and one's spouse and children (Han et al., 2016), suggesting overlapping neural representations of social attributes of the self and close others in a sample from collectivistic Chinese culture.

We did not find evidence for associations between participants' interdependence and trait creativity or between participants' trait creativity and their brain activities during reflection of oneself and a close other. However, as predicted, we found that self-construals significantly moderate the association between trait creativity and brain activities underlying self- and friend-judgments. The moderation effects seemed arise from opposite patterns of the relationship between trait creativity and brain activity in individuals with high and low interdependence. For instance, for participants with high interdependence, stronger activities in the right TPJ and anterior insular predict lower trait creativity, whereas reverse patterns were observed for those with low interdependence. These results allow us to speculate that, for those with high interdependence, stronger brain activity due to reflection of the self and others affects creativity in a negative way. By contrast, for those with low interdependence, stronger brain activity due to reflection of the self and others may facilitate creativity. We also showed evidence that self-construals significantly moderated the association between trait creativity and the functional connectivity between the MPFC and other brain regions during friend-judgments. Specifically, for individuals with high interdependence, stronger functional connectivity between the MPFC and the post-central cortices predicted greater trait creativity. These results indicate that self-construals moderate not only the relationships between trait creativity and activities in specific brain regions but also the relationships between trait creativity and functional links between different brain regions.

Our findings compliment the previous brain imaging studies of creativity (Aziz-Zadeh et al., 2013; Benedek et al., 2013; Chen et al., 2015; Fink et al., 2012; Li et al., 2015; Mayseless et al., 2015; Shah et al., 2013; Takeuchi et al., 2012; Villarreal et al., 2013; Zhu et al., 2013, 2016) by revealing associations between the trait creativity and the social brain network. Why do self-construals moderate the associations between trait creativity and brain activities engaged in self- and other-related processing? Given that the TPJ mediates taking others' perspectives (Saxe and Kanwisher, 2003) and the anterior insular is engaged in self-awareness (Craig, 2009), our results can be understood by assuming that, for individuals with high interdependence, decreased intention to take others' perspective and decreased self-awareness may help to overcome the concern of others' critics and thus facilitate their trait creativity. For those with low interdependence, however, increased intention to take others' perspective and increased self-awareness may enhance trait creativity. In addition, trait creativity of individuals with high interdependence is also more strongly coupled with the brain activity associated with reflection on a friend. These brain imaging results are consistent with the implications of behavioral studies that interdependent self-construals encourage harmonious relationships with others that contribute to creativity (Hannover, 2006; Bechtoldt et al., 2010) and independent self-construals encourage creation of original ideas by emphasizing uniqueness of the self (Goncalo and Staw, 2006; Wiekens and Stapel, 2008).

The results of our discriminant analyses suggest that individuals with high or low trait creativity can be classified by their brain activities in the social brain network, which, however, must be integrated with their self-construals (i.e., interdependence). The results suggest that, creativity — a complex trait or ability that is critical for social adaptation — cannot be understood by considering only brain activity or cultural orientations. Creativity may arise from interactions between cultural experience and brain functional organization during development. It should be acknowledged that these moderation effects were observed in Chinese culture that is characterized by collectivism. Our work only tested Chinese participants who showed overlapping neural representations of the self and close others (Zhu et al., 2007). This thus leaves an open question of whether and how self-construals interact with the social brain network to shape trait activity in other cultural societies.

The current work employed the Self-Construal Scale (Singelis, 1994) that has only two dimensions (i.e., interdependence and independence). Recent research has proposed a seven-dimensional model of self-construal (defining the self, experiencing the self, making decisions, looking after oneself, moving between contexts, communicating with others, and dealing with conflicting interests, Vignoles et al., 2016). This model provides a more nuanced measurement of being independent or interdependent in different cultural groups and raises the question of which dimension(s) of independent/interdependent self-construals play more important roles in modulating the association between trait creativity and the social brain network. The current work only tested male participants as previous research has suggested gender difference in self-construals (e.g., Cross and Madson, 1997; Guimond et al., 2006) and in self-reported creativity trait or performance (e.g., Baer and Kaufman, 2008; Abraham, 2016). Thus it is unclear whether self-construals moderate the association between trait creativity and the social brain network in a similar fashion in females. These issues should be addressed in future research.

In conclusion, our work provided the first brain imaging evidence that a cultural trait (i.e., interdependence) that emphasizes fundamental connections between the self and others moderates how the social brain network is associated with individuals' trait creativity. Our findings compliment the previous findings by highlighting the possible function of the social brain network in trait creativity. Given the cultural differences in self-construals (Markus and Kitayama, 1991; Oyserman et al., 2002) and cultural influences on human brain activity (Han and Northoff, 2008; Han et al., 2013; Han, 2017), our brain imaging results also raise an interesting question regarding how cultural orientations and experiences influence human creativity.

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