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Original Article

The neural basis of trait self-esteem revealed by the amplitude of low-frequency fluctuations and resting state functional connectivity

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Abstract

Self-esteem is an affective, self-evaluation of oneself and has a significant effect on mental and behavioral health. Although research has focused on the neural substrates of self-esteem, little is known about the spontaneous brain activity that is associated with trait self-esteem (TSE) during the resting state. In this study, we used the resting-state functional magnetic resonance imaging (fMRI) signal of the amplitude of low-frequency fluctuations (ALFFs) and resting state functional connectivity (RSFC) to identify TSE-related regions and networks. We found that a higher level of TSE was associated with higher ALFFs in the left ventral medial prefrontal cortex (vmPFC) and lower ALFFs in the left cuneus/lingual gyrus and right lingual gyrus. RSFC analyses revealed that the strengths of functional connectivity between the left vmPFC and bilateral hippocampus were positively correlated with TSE; however, the connections between the left vmPFC and right inferior frontal gyrus and posterior superior temporal sulcus were negatively associated with TSE. Furthermore, the strengths of functional connectivity between the left cuneus/lingual gyrus and right dorsolateral prefrontal cortex and anterior cingulate cortex were positively related to TSE. These findings indicate that TSE is linked to core regions in the default mode network and social cognition network, which is involved in self-referential processing, autobiographical memory and social cognition.

Key words: trait self-esteem (TSE); resting state fMRI; amplitude of low-frequency fluctuations (ALFF); functional connectivity; default mode network

Introduction

Self-esteem is an attitude that is determined by self-evaluation using positive and negative features of oneself (Rosenberg, 1965). Numerous studies have indicated that self-esteem has a critical role in mental health. Specifically, high self-esteem acts as an anxiety buffer (Brown, 2010; Du *et al.*, 2013) and happiness promoter (Baumeister *et al.*, 2003). In contrast, low self-esteem contributes to depression (De Jong *et al.*, 2012; Sowislo and Orth, 2013), enhances social pain (Onoda *et al.*, 2010) and is related to an unhealthy life style (such as alcohol consumption) (Zeigler-Hill *et al.*, 2013) and aggression, antisocial behaviors and delinquency (Donnellan *et al.*, 2005).

Essentially, self-esteem is an evaluative phenomenon (Tafarodi *et al.*, 2003) that features cognitive and affective processes (Rosenberg *et al.*, 1995; Moran *et al.*, 2006). The two-factor model of self-esteem suggests that global self-esteem consists of two dimensions: a sense of self-competence and a sense of self-liking. These dimensions involve the self-appraisal of one's ability and are linked to self-reflection and emotional reactions to social feedback (Brown *et al.*, 2001; Tafarodi and Milne, 2002;

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Brown and Marshall, 2006). The self-enhancement theory proposes that people tend to search for positive self-evaluation and social feedback in order to promote self-esteem (Shrauger, 1975). Furthermore, the sociometer theory suggests that people are not motivated to maintain their self-esteem *per se*, but rather to increase their relational value and social acceptance wherein self-esteem is a gauge of effectiveness (Leary, 2005). These theories highlight the cognitive and affective components of self-esteem, which are formed by self-related information processing and social cognition.

Neuroimaging studies have deepened our understanding of self-esteem. There is a general consensus concerning the central role of cortical midline structures in self-referential processing (Northoff *et al.*, 2006; Chen *et al.*, 2008; Qin and Northoff, 2011; Doerig *et al.*, 2014;). The cortical midline structure involves a wide range of regions, including the ventromedial prefrontal cortex (vmPFC), dorsomedial prefrontal cortex, anterior cingulate cortex and posterior cingulate cortex (Northoff *et al.*, 2006; Uddin *et al.*, 2007). Specifically, the vmPFC was found to contribute in the assignment of personal value or significance to self-related content (D'Argembeau, 2013) and is activated during positive self-evaluation (Pauly *et al.*, 2013). The cortical midline structure is a core subsystem of default mode network. Another important subsystem of the default mode network is the medial temporal lobe subsystem, which includes the hippocampus, parahippocampal cortex and inferior parietal lobule as central nodes (Andrews-Hanna *et al.*, 2010; Kim, 2012). This subsystem is related to the memory-based construction of the self (Andrews-Hanna *et al.*, 2010; Qin and Northoff, 2011; Andrews-Hanna, 2012). Recent structural imaging research has confirmed that the medial temporal lobe subsystem is correlated with self-esteem. Two voxel-based morphometry studies found that hippocampal volume was significantly positively correlated with self-esteem (Kubarych *et al.*, 2012; Agroskin *et al.*, 2014). On the other hand, self-esteem is related to the social cognition network. The social cognition network includes regions such as the medial prefrontal cortex, temporoparietal junction, posterior superior temporal sulcus and inferior frontal gyrus (Blakemore, 2008). These regions are involved in the awareness of mental states and processing of social information (Iacoboni and Dapretto, 2006; Blakemore, 2008; Ochsner, 2008; Kreifelts *et al.*, 2010). Interestingly, the sociometer theory emphasizes the roles of relational value and social acceptance in the acquisition of self-esteem (Leary and Baumeister, 2000; Leary, 2005). Accordingly, the social cognition network may be engaged in the formation of trait self-esteem (TSE).

Nevertheless, there are two important limitations to these studies. First, most research has focused on the mechanism of various components of self-esteem. Accordingly, there are fewer studies that have investigated the neural correlates of total self-esteem. Second, although several studies have examined the structural substrates and task-evoked regions of self-esteem, it is necessary to place more attention on the intrinsic neural bases that are related to self-esteem. Resting state fMRI has many advantages in addressing the neural correlates of the enduring trait (Zhou *et al.*, 2014). Because TSE reflects global and stable self-esteem, investigating the intrinsic neural activity of TSE will provide important new insights into understanding the nature and function of TSE.

The spontaneous fluctuations that occur during the resting state reveal the intrinsic functional architecture of the brain and are related to extrinsic behavior performance (Fox and Raichle, 2007). Furthermore, the task-free condition makes it more straightforward to investigate spontaneous brain activities that are related to behavioral performances (Xie *et al.*, 2013). Thus, the resting state blood oxygen level-dependent signal provides a unique advantage in identifying the underlying neural basis of TSE. The amplitude of spontaneous low-frequency fluctuation (ALFF) is a widely used indicator that reflects the extent of spontaneous neuronal activity (Zang *et al.*, 2007, 2008). It has been shown that ALFF is correlated with task-induced neural activity (Mennes *et al.*, 2011) and is an effective and predictive indicator of personality traits (Kühn *et al.*, 2012; Pan *et al.*, 2014; Wei *et al.*, 2014; Xu *et al.*, 2014). Resting state functional connectivity (RSFC) measures the synchronization of different regional spontaneous neuronal signals and reflects the tendency of cortical networks to be co-activated (Worsley and Friston, 1995; Kelly *et al.*, 2009; Mennes *et al.*, 2010). In this way, it is useful in identifying the underlying neural circuitry of stable behavioral performance. RSFC has been shown to be able to detect brain regions or networks that are correlated with personality traits, such as Big Five personality (Ryan *et al.*, 2011; Sampaio *et al.*, 2014), risk propensity (Zhou *et al.*, 2014), impulsivity (Shannon *et al.*, 2011) and autistic traits (Di Martino *et al.*, 2009).

To our knowledge, no research has yet investigated whether spontaneous brain activity during the resting state is related to TSE using a resting state fMRI analysis, such as ALFF or RSFC. Thus, in this study, we measured ALFFs and the RSFC of the resting state fMRI signals to investigate TSE-related brain regions and networks. TSE is a dispositional attitude that is determined by affective self-evaluation, and so it reflects how individuals most typically feel about themselves (Agroskin *et al.*, 2014). This propensity of affective self-evaluation depends on one's self-concept, social feedback in interpersonal interactions, as well as long-term life experiences that are stored in the autobiographical memory. Accordingly, we hypothesized that TSE might be linked to core regions in the default mode network, social cognition network and autobiographical memory network. As TSE involves multiple networks, these regions may work together to subserve TSE.

Methods

Ethics statements

This study was approved by the Ethics Committee of the Southwest University. Written consent was obtained from all participants. Before the experiments, all participants were informed of their right to privacy, and that they could quit the experiments at any time. After the experiments, they were paid $10 for their participation.

Participants

Participants were recruited from Southwest University of China. Sixty-five right-handed participants were recruited into this study. Five participants were removed from the sample due to excessive head motion during data preprocessing. Finally, the remaining 60 participants were included in the formal data analysis. They were all young, healthy adults (31 females and 29 males; 21.28 ± 1.67 years, range: 18–25 years) and had no history of neurological or psychiatric disorders, as determined by a self-report inventory. The education level varied from 11 to 18 years (mean = 14.32 ± 1.66 years). Each participant was required to complete the Rosenberg self-esteem scale immediately after the resting state scanning.

TSE scale

All participants completed the Rosenberg self-esteem scale (Rosenberg, 1965). It has been widely used in many nations and its effectiveness in the measurement of global TSE has been well proven (Schmitt and Allik, 2005). The total score of this scale reflects a global attitude toward the self and does not depend on the specific context or domains. The expression of the items in the Chinese version has been revised to be relevant to Chinese culture (Cheng and Hamid, 1995; Song *et al.*, 2011). This scale is a 10-item self-report questionnaire. Example items are 'I feel that I have a number of good qualities' and 'I take a positive attitude toward myself'. All responses were made on 4-point Likert-type scales (from 1: strongly disagree, to 4: strongly agree), with higher scores indicating higher TSE. The Chinese version of this scale has been demonstrated to be reliable and valid in assessing Chinese global TSE (Brown and Cai, 2010; Ye *et al.*, 2012). In this study, the internal consistency reliability (Cronbach α) of the total scale was 0.84.

Image acquisition

Participants were scanned in a 3.0 Tesla Siemens Trio scanner (Siemens Medical, Erlangen, Germany) in Southwest University, China. First, high-resolution T1-weighted structural images were acquired sagittally. The scanning parameters were as follows: 176 slices, 1, 900/2.52 ms (repetition time/echo time), 1 mm (thickness), 256×256 mm^2 (field of view), 900 ms (inversion time), 9° (flip angle) and 1 mm × 1 mm × 1 mm (voxel size). Then, functional images were obtained using an echoplanar imaging sequence with the following parameters: 32 axial slices; slice thickness, 3 mm; repetition time, 2000 ms; echo time, 30 ms; image matrix, 64×64; flip angle, 90°; field of view, 220×220 mm^2; voxel size, $3.4 \times 3.4 \times 4$ mm^3; and 240 volumes. During the resting state scanning, participants were instructed to maintain an awakened state with their eyes closed and to not think about anything in particular.

Data preprocessing

Data were preprocessed using SPM8 (http://www.fil.ion.ucl.ac.uk/spm) and Data Processing Assistant for Resting-State fMRI (DPARSF; Yan and Zang, 2010). Images from the first 10 volumes at the beginning of the resting state scanning were discarded to ensure steady-state magnetization. The remaining 230 volumes were included in the final analysis. Then, slice timing and head motion correction were performed to correct slice order and head motion effects, respectively. Then, a mean functional image was obtained for each participant. Five participants exhibited head motion that was greater than the 2 mm maximal displacement and/or 2° rotation in the *x*, *y*, or *z* axes throughout the course of scans. For this reason, these data were discarded during the formal analysis. Next, the participants' structural images were coregistered to the mean functional image and were subsequently segmented as gray matter, white matter and cerebrospinal fluid. Then, each functional image was normalized to the standard Montreal Neurological Institute space in 3 mm × 3 mm × 3 mm voxel sizes with the application of the parameters that were obtained during segmentation. The East Asian brain template provided by SPM8 was used for normalization. After normalization, spatial smoothing was performed with an 8-mm full-width at half maximum. Subsequently, the linear trends were removed. Finally, the images were temporally band-pass filtered (0.01–0.08 Hz) to reduce low-frequency drift and high-frequency noise (Biswal *et al.*, 1995).

Data analysis

ALFF calculations. ALFF calculations were performed using the Resting-State fMRI Data Analysis Toolkit (REST 1.8; Song *et al.*, 2011). The ALFF indicates the strength of regional spontaneous fluctuations of a given brain region. According to the methods proposed by Zang *et al.* (2007), the time series in each voxel was transformed to a frequency domain with a fast Fourier transform. Next, the power spectrum was obtained. Then, the square root of the power spectrum was calculated and averaged across 0.01–0.08 Hz for each voxel. This averaged square root was considered to be the ALFF. For standardization purposes, the ALFF value of each voxel was divided by the global mean ALFF value to normalize the global volume effects (Zang *et al.*, 2007). Because low-frequency fluctuations in the gray matter are higher than those in the white matter (Biswal *et al.*, 1995; Wei *et al.*, 2012), we calculated ALFFs only in the gray mask. We included voxels with a probability that was higher than 0.4 in the SPM8 template onto the gray matter mask in a manner that was similar to the procedure of Wang *et al.* (2013) and Wei *et al.* (2012). Ultimately, there were 42,540 voxels (1,148,580 mm^3) in the gray matter mask.

ALFF-behavior correlation analysis. We performed a whole-brain analysis to examine the relationship between the regional spontaneous functional activity of the brain and TSE. A multiple regression analysis was conducted between the mean ALFF values and the total TSE score with age, gender and years of education as nuisance covariates. The results were multiple comparisons corrected using AlphaSim, which was originally implemented in AFNI software. The threshold was set as a corrected cluster $P < 0.05$ [single voxel $P < 0.01$, cluster size ≥ 56 voxels (1512 mm^3)].

Functional connectivity analysis. To examine whether the regions that were observed in the ALFF-behavior correlation analysis work in concert with other regions as a network that correlate with TSE, we conducted a functional connectivity analysis. We used regions that were significantly correlated with TSE in previous analyses as seed regions of interest and computed functional connectivity between the seeds and other voxels in the whole brain. Then, we correlated the functional connectivity strength with the TSE score to examine whether any specific connections within these networks were associated with TSE. The RSFC analysis was performed in REST. Before the analysis, nuisance covariates, including white matter signal, cerebrospinal fluid signal, global mean signal and Friston 24 motion parameters (Friston *et al.*, 1996), were regressed out. First, the mean time series of the seeds were calculated for each participant and correlated with the time series of all other voxels in the gray matter, as previously described. The correlation maps produced in this analysis were then converted to Z-maps using Fisher's r-to-z transformation. One sample *t*-test was conducted to identify the regions that were significantly connected with the seeds. AlphaSim was used for multiple comparison correction (corrected cluster $P < 0.05$, single voxel $P < 0.01$). The significant regions were then defined as masks, and the RSFC-behavior correlation analyses were conducted in these masks to examine which functional connectivity strength was correlated with TSE. The results were corrected using AlphaSim in the corresponding masks.

Results

Behavior data

The mean, standard deviation (s.d.) and range of TSE scale for each gender is listed in Table 1. No significant gender difference in TSE score was observed ($t = 0.23$, $P = 0.82$).

Table 1. Mean, s.d. and range of TSE scale by gender

	Females	Males	Total
Mean	30.68	30.45	30.57
s.d.	3.49	4.36	3.90
Range	20–36	21–38	20–38

TSE-related brain regions

To explore the association between TSE and regional resting-state activity, we performed a regression analysis with age, gender and years of education as nuisance covariates. As shown in Table 2 and Figure 1, TSE was positively correlated with ALFFs in the left vmPFC ($r_{\text{peak}} = 0.52$, $r_{\text{cluster}} = 0.52$, $P < 0.001$) and negatively correlated with ALFFs in the left cuneus/lingual gyrus ($r_{\text{peak}} = -0.50$, $r_{\text{cluster}} = -0.49$, $P < 0.001$) and right lingual gyrus ($r_{\text{peak}} = -0.55$, $r_{\text{cluster}} = -0.51$, $P < 0.001$).

Functional network associated with TSE

To examine whether the brain regions that were observed in previous analyses function synergistically with other regions to produce TSE, we performed a functional connectivity strength-behavior correlation analysis with age, gender and years of education as nuisance covariates. The significant regions in the ALFF-behavior correlation analysis were used as seeds in the RSFC analysis. As shown in Table 3 and Figures 2 and 3, we found that the strengths of functional connectivity between the left vmPFC and the following regions were significantly associated with TSE: the right hippocampus ($r_{\text{peak}} = 0.47$, $r_{\text{cluster}} = 0.49$, $P < 0.001$), left hippocampus ($r_{\text{peak}} = 0.50$, $r_{\text{cluster}} = 0.49$, $P < 0.001$), right inferior frontal gyrus ($r_{\text{peak}} = -0.44$, $r_{\text{cluster}} = -0.47$, $P < 0.001$) and right posterior superior temporal sulcus ($r_{\text{peak}} = -0.48$, $r_{\text{cluster}} = -0.46$, $P < 0.001$). With the left cuneus/lingual gyrus as the seed region, the strengths of functional connectivity between this seed and the following regions were significantly related to TSE: the right dorsolateral prefrontal cortex ($r_{\text{peak}} = 0.45$, $r_{\text{cluster}} = 0.42$, $P < 0.001$), right anterior cingulate cortex ($r_{\text{peak}} = 0.43$, $P < 0.001$; $r_{\text{cluster}} = 0.39$, $P < 0.002$) and left middle occipital gyrus ($r_{\text{peak}} = -0.50$, $r_{\text{cluster}} = -0.49$, $P < 0.001$). No significant results were identified by this analysis when considering the right lingual gyrus as a seed.

Discussion

In this study, we performed ALFF-TSE correlation analysis and seed-based RSFC analysis to investigate the neural correlates of TSE. We found that interindividual differences in TSE were reflected in the ALFFs and RSFC during the resting state. Specifically, we found that higher TSE was associated with higher ALFFs in the left vmPFC and lower ALFFs in the left cuneus/lingual gyrus and right lingual gyrus. We further observed that higher functional connectivity between the left vmPFC and the bilateral hippocampus was associated with higher TSE. In contrast, a lower functional connectivity between the left vmPFC and the right inferior frontal gyrus and posterior superior temporal sulcus was associated with higher TSE. Moreover, the strengths of functional connectivity between the left cuneus/lingual gyrus and right dorsolateral prefrontal cortex and anterior cingulate cortex were positively related to TSE. Meanwhile, the connection between the left cuneus/lingual gyrus and left middle occipital gyrus was negatively associated with TSE.

We found that ALFFs in the vmPFC were positively associated with TSE, thereby indicating that individuals with high TSE show high spontaneous neural activity in this region. The vmPFC is considered to be a central node of cortical midline structures and has a central role in self-referential processing (D'Argembeau *et al.*, 2005; Northoff *et al.*, 2006; Pauly *et al.*, 2013; Frewen *et al.*, 2013). Specifically, the vmPFC was deemed as a valuation system (Hare *et al.*, 2009) and was found to assign personal value or significance to self-related content (D'Argembeau, 2013). Moreover, a positive self-evaluation was significantly associated with neural activity in this area (Blair *et al.*, 2013; Pauly *et al.*, 2013). When considered with previous findings, these data support the hypothesis that individuals with high TSE tend to possess positive self-evaluation and self-worth. It is worth noting that the trait code was represented in the vmPFC (Ma *et al.*, 2014). These findings suggest that individuals with high TSE tend to have stable positive self-evaluations.

In contrast to the vmPFC, ALFFs in the bilateral lingual gyri were negatively linked to TSE, which suggests that lower activity in the lingual gyrus was associated with higher TSE. Previous studies have suggested that the lingual gyrus contributes to self-referential processing and social cognition (Kircher *et al.*, 2000; D'Argembeau *et al.*, 2007; Brühl *et al.*, 2014). Notably, activation in the lingual gyrus was associated with negative self-appraisal (Brühl *et al.*, 2014), self-criticism (Longe *et al.*, 2010) and the retrieval of self-encoded negative personality traits (Fossati *et al.*, 2004). In accordance with these findings, our results demonstrate that individuals with high TSE are less likely to have a negative attitude toward themselves. Additionally, the lingual gyrus has been reported to be related to autobiographical memory retrieval (Greenberg and Rubin, 2003). It is plausible that individuals with higher TSE tend to store more positive self-related long-term memories.

Nevertheless, the regions that were detected in the ALFF-behavior correlation analysis were not independently linked to TSE. We observed that the strengths of functional connectivity between the left vmPFC and bilateral hippocampus were positively correlated to TSE, while the connections between the left vmPFC and right inferior frontal gyrus and posterior superior temporal sulcus were negatively associated with TSE. These results indicate a correlation between the synchronous activities in these regions and TSE.

The vmPFC and hippocampus are core nodes of the medial temporal lobe subsystem of the default mode network, and they contribute to autobiographical thought processes (Andrews-Hanna *et al.*, 2014). Two meta-analyses have suggested that the hippocampus is the neural basis of autobiographical memory (Spreng *et al.*, 2009; Andrews-Hanna *et al.*, 2014), which is an explicit type of memory of an event that occurred in a specific time and place in the personal past (Nelson and Fivush, 2004). Nevertheless, the autobiographical memory is not always accurate. Indeed, individuals practice a self-positive bias wherein individuals tend to make their self-evaluations more desirable (Korn *et al.*, 2012). Furthermore, this bias was stronger for people with higher self-esteem (D'Argembeau et al., 2005; D'Argembeau and Van der Linden, 2008). Therefore, individuals

Table 2. Regions in which ALFFs were significantly related to TSE

Brain regions	BA	Peak MNI coordinates			Peak R	No. of voxels
		x	y	z		
L vmPFC	10/11	0	60	−6	0.52	57
L Cuneus/lingual gyrus	17/18/19	−15	−96	3	−0.50	291
R Lingual gyrus	17/18	21	−87	−3	−0.55	218

Note: The threshold was set at $P < 0.05$ [AlphaSim corrected: single voxel $P < 0.01$, cluster size > 56 voxels (1512 mm^3)]. L, left; R, right; BA, Brodmann area; MNI, Montreal Neurological Institute. The analysis was conducted in the gray mask with 42,540 voxels (1,148,580 mm^3).

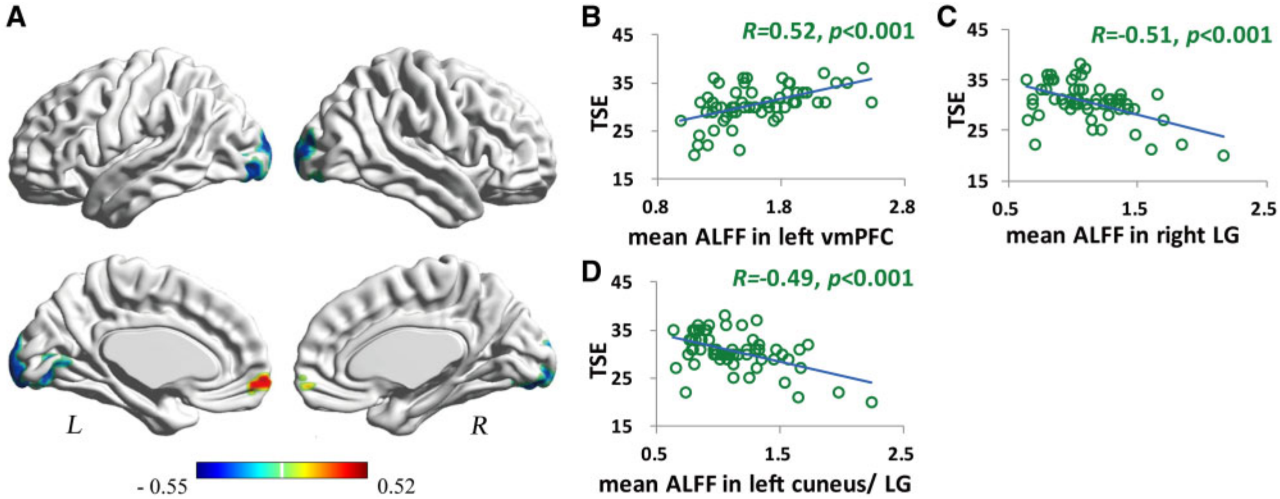

Fig. 1. Brain regions that show significant correlations between ALFFs and TSE (Panel A). Color bars represent *R*-values. L = left, R = right. The panels B–D indicate significant correlations between TSE score and mean ALFFs in the left vmPFC, right lingual gyrus (LG) and left cuneus/LG, respectively. The threshold of corrected cluster was set at $P < 0.05$ [single voxel $P < 0.01$, cluster size > 56 voxels (1512 mm^3)]. The analysis was conducted in the gray mask with 42,540 voxels (1,148,580 mm^3).

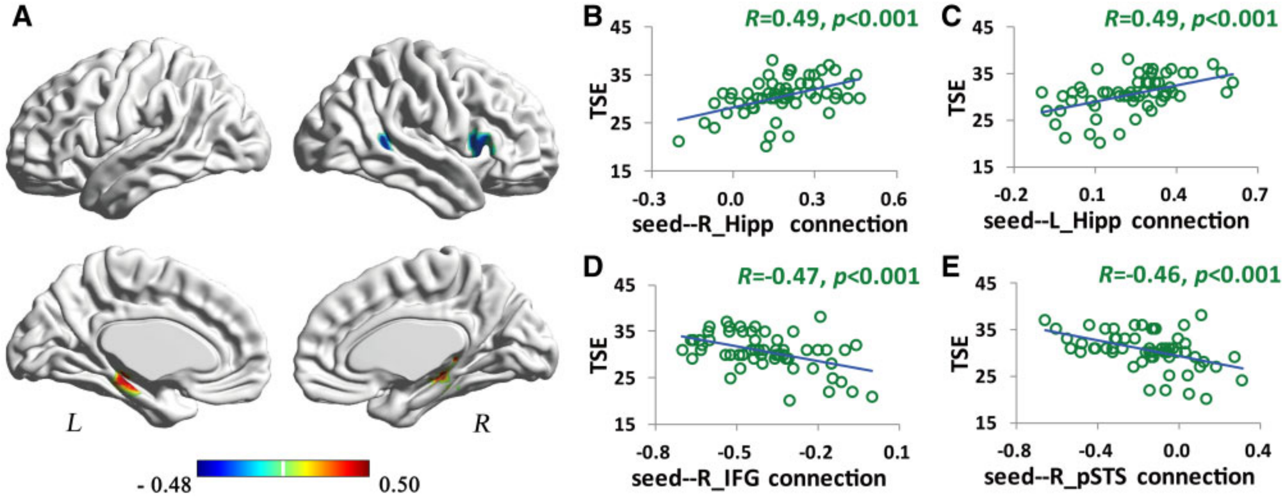

Fig. 2. Clusters whose functional connectivity strengths with the left vmPFC (seed) were significantly associated with TSE (Panel A). Color bars represent R-values. L = left, R = right. The panels B–E indicate significant correlations between TSE and functional connectivity strength between the left vmPFC and right hippocampus (R_Hipp), left hippocampus (L_ Hipp), right inferior frontal gyrus (R_IFG) and right posterior superior temporal sulcus (R_pSTS), respectively. The threshold of corrected cluster was set at $P < 0.05$ [single voxel $P < 0.01$, cluster size > 43 voxels (1161 mm^3)]. The analysis was conducted in the gray mask with 28,567 voxels (771,309mm^3).

with higher TSE may experience more positive self-related memories and have a higher neural activity in the hippocampus. This agrees with the self-enhancement theory, which posits that people tend to promote self-esteem by means of searching for positive self-evaluation and social feedback (Shrauger, 1975). Recent structural neuroimaging research has confirmed this speculation and found a positive correlation between TSE and hippocampal volumes (Pruessner *et al.*, 2005; Kubarych *et al.*, 2012; Agroskin *et al.*, 2014). Our results have shown that the vmPFC and hippocampal connection was positively related to TSE. We suppose that the process of self-evaluation may involve the recalling of long-term experiences in the past. Therefore, individuals who store positive self-related memories often have a positive self-evaluation,

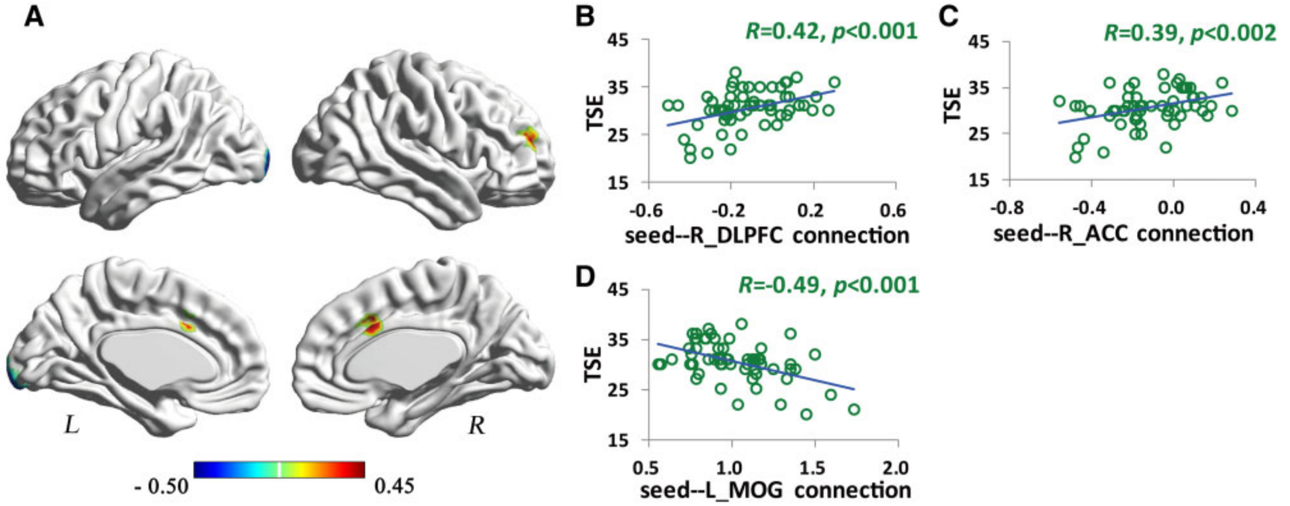

Fig. 3. Clusters whose functional connectivity strengths with the left cuneus/LG (seed) were significantly associated with TSE (Panel A). Color bars represent *R*-values. The panels B–D indicate significant correlations between TSE and functional connectivity strength between the left cuneus/LG and right dorsolateral prefrontal cortex (DLPFC), right anterior cingulate cortex (ACC) and left middle occipital gyrus (MOG), respectively. The threshold of corrected cluster was set at $P < 0.05$ [single voxel $P < 0.01$, cluster size > 42 voxels (1134 mm^3)]. The analysis was conducted in the gray mask with 25,693 voxels (693,711 mm^3).

Table 3. Regions in which functional connectivity strengths with seeds were significantly related to TSE

Brain regions	Peak MNI coordinates			Peak R	Cluster size
	x	y	z		
L vmPFC as the seed					
R-Hippocampus	33	−24	−12	0.47	68
L-Hippocampus	−21	−27	−12	0.50	49
R-Inferior frontal gyrus	48	18	3	−0.44	104
R-Posterior superior temporal sulcus	48	−45	9	−0.48	44
L cuneus/lingual gyrus as the seed					
R-Dorsolateral prefrontal cortex	27	48	15	0.45	69
R-Anterior cingulate cortex	6	15	30	0.43	68
L-Middle occipital gyrus	−15	−102	6	−0.50	79
R lingual gyrus as the seed					
None significant					

Note: The threshold was set at $P < 0.05$ (AlphaSim corrected). L = left; R = right.

thereby resulting in the formation of high TSE. This supposition was supported by the observation of effective connectivity wherein we observed an increase in positive connectivity between the vmPFC and the hippocampus, which could subserve the sustained attention toward positive information and improved memory for positive events (Addis *et al.*, 2010).

The inferior frontal gyrus and posterior superior temporal sulcus are key nodes of the mirror neuron system (Iacoboni and Dapretto, 2006) and have been suggested as functioning in an individual's ability to understand others' goals, feelings and thoughts (i.e. social cognition; Gallese *et al.*, 2004; Iacoboni and Dapretto, 2006; Adolphs, 2009). Furthermore, activity in these regions was correlated with the comparison-related component of social feedback (Korn *et al.*, 2012). As stated by the sociometer hypothesis (Leary *et al.*, 1995), self-esteem is affected by social feedback from others. Positive social feedback is often integrated into the self-concept, which further promotes self-esteem. Nevertheless, a large body of research suggests that we think quite positively, and often unrealistically, of ourselves (Fields and Kuperberg, 2015). Thus, feedback from others may be relatively more objective and negative than self-evaluation. When people pay more attention to the evaluation of others, the 'better-than-average effect' disappears and then self-esteem decreases. In our study, we found that lower functional connectivity between the left vmPFC and right inferior frontal gyrus and posterior superior temporal sulcus was associated with higher TSE, thereby indicating that the vmPFC and these two mentalizing regions work inversely to develop TSE. The vmPFC was observed to have an anatomical connection to the inferior frontal gyrus (Hare *et al.*, 2009) and exhibited functional connectivity with both the inferior frontal gyrus and posterior superior temporal sulcus during the process of value computation (Hare *et al.*, 2010). In addition, the vmPFC was functionally connected with the posterior temporal sulcus and involved in mental state attribution (Ciaramidaro *et al.*, 2015). Therefore, it has been speculated that individuals must reconcile self-evaluation and the evaluation of others to maintain self-esteem at an appropriate level. As a result, the decrease in connectivity between the vmPFC and these nodes of the social cognition network (the inferior frontal gyrus and posterior superior temporal sulcus) may result in individuals mainly focusing on a positive self-view while ignoring negative social feedback. In this way, self-esteem is maintained. Nevertheless, future research is required to investigate how functional connectivity is associated with TSE.

We also observed that the left cuneus/lingual gyrus functions synergistically with the right dorsolateral prefrontal cortex and anterior cingulate cortex as networks that connect to TSE. The dorsolateral prefrontal cortex and anterior cingulate cortex are critical hubs in the cognitive control network (Cole and Schneider, 2007; Dosenbach *et al.*, 2008). The anterior cingulate cortex was activated in conflict monitoring (Botvinick *et al.*, 2001) and the dorsolateral prefrontal cortex was engaged to reduce conflict (Egner and Hirsch, 2005). As mentioned earlier, the lingual gyrus was sensitive to negative self-appraisal. This may be the result of the lingual gyrus processing information that was threatening to self-esteem. Subsequently, the anterior cingulate cortex was activated to detect this threat and the dorsolateral prefrontal cortex was activated to suppress the negative self-view and maintain self-worth. This speculation is consistent with the findings that strong anterior cingulate cortex activation was observed in response to threatening stimuli (Taylor *et al.*, 2008), and positive associations between self-esteem and regional gray matter volume were found in the anterior cingulate cortex and lateral prefrontal cortex (Agroskin *et al.*, 2014). In addition, evidence from the effective connectivity study suggested that the anterior cingulate cortex and dorsolateral prefrontal cortex interacted with each other to facilitate attentional control (Wang *et al.*, 2010). Consequently, the decrease in connectivity between the lingual gyrus and central nodes of the cognitive control network (i.e. the anterior cingulate cortex and dorsolateral prefrontal cortex) may bias attention toward negative information and further hinder the maintenance of self-esteem. Research on low self-esteem further confirms the present interpretations. Individuals with low self-esteem demonstrated more attentional bias to reject stimuli (Dandeneau and Baldwin, 2004), and low self-esteem serves as a risk factor for depression (Orth *et al.*, 2008); however, attentional control training could reduce the defensive physiological reactions to rejection (Gyurak and Ayduk, 2007).

When considered together, this study provides neural evidence for the hypothesis that individuals with high TSE tend to have a stable positive self-evaluation and that the process of self-evaluation involves the recalling of long-term experience of one's past life. Furthermore, TSE was associated with the attentional control of negative social feedback and the filtering of undesirable social feedback in social interaction that could promote self-esteem. These results have potential clinical applications. Many researchers have shown a correlation between low self-esteem and social anxiety, depression or delinquency. Individuals with low self-esteem store more negative self-related memories and are sensitive to rejection. Meanwhile, they exhibit deficiencies in control over the information that threatens self-esteem and hence are susceptible to mental or behavioral symptoms. This suggests that a special intervention program could promote self-esteem and relieve mental or behavioral symptoms. For example, cognitive training strategies based on event-specific autobiographical memory could reduce depressive symptomatology (Ricarte *et al.*, 2012). In addition, the attentional control training could reduce vigilance and responsiveness to social threat and lead to increased self-esteem (Dandeneau *et al.*, 2007).

In summary, we examined whether individual differences in TSE were reflected in variations in values of ALFFs and RSFC. We found that TSE was linked to core regions in the default mode network, social cognition network and autobiographical memory-related network. Moreover, the synchronous activity in these regions enhances our understanding of the nature and function of TSE and has potential clinical applications.

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