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Neural correlates of reflection on actual versus ideal self-discrepancy

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ABSTRACT

Subjective feelings of actual/ideal self-discrepancy vary across individuals and influence one's own affective states. However, the neural correlates of actual/ideal self-discrepancy and their genetic individual differences remain unknown. We investigated neural correlates of actual/ideal self-discrepancy and their associations with the serotonin transporter promoter polymorphism (5-HTTLPR) that moderates human affective states during self-reflection. We scanned short/short and long/long allele carriers of 5-HTTLPR, using functional MRI, during reflection on the distance between actual and ideal self in personality traits. We found that larger actual/ideal self-discrepancy was associated with activations in the ventral/dorsal striatum and dorsal medial and lateral prefrontal cortices. Moreover, these brain activities were stronger in short/short than long/long allele carriers and predicted self-report of life satisfaction in short/short carriers but trait depression in long/long carriers. Our findings revealed neural substrates of actual/ideal self-discrepancy and their associations with affective states that are sensitive to individuals' genetic makeup.

Introduction

A key Buddhism doctrine is that the desire for a 'good' self deteriorates human happiness (Ñāṇamoli and Bodhi, 1995). Consistent with this traditional insight, modern psychologists posit that each person has beliefs of what attributes he/she actually possesses (actual self) and wishes to possess (ideal self) and the actual/ideal self-discrepancy induces negative emotion that is harmful to individuals' well-being (Rogers, 1961; Higgins, 1987; Carver et al., 1999). In support of this proposition, behavioral research found that a memory task that made self-structure dominated by actual/ideal self-discrepancy increased sensitivity to the presence and absence of positive outcomes of events (Higgins and Tykocinski, 1992). Questionnaire measures revealed that actual/ideal self-discrepancy was associated with negative affect such as shame/embarrassment (Higgins et al., 1985) and dissatisfaction/disappointment (Strauman and Higgins, 1987). In addition, self-report of actual/ideal self-discrepancy inversely predicted self-report of life satisfaction (Czaja, 1975).

Despite the significance of actual/ideal self-discrepancy for human well-being, the neural correlates of actual/ideal self-discrepancy and their relationships with affective states remain unknown. The current research addressed three questions regarding the neural correlates of actual/ideal self-discrepancy. First, since thinking about self-discrepancy engages evaluation of one's desire for good outcomes (Higgins, 1987), we investigated whether reflection on actual/ideal self-discrepancy on personality traits, which may automatically and implicitly inspire desire for a good self, recruits brain regions that overlap with the rewards neural network that mediates the desire for food or addictive substances. This rewards neural network, identified in functional magnetic resonance imaging (fMRI) studies, consists of the ventral striatum (VS), ventral tegmental area (VTA), amygdala, medial prefrontal cortex (MPFC), anterior cingulate cortex (ACC), and insula, which showed activations in drug users and smokers when perceiving drug/cigarette associated cues (Due et al., 2002; David et al., 2005; Wilson et al., 2005; Franklin et al., 2007; Kober et al., 2010). If reflection on actual/ideal self-discrepancy induces desire for positive attributes, reflection on actual/ideal self-discrepancy may activate brain regions in the neural circuit involved in desire for external rewards such as the VS and MPFC.

To test this hypothesis, we developed a paradigm to uncover the neural correlates of reflection on actual/ideal self-discrepancy. The previous fMRI studies of self-reflection usually asked participants to make judgments on whether a specific trait adjective can describe oneself or a celebrity and the neural correlates of self-reflection have been identified by calculating the contrast of judgments on the self vs. a celebrity. The studies have repeatedly shown that reflection on the self compared to a celebrity significantly activated the brain regions such the MPFC and precuneus (Kelley et al., 2002; Ma and Han, 2011; Northoff et al., 2006). In addition, trait words rated high versus low in self-relevance increased MPFC activity (Moran et al., 2006) and MPFC activity correlated with memory performances on recall of self-related trait words (Macrae et al., 2004; Ma and Han, 2011). Thus the MPFC has been suggested to be involved in encoding of self-relevance of stimuli (Northoff et al., 2006; Han and Northoff, 2009). The current study modified the previous paradigm by showing participants with trait adjectives and

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asking them to think over each trait word and to indicate how far the actual self is away from the ideal self in terms of a personality trait. Participants pressed one of four buttons to indicate the distance between the actual self and the ideal self (1 = "very close", 2 = "some-

Imaging parameters

One hundred and twenty-nine functional images were acquired during one functional run using a 3.0 T GE Signa MR750 scanner (GE Healthcare; Waukesha, WI) with a standard head coil. Functional images were acquired using a T2-weighted, gradient-echo, echo-planar imaging (EPI) sequence ($64 \times 64 \times 32$ matrix with $3.75 \times 3.75 \times 5$ mm^3 resolution, repetition time = 2000 ms, echo time = 30 ms, flip angle = 90°, field of view = 24×24 cm^2). A high-resolution T1-weighted structural image ($512 \times 512 \times 180$ matrix with a spatial resolution of $0.47 \times 0.47 \times 1.0$ mm^3, repetition time = 8.204 ms, echo time = 3.22 ms, flip angle = 12°) was acquired before the functional run.

Imaging data analysis

Images were preprocessed using SPM8 software (the Wellcome Trust Centre for Neuroimaging, London, UK). The first three volumes were removed to allow for T1 equilibration effects. Images were adjusted for slice timing, realigned to the fi

Table 3), while no significant neural activity was observed for l/l participants.

Across all participants, self-discrepancy related neural activity in the left vStr ($r = -0.34$, $p < 0.02$), left dStr ($r = 0.30$, $p < 0.04$), and dorsal MPFC ($r = -0.28$, $p < 0.05$), but not in the right vStr/dStr or bilateral LPFC ($ps > 0.1$), negatively predicted self-report life satisfaction. The moderator effect analysis revealed that genotype (s/s vs. l/l) significantly influenced the associations between life satisfaction and the striatal activity (left vStr: $\beta = 0.44$, $t(46) = 3.59$, $p < 0.001$; left dStr: $\beta = 0.28$, $t(46) = 2.08$, $p < 0.05$; right vStr: $\beta = 0.32$, $t(46) = 2.17$, $p < 0.04$; except for right dStr: $\beta = -0.20$, $t(46) = -1.44$, $p = 0.16$). Further analyses uncovered significant negative associations of life satisfaction scores with the activity in left vStr ($r = -0.71$, $p < 0.0001$), left dStr ($r = -0.51$, $p < 0.01$), and right vStr ($r = -0.44$, $p < 0.03$) in s/s carriers but not in l/l carriers ($ps > 0.61$) (see Fig. 4A). Similar moderator effects were observed between life satisfaction and the dorsal MPFC and LPFC activity (dorsal MPFC: $\beta = -0.41$, $t(46) = -3.20$, $p < 0.003$; left LPFC: $\beta = -0.32$, $t(46) = -2.33$, $p < 0.03$; except for right LPFC: $\beta = -0.17$, $t(46) = -1.19$, $p = 0.24$) due to that the MPFC and LPFC activity negatively predicted life-satisfaction in s/s carriers (MPFC: $r = -0.62$, $p < 0.001$; left LPFC: $r = -0.50$, $p < 0.02$) but not in l/l carriers ($ps > 0.44$). These results indicate that stronger striatal and prefrontal neural response to actual/ideal self-discrepancy predicted lower life satisfaction in s/s carriers but not in l/l carriers.

Similar analyses of trait depression revealed that, across all par-

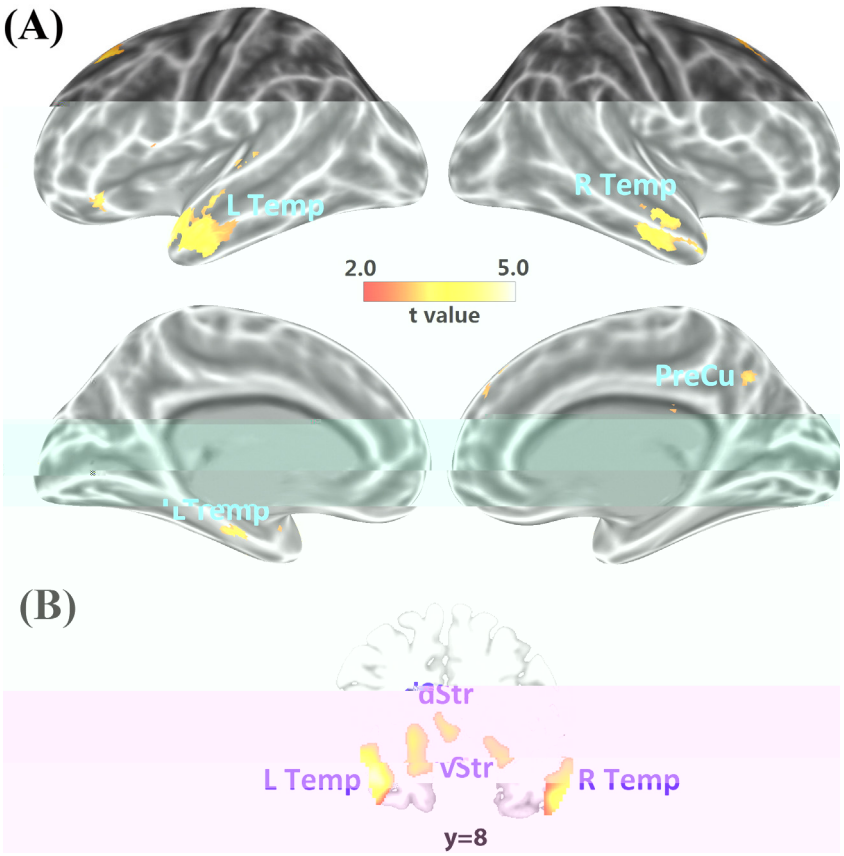

Fig. 2. Illustration of genetic differences in brain activity. Stronger self-discrepancy related neural activity was observed in s/s than l/l carriers over (A) the bilateral and medial cortical regions and (B) the bilateral striatum and amygdala. (Striatal activation was shown at a threshold of voxel-level $p < 0.01$ and cluster size > 50 for illustration). L/R Temp: left/right temporal cortex; PreCu: precuneus; dStr/vStr: dorsal/ventral striatum.

trait adjectives can describe the ideal self. These results suggest a link between this brain region and desire for ideal personality traits. Larger actual/ideal self-discrepancy was also associated with increased activity in the dorsal MPFC. The previous brain imaging findings indicate that the ventral MPFC is engaged in craving for substance (Wilson et al., 2005) whereas the dorsal MPFC is involved in down-regulation of emotional responses during craving (e.g., Kober et al., 2010). Thus our results suggest that down-regulation of emotional responses to actual/ideal self-discrepancy self may occur during reflection on actual/ideal self-discrepancy. Together, these fMRI results suggest that desire for ideal personality traits and craving for favored substance/behavior may share neural underpinnings in the striatum and prefrontal cortex. Reflection on actual/ideal discrepancy might also require monitoring of the conflict between the wish to achieve the ideal self and the awareness of the actual/ideal discrepancy and thus activated the dorsal ACC that has been demonstrated to play a key role in conflict monitoring (Shackman et al., 2011).

Table 2
Self-discrepancy related neural activity that was stronger in s/s carriers than l/l carriers.

Region	Cluster size (voxel no.)	Z value	MNI coordinates		
			x	y	z
Left temporal pole	2343	4.68	−45	17	−26
Left amygdala		2.75	−24	−1	−20
Right temporal pole	576	3.74	54	−16	−23
Right ventral and dorsal striatum		2.89	15	5	−5
Right amygdala		2.76	33	−1	−23
Left middle frontal gyrus	164	3.48	−24	29	43
Dorsal medial prefrontal cortex	190	3.47	3	38	52
Left ventral and dorsal striatum	65	3.16	−6	5	1
Precuneus	93	3.11	6	−61	40
Right superior frontal gyrus	66	3.1	18	23	52
Right parietal cortex	60	2.98	39	−61	55
Left parietal cortex	48	2.93	−54	−37	55
Posterior cingulate cortex	114	2.87	12	−34	31

(Corrected $p < 0.05$ achieved by voxel-level $p < 0.005$ and cluster size > 32).

Our fMRI results further revealed that 5-HTTLPR moderated the neural activity underlying reflection on actual/ideal self-discrepancy. Specifically, we found that s/s compared to l/l allele carriers of 5-HTTLPR showed stronger activity in the bilateral striatum, amygdala, LPFC, parietal cortex, MPFC and PCC during reflection on actual/ideal self-discrepancy. The genotype differences in the brain activity cannot be explained by group differences in personality traits or mood because these were matched between the two genotype groups. Similarly, our previous research reported that 5-HTTLPR moderated the neural activity related to reflection on one's own negative personality traits (Ma et al., 2014a). Relative to l/l carriers of 5-HTTLPR, s/s carriers reported greater feeling of distress and exhibited greater activity in the dorsal ACC and bilateral anterior insula in response to acknowledgement of one's own negative personality traits. Although our previous and current findings showed that the 5-HTTLPR effects on the neural activity related to self-referential processing varied depending on which aspects of the self was reflected, these findings are consistent in that s/s compared l/l carriers of 5-HTTLPT were more sensitive to reflection on one's own internal traits. These fMRI findings are consistent in the sense that s/s compared to l/l carriers showed stronger neural activity related to desire for ideal personality traits and stronger neural activity related to distress feelings when thinking of one's own negative traits. The previous brain imaging research has shown evidence that the s allele compared to l/l allele carriers of 5-HTTLPR are more susceptible to environmental influences (Belsky et al., 2009). The current fMRI findings expand the previous studies by showing that the s/s compared to l/l allele carriers are also sensitive to their own internal traits.

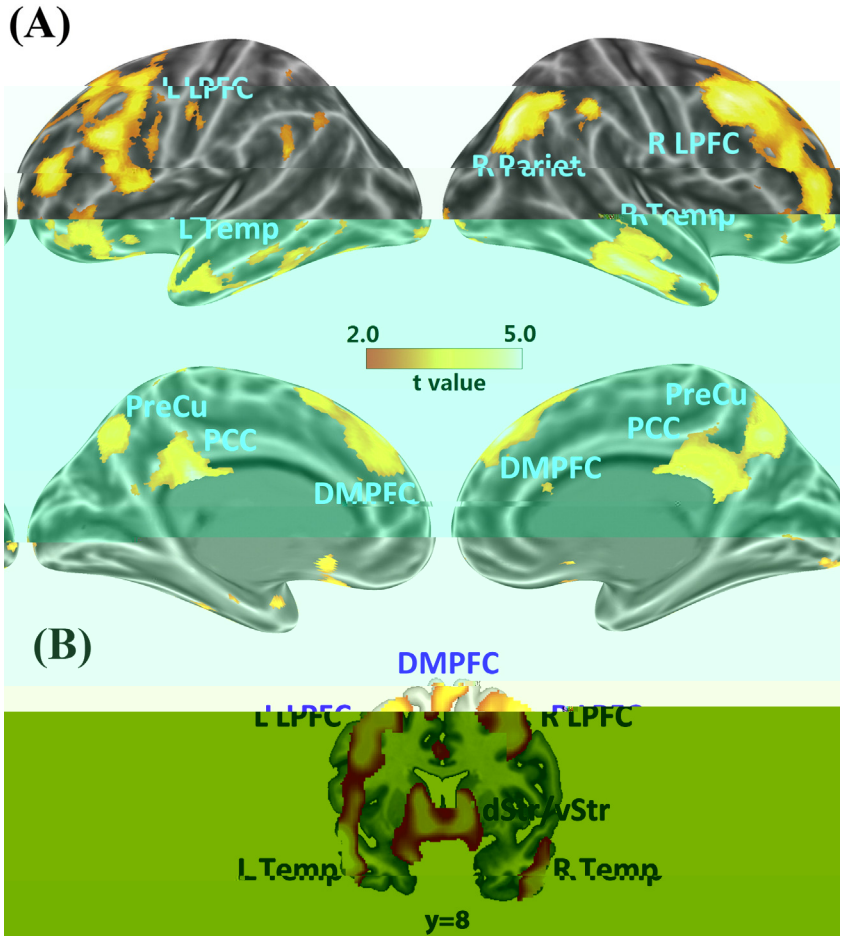

Fig. 3. Illustration of fMRI results from s/s carriers. Self-discrepancy related neural activity was evident over (A) the bilateral and medial cortical regions and (B) the bilateral striatum. (Striatal activation was shown at a threshold of voxel-level $p < 0.01$ and cluster size > 50 for illustration). L/R LPFC: left/right lateral prefrontal cortex; L/R Temp: left/right temporal cortex; R Pariet: right parietal cortex; PreCu: precuneus; PCC: posterior cingulate cortex; DMPFC: dorsal medial prefrontal cortex; dStr/vStr: dorsal/ventral striatum.

Interestingly, our fMRI results revealed that the 5-HTTLPR moderated the association between the neural activity related to actual/ideal self-discrepancy and subjective feelings of life satisfaction. Stronger striatal and prefrontal activities in response to greater actual/ideal self-discrepancy predicted lower subjective feelings of life-satisfaction in s/s carriers but not in l/l carriers. While the previous behavior research reported negative correlation between self-discrepancy and life satisfaction (Czaja, 1975), our fMRI results indicate that the link between self-discrepancy and life satisfaction may not be the same for the whole population but can be moderated by ones' own genetic make-up. Our imaging findings suggest a potential neural mechanism of the negative correlation between self-report actual/ideal self-discrepancy and life satisfaction, which, though, might only fit s/s carriers of 5-HTTLPR. Accumulating evidence suggests that s compared to l/l allele carriers of 5-HTTLPR exhibit higher risk for depression (Lotrich and Pollock, 2004; Lasky-Su et al., 2005; Uher and McGuffin, 2008) and stronger association between stressful life events and risk for depression (Caspi et al., 2003; Taylor et al., 2006). The underlying neural mechanisms have been associated with stronger amygdala activity to negative environmental stimuli (Hariri et al., 2002; Canli et al., 2005; Heinz et al., 2005; Ma et al., in press) and stronger activity in the ACC and anterior insula associated with negative self-schema (Ma et al., 2014a). The current findings complement the previous behavioral research (Czaja, 1975; Higgins, 1987; Carver et al., 1999; Higgins et al., 1985; Strauman and Higgins, 1987) and suggest that the stronger neural activity in response to actual/ideal self-discrepancy may serve as an additional possible neurocognitive mechanism underlying higher risk for depression in s/s carriers.

Our fMRI results also uncovered that the 5-HTTLPR moderated the association between the neural activity related to actual/ideal self-discrepancy and self-report of trait depression. Specifically, stronger striatal and prefrontal neural response to actual/ideal self-discrepancy predicted lower trait depression in l/l carriers but not in s/s carriers.

Table 3
Self-discrepancy related neural activity in s/s participants.

Region	Cluster size (voxel no.)	Z value	MNI coordinates		
			x	y	z
Left temporal pole	11,015	4.59	−57	8	−14
Right inferior temporal gyrus		4.32	66	−19	−26
Dorsal medial prefrontal cortex		4.29	9	44	46
Right middle frontal gyrus		4.24	42	17	52
Right parietal cortex		4.17	36	−73	46
Precuneus		4.10	0	−76	43
Posterior cingulate cortex		4.02	6	−40	22
Right cerebellum		3.98	45	−61	−35
Left middle frontal gyrus		3.76	−39	47	19
Right ventral and dorsal striatum		3.76	12	5	−2
Left ventral and dorsal striatum		3.67	−9	14	−8
Right thalamus		3.53	12	−4	7
Left cerebellum		3.52	−15	−76	−38
Left amygdala		3.37	−30	−1	−29
Anterior cingulate cortex		2.79	−9	29	19
Left parietal cortex	222	3.36	−63	−49	22
Right hippocampus	106	2.92	30	−19	−11
Left parahippocampal gyrus	99	3.62	−18	−16	−23
Left occipital cortex	89	3.11	−6	−103	4

(Corrected $p < 0.05$ achieved by voxel-level $p < 0.005$ and cluster size > 32).

This finding is interesting because it suggested that l/l and s/s carriers may employ different neurocognitive strategies for coping with negative affect related to actual/ideal self-discrepancy. Previous imaging genetic findings characterized the brain activity in s allele carriers with hyperactivity in the emotion-related brain regions such as the amygdala (Hariri et al., 2002; Ma et al., 2015; Stoeckel et al., 2015; Klucken et al., 2015) and ACC/insula (Ma et al., 2014a,2014b,2014c; Klumpp et al., 2014) and increased connectivity between the amygdala and other brain regions (e.g., amygdala and ventral MPFC, Pezawas et al., 2005; amygdala and insula, Klucken et al., 2015). Most of the previous studies focused on the account of high anxiety in s allele carriers by taking their hyperactivity in the amygdala and other brain regions into consideration. In the current study the stronger neural activity to actual/ideal self-discrepancy corresponded to lower well-being (i.e., lower life satisfaction) in s/s carriers but to higher well being (i.e., lower trait depression) in l/l carriers. These brain imaging results challenge the assumption of a reverse association between perceived actual/ideal self-discrepancy and well-being in general. In addition, because l/l compared to s carriers of 5-HTTLPR exhibited greater motives to cope with negative life events (Armeli et al., 2008), it may be further speculated based on our brain imaging results that l/l carriers with high compared to low trait depression may employ different strategies for coping with actual/ideal self-discrepancy such as suppressing the desire for ideal self, which may in turn decrease their anxiety.

Our questionnaire measures showed that s/s carriers tended to report lower positive affective states but higher negative affective states. However, these differences did not reach significance possibly due to the small sample size of our brain imaging study. Alternatively, it is possible that self-report of general affective states is easily influenced by many factors and this is why the previous studies that employed fairly large samples also reported inconsistent findings (e.g. Sen et al., 2004; Terracciano et al., 2009). Measures of affective states related to a specific task may be more powerful to reveal genetic differences compared to the questionnaire measures. Indeed, our recent work found that, when participants were instructed to reflect upon their negative traits, s/s in-

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