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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.

Keywords: 5-HTTLPR; fMRI; self-discrepancy; striatum; life satisfaction

Introduction

A key Buddhism doctrine is that the desire for a 'good' self deteriorates human happiness (Nikaya, 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 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= somewhat close", 3="somewhat far", 4="very far"). Such parametric behavioral response allowed us to identify the brain activations that were associated with one's own feelings of actual/ideal self-discrepancy.

The second question addressed in the current work is whether the neural activity underlying reflection on actual/ideal self-discrepancy differs between the two variants of the serotonin transporter promoter polymorphism (5-HTTLPR), a gene that affects neural responses to negative emotions (Hariri et al., 2002; Pezawas et al., 2005; Canli and Lesch, 2007; Ma et al., 2015) that dampen life satisfaction and are linked to depression. Early brain imaging studies found that, relative to homozygous long variant (l/l), the short variant of 5-HTTLPR exhibited stronger amygdala activity to negative environmental stimuli (Hariri et al. 2002; Canli et al. 2005; Heinz et al. 2005) and relative uncoupling of the amygdala and perigenual cingulate during the processing of negative emotion (Pezawas et al., 2002). Moreover, the degree of amygdala/perigenual cingulate uncoupling reversely predicted individuals' anxiety (Pezawas et al., 2002). Recent research further revealed that, relative to l/l carriers of 5-HTTLPR, the short homozygotes (s/s) showed stronger distressed feelings and greater activity in the ACC/MPFC and insula during reflection on their own negative traits (Ma et al., 2014a). Given that greater actual/ideal self-discrepancy reflects a larger gap between one's actual self and one's expectation, s/s relative to l/l carriers may show stronger neural responses to actual/ideal self-discrepancy that are sensitive to affective states. We tested these hypotheses

by scanning s/s and l/l carriers of the 5-HTTLPR using fMRI during reflection on actual/ideal self-discrepancy in personality traits.

The third question addressed in the current study is whether the neural activity related to actual/ideal self-discrepancy can predict subjective feelings of life satisfaction and trait depression. Although the behavioral measures suggest that actual/ideal self-discrepancy is associated with life satisfaction (Czaja, 1975), negative affect (Higgins, 1987) and depression (Bibring, 1953), it remains unclear whether the association between self-discrepancy and subjective well-being as indicated by self-report of life satisfaction and depression varies across individuals with different genetic makeups. One possibility is that self-discrepancy is associated with subjective well-being in a similar vein in s/s and l/l carriers of the 5-HTTLPR. Alternatively, there may be stronger coupling of self-discrepancy and subjective well-being in those whose brain activity is more sensitive to actual/ideal self-discrepancy. These were clarified by investigating whether 5-HTTLPR moderates the relationships between neural correlates of self-discrepancy and self-report indicators of subjective well-being (e.g., life satisfaction and depression).

Materials and Methods

Participants

Fifty Chinese students from Peking University (24 female; aged between 17 and 25 years, Mean±SD=21.00±1.51) participated in this study as paid volunteers. There were 25 s/s homozygotes (13 female; 17 to 24 years, Mean±SD=20.88±1.72) and 25 l/l homozygotes (11 female; 20 to 25 years, Mean±SD=21.12±1.30). s/s and l/l carriers did not significantly differ in gender ($\chi^2(1)=0.32$, $p=0.57$) or age ($t(48)=-0.56$, $p=0.58$). All participants were right-handed, had normal or corrected-to-normal vision, and reported no abnormal neurological or psychiatric history. Participants provided informed consent prior to fMRI scanning. This study was approved by a local ethics committee.

DNA Isolation and Analysis

We used a PCR method (Ota et al. 2007) to determine the genotypes of 5-HTTLPR. In a total volume of 50 μL, about 25 ng of genomic DNA were amplified in the presence of 1 × TransStart FastPfu DNA Polymerase (TransGen Biotech) reaction system and oligonucleotide primers (forward 5′-GCATCCCCCATTATCCCCCCCT-3′ and reverse

5′-AGGCTTGGAGGCCGGGATGC-3′) at final concentration of 200 nM. Thermal cycling consisted of a 15 min of initial denaturation at 95 °C followed by 35 cycles of 95 °C (20 s), 69 °C (20 s) and 72 °C (15 s) each with a final extension step of 10 min at 72 °C. Subsequently, the PCR product was loaded onto a 3% agarose gel (BioWest G-10) to perform electrophoresis to distinguish genotypes of s/s, s/l, and l/l. All genotyping was performed in duplicate. Blood samples of 901 university students (490 males and 411 females, 18-33 years, mean age±SD =19.99±2.76 years) were collected for genotyping 5-HTTLPR, which identified 88 long allele homozygotes (l/l), 194 heterozygotes (l/s), and 619 short allele homozygotes (s/s).

Stimuli and Procedure

Forty-eighty positive trait adjectives (each consisting of two Chinese characters) were selected from the established personality trait adjective pool (Liu 1990). Each participant completed a task of rating how important it is to possess each trait before fMRI scanning. Participants rated each trait adjective on a four-point Likert scale (1="not important at all", 2="a little bit important", 3="moderately important", 4="very important") by a key press. They were informed that ratings indicate the importance of owning a trait rather than actually possessing it. The importance rating scores were used as implicit estimation of participants' desire for each personality trait. The rating task was self-paced during which trait words were presented at the center of a computer screen above a four-point scale and in a random order.

During fMRI scanning participants performed actual/ideal self-discrepancy judgments on these trait words. Trait words were presented at the center of a screen in a random order, with the four-point scale presented below. Each Chinese character subtended a visual angle of 1.7° × 2.3° (width × height) for the trait adjectives at a viewing distance of 80 cm. The fixation cross subtended a visual angle of 1.31° × 1.31°. Participants were instructed to think over each trait word and to indicate how far the actual self is away from the ideal self in terms of that trait. Participants responded on each trait word by pressing one of four buttons that were associated with a four-point Likert scale (1="very close", 2= somewhat close", 3="somewhat far", 4="very far"). Each trait word was presented for 2000 ms, with inter-stimulus-interval varying among 1 s, 2 s, 3 s, 4 s, or 5 s (mean=3 s). The mapping of the scale to the four response keys was counterbalanced across participants.

After scanning, participants indicated their general life satisfaction on a seven-point Likert scale (1="very unsatisfied", 7="very satisfied") (Campbell 1976) and their trait depression (subscale of the State-Trait Depression Inventory, Krohne et al. 2002). Participants also completed the Positive and Negative Affect scale (Watson, Clark, & Tellegen 1988), the Rosenberg Self-Esteem scale (Rosenberg 1965), the neuroticism subscale of the short version of the Revised Eysenck Personality Questionnaire (Eysenck, Eysenck, & Barrett 1985), and the Relationship Assessment scale (Hendrick 1988) to control for the influences of affect, self-esteem, neuroticism, and family relationship. Participants were also asked to finish an ideal-self rating task during which participants were presented with each trait adjective used during scanning and had to answer "to what degree does this word describe your ideal self?" on each trait adjective on a four-point Likert scale (1="not at all", 4="very well"). This measure was used as explicit estimation of participants' desire for each personality trait.

Imaging Parameters

One hundred and twenty-nine functional images were acquired during one functional run using a 3.0T 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 × 64 × 32 matrix with 3.75 × 3.75 × 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 × 512 × 180 matrix with a spatial resolution of 0.47 × 0.47 × 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 first scan to correct for head motion, normalized into stereotactic Montreal Neurological Institute (MNI) space with 3-mm cubic voxels, and spatially smoothed by a Gaussian filter with full-width/half-maximum parameter (FWHM) set to 8 mm. We then modeled trials by convolving canonical hemodynamic response function (HRF) and its time derivative at the onset of the presentation of trait words. Furthermore, the model included subjects' self-discrepancy rating scores on trait words in order to test the parametric modulation of self-discrepancy. Six motion parameters

(translation: x, y, z; rotation: pitch, roll, yaw) were also included in the model to account for effects of no interest. Low-frequency signal drifts were removed by high-pass filtering (cutoff 128 s), and temporal autocorrelations were corrected by using an autoregressive AR(1) function. Random effect analyses were then conducted based on contrast images to allow population inference. One-sample t-test was conducted to examine the parametric modulation effect of self-discrepancy across all subjects. We also conducted two-sample t-test to examine the genotype differences in neural activity related to self-discrepancy. Significant activation was identified using a threshold of corrected $p < 0.05$ (using a combined threshold of voxel-level $p < 0.005$ and cluster extent > 32 voxels, determined by a 2000-iteration Monte-Carlo simulation; Slotnick et al. 2003). Regions of interest (ROIs) analyses were conducted to assess the association between the neural activity related to self-discrepancy and subjective feelings of life satisfaction and trait depression. ROIs were defined based on the results of whole-brain one-sample t-test that revealed neural activity related to self-discrepancy across all participants. MarsBaR 0.42 (http://marsbar.sourceforge.net) was used to define ROIs as spheres centered at the peak voxels of activations related to self-discrepancy with radii of 5 mm. Parameter estimates were extracted from ROIs and subjected to correlation and regression analyses with behavioral findings.

To examine whether 5-HTTLPR influences the association between neural activity related to self-discrepancy and life-satisfaction/trait depression, moderator effect analyses were conducted by 1) creating a grouping variable for genotype as a moderator (s/s=-1, l/l=1), 2) computing the interaction term for the moderator and the independent variable, 3) normalizing the dependent variable, the independent variable, the moderator, and the interaction term, 4) entering the variables into the linear regression model, 5) determining the significance of the moderator effect by evaluating the parameter estimate (β) for the interaction term, and 6) given significant moderator effect, probing the simple effect of the independent variable by testing its correlation with the dependent variable at each level of the moderator (i.e. for s/s and l/l separately) (Frazier et al., 2004).

Results

Behavioral Results

Trait words were rated as moderately important across all participants (3.03±0.42), suggesting participants' desire for these traits. However, ratings of importance and

self-discrepancy did not differ significantly between s/s and l/l carriers (importance: 3.06±0.44 vs. 3.01±0.41, t(48)=0.44, p=0.66; self-discrepancy: 2.16±0.36 vs. 2.19±0.37, t(48)=-0.27, p=0.79). Rating scores in the ideal-self rating task did not differ significantly between s/s and l/l carriers either (s/s: 3.35±0.37; l/l: 3.40±0.27, t(48)=-0.54, p=0.59). However, there was a significant correlation between rating scores of importance and ideal-self across all participants (r=0.69, $p < 0.001$). s/s and l/l allele carriers did not differ significantly in self-report of life satisfaction (4.80±1.19 vs. 5.12±1.01, t(48)=-1.02, p=0.31) and trait depression (1.76±0.30 vs. 1.76±0.42, t(48)=-0.04, p=0.97). s/s and l/l allele carriers were also comparable in affective states and other psychological traits (positive affect: 2.61±1.08 vs. 2.79±1.11, t(48)=-0.57, p=0.57; negative affect: 1.65±0.75 vs. 1.47±0.68, t(48)=0.89, p=0.38; self-esteem: 3.07±0.32 vs. 2.98±0.43, t(48)=0.89, p=0.38; neuroticism: 0.34±0.25 vs. 0.38±0.28, t(48)=-0.53, p=0.60; family relationship: 4.14±0.63 vs. 3.93±0.75, t(48)=1.08, p=0.29). Rating scores of actual/ideal self-discrepancy tended to be negatively correlated with those of life satisfaction but positively with those of trait depression, though the correlation did not reached significance (r=-0.16 and 0.22, p=0.27 and 0.13).

fMRI Results

The fMRI data analysis across all participants first identified brain regions that showed increased activity to larger actual/ideal self-discrepancy. These included the dorsal region of the MPFC, lateral prefrontal cortex (LPFC), dorsal ACC, left anterior insula, bilateral ventral and dorsal striatum (vStr and dStr), bilateral parietal cortex, bilateral thalamus, right inferior temporal gyrus, and cerebellum (Figure 1A and 1B, Table 1). However, no brain activation was observed to be associated with smaller actual/ideal self-discrepancy. The association between self-discrepancy related neural activity and desire for ideal personality traits was further verified by correlation analyses that revealed that, across all participants, rating scores of the importance of each personality trait for oneself were positively associated with the neural activity of the left vStr (r=0.28, p<0.05), left dStr (r=0.29, p<0.05), dorsal MPFC (r=0.32, p<0.03), and right dStr (r=0.27, p=0.06), but not the right vStr and bilateral LPFC (r=0.10 to 0.21, ps>0.14). Such associations were not significantly moderated by genotype (s/s vs. l/l) (β=-0.11 to 0.05, t(46)=-0.82 to 0.34, ps>0.41) (Figure 1C). In addition, the rating scores of the ideal-self were positively correlated with the neural activity of the left dStr (r=0.29, p=0.039).

These results suggest that, across all participants, a greater motive to possess positive personal traits measured in both implicit and explicit estimation was associated with greater striatal (especially left striatal) and dorsal MPFC responses to actual/ideal self-discrepancy.

Genotype differences in the neural activity related to actual/ideal self-discrepancy were examined using a two-sample t-test that compared brain activity from the two genotype groups. Relative to l/l carriers, s/s carriers exhibited stronger activations during reflection on actual/ideal self-discrepancy in the bilateral vStr and dStr, anterior temporal cortex, amygdala, LPFC, parietal cortex, dorsal MPFC and posterior cingulate cortex (PCC) (Figure 2 and Table 2). l/l carriers did not show any stronger neural activity compared to s/s carriers. One-sample t-tests conducted on each genotype group revealed that, for s/s participants, larger actual/ideal self-discrepancy was associated stronger neural activity in the bilateral vStr and dStr, LPFC, and dMPFC (Figure 3 and 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 Figure 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 participants, trait depression scores were negatively correlated with the neural activity in the right vStr ($r=-0.28$, $p<0.05$), but not in other brain regions (ps>0.18). The genotype (s/s vs. l/l) significantly moderated the association between the striatal activity and trait depression (left vStr: $\beta=-0.41$, $t(46)=-3.09$, $p<0.005$; left dStr: $\beta=-0.32$, $t(46)=-2.30$, $p<0.03$; right vStr: $\beta=-0.28$, $t(46)=-1.89$, $p=0.06$; right dStr, $\beta=-0.31$, $t(46)=-2.18$, $p<0.04$). Further analyses confirmed significant negative correlations between trait depression and the striatal activity in l/l carriers (left vStr: $r=-0.49$, $p<0.02$; left dStr: $r=-0.40$, $p<0.05$; right vStr: $r=-0.47$, $p<0.02$; except for right dStr: $r=-0.29$, $p=0.16$) but not in s/s carriers (ps>0.1, Figure 4B). A similar moderator effect was observed between trait depression and the MPFC activity ($\beta=0.36$, $t(46)=2.68$, $p<0.02$) but not the LPFC activity (ps>0.13) due to that the MPFC activity negatively predicted trait depression in l/l ($r=-0.49$, $p<0.02$) but not in s/s carriers ($p=0.33$). Thus stronger striatum and prefrontal neural response to actual/ideal self-discrepancy predicted lower trait depression in l/l carriers but not in s/s carriers.

Discussion

The current study developed a paradigm to investigate the neural correlates of reflection on actual/ideal self-discrepancy. Previous fMRI studies have shown considerable evidence that reflection on personality traits of the actual self recruits in the ventral MPFC (Kelley et al., 2002; Zhu et al., 2007; Wang et al., 2012; Ma et al., 2014b). Reflection on the past and future self also activates the ventral MPFC but to a lower degree (D'Argembeau et al., 2010). The current work revealed that reflection on actual/ideal self-discrepancy recruited a more complicated neural network that does not overlap with the ventral MPFC involved in coding self-relevance (Northoff et al. 2006; Han and Northoff 2009). The neural circuit activated by reflection on actual/ideal self-discrepancy consisted of both cortical and subcortical structures. Particularly related to our hypothesis, we found that greater actual/ideal self-discrepancy was linked to increased activity in the brain regions such as the vStr and dStr that were shown to be involved in desire for external rewards in the previous studies (Due et al., 2002; David et al., 2005; Wilson et al., 2005; Franklin et al., 2007; Kober et al., 2010). Moreover, the left striatal activity positively predicted individuals' subjective feelings of how important the positive personality traits are for the self and how the 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).

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.

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 makeup. 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., 2014 a). 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. 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; Rao et al., 2007; Ma et al., 2015; Stoeckel et al., 2015; Klucken et al., 2015) and ACC/insula (Ma et al., 2014; 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 individuals reported greater distress than l/l individuals (Ma et al. 2014a). Future research should consider measuring affective states related to a specific task in order to uncover genotype differences in subjective feelings of emotion.

Finally, a few limitations of the current work should be acknowledged. First, our work only tested one cultural sample. The previous research has shown behavior and brain imaging evidence for cultural differences in self-concept and the underlying neural mechanisms (Markus and Kitayama, 1991; Han and Northoff 2009; Han et al., 2013; Han and Ma, 2015). Moreover, recent brain imaging findings suggest that genes may interact with self-construals to modulate brain activity involved in social cognition (Ma et al., 2014c; Luo et al., in press). These findings raise the question of whether actual/self-discrepancy is similarly linked to the reward system in other cultural groups and, if so, whether the strength of such link varies across cultures that differ in self-construals (e.g., independence vs. interdependence). Second, the

current work only tested neural substrates underlying reflection on one's own mental attributes (i.e., personality traits). Our recent research has revealed that self-reflection on mental, social and physical attributes recruits distinct brain regions (e.g., Ma et al., 2014b). While self-reflection on social, mental and physical attributes activated the ventral MPFC, self-reflection on social attributes also increased activity in the temporoparietal junction in Chinese. An interesting issue arising from these findings is whether desire for mental, social and physical attributes of the ideal self similarly activates the brain regions in the reward system. These should be clarified in future research.

In conclusion, we showed brain imaging evidence that reflection on actual/self-discrepancy activated brain regions that have been demonstrated to be engaged in desire for external rewards. In addition, the striatal and prefrontal activities related to actual/self-discrepancy were moderated by individuals' genetic makeup, being stronger in s/s than l/l carriers of 5-HTTLPR. The striatal and prefrontal activities predicted self-report of life satisfaction in short/short carriers but trait depression in long/long carriers. These results implicate that the two variants of 5-HTTLPR may adopt distinct coping strategies to deal with actual/ideal self-discrepancy and the desire for ideal self. Since our brain imaging findings are highly related to individuals' well-being, future research should further clarify cognitive strategy or cognitive training that can produce salient modulation of the brain activity in response to desire for the ideal self.

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Figure legends

Figure 1. Illustration of fMRI results in our stud. Self-discrepancy related neural activity across all participants 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). (C) The correlation between importance rating scores and the left vStr activity across all participants. L/R LPFC: left/right lateral prefrontal cortex; R Pariet: right parietal cortex; PreCu: precuneus; DMPFC: dorsal medial prefrontal cortex; dStr/vStr: dorsal/ventral striatum.

Figure 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.

Figure 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.

Figure 4. Illustration of the differential associations between brain activity and self-report. (A) The correlation between life satisfaction and the left vStr activity was moderated by genotype. (B) The correlation between trait depression and the left vStr activity was moderated by genotype. dStr/vStr: dorsal/ventral striatum.

Table 1. Self-discrepancy related neural activity across all participants.

Region	Cluster size (voxel no.)	Z value	MNI coordinates		
			x	y	z
Left middle frontal gyrus	1422	4.62	-39	20	28
Right middle frontal gyrus	1147	4.37	33	14	40
Pre-supplementary motor area		3.79	-6	11	58
Dorsal medial prefrontal cortex		3.69	9	35	43
Dorsal anterior cingulate cortex		2.83	15	26	25
Right parietal cortex	422	4.29	42	-79	37
Precuneus	399	3.78	-6	-67	40
Left anterior insula	238	3.76	-24	23	-11
Left ventral striatum		3.28	-9	11	-5
Right ventral striatum		2.96	6	2	-8
Left dorsal striatum		2.84	-15	8	4
Right dorsal striatum	38	3.70	3	11	10
Left parietal cortex	186	3.65	-36	-52	40
Right inferior temporal gyrus	76	3.65	54	-28	-20
Right inferior frontal gyrus	63	3.56	60	20	7
Left cerebellum	139	3.56	-51	-40	-32
Right thalamus	195	3.13	9	-7	7
Left thalamus		2.74	-9	-13	4

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

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)

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	11015	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)

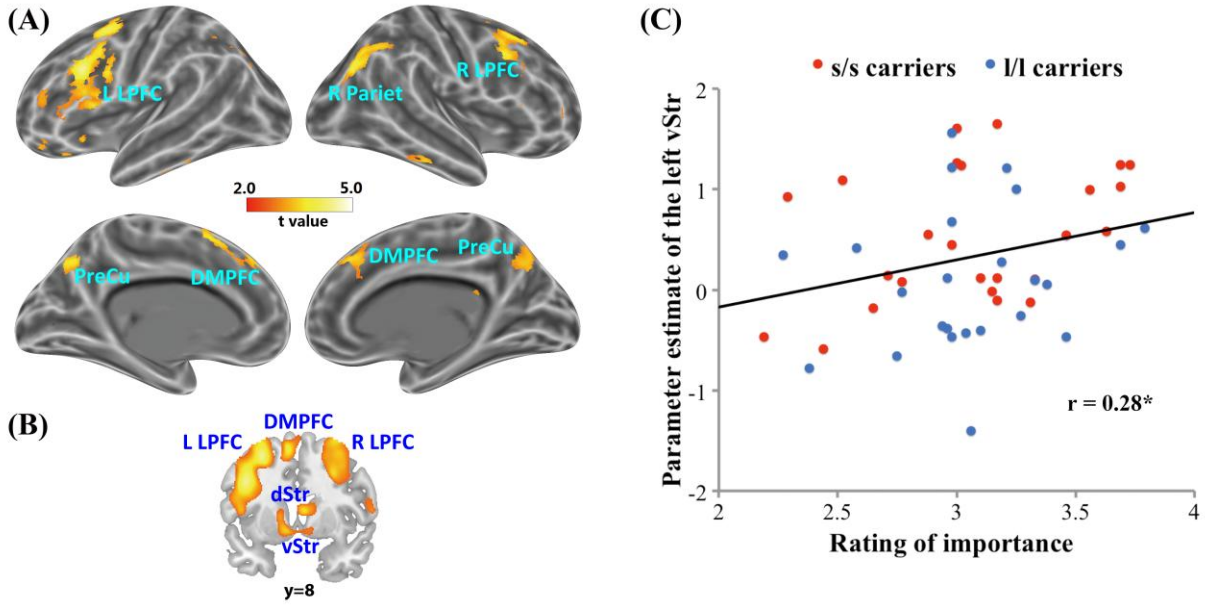

Figure 1

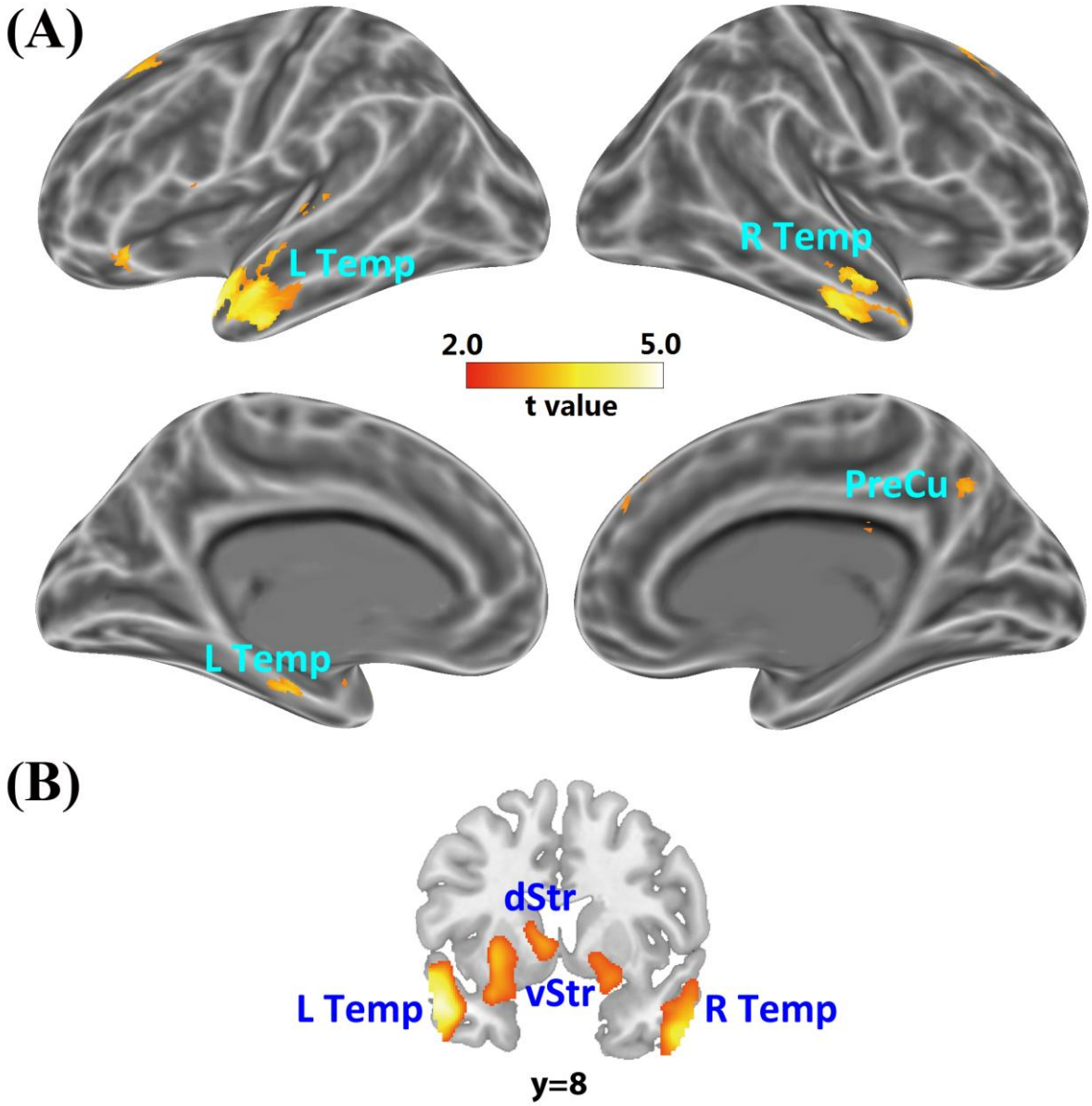

Figure 2

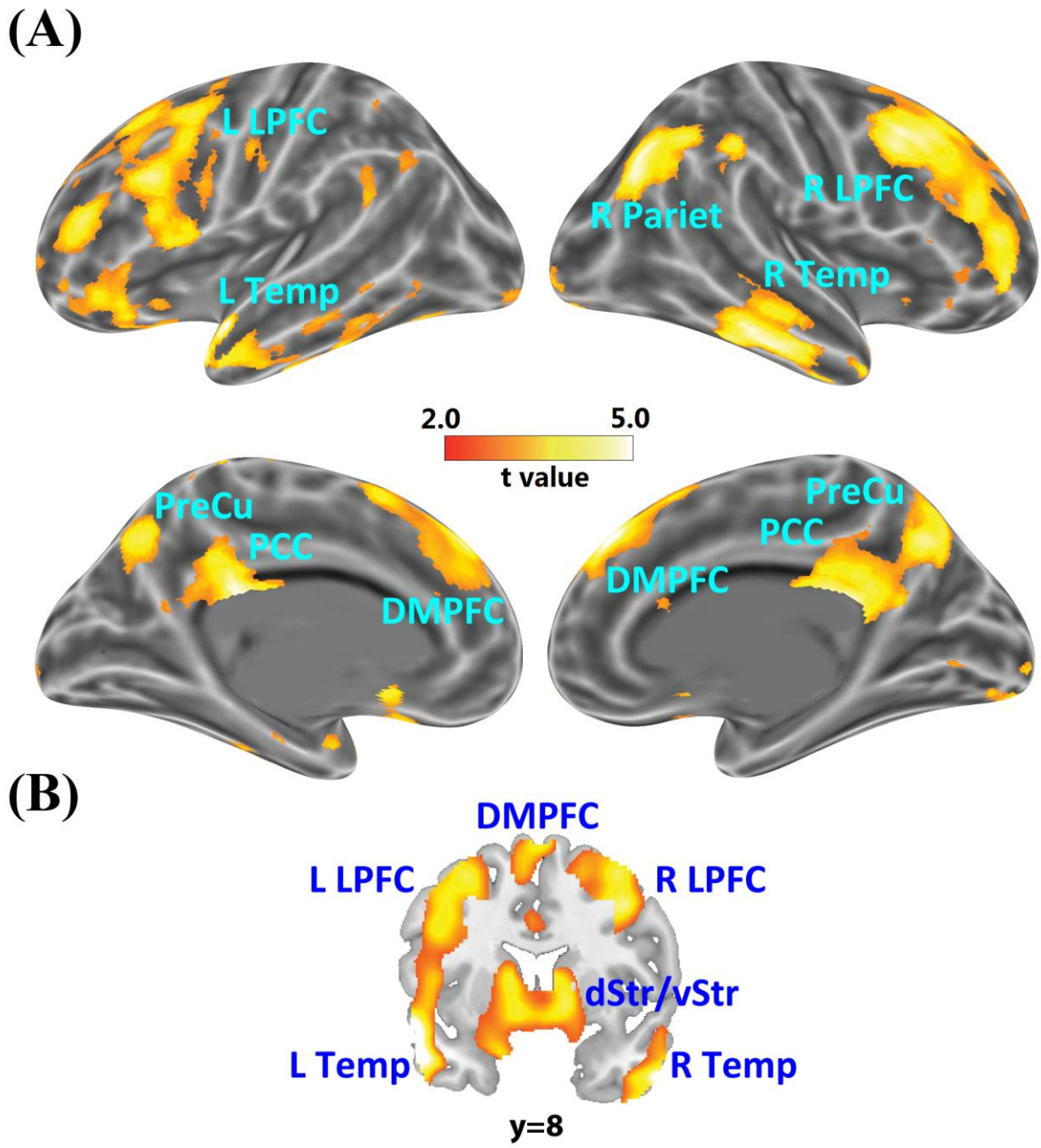

Figure 3

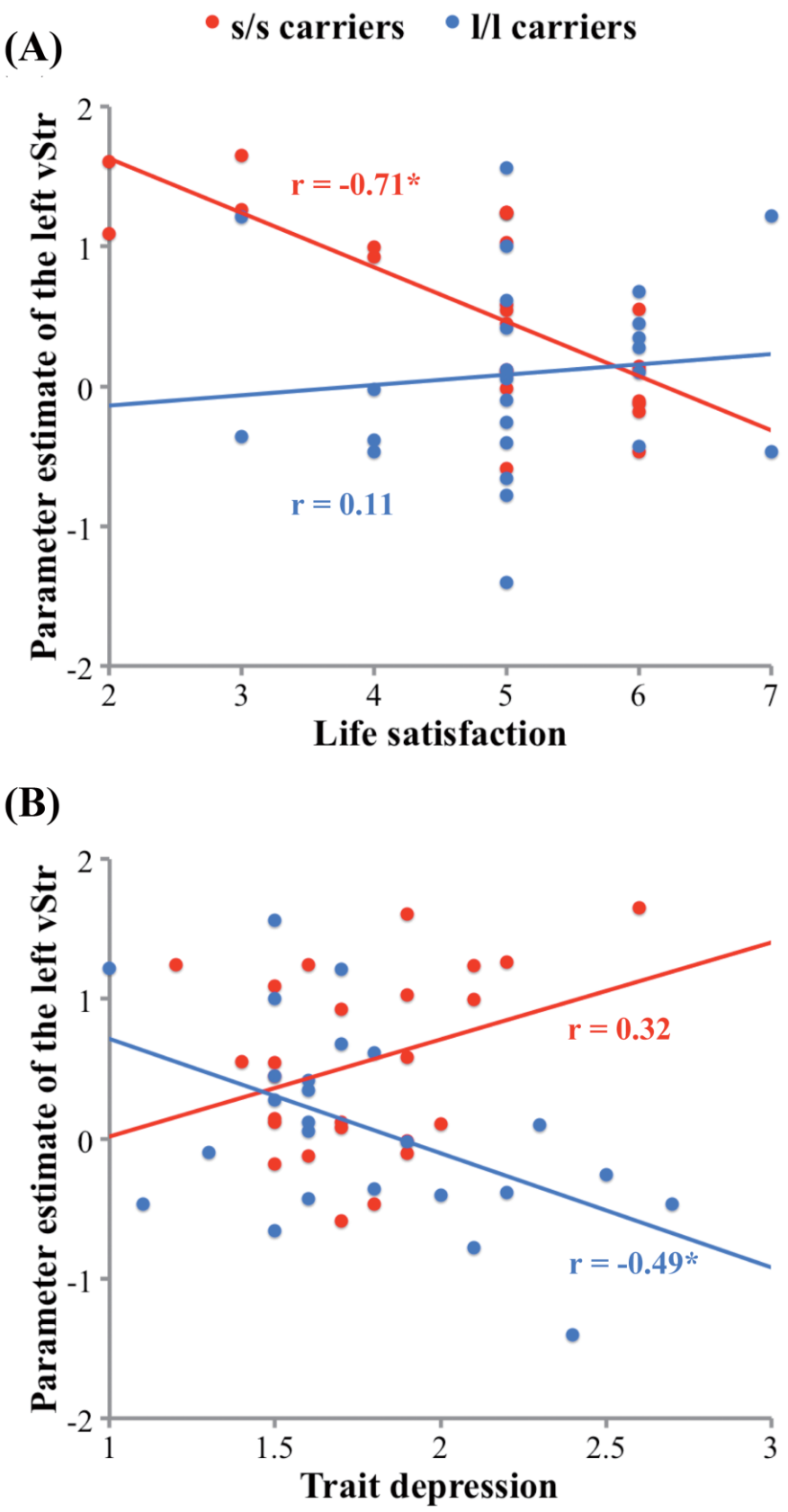

Figure 4

Highlights

- To investigate neural correlates of reflection on actual/ideal self-discrepancy
- Identified activations in the ventral/dorsal striatum and dMPFC/LPFC
- These activations were stronger in s/s than l/s allele carriers of 5-HTTLPR
- Neural substrates of actual/ideal self-discrepancy are sensitive to genetic makeup