Extraversion mediates the relationship between structural variations in the dorsolateral prefrontal cortex and social well-being

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A R T I C L E   I N F O
Article history:
Accepted 28 October 2014
Available online 1 November 2014

Keywords:
Social well-being
Extraversion
Prefrontal cortex
Voxel-based morphometry

A B S T R A C T
Social well-being reflects the appraisal of one's circumstance and functioning in society, which is crucial for individuals' mental and physical health. However, little is known about the neural processes associated with social well-being. In this study, we used voxel-based morphometry (VBM) to identify the brain regions underlying individual differences in social well-being, as measured by the Social Well-being Scale (SWBS), in a large sample of young healthy adults. We found that social well-being was negatively correlated with gray matter volume in left mid-dorsolateral prefrontal cortex (mid-DLPFC) that is implicated in executive functioning, emotional regulation and social reasoning. The results remained significant even after controlling for the effect of socioeconomic status. Furthermore, although basic personality factors such as neuroticism, extraversion, and conscientiousness (as measured by the NEO Personality Inventory) all contributed to social well-being, only extraversion acted as a mediational mechanism underlying the association between the left mid-DLPFC volume and social well-being. Together, our findings provide the first evidence for the structural basis of individual differences in social well-being, and suggest that the personality trait of extraversion might play an important role in the acquisition and process of social well-being.

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Introduction

Most studies on well-being focus on quality of life and personal functioning such as emotional or psychological well-being, relatively little attention has been given to social functioning in public and social life. Social well-being is conceptualized as the appraisal of one's circumstance and functioning in society (Keyes, 1998), which is important for individuals' mental and physical health (Keyes, 1998; Zhang et al., 2011). It involves in the perception of one's social integration, of one's acceptance of others, of one's contribution to society, of the coherence of society and of the potential and trajectory of society (Keyes, 1998). Previous studies have shown that social well-being is moderately correlated with well-being in private life (i.e., individual well-being) including positive affect, life satisfaction, happiness and psychological well-being (Keyes, 1998; Lamers et al., 2011; M. Li et al., 2014; Wilt et al., 2010), which suggests that both social and individual well-being are related but distinct constructs. Recently, researchers have paid a lot of attention to how individuals increase their well-being, which to a certain extent relies on their individual differences or personality dispositions (Steel et al., 2008). Several behavioral studies demonstrating the importance of personality characteristics, especially the Five-Factor Model of personality (FFM; McCrae and Costa, 1991) in social well-being have found that all five basic personality traits such as neuroticism, extraversion, openness, agreeableness and conscientiousness are associated with social well-being (Hill et al., 2012; Joshanloo et al., 2012; Wilt et al., 2010). In this study, we used structural magnetic resonance imaging (sMRI) to investigate the brain structures underlying individual differences in social well-being and the role of personality in these associations.

To the best of our knowledge, no study has directly explored the neural correlates of social well-being, but recently, neuroscientists have begun to investigate the association between the brain and individual well-being. Evidence from an electroencephalography study has revealed that greater left than right superior frontal activation is associated with individual well-being including life satisfaction, positive affect and psychological well-being (Urry et al., 2004). Furthermore, two functional MRI (fMRI) studies reported that psychological well-being was associated with activities of the ventromedial (VMPC) in response to negative stimuli (van Reekum et al., 2007) and dorsolateral prefrontal cortex (DLPFC) in response to positive stimuli (Heller et al., 2013). Recently, using voxel-based morphometry (VBM), Takeuchi et al. (2014) found significant negative relationships between regional gray matter volume (rGMV) in specific regions of the PFC including left dorsomedial and rostrolateral regions and individuals' total life...
satisfaction (as measured by the self-report WHOQOL questionnaire). These findings consistently indicate that the PFC, which is known to be involved in cognitive–emotional functions such as executive functioning (Alvarez and Emory, 2006; Blumenfeld and Ranganath, 2006), emotional regulation (Kalisch, 2009; Ochsner and Gross, 2005; Pessoa, 2008) and social cognition (Barbey et al., 2009; Forbes and Grafman, 2010; Rilling and Sanfey, 2011), may play an important role in individual well-being. Nevertheless, it is not clear whether these relationships with the PFC regions (e.g., DLPCF, VMPFC) would be seen in social well-being.

The PFC has been also thought to contribute to development of personality traits, particularly neuroticism and extraversion, which are of particular interest because they are closely related to mood and anxiety disorders (Bienvenu et al., 2004; Clark et al., 1994; Khan et al., 2005). Previous functional imaging studies have shown that extraversion and neuroticism measures are associated with the activities of specific PFC regions including the DLPCF and orbitofrontal cortex in the resting state (Adelstein et al., 2011; Johnson et al., 1999; Kunisato et al., 2011; Wei et al., 2011, 2014) or in response to some specific activation procedures (Brühl et al., 2011; Canli et al., 2001; Canli, 2004; Giao et al., 2009; Gray et al., 2005; Harenstein et al., 2009; Kumari et al., 2004). This is in accordance with previous VBM studies that reported the associations between regions of the PFC and extraversion and neuroticism (Coutinho et al., 2013; DeYoung et al., 2010; Forbes et al., 2014; Idakwa et al., 2006; Lu et al., 2014; Rauch et al., 2005; Wright et al., 2007). In contrast to extraversion and neuroticism, limited studies have identified the role of the PFC regions in conscientiousness (DeYoung et al., 2010; Forbes et al., 2014; Kunisato et al., 2011) and openness (DeYoung et al., 2005; Koelsch et al., 2013). In light of the importance of personality in social well-being (Hill et al., 2012; Joshua et al., 2012; Wilt et al., 2010) and the fact that personality traits are more robust psychological constructs with a more solid biological basis when compared with social well-being, personality traits might mediate the effects of structural differences in the PFC, particularly the DLPCF on social well-being.

To examine these two questions, this study used well-validated measures of personality and social well-being, and VBM methodology. Studies have shown that the VBM methodology can be used to investigate the neural basis of individual differences in behavioral performance (e.g., personality characteristics) (DeYoung et al., 2010; Kanai and Rees, 2011; Kong et al., 2014; Song et al., 2014; Takeuchi et al., 2014). Based on the previous neuroscience findings on individual well-being (Heller et al., 2013; Takeuchi et al., 2014; Urry et al., 2004; van Reekum et al., 2007), we hypothesized that individual differences in social well-being would be associated with rGMV in the PFC regions (e.g., DLPCF, DMPFC) that has been linked to cognitive–emotional functions (Alvarez and Emory, 2006; Curtis and D’Esposito, 2003; Ochsner and Gross, 2005). Here we hoped to identify which PFC regions are important for social well-being by examining the relationship between social well-being and brain structure across the whole brain in a large sample of participants (N = 294). Furthermore, given the association between personality and social well-being (Hill et al., 2012; Joshua et al., 2012; Wilt et al., 2010) and the crucial role of the PFC, particularly the DLPCF in personality (Coutinho et al., 2013; DeYoung et al., 2010; Lu et al., 2014; Rauch et al., 2005; Wright et al., 2007), we hypothesized that some specific personality traits (e.g., extraversion) would be able to mediate the relationship between the PFC, particularly the DLPCF and social well-being.

**Methods**

**Participants**

Two hundred and ninety-four healthy volunteers (157 females; mean age = 21.57 years, standard deviation (SD) = 1.01) from Beijing Normal University participated in this study as part of our ongoing project investigating associations among brain imaging, cognitive functions, and genetics (Huang et al., 2014; Kong et al., 2014; W. Li et al., 2014; Song et al., 2014; Wang et al., 2014). Participants were instructed to undertake a series of computer-based cognitive ability tests, paper–pencil questionnaires, and MRI scans. Computer-based cognitive ability tests assess abilities primarily involved in reason, attention, memory, numerosity, object/face recognition ability, spatial ability, musical ability, theory of mind and language skills. Paper–pencil questionnaires mainly assess one’s family environment (e.g., socioeconomic status, parental conflict and parenting styles), school environment (e.g., peer attachment and teaching styles), Big Five personality, positive character traits such as self-esteem, optimism and resilience, emotional and social competence, social support system, health outcomes such as loneliness, sleep quality, physical health and psychological health, and other outcomes such as aggression, internet addiction, and prosocial behavior. Data that are not relevant to the theme of this study were not reported here. Because the acquisition of MRI data was time-consuming for the large sample of participants, the questionnaires were measured at least a month after MRI data acquisition. Given that the questionnaires have shown adequate long-term test–retest reliability (Costa and McCrae, 1992; Goodman et al., 2001; Yang et al., 1998), the time interval likely had little impact on the results in the present study. No participants had history of neurological or psychiatric disorders. The majority of the participants were right-handed (n = 275) based on a single-item handedness questionnaire (“Are you (a) right-handed, (b) left-handed, (c) mixed-handed?”). Written informed consent was obtained from all participants. The study was approved by the Institutional Review Board of Beijing Normal University.

**Measures**

**Social well-being scale**

Social well-being was assessed using a 15-item version of Keyes’s (1998) social well-being scale (SWBS). It measures the five components of social well-being: social acceptance, social actualization, social coherence, social contribution, and social integration (three items each). It includes items such as, “I feel close to other people in my community.” (Social integration), “I believe that people are kind.” (Social acceptance), “I have nothing important to contribute to society.” (Social contribution), “Society has stopped making progress.” (Social actualization), and “The world is too complex for me.” (Social coherence). Each item required a respondent to answer on a 6-point scale the degree to which the item applies (1 = strongly disagree, 6 = strongly agree). Negatively worded items were reverse coded prior to all analyses. A higher score indicates higher levels of social well-being. Previous studies have shown that the scale has high reliability, construct validity and discriminant validity with other constructs such as life satisfaction, positive affect and negative affect in Chinese populations (M. Li et al., 2014). In the present study, the scale demonstrated adequate internal reliability (α = 0.81).

**NEO Personality Inventory**

The Revised NEO Personality Inventory (NEO-PI-R, Costa and McCrae, 1992) is a 120-item self-report questionnaire based on the five-factor model of personality (Costa and McCrae, 1990, 1995). Each dimension was measured with 24 items and participants responded to each item using a 5-point Likert scale with response options ranging from strongly disagree to strongly agree. Negatively worded items were reverse coded prior to all analyses. This inventory provides summary scores for the five different dimensions of personality: neuroticism, extraversion, openness to experience, agreeableness and conscientiousness. Previous studies have shown that the scale has high reliability and validity in Chinese populations (Yang et al., 1999; W. Li et al., 2014). In the present study, Cronbach’s α of the NEO-PI-R scales ranged from 0.71 and 0.88, indicating that these five personality dimensions of NEO-PI-R exhibited adequate internal reliability. Fifteen participants were excluded due to missing data.
Socioeconomic status

Subjective socioeconomic status (SES) was assessed using a graphical representation of a ladder with 10 rungs (1 being the lowest rank; 10 being the highest rank). The instructions are as follows: “Think of this ladder as representing where people stand in our society. At the top of the ladder are the people who are the best off – those who have the most money, most education and best jobs. At the bottom are the people who are the worst off – who have the least money, least education, and the worst jobs or no jobs. The higher up you are on this ladder, the closer you are to the people at the very top and the lower you are, the closer you are to the people at the very bottom. Please mark a cross on the rung on the ladder where you would place yourself.” (Adler et al., 2000). Prior research has indicated that the subjective SES has stronger relationships with stress and health-related factors than objective SES measures (Adler et al., 2000).

MRI data acquisition

Scanning was performed on a Siemens 3 T scanner (MAGNETOM Trio, a Tim system) with a 12-channel phased-array head coil at BNU Imaging Center for Brain Research, Beijing, China. MRI structural images were acquired using a 3D magnetization prepared rapid gradient echo (MP-RAGE) T1-weighted sequence (TR/TE/T1 = 2530/3.39/1100 ms, flip angle = 7°, acquisition matrix = 256 × 256). One hundred and twenty-eight contiguous sagittal slices were acquired with 1 × 1 mm in-plane resolution and 1.33 mm slab thickness for whole brain coverage.

Data preprocessing

MRI images were processed using the SPM8 (Statistical Parametric Mapping, Wellcome Department of Imaging Neuroscience, London, UK). Each image was first displayed in SPM8 to screen for artifacts or gross anatomical abnormalities. Five participants whose images had excessive scanner artifacts or showed gross anatomical abnormalities were excluded. For better registration, the origin of the brain was manually set to the anterior commissure for each participant. Segmentation of T1-weighted anatomical images into gray matter (GM) and white matter (WM) was done using the unified segmentation in SPM8. Subsequently, we performed Diffeomorphic Anatomical Registration through Exponentiated Lie (DARTEL) algebra for registration, normalization, and modulation (Ashburner, 2007). Gray matter images were rigidly aligned and resampled to 2 × 2 × 2 mm³ and normalized to a study-specific template in MNI152 space. To ensure local GM volumes were conserved, the image intensity of each voxel was modulated by multiplying the Jacobian determinants derived from the normalization to preserve the volume of tissue from each structure after warping. Then, registered images were then smoothed with an 8-mm full-width at half-maximum Gaussian kernel. Finally, to exclude noisy voxels, the modulated images were masked using absolute masking with a threshold of 0.2.

Statistical analysis

To detect the neuroanatomical correlates of individual differences in social well-being, we performed a linear regression analysis with age, gender, and total GMV as the confounding covariates, and the SWBS scores as the covariate of interest. To perform the multiple comparisons correction, the voxel-wise intensity threshold was set at \( p < 0.005 \) and a cluster-level threshold was calculated using the AlphaSim program in AFNI (10,000 iterations, 91 × 91 × 91 dimensions, 2 × 2 × 2 m³, 151,388 voxels in mask, 8-mm smoothness). AlphaSim program is one of the methods for multiple comparison correction combining voxel intensity and cluster extent. Effects were considered to be significant when the volume of a cluster was greater than the minimum cluster size on whole brain GMV (determined using the Monte Carlo simulation; 1032 mm³), in which case the probability of a type I error was less than 0.01. Generally, AlphaSim has been widely used in previous VBM studies (DeYoung et al., 2010; Fink et al., 2013; Kong et al., 2013; Leung et al., 2013; W. Li et al., 2014; Schwartz et al., 2010).

Previous studies have shown that personality is an important predictor of social well-being (Hill et al., 2012; Joshanloo et al., 2012; Wilt et al., 2010). To examine the associations between personality and social well-being, we first performed a stepwise multiple regression analysis with the SWBS as the dependent variable and subscales of the NEO-PI-R (i.e., five personality traits: neuroticism, extraversion, openness to experience, agreeableness and conscientiousness) as the independent variables. Further, we tested whether social well-being may have its own dissociable structural correlates or personality traits are the underlying mechanisms for the association between brain structure and social well-being. Specifically, a linear regression model examining the association of social well-being with rGMV was implemented with five personality traits (i.e., neuroticism, extraversion, openness to experience, agreeableness and conscientiousness), as well as age, gender and global GMV as covariates. The resulting voxel threshold of \( p < 0.005 \) with a cluster ≥ 1032 mm³ was considered corrected for multiple comparisons across the whole brain.

Results

Table 1 shows means, SDs, skewness, and kurtosis for all questionnaires. The kurtosis and skewness of all the scores ranged from −1 and +1, which indicated the normality of the data (Marcoulides and Hershberger, 1997). The mean SWBS scores for the current sample was 61.72 (SD = 7.64), indicating that the sample had a moderate level of social well-being. This is consistent with previous findings of Wilt et al. (2010) who reported means of 64.65 in an adult sample. No significant gender difference in SWBS scores was found \( t(287) = 0.08, p = 0.94 \). The SWBS scores had no significant relations with age \( r = −0.01, p = 0.94 \) or total GMV \( r = 0.03, p = 0.59 \). Furthermore, the stepwise multiple regression analysis revealed that conscientiousness, neuroticism and extraversion accounted for 29.4% of the variance in social well-being \( R^2 = 0.294 \); \( F(5,268) = 37.55, p < 0.001 \). Specifically, there was a moderate relation between the SWBS and neuroticism \( \beta = −0.23, p < 0.001 \) and extraversion \( \beta = 0.26, p < 0.001 \), whereas the relation between the SWBS and conscientiousness was weak but significant \( \beta = 0.15, p = 0.008 \). Further one-tailed Steiger’s Z tests revealed that the effect size of neuroticism \( Z = 2.00, p = 0.022 \) and extraversion \( Z = 1.36, p = 0.087 \) was larger than that of conscientiousness, suggesting that neuroticism and extraversion tend to have a closer relationship with social well-being when compared with conscientiousness. Next, we explored the neural correlates of social well-being, and then examined how personality traits affected them.

To obtain the neural correlates of social well-being, we correlated the SWBS scores with the GMV of each voxel across the whole brain. After correcting for age, gender and global GMV, the SWBS scores had a significant negative correlation with rGMV in a cluster that included the left mid-DLPFC (superior frontal gyrus) \( \beta = 0.2, 50, 32; r = −0.22, t = −3.84; \) Cluster size = 1520 mm³; \( p < 0.01 \) (See Fig. 1, Table 1).
Table 2). No other significant relations were observed. To examine whether this association is specific to social well-being, we also included the confounding factor of subjective SES. Behaviorally, we observed a significant relationship with the subjective SES ($r = 0.14$, $p = 0.020$), consistent with previous findings (e.g., Wilt et al., 2010). To examine whether the association between the rGMV of mid-DLPC and social well-being was affected by subjective SES, a linear regression model was tested with subjective SES, as well as age, gender and global GMV as covariates. This correlation remained significant after controlling for subjective SES, and a region identical to that identified in the initial analysis was identified (left mid-DLPC; MNI coordinate: $-20, 50, 32$; $t = -3.84$; Cluster size = 1184 mm$^3$; $p < 0.01$), although the cluster size exhibited small changes.

After identifying the neural correlates of social well-being, we further examined the role of personality traits in the association between social well-being and the rGMV of the mid-DLPC. Interestingly, after the scores of five personality traits were added as confounding covariates, no significant cluster showing the association with social well-being was observed. To specifically examine the DLPC where the association was identified previously, small-volume corrections (SVCs) were performed in the DLPC (49328 mm$^3$) selected from the Wake Forest University (WFU) Pick Atlas (Maldjian et al., 2003). A corrected cluster threshold was set as $p < 0.05$ (single voxel $p < 0.005$, cluster size = 304 mm$^3$). The SVC analysis revealed that no cluster was significant.

Furthermore, to identify which specific personality trait plays a more prominent role in the association of social well-being and rGMV, three additional linear regression models were tested with neuroticism, extraversion, and conscientiousness that contributed to social well-being in aforementioned behavioral analysis, as covariates respectively. The results revealed that after conscientiousness was controlled for, the association between the SWBS scores and the rGMV of a cluster in the left mid-DLPC remained (MNI coordinate: $-20, 50, 32$; $t = -3.12$; Cluster size = 472 mm$^3$; $p < 0.05$, SVC). Importantly, the location of this cluster was identical to that identified in the initial analysis, suggesting that conscientiousness is unlikely the mechanism underlying the association between social well-being and the rGMV of the mid-DLPC. Similar results were observed after neuroticism was controlled for (left mid-DLPC; MNI coordinate: $-20, 50, 32$; $t = -3.21$; Cluster size = 312 mm$^3$; $p < 0.05$, SVC). By contrast, after extraversion was controlled for, the association did not reach significance (left mid-DLPC; MNI coordinate: $-20, 50, 32$; $t = -2.97$; Cluster size = 120 mm$^3$; $p > 0.05$, SVC). Together, the personality trait of extraversion played a more prominent role in the association between social well-being and brain structure.

Although no clusters associated with social well-being survived the correction for multiple comparisons after controlling for the personality trait of extraversion, this non-significant result does not necessarily signify that extraversion may mediate the association of social well-being with the mid-DLPC. To address the question, we first extracted rGMV in the mid-DLPC identified in the initial analysis and examined the association between five personality factors and rGMV of left mid-DLPC, with gender, age, and total GMV as covariates. We found that extraversion ($r = -0.18$, $p = 0.020$, Bonferroni corrected) was correlated with the mid-DLPC volume. All other personality factors showed no significant correlation with the cluster. Furthermore, after age, gender, global GMV, and the score of subjective SES were controlled for, the correlation remained significant ($r = -0.18$, $p = 0.020$, Bonferroni corrected). This indicated a closer association among the personality trait of extraversion, social well-being and the mid-DLPC volume compared to other personality dimensions.

To further examine whether extraversion indeed mediated the association of social well-being and the mid-DLPC volume, we performed a mediation analysis using an INDIRECT macro implemented in SPSS (Preacher and Hayes, 2008). While adding gender, age, the score of subjective SES and total GMV of individual brains as covariates in the model, the effect of the mid-DLPC on social well-being decreased, though still significant ($β = -0.25$, $p = 0.005$) after including extraversion as a mediator in the model. In contrast, the direct relationship (i.e., the total effect) was significant ($β = -0.34$, $p < 0.001$). A bootstrap simulation ($n = 10,000$) further confirmed this reduction was statistically significant (95% confidence interval = $[-1.29, -0.23]$, $p < 0.05$) (See Fig. 2). Furthermore, after age, sex, global GMV, subjective SES and other four personality traits were controlled, the indirect effect remained significant (95% confidence interval = $[-0.72, -0.03]$, $p < 0.05$). These results suggest that extraversion plays a mediating role in the influence of the mid-DLPC volume on social well-being.

![Image 1](image1.png)

**Fig. 1.** Brain regions that correlated with social well-being. (A) The rGMV in the left mid-dorsolateral prefrontal cortex (mid-DLPC) was negatively correlated with social well-being. The coordinate is shown in the MNI stereotactic space. (B) Scatter plots depicting correlations between rGMV and social well-being. Scatter plots depicting correlations between rGMV in the left mid-DLPC and individual differences in social well-being ($r = -0.22$, $p < 0.001$).

<table>
<thead>
<tr>
<th>Region</th>
<th>BA Side</th>
<th>MNI coordinate</th>
<th>Peak t-value</th>
<th>Cluster size (mm$^3$)</th>
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<tr>
<td>Negative correlation</td>
<td>mid-DLPC</td>
<td>9 L</td>
<td>$-20$ $50$ $32$</td>
<td>$-3.84$</td>
</tr>
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Note: mid-DLPC, dorsolateral prefrontal cortex; MNI = Montreal Neurological Institute; L = left; R = right. All T-value reported are Bonferroni corrected. * $p < 0.05$ corrected for multiple comparisons at the cluster level.
To test whether the results reported here are stable and replicable, we randomly divided the participants into two groups and assessed whether both groups show the same result (N1 = 138, 74 female, mean age = 21.50, SD = 1.04; N2 = 136, 74 female, mean age = 21.62 SD = 0.99). In the group 1, after controlling for age, gender and total GMV, social well-being was correlated with extraversion (r = 0.45, p < 0.001) and the mid-DLPC volume (r = −0.24, p = 0.005). Extraversion was negatively correlated with the mid-DLPC volume (r = −0.17, p = 0.049). Further mediation analysis indicated that extraversion significantly mediated the relationship between the mid-DLPC volume and social well-being (95% confidence interval = [−1.94, −0.03], p < 0.05). In the group 2, after controlling for age, gender and total GMV, social well-being was correlated with extraversion (r = 0.34, p < 0.001) and the mid-DLPC volume (r = −0.19, p = 0.027). Extraversion was negatively correlated with the mid-DLPC volume (r = −0.19, p = 0.032). Further mediation analysis indicated that extraversion significantly mediated the relationship between the mid-DLPC volume and social well-being (95% confidence interval = [−1.76, −0.06], p < 0.05). Thus, the results reported in this study were stable and replicable.

Discussion

In this study, we investigated the associations between brain structure and social well-being in young healthy individuals. Behavioral results showed that three domains of personality – conscientiousness, neuroticism and extraversion – contribute to social well-being. VBM results showed that social well-being was negatively correlated with the rGMV in the left mid-DLPC. Importantly, after controlling for the personality trait of extraversion, the association between social well-being and the rGMV of the mid-DLPC did not reach significance, suggesting that social well-being may not have its own dissociable structural correlates. The mediation analysis further confirmed that extraversion mediated the association between the left mid-DLPC volume and social well-being. To the best of our knowledge, this is the first study to reveal the anatomical correlates of individual differences in social well-being. Taken together, our results suggest that the basic personality trait of extraversion might play an important role in shaping an individual’s social well-being.

The relationship between personality and well-being has received much attention for a long time (DeNeve and Cooper, 1998; Steel et al., 2008), but relatively less research has focused on the topic of social well-being. Several studies have shown that all five basic personality traits are correlated with social well-being (Hill et al., 2012; Joshanloo et al., 2012; Witt et al., 2010), which is consistent with the results in our dataset (r = 0.14 to −0.46, p < 0.05). Our study further confirmed that the specific personality traits of conscientiousness, neuroticism and extraversion explained the unique variance in social well-being. Previous studies have demonstrated that extraversion, encompassing the social dimension of personality, predispenses individuals to experience more positive life events such as fulfilling social interactions, whereas neuroticism predisposes individuals to experience more negative life events (Heady and Wearing, 1989; Magnus et al., 1993). Therefore, it is not surprising that people who are more extravert and less neurotic are more apt to acquire better social well-being. Conscious people are thought to engage in goal-directed activity and exert control over themselves and their environment (DeNeve and Cooper, 1998), so they may cope with numerous social challenges, which also lead to an increase in social well-being.

The association seen between social well-being and the rGMV in the left mid-DLPC is consistent with previous studies who reported the role of the left PFC in individual well-being. For example, using electrophysiology, greater left than right superior frontal activation was reported to be associated with individual well-being (Urry et al., 2004). Furthermore, happy people were found to have decreased activity in the left mid-DLPC during the resting-state (Luo et al., 2014) and smaller rGMV in the left dorsomedial and rostral lateral PFC (Takeuchi et al., 2014). These findings indicate that the left PFC, especially left mid-DLPC might contribute to both individual and social well-being. The left mid-DLPC is more commonly found to be implicated in working memory (Blumenfeld and Ranganath, 2006; Curtis and D’Esposito, 2003; Owen et al., 2005), cognitive control (Badre and Wagner, 2004; Greene et al., 2004; Lau and Passingham, 2007; MacDonald et al., 2000) and the integration between emotion and cognition such as emotional regulation (Goldin et al., 2008; Kalisch, 2009; Ray and Zald, 2012). Furthermore, this region is also found to represent behavior-guiding principles for evaluating the permissibility or fairness of observed behavior (i.e., social reasoning) (Barbey et al., 2009; Spitzer et al., 2007; Weissman et al., 2008), which are crucial for the formation of human moral, ethical and political systems of value and belief. In addition, the negative correlation between social well-being and regional structure might be related to the intracortical myelination and synaptic pruning during development, which is believed to increase the efficiency of cognitive processes (Kanai and Rees, 2011; Sowell et al., 2001; Paus, 2005; Takeuchi et al., 2014). Thus, the intracortical myelination and synaptic pruning in the mid-DLPC might help individuals to regulate their emotions in social lives, maintain their intentions in working memory and implement adaptive social norms (e.g., altruism and fairness norms), thus leading to higher levels of social well-being.

Interestingly, we found that the personality trait of extraversion mediated the association between the left mid-DLPC volume and social well-being. Previous functional imaging studies have shown an association between extraversion and the mid-DLPC activity during some specific tasks related to emotional reactivity and working memory (Canli et al., 2001; Gray et al., 2005; Gioia et al., 2009; Kumari et al., 2004). Furthermore, VBM studies have also reported the associations between the mid-DLPC and extraversion (Coutinho et al., 2013; Kapogiannis et al., 2013). Recently, using 3-Tesla proton magnetic resonance spectroscopy (1H-MRS), Grimm et al. (2012) found increased glutamate levels in the DLPC including the mid-DLPC in introverts when compared with extraverts. Using transcranial direct current stimulation (tDCS) over the left DLPC, Peña-Gómez et al. (2011) found transiently increasing the activity of this region resulted in increased ratings during negative emotional picture processing and this effect was stronger in individuals low in extraversion. Extraversion is characterized as a sensitivity to positive or pleasurable cues in the environment (e.g., McCrae and Costa, 1991; Costa and McCrae, 1992; Watson and Clark, 1992; Izard et al., 1993) and it is considered to be an indicator of approach temperament (Elliot and Thrash, 2002; Heimpel et al., 2006). Furthermore, the left PFC is activated when an individual responds to appetitive stimuli evoking the experience of positive affect because these stimuli induce a fundamental tendency to approach the source of stimulation (Harmon-Jones et al., 2006; Urry et al., 2004). Thus, the left mid-DLPC contributes to extraversion since individuals who are more extravert have a greater ability to regulate positive life...
events from private and social life, which are important for enhancing social functioning. Briefly, our results substantiate that the personality trait of extraversion may serve as an underlying mechanism that explains the impact of the rGMV in the mid-DLPFC on individual differences in social well-being.

Several limitations of the present study should be mentioned. First, the data relied on self-report instruments since current techniques were mainly the questionnaires. Although they were selected for their good reliability and validity, self-report instruments are vulnerable to biases, such as social desirability. The use of multiple methods for evaluation may lower the impact of subjectivity. Second, this study had a cross-sectional design, which cannot determine a causal relationship; therefore, interpretation of the present results must proceed with caution. Further studies are required to investigate the longitudinal relationship among social well-being, personality and gray matter volume change. Third, beyond the big five personality factors, other factors such as gratitude, social participation and sense of community are shown to be important predictors of individuals’ social well-being (Cicognani et al., 2008; Froh et al., 2010). Further studies are needed to investigate the relationships of these factors with social well-being and gray matter volume. Fourth, this study only found a significant association with the mid-DLPFC but not with the other PFC regions, especially the OFC and MPFC. The OFC has been implicated in encoding the reward value of pain or pleasure including sensory and social pleasure (Berridge and Kringelbach, 2008; Leknes and Tracey, 2008; Rademacher et al., 2010), whereas the MPFC is found to be involved in social-cognitive processes such as theory of mind, emotional perspective taking, sympathy, and social decision-making (Gusnard and Raichle, 2001; Saxe, 2006; Skuse and Gallagher, 2009). The functions of these regions seem to be important for social well-being. The findings of the present study relied on exclusively the measure of GMV of the brain structure; therefore, the associations between these regions and social well-being might be reflected in other types of measures on the brain structure (such as cortical thickness, surface area and local gyriation index) and measures on functional brain activities (e.g., task-related functional activities and resting-state brain activities). In addition, the OFC and MPFC are believed to be two core nodes of the neural network in social cognition (SCN) (Blakemore, 2008; Skuse and Gallagher, 2009); therefore, the association between social well-being and these two regions may be present at the network level, and further investigation is needed to explore the relation between the network properties of the SCN and social well-being.

In summary, we employed the VBM approach to investigate the neuromorphological correlates of individual differences in social well-being. We found that rGMV in the left mid-DLPFC could be used to predict individual differences in social well-being, thus revealing a potential neural mechanism for social well-being. Moreover, although basic personality factors such as neuroticism, extraversion, and conscientiousness all contributed to social well-being, only extraversion could serve as an underlying mediational mechanism that explained the impact of the rGMV in the mid-DLPFC on social well-being. Finally, our findings have important clinical implications, providing potential biomarkers for the early detection of the social functioning deterioration.

Funding
This study was funded by the National Natural Science Foundation of China (31230031, 91132703, 31100808, C090304), National Social Science Foundation of China (11&ZD187), and Changjiang Scholars Programme of China.

Conflict of interest
The authors declare no competing interests.

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