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Amplitude of low frequency fluctuations during resting state predicts social well-being

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Highlights

1. fALFF was used to explore the neural basis of social well-being
2. Social well-being correlated with the fALFF of multiple regions
3. The pursuits of meaning and engagement predicted social well-being
4. Pursuit of meaning mediated the link between fALFF and social well-being
5. Pursuit of engagement mediated the link between fALFF and social well-being

Abstract

Social well-being represents primarily public phenomena, which is crucial for mental and physical health. However, little is known about the neural basis of this construct, especially how it is maintained during resting state. To explore the neural correlates of social well-being, this study correlated the regional fractional amplitude of low frequency fluctuations (fALFF) with social well-being of healthy individuals. The results revealed that the fALFF in the bilateral posterior superior temporal gyrus (pSTG), right anterior cingulate cortex (ACC), right thalamus and right insula positively predicted individual differences in social well-being. Furthermore, we demonstrated the different role of three pursuits of human well-being (i.e., pleasure, meaning and engagement) in these associations. Specifically, the pursuits of meaning and engagement, not pleasure mediated the effect of the fALFF in right pSTG on social well-being, whereas the pursuit of engagement mediated the effect of the fALFF in right thalamus on social well-being. Taken together, we provide the first evidence that spontaneous brain activity in multiple regions related to self-regulatory and social-cognitive processes contributes to social well-being, suggesting that the spontaneous activity of the human brain reflect the efficiency of social well-being.

Keywords: Social well-being; Meaning; Pleasure; Engagement; Fractional amplitude of low-frequency fluctuations

Introduction

In the well-being literature, most studies focus on psychological well-being in private life that reflects the realization of one's true potential (Ryff and Keyes 1995), relatively little attention has been directed to social well-being, which is crucial for mental and physical health (Zhang et al., 2011). Social well-being refers to "appraisal of one's circumstance and functioning in society" (Keyes, 1998, p. 122). It involves the degree to which individuals feel they contribute to the world (social contribution), believe in the realization of the potential of society (social actualization), belong to their communities and society (social integration), view society as sensible and predictable (social coherence), and keep a positive attitude toward others (social acceptance) (Keyes, 1998). Although social well-being has drawn continuous attention from researchers (e.g., Zhang et al., 2011), the neural processes associated with social well-being are still largely unknown.

To the best of our knowledge, only one study investigated the structural neural correlates of social well-being (Kong et al., 2015a). This study revealed that regional gray matter volume in the dorsolateral prefrontal cortex (DLPFC) was correlated with individual differences in social well-being. As its name suggests, social well-being is the appraisal of one's social functioning and thus is likely to be associated with brain regions that are involved in social-cognitive processes such as the understanding of others' emotions, intentions and beliefs. These brain regions that are involved in social cognition are collectively referred to as the social brain, which includes the medial prefrontal cortex (mPFC), anterior cingulate cortex (ACC), interparietal sulcus (IPS), superior temporal sulcus and gyrus (STS/STG), temporoparietal junction (TPJ), inferior frontal gyrus (IFG), amygdala, and insula (Blakemore, 2008; Saxe, 2006). Thus, we speculated that these social brain regions might also reflect individual differences in social well-being. Here we used resting-state fMRI (rs-fMRI) to examine whether social well-being is related to spontaneous brain activity of the social brain regions.

Recently, researchers have begun to explore how best to achieve well-being. Peterson et al. (2005) have noted three distinct pathways to achieve well-being: pleasure, engagement, and meaning. Pleasure reflects the concept of hedonism (maximizing pleasure and minimizing pain). Meaning reflects the concept of eudaimonism (being true to one's inner self/demon). Engagement is based on Csikszentmihalyi's (1990) concept of flow that is characterized by being fully immersed in a specific activity. Flow experiences may occur in both eudaimonic and hedonic activities (Peterson et al., 2005). Furthermore, several studies have demonstrated that all the three types of pursuits contribute to well-being in private life (Chen, 2010; Peterson et al., 2005; Schueller and Seligman, 2010). However, it is not clear how these types of pursuits contribute to social well-being. Given the fact that motivation factors are reasons for acting or behaving in a particular way, the association between spontaneous brain activity and behavioral outcomes (e.g., social well-being) should be mediated by motivation factors (e.g., the three types of pursuits).

To address these questions, we firstly used the Social Well-being Scale (SWBS, Keyes, 1998) to social well-being assess of healthy individuals (N = 292). Then, we conducted a correlation analysis between social well-being and regional fractional amplitude of low-frequency fluctuations (fALFF, Zou et al., 2008) to identify the brain regions that could explain individual differences in social well-being. Although the nature of the spontaneous low-frequency fluctuations (LFFs) is unclear, LFFs, which arise from neurovascular mechanisms (Biswal et al., 1995), are believed to be associated with regional spontaneous neuronal activity (Biswal et al., 1995; Fox and Raichle, 2007; Logothetis et al., 2001). The method has been widely used to probe the neural basis of individual differences in behavior (e.g., Cox et al., 2012; Haag et al., 2015; Hoptman et al., 2010; Kong et al., 2015b; Mennes et al., 2011; Wang et al., 2013; Wei et al., 2014). In this study, we hypothesized that social well-being would be related to the fALFF in the social brain regions. Finally, we conducted a mediation analysis to examine whether and how three types of pursuits mediate the association between fALFF and social well-being.

Methods

Participants

We recruited 292 healthy university students (157 females; mean age = 21.56 years, standard deviation (SD) = 1.01) with no history of neurological or psychiatric disorders as paid participants. This is part of our ongoing project investigating associations among gene, environment, brain, and behavior (for more details, see Kong et al., 2015a, b, c, d, e; Wang et al., 2014). Most of the students were right-handed (n=274) based on a single-item handedness questionnaire ("Are you (a) right-handed, (b) left-handed, (c) mixed-handed?"). Both behavioral and MRI protocols were approved by the Institutional Review Board of Beijing Normal University. Written informed consent was obtained from all participants prior to the study.

Psychological measures

Social well-being was assessed using a 15-item version of Social Well-being Scale (SWBS, Keyes, 1998). The SWBS measures the five aspects of social well-being: social acceptance, social contribution, social coherence, social actualization, and social integration. It includes items such as, "I don't feel I belong to anything I'd call a community."(social integration), "People do not care about other people's problems." (social acceptance), "I have something valuable to give to the world." (social contribution), "The world is becoming a better place for everyone." (social actualization), and "I cannot make sense of what's going on in the world." (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). To compute an overall score of social well-being, mean score across the five subscales was calculated. Higher score indicates higher levels of social well-being. Previous studies have shown that the SWBS has high reliability, construct validity and discriminant validity with other constructs such as life satisfaction, positive affect and negative affect (Kong et al., 2015a; Li et al., 2014). In the present study, the scale demonstrated adequate internal reliability (α = 0.81). Three participants were excluded due to missing data.

Pursuits of well-being were assessed by the Orientation to Happiness Questionnaire (OHQ, Peterson et al. 2005) that is an 18-item self-report measure for the subjective assessment of pleasure, engagement, and meaning (six items each). It includes items such as, "Life is too short to postpone the pleasures it can provide" (pleasure), and "I am always very absorbed in what I do" (engagement), "I have a responsibility to make the world a better place" (meaning). Each item required a respondent to answer on a 6-point scale the degree to which the item applies (1 = very much unlike me, 6 = very much like me). Previous studies have shown that the OHQ has high reliability, construct validity and discriminant validity with other constructs such as life satisfaction, happiness, positive affect and depression (Chen, 2010; Peterson et al., 2005; Schueller and Seligman, 2010). In the present study, the reliability coefficients of the three scales were α = 0.77 (engagement), α = 0.65 (pleasure) and α = 0.71 (meaning), respectively. Five participants were excluded due to missing data.

rs-fMRI data acquisition

The rs-fMRI scan was performed on a 3T Siemens Trio scanner with a 12-channel phased-array head coil at Beijing Normal University Imaging Center for Brain Research, Beijing, China. During rs-fMRI scanning, participants were instructed to close their eyes, keep still, and not think about anything systematically or fall asleep. The scanning consisted of 240 contiguous EPI volumes (TE = 30ms;TR = 2000ms; number of slices = 33; flip angle = 90°; matrix = 64 × 64; FOV = 200 × 200 mm^2; acquisition voxel size = 3.1 × 3.1 × 3.6 mm^3). Moreover, High-resolution T1-weighted images were also acquired with magnetization prepared gradient echo sequence (MPRAGE: TR/TE/TI = 2530/3.39/1100 ms; flip angle = 7°; acquisition matrix = 256 × 256) for spatial registration. One hundred and twenty-eight contiguous sagittal slices were obtained with 1 × 1 mm^2 in-plane resolution and 1.33 mm slice thickness.

Data preprocessing

Preprocessing was performed using FSL (www.fmrib.ox.ac.uk/fsl/). For the rs-fMRI data, the first four volumes were discarded for signal equilibrium. Preprocessing steps of rs-fMRI data included spatial Gaussian smoothing (FWHM = 6 mm), realignment, motion correction (by aligning each volume to the middle volume of the image with MCFLIRT), intensity normalization, and removing linear trends. One participant whose head motion was greater than 3.0 mm or 3.0° throughout the rs-fMRI scan was excluded from further analyses. Registration of each participant's high-resolution anatomical image to a common stereotaxic space (the MNI152 template with a resolution of 2 × 2 × 2 mm^3) was accomplished using a two-step process (Andersson et al., 2007).

Calculation of fALFF

Given that LFFs are sensitive to signals in the gray matter (Biswal et al., 1995), we conducted all analyses on a gray matter mask without the cerebellar regions. For a time series in each voxel, we extracted the sum of amplitudes within a low frequency range (0.01–0.1 Hz). Then, the fALFF was computed as the fractional sum of amplitudes within the low frequency range that was divided by the sum of amplitude across the entire frequency range (0–0.25 Hz) (Zou et al., 2008). For standardization purposes, the individual data was transformed to Z score (i.e., minus the global mean value and then divided by the standard deviation). Then, the standardized fALFF maps were registered to MNI152 space by applying the previously calculated transformation information.

fALFF-behavior correlation analysis

To obtain the brain regions related to social well-being, we conducted a whole-brain correlation analysis using the general linear model (GLM), with age and sex as the confounding covariates, and the score of social well-being as the covariates of interest. Multiple comparison correction was performed using the 3dClustSim program (10000 iterations, 91 × 109 × 91 dimensions, 2 ×2 × 2 m^3, 125563 voxels in mask, 2 sided) in AFNI (http://afni.nimh.nih.gov/pub/dist/doc/program_help/3dClustSim.html). A threshold of corrected cluster $p < 0.05$ (single voxel $p < 0.01$, cluster size ≥ 74 voxels; 592 mm^3) was set.

Furthermore, small-volume corrections (SVCs) were performed in regions that might be associated with social well-being. Specifically, the regions of interest (ROIs) were chosen from regions of the social brain including the ACC, mPFC, TPJ, STS, IPS, IFG, amygdala and insula as well as DLPFC. These regions were defined using the Wake Forest University (WFU) Pick Atlas (Maldjian et al., 2003). Multiple comparison correction was performed using the 3dClustSim program (10000 iterations, 91 × 109 × 91 dimensions, 2 ×2 × 2 m^3, 37490 voxels in mask, 2 sided). A threshold of corrected cluster $p < 0.05$ (single voxel $p < 0.01$, cluster size ≥ 60 voxels; 480 mm^3) was set.

Mediation analysis

To examine whether three types of pursuits can reliably explain the covariation of fALFF and social well-being, we conducted a mediation analysis, using the SPSS macro programmed by Preacher and Hayes (2008). A bootstrapping approach was employed to test the significance of the indirect effect of the independent variable (IV; fALFF of brain regions) on the outcome variable (DV; social well-being) through the mediator (M; three pursuits of well-being). The total effect (Path c) refers to the relation between IV and DV without controlling for M. The direct effect (Path c') refers to the relation between IV and DV after controlling for M (Preacher and Hayes, 2008). An empirical 95% confidence interval does not include zero, indicating the mediating effect is significant at the $p < 0.05$ level. We also calculated the percentage mediation of the potential mediator ((c-c')/c) to assess the percentage of the effect of X on Y that could be explained by M.

Results

The neural correlates of social well-being

Descriptive statistics for all measures are presented in Table 1. The kurtosis and skewness of all the scores ranged from -1 and +1, which indicated the normality of the data (Marcoulides and Hershberger, 1997).

----Insert Table 1 here ----

----Insert Table 2 here ----

The whole brain analysis revealed that social well-being was positively correlated with the fALFF in four clusters including the right posterior STG (pSTG; MNI coordinate: 66, -18, 8; $t = 4.58$; Cluster size = 1304; $p < 0.05$), left pSTG (MNI coordinate: -50, -36, 8; $t = 3.53$; Cluster size = 832; $p < 0.05$), right thalamus (MNI coordinate: 8, -30, 2; $t = 4.12$; Cluster size = 2024; $p < 0.05$) and right insula (MNI coordinate: 46, 2, -2; $t = 3.49$; Cluster size = 784; $p < 0.05$) (Fig. 1 and 2, Table 2). No other significant relationships were observed.

----Insert Figure 1 here ----

----Insert Figure 2 here ----

To specifically examine the relation of the social brain and social well-being, we performed an ROI analysis, and found that social well-being was positively correlated with the fALFF in the right pSTG (MNI coordinate: 66, -18, 8; $t = 4.58$; Cluster size = 1304; $p < 0.05$, SVC), left pSTG (MNI coordinate: -50, -36, 8; $t = 3.53$; Cluster size = 1016; $p < 0.05$, SVC), right insula (MNI coordinate: 46, 2, -2; $t = 3.49$; Cluster size = 784; $p < 0.05$, SVC). Although the size of these clusters exhibited small changes, the regions were identical to those identified in the whole brain analysis. Furthermore, beyond these three regions identified in the whole brain analysis, we also found that social well-being was positively correlated with the fALFF in the right ACC (MNI coordinate: 2, 36, 14; $t = 3.68$; Cluster size = 520; $p < 0.05$, SVC) (Fig. 3, Table 2). No significant relationships were observed in the DLPFC, mPFC, TPJ, IPS, IFG and amygdala of the social brain.

----Insert Figure 3 here ----

Previous studies have revealed that head motion can influence resting-state brain activity (Power et al., 2012; Satterthwaite et al., 2012), so we also tested whether the results reported here are affected by head motion. Age, sex and mean framewise displacement (FD) was treated as nuisance covariates. We found that social well-being was positively correlated with the fALFF in the right pSTG (; MNI coordinate: 66, -18, 8; $t = 4.57$; Cluster size = 1296; $p < 0.05$), left pSTG (MNI coordinate: -50, -36, 8; $t = 3.52$; Cluster size = 1024; $p < 0.05$), right thalamus (MNI coordinate: 8, -30, 2; $t = 4.14$; Cluster size = 2008; $p < 0.05$), right insula (MNI coordinate: 46, 2, -2; $t = 3.47$; Cluster size = 920; $p < 0.05$) and the right ACC (MNI coordinate: 2, 36, 14; $t = 3.66$; Cluster size = 528; $p < 0.05$, SVC). Although the size of these clusters exhibited small changes, the regions were identical to that identified in the above analyses.

Three types of pursuits mediated the association between fALFF and social well-being

To examine the role of the pursuits of pleasure, meaning, and engagement in the association between fALFF and social well-being, we first performed a behavioral correlation analysis between these pursuits and social well-being. The results revealed that the pursuits of meaning ($r = 0.43$, $p < 0.001$, Bonferroni corrected) and engagement ($r = 0.31$, $p < 0.001$, Bonferroni corrected) but not pleasure ($r = -0.02$, $p = 0.714$) were significantly correlated with social well-being. Furthermore, we performed a multiple regression analysis to test whether these pursuits independently contribute to social well-being. The results revealed the pursuits of meaning and engagement accounted for 21.6 % of the variance in social well-being ($F_{[3, 279]} = 38.59$; $p < 0.001$). Specifically, there was a moderate relation between social well-being and the pursuits of meaning ($\beta = 0.37$, $p < 0.001$) and engagement ($\beta = 0.18$, $p = 0.002$). These results suggest that the pursuits of engagement and meaning, but not pleasure, contribute to social well-being.

Then, we performed a correlation analysis to examine the association between these pursuits and cortical regions associated with social well-being. We found that the pursuit of meaning was significantly correlated with the fALFF in the right pSTG ($r = 0.20$, $p = 0.015$, Bonferroni corrected), whereas the pursuit of engagement was significantly correlated with the fALFF in the right pSTG ($r = 0.19$, $p = 0.030$, Bonferroni corrected), left pSTG ($r = 0.17$, $p = 0.045$, Bonferroni corrected) and right thalamus ($r = 0.24$, $p < 0.001$, Bonferroni corrected). However, after controlling for age, sex and mean FD, the relationship between the pursuit of engagement and the left pSTG was no longer significant ($r = 0.16$, $p = 0.105$, Bonferroni corrected). No significant correlation between the pursuit of pleasure and these regions was obtained.

To further examine the role of the pursuits of meaning and engagement in the influence of the fALFF in the right pSTG and thalamus on social well-being, we performed two mediation analyses. Age, sex and mean FD were treated as nuisance covariates in the mediational model. For the right thalamus, the original effect of the right thalamus on social well-being was reduced from 0.28 to 0.22, when the pursuits of meaning and engagement were entered into the model. Percentage mediation was 21% (i.e., (0.28 – 0.22)/0.28) in the mediational model. Further bootstrap simulation (n = 5000) found that only the pursuit of engagement (95% CI = [0.57, 2.33], $p < 0.05$) mediated the association between right thalamus and social well-being (Fig. 4).

For the right pSTG, the original effect of the fALFF in the right pSTG on social well-being was reduced from 0.28 to 0.18 when the pursuits of meaning and engagement were entered into the model. Further bootstrap simulation (n = 5000) found that the pursuits of meaning (95% CI = [0.38, 1.76], $p < 0.05$) and engagement (95% CI = [0.07, 0.99], $p < 0.05$) mediated the association between right pSTG and social well-being. Percentage mediation was 36% (i.e., (0.28 – 0.18) /0.28) in the mediational model. Further indirect effect contrasts found that the indirect effect size for both the pursuits has no significant difference (95% CI = [-0.20, 1.44], $p < 0.05$), suggesting that the pursuits of meaning and engagement play an equally important role in the association between spontaneous brain activity of the right pSTG and social well-being (Fig. 5).

----Insert Figure 4 here ----

----Insert Figure 5 here ----

Discussion

The purpose of the current study was to examine the potential contribution of spontaneous brain activity to social well-being in a large sample of healthy adults. The fALFF-behavior analysis revealed that with the fALFF in the bilateral pSTG, right ACC, right thalamus, and right insula positively predicted individual differences in social well-being. Crucially, we found that the pursuits of meaning and engagement, but not pleasure mediated the effect of the right pSTG on social well-being, whereas the pursuit of engagement mediated the effect of the right thalamus on social well-being. Taken together, we provide the first evidence linking spontaneous brain activity with social well-being, and highlight the important role of the pursuits of meaning and engagement in cultivating social well-being.

Previous research has reliably found that the ACC and insula compose the salience network (SN) subserving detection of salient stimuli (Seeley et al., 2007). The SN also has an important role in switching among different brain networks such as the executive network and the default mode network (Doucet et al., 2011; Goulden et al., 2014; Sridharan et al., 2008). Thus, the correlation of social well-being with the ACC and insula indicates a critical role of the SN in social well-being. The ACC within the SN has been involved in a wide range of functions such as executive control, working memory, and emotion regulation, as well as perception and modulation of social pain (Bartels and Zeki, 2004; Bush et al., 2000; Cacioppo et al., 2012; Etkin et al., 2011; Rudebeck et al., 2006). Thus, the involvement of the ACC might contribute to regulate cognitive and affective responses to stressors in social lives and thus result in high levels of social well-being. The insula within the SN has been found to play a key role in understanding others' feeling and bodily states (Cox et al., 2012; Craig, 2009; Lamm and Singer, 2010; Singer et al., 2009). Thus, the involvement of the insula might help improve emotional awareness and thus result in high levels of social well-being.

The fALFF in the pSTG was positively associated with social well-being, which might result from its role in social- and self-related processes. The pSTG/pSTS is found to be involved in biological motion perception (Blakemore, 2008; Dziura and Thompson, 2014), voice perception (Belin et al., 2004), and social perception (Kanai et al., 2012; Yang et al., 2015). Furthermore, the structural changes and functional activation of this region have been reported to be associated with social network complexity (e.g., network size or diversity) and loneliness (Dziura and Thompson, 2014; Kanai et al., 2012). In addition, although the STG is a core node of the network involved in social cognition, previous studies have also shown that this region plays an important role in self-related processing such as self-face recognition and self-location (Blanke, 2012; Platek et al., 2008). All these functions of the region might have immense value for adaptive social behaviors. Thus, the correlations in the pSTG observed in this study might help individuals improve social perception ability and thus increase their social well-being.

The fALFF in the thalamus was positively associated with social well-being, which might result from its role in self-regulatory processes. The thalamus has been found to play an important role in sleep regulation (Sherman and Guillery, 2006), self-consciousness (Crick and Koch, 2003; Tsakiris et al., 2007), self-recognition (Devue and Brédart, 2011), as well as meditation (Wang et al., 2014; Zeidan et al., 2011). Thus, perhaps the involvement of the thalamus can help improve self-regulation in face of socials tasks and challenges, thus leading to higher levels of social well-being. In short, our study provides the first evidence linking spontaneous brain activity of the bilateral pSTG, right ACC, right thalamus with individual differences in social well-being.

Crucially, we found that the pursuit of engagement mediated the effect of the fALFF in the right thalamus on social well-being. This is consistent with the study by Klasen et al. (2012) that reported the role the thalamus in flow experience. Although relatively little neuroimaging data are available regarding the neural basis of engagement, some imaging studies on some other related concepts, especially meditation can help understand the neural correlates of engagement. Meditation practice has been linked to flow experience (Csikszentmihalyi, 1990; Posner et al., 2010), since they are similar attentional states. Numerous imaging studies have demonstrated that the thalamus is a core node of the neural network involved in meditation (Wang et al., 2014; Zeidan et al., 2011). Furthermore, previous behavioral studies have shown that self-regulatory training (e.g., meditation training) may promote social skills and well-being (Beauchemin et al., 2008; Carmody and Baer, 2008). Thus, perhaps the involvement of the thalamus can enhance engagement in eudaimonic activities, and thus help individuals face socials tasks and challenges, which lead to higher levels of social well-being.

Additionally, we also found that the pursuits of meaning and engagement, but not pleasure mediated the effect of the fALFF in the right pSTG adjacent to the right pSTS on social well-being. On the one hand, our findings suggest that pursuing a meaningful and engaged life, not a pleasant life is important for social well-being. Seligman (2002) have proposed that the pursuit of engagement may result in long-term well-being through promoting one's resources such as nurturing talents. Furthermore, the pursuit of meaning may contribute to the development of sustainable resources through motivating individuals to use their strengths and talents to belong to or serve a "positive institution" (e.g., community) with a higher purpose than the self (Seligman et al. 2006). In contrast, the pursuit of pleasure provides only transient improvements in mood, so people have difficulty in gaining durable resources (Seligman, 2002). Therefore, the pursuits of meaning and engagement but not pleasure help individuals achieve high levels of social well-being. On the one hand, our findings suggest that the right pSTG may play a crucial role in pursuing a meaningful and engaged life. To the best of our knowledge, this is the first study to investigate the relation between the pSTG and the pursuits of meaning and engagement. Baumeister and Vohs (2002) have stated that pursuing meaningful activities helps build social connections as well as provide purpose and self-relevant goals. This is consistent with the role of the pSTG in social- and self-related processes (Belin et al., 2004; Blakemore, 2008; Blanke, 2012; Dziura and Thompson, 2014; Kanai et al., 2012; Platek et al., 2008). Thus, the involvement of the STG might help individuals pursue a large number of meaningful activities and engage in these meaningful activities, which thus increase their levels of social well-being.

In the present study, the e□ect size of the associations between social well-being and fALFF of brain regions was modest. Previous studies have indicated that small sample sizes may cause grossly inflated correlations in the fMRI analyses (Yarkoni, 2009), so a larger sample is more likely to detect a true effect than a smaller sample. Furthermore, our small but modest correlations are consistent with previous studies showing the correlation of 0.15−0.22 between brain structures and behavioral performance (e.g., mindfulness) with large sample sizes (N = 155−247, Lu et al., 2014; Taren et al., 2013). There are three possible reasons for these small correlations. First, social well-being is a complex construct, so the self-report instrument on social well-being used in this study (i.e., the SWBS) might capture only a portion of variance in social well-being. Second, the reliability of the measures of the fALFF and social well-being is not perfect, thus leading to a substantial underestimate of the correlation (Schmidt and Hunter, 1999). Finally, the fALFF index measures only one aspect of a given region, so other types of measures such as cortical thickness, surface area, and resting-state functional connectivity might also capture a portion of variance in social well-being.

Several limitations of this study should be mentioned. First, this sample was drawn from a college student population. The narrow age range may limit the generalizability of our findings, though it is common to choose college students as participants (Kong et al., 2014; Lewis et al., 2014; Takeuchi et al., 2014; Wang et al., 2013). Second, although the mediational model is theoretically possible, we cannot determine the direction of causation between human pursuits, social well-being and brain structure. The implementation of longitudinal or experimental studies will help elucidate these complex relationships. Third, this study did not find a significant association of social well-being with the DLPFC that has been demonstrated to play a crucial role in social well-being (Kong et al., 2015a). This may be because the findings of the present study relied on exclusively the measure of fALFF. Further investigation is needed to explore the association between the region and social well-being using other types of measures on spontaneous brain activity such as resting-state functional connectivity.

In summary, we employed the fALFF approach to investigate the potential contribution of spontaneous brain activity to social well-being. Our study provides the first empirical evidence for a functional biomarker for social well-being by demonstrating that the fALFF in the bilateral pSTG, right ACC, right thalamus, and right insula was associated with individual differences in social well-being. Crucially, our study also highlights the different role of the pursuits of meaning and engagement in cultivating well-being by revealing that the pursuits of meaning and engagement mediated the effect of the right pSTG on social well-being, whereas the pursuit of engagement mediated the effect of the right thalamus on social well-being. In consideration of these probable mechanisms, our work may provide valuable guidance for how to implement positive psychological intervention (e.g., meaning-making intervention or engagement intervention) aimed at enhancing an individual’s social well-being.

The authors declare no competing interests.

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Figure Captions

Fig. 1. Brain regions that correlated with social well-being in the whole brain analysis. The fALFF in the right posterior superior temporal gyrus (pSTG) (A), left pSTG (B), right thalamus (C), and right insula (D) was positively correlated with individual differences in social well-being. The coordinate is shown in the MNI stereotactic space.

Fig. 2. Scatter plots depicting correlations between fALFF and social well-being. Scatter plots depicting correlations between individual differences in social well-being and fALFF in the right pSTG (A), left pSTG (B), right thalamus (C), and right insula (D) after adjusting for age and sex.

Fig. 3. Brain regions that correlated with social well-being in the SVC analysis. (A) The fALFF in the right anterior cingulate cortex (ACC) was positively correlated with social well-being. The coordinate is shown in the MNI stereotactic space. (B) Scatter plots depicting correlations between individual differences in social well-being and fALFF in the right ACC after adjusting for age and sex.

Fig. 4. Pursuit of engagement mediates the association between fALFF of the thalamus and social well-being. Depicted is the path diagram (including standard regression coefficients) of the mediation analysis. *: $p < 0.05$. **: $p < 0.01$. ***: $p < 0.001$.

Fig. 5. Pursuits of meaning and engagement mediate the association between fALFF of the right pSTG and social well-being. Depicted is the path diagram (including standard regression coefficients) of the multiple mediation analysis. *: $p < 0.05$. **: $p < 0.01$. ***: $p < 0.001$.

Tables

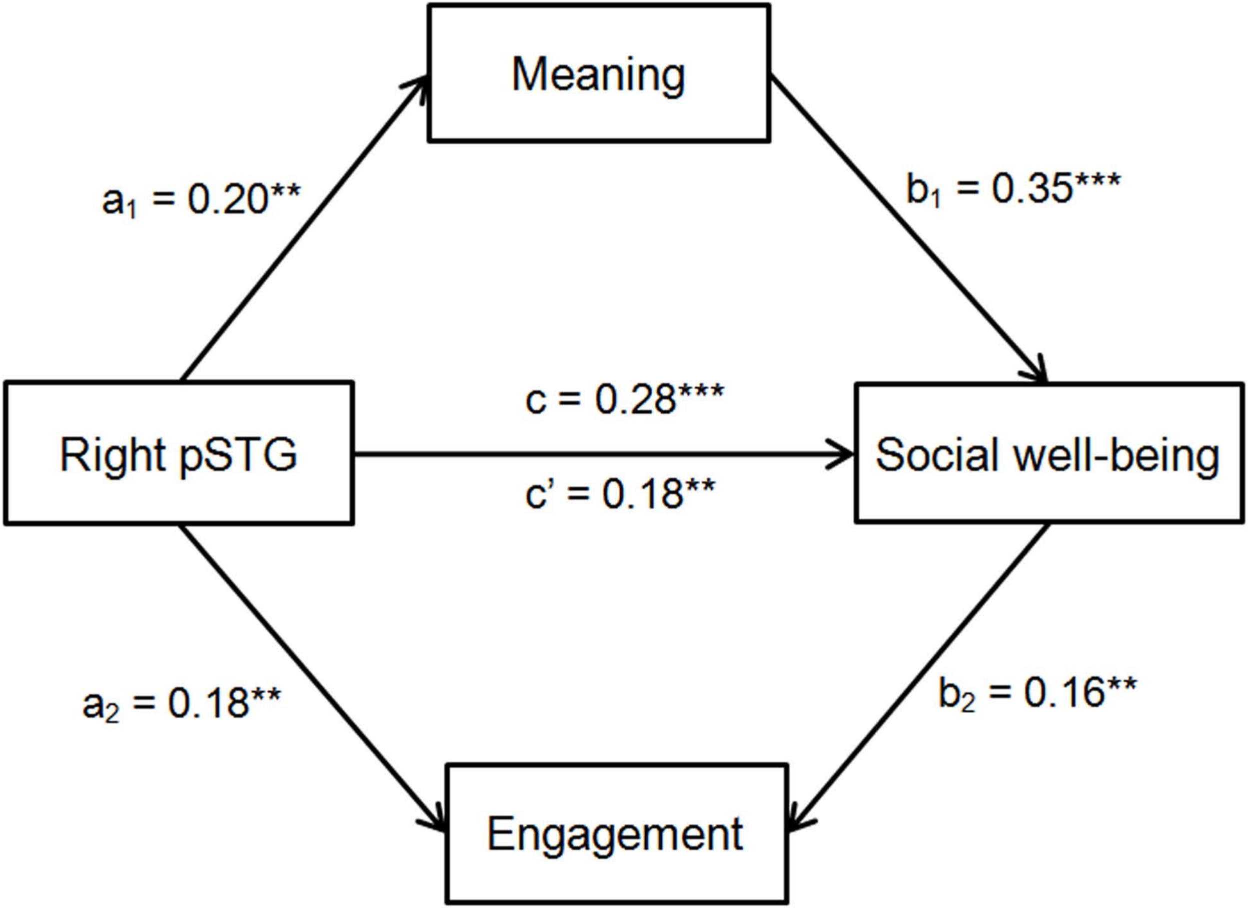
Table 1 Descriptive statistics for all the measures

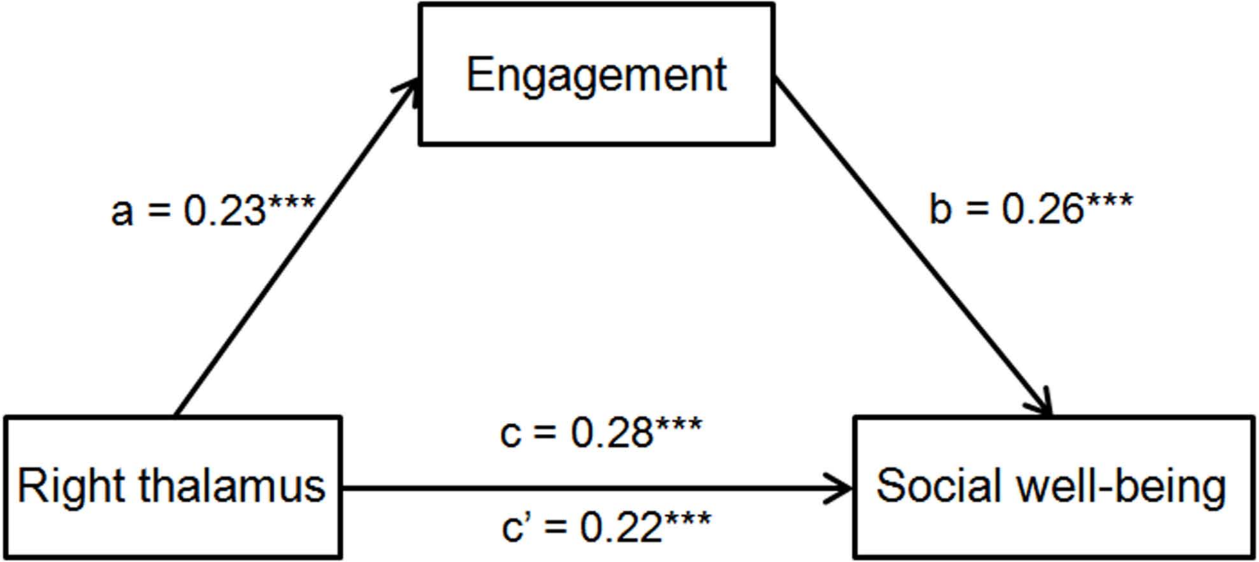
Variables	Mean	SD	Range	Skewness	Kurtosis
age	21.56	1.00	18-25	-0.08	0.7
Social well-being	61.69	7.61	41-82	0.03	-0.48
Pursuit of meaning	23.44	3.85	11-33	-0.17	0.12
Pursuit of engagement	22.63	3.76	11-32	0.06	-0.16
Pursuit of pleasure	23.35	3.77	12-33	-0.05	-0.06

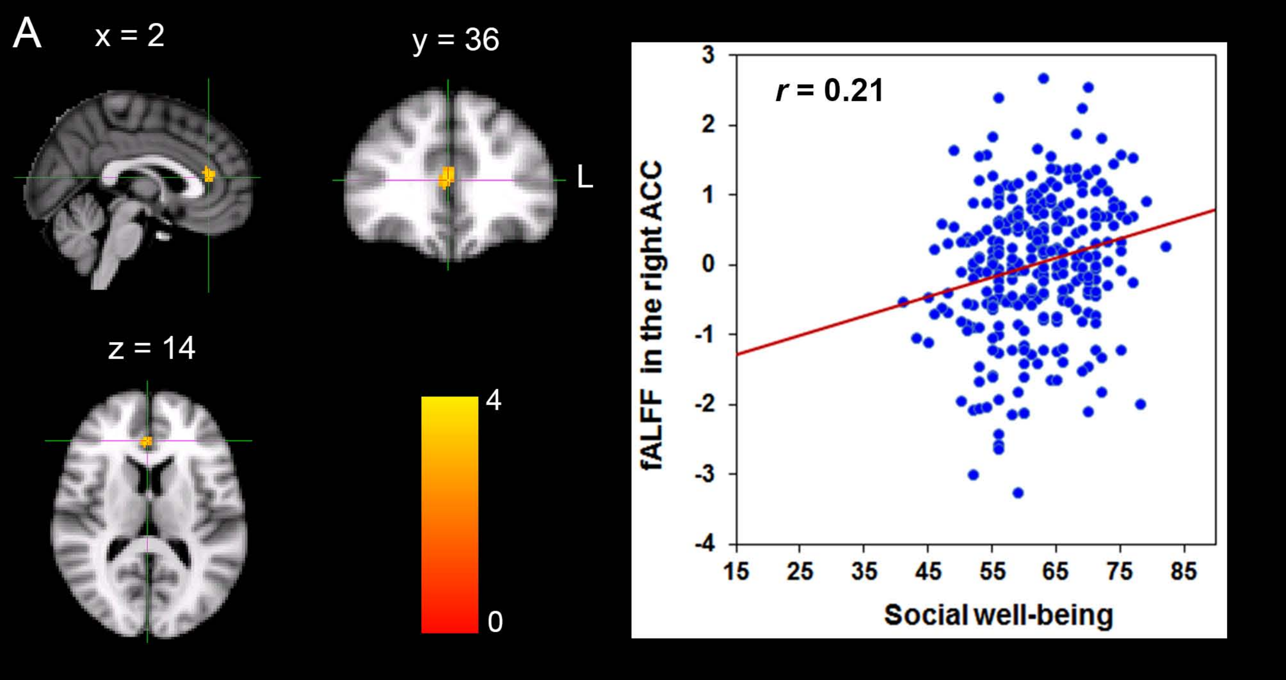
Table 2 Regions correlating with social well-being

Region	Side	MNI coordinate			*Z*	Cluster size
		x	*y*	*z*		(mm^3)
Thalamus	R	8	-30	2	4.12	2024*
Posterior superior temporal gyrus	R	66	-18	8	4.58	1304*
Posterior superior temporal gyrus	L	-50	-36	8	3.53	1016*
Insula	R	46	2	-2	3.49	856*
Anterior cingulate cortex	R	2	36	14	3.68	520*

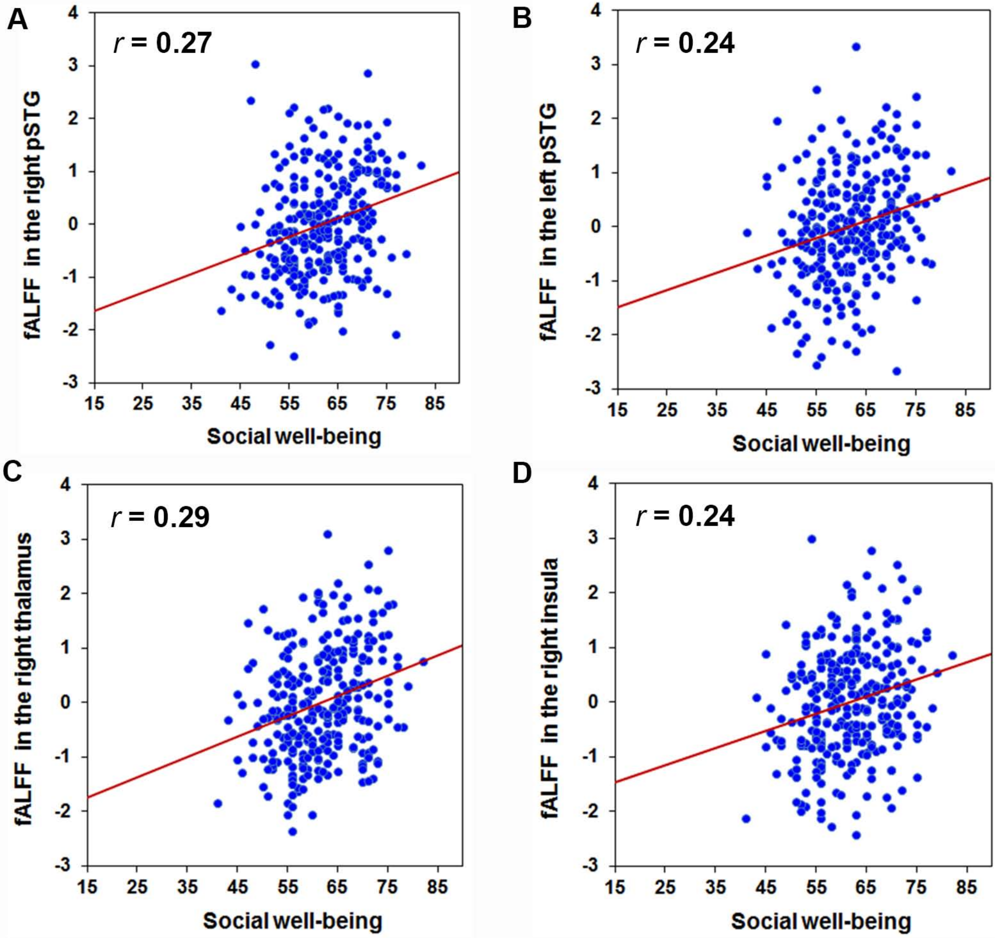
Note: MNI = Montreal Neurological Institute; L = left; R = right. All z-scores reflect a threshold of $p <$ 0.01 (uncorrected). * $p < 0.05$ corrected for multiple comparisons at the cluster level.


Meaning
a1 = 0.20**
b1 = 0.35***
Right pSTG
c = 0.28***
c' = 0.18**
Social well-being
a2 = 0.18**
b2 = 0.16**
Engagement

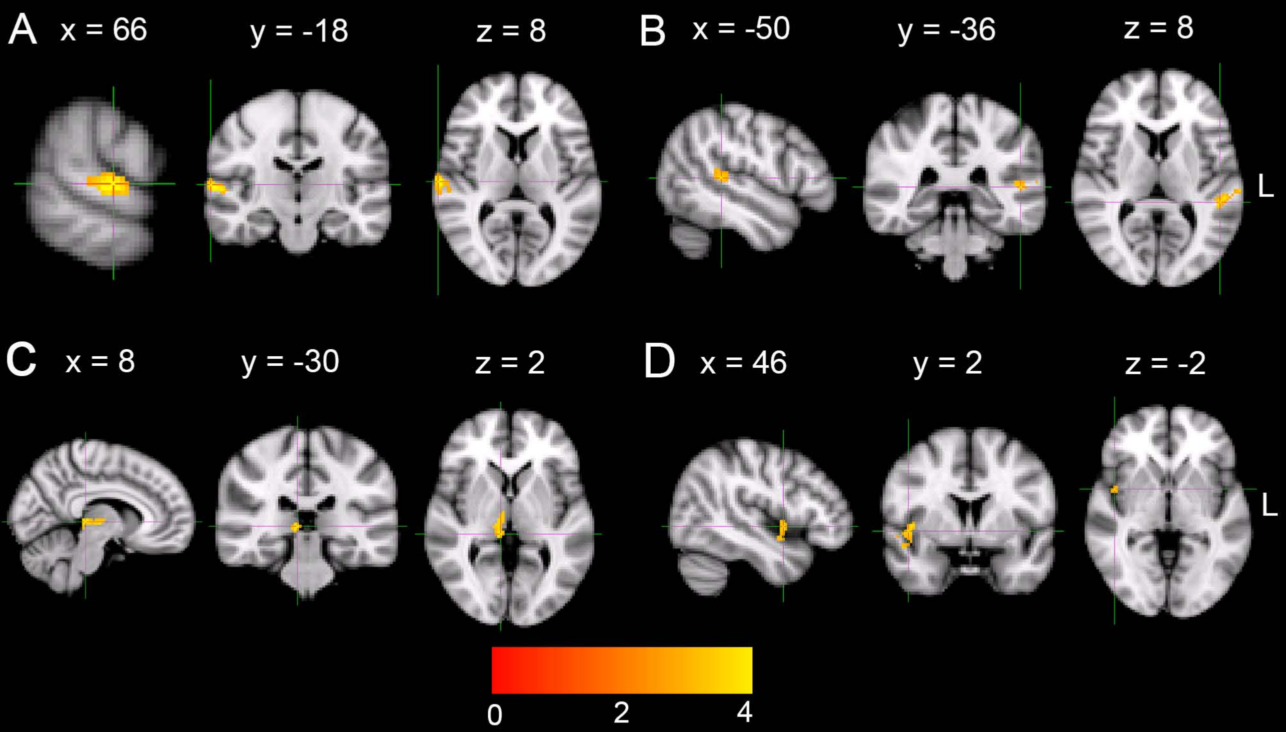

Engagement
a = 0.23***
b = 0.26***
c = 0.28***
Right thalamus
Social well-being
c’ = 0.22***



A
x = 2
y = 36
L
z = 14
4
0
r = 0.21
fALFF in the right ACC
Social well-being
3
2
1
0
-1
-2
-3
-4
15
25
35
45
55
65
75
85



A
r = 0.27
fALFF in the right pSTG
Social well-being
B
r = 0.24
fALFF in the left pSTG
Social well-being
C
r = 0.29
fALFF in the right thalamus
Social well-being
D
r = 0.24
fALFF in the right insula
Social well-being



A
x = 66
y = -18
z = 8
B
x = -50
y = -36
z = 8
L
C
x = 8
y = -30
z = 2
D
x = 46
y = 2
z = -2
L
0
2
4