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# Neural correlates of psychological resilience and their relation to life satisfaction in a sample of healthy young adults

Feng Kong [a,b,*], Xu Wang [a,b], Siyuan Hu [c], Jia Liu [c,*]

[a] State Key Laboratory of Cognitive Neuroscience and Learning and IDG/McGovern Institute for Brain Research, Beijing Normal University, Beijing, China
[b] Center for Collaboration and Innovation in Brain and Learning Sciences, Beijing Normal University, Beijing, China
[c] School of Psychology, Beijing Normal University, Beijing, China

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ABSTRACT

Psychological resilience refers to the ability to thrive in the face of risk and adversity, which is crucial for individuals' mental and physical health. However, its precise neural correlates are still largely unknown. Here we used resting-state functional magnetic resonance imaging (rs-fMRI) to identify the brain regions underlying this construct by correlating individuals' psychological resilience scores with the regional homogeneity (ReHo) and then examined how these resilience-related regions predicted life satisfaction in a sample of healthy young adults. We found that the ReHo in the bilateral insula, right dorsal anterior cingulate cortex (dACC) and right rostral ACC (rACC) negatively predicted individual differences in psychological resilience, revealing the critical role of the salience network (SN) in psychological resilience. Crucially, the ReHo in the dACC within the SN mediated the effects of psychological resilience on life satisfaction. In summary, these findings suggest that spontaneous activity of the human brain reflect the efficiency of psychological resilience and highlight the dACC within the SN as a neural substrate linking psychological resilience and life satisfaction.



## Introduction

Psychological resilience refers to an individual's ability to thrive in the face of risk and adversity (Luthar et al., 2000; Connor and Davidson, 2003). It is associated with better physical and mental health outcomes (Connor and Davidson, 2003) and confers protection against the development of mental disorders (e.g., posttraumatic stress disorder, PTSD) in the context of risk and adversity (Bonanno, 2004). As a major positive psychological construct, resilience is believed to play an important role in fostering one's life satisfaction (Gable and Haidt, 2005). Life satisfaction refers to people's global cognitive evaluation of the satisfaction with their own lives (Diener et al., 2003). Numerous studies have demonstrated that psychological resilience is related to high levels of life satisfaction (Cohn et al., 2009; Hu et al., 2015; Mak et al., 2011). Furthermore, with an increase in resilience through resilience interventions (e.g., the Penn Resiliency Program), individuals' well-being has also tended to increase (Brunwasser et al., 2009; Burton et al., 2010; Seligman et al., 2009). Although psychological resilience has drawn a lot of attention from researchers (e.g., Connor and Davidson, 2003), the precise neural correlates underlying this construct are still largely unknown. In this study, we used resting-state functional magnetic resonance imaging (rs-fMRI) to investigate the neural basis of individual differences in psychological resilience and its association with life satisfaction.

A growing body of evidence from lesion studies in humans and neuroimaging research in patient populations (e.g., stress-related psychopathologies or posttraumatic stress disorder [PTSD]) has shown that resilience to stress implicates multiple subcortical and cortical regions including the amygdala, thalamus, hippocampus, insula, ventromedial prefrontal cortex (vmPFC), and anterior cingulate cortex (ACC) (Dedovic et al., 2009; Pitman et al., 2012; Shin and Liberzon, 2009; van der Werff et al., 2013). In large part, previous studies have examined the neural patterns to resilience in clinical populations; however, it is not well known about the neural correlates of psychological resilience in healthy populations. Psychological resilience has been increasingly recognized as an important domain in individual differences (Connor and Davidson, 2003). To the best of our knowledge, there are a limited number of fMRI studies that explore the neural basis of psychological resilience in healthy samples (Reynaud et al., 2013; Waugh et al., 2008). Waugh et al. (2008) have found that in face of threat, low-resilient individuals exhibit prolonged insula activation to both the aversive and neutral pictures, whereas high-resilient individuals show insula activation only to the aversive pictures, suggesting that resilient people can flexibly use emotional resources. In addition, in a resilient population of fire-fighters, resilience is positively correlated with the amygdala and orbitofrontal activation in response to stressful events (Reynaud et al., 2013). These studies reveal that local neural activation in a region is associated with a specific resilient task; however, because of the

* Corresponding author at: Room 405, Yingdong Building, 19 Xinjiekouwai St, Haidian District, Beijing 100875, China. Fax: +86 10 58806154.
*E-mail addresses:* kongfeng87@126.com (F. Kong), liujia@bnu.edu.cn (J. Liu).

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complex, dynamic nature of the construct of resilience, psychological resilience should be associated with the functions of multiple brain regions instead. Therefore, we used rs-fMRI to examine how psychological resilience is related to spontaneous brain activity without explicit task-directed behaviors in a sample of healthy young adults.

Non-invasive rs-fMRI is a promising tool for measuring spontaneous brain activity that can be used to explore the functional neural basis of individual differences in behaviors (Biswal, 2012; Fox and Raichle, 2007; Raichle, 2010). Here we focused on the low frequency fluctuations (LFFs, 0.01–0.10 Hz) in the blood oxygen level-dependent (BOLD) signal at rest, which are related to spontaneous neuronal activity (Biswal, 2012; Fox and Raichle, 2007; Raichle, 2010). Specifically, we used a standard measure of LFFs, the regional homogeneity (ReHo) that explores regional brain activity at rest by examining the degree of regional coherence of re-fMRI time courses. Previous studies have demonstrated that ReHo is able to measure the synchronization of activity in different brain regions (Zang et al., 2004), which overcomes the limitation of conventional fMRI as it does not require any knowledge of experimental designs. The method has been used to identify populations with various types of neuropsychiatric disorders such as ADHD (Zang et al., 2007), major depressive disorder (Guo et al., 2011), mild cognitive impairment (Zhang et al., 2012), and schizophrenia (Liu et al., 2006). Furthermore, healthy individuals' ReHo is found to correlate with individual differences in intelligence (Wang et al., 2011), response inhibition (Tian et al., 2012), conflict adaptation (Wang et al., 2014), and personality traits (e.g., trait anxiety) (Hahn et al., 2013). These findings indicate that ReHo can be used to explore the neural mechanisms for cognitive and emotional functions. Based on the resilience literature in healthy and clinical populations, we speculated that the ReHo in these regions including the amygdala, thalamus, hippocampus, insula, vmPFC, OFC, and ACC might be associated with individual differences in psychological resilience.

Among these hypothesized resilience-related brain regions, the prefrontal cortices have also been thought to contribute to the development of life satisfaction, which are of particular interest because it is an essential ingredient of the good life (Diener et al., 2003). Previous studies have consistently revealed that measures related to life satisfaction are mostly associated with the brain structure or function of the prefrontal cortex (PFC) like the ACC and vmPFC, which have been implicated in cognitive and emotional processing (Gilleen et al., 2015; Kong et al., 2014a; Kong et al, 2015a; Takeuchi et al., 2014; Urry et al., 2004). Thus, on the basis of previous neuroscience findings on resilience, we speculated that spontaneous brain activity of the PFC such as ACC and vmPFC might predict individual differences in life satisfaction. Thus, the PFC might serve as a key node in the neural circuit linking psychological resilience and life satisfaction. Considering the importance of psychological resilience in life satisfaction (Cohn et al., 2009; Mak et al., 2011), spontaneous brain activity of the PFC might mediate the relationship between psychological resilience and life satisfaction.

To answer these questions, we first used the 10-Item Connor–Davidson Resilience Scale (CD-RISC) (CD-RISC, Campbell-Sills and Stein, 2007) to assess psychological resilience of healthy individuals. Second, we conducted a correlation analysis between participants' psychological resilience scores and their regional ReHo to identify the brain regions that could explain individual differences in psychological resilience. Finally, we performed mediational analyses to examine whether the ReHo in these resilience-related regions would be able to mediate the relationship between psychological resilience and life satisfaction.

## Methods

### *Participants*

Two hundred and seventy-six university students (127 males; mean age = 21.57 years, standard deviation (SD) = 1.01) participated in this study as a part of an ongoing project investigating gene, environment, brain, and behavior (e.g., Kong et al., 2015a,2015b,2015c; Song et al., 2015; Wang et al., 2012; Zhen et al., 2015). Data that are irrelevant to the scope of this study were not reported in this study. Participants reported no past or current psychiatric illness or a history of neurological illness. 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 study onset.

### *Behavioral tests*

#### *Connor–Davidson Resilience Scale*

Psychological resilience was assessed using the 10-Item Connor–Davidson Resilience Scale (CD-RISC) (CD-RISC, Campbell-Sills and Stein, 2007). The scale has a unidimensional structure and includes items, such as “I am able to adapt to change” and “I tend to bounce back after illness or hardship.” Participants are instructed to rate their agreement on a 6-point Likert-type scale ranging from 1 = strongly disagree to 6 = strongly agree. Higher scores reflect higher levels of psychological resilience. The CD-RISC has high internal consistency, test–retest reliability, and criterion-related validity (Campbell-Sills and Stein, 2007; Connor and Davidson, 2003). In this study, the CD-RISC exhibited adequate reliability ($\alpha = 0.85$).

To replicate the previously reported one-factor structure of the CD-RISC in our data set, we performed a confirmatory factor analysis using AMOS software (Version 20). Four indices were selected to evaluate the goodness of fit of the model: the goodness of fit index (GFI), the comparative fit index (CFI), the root mean square error of approximation (RMSEA), and the standardized root mean square residual (SRMR). The following criteria were used to indicate goodness of fit: GFI ≥ 0.90, CFI ≥ 0.90, RMSEA ≤ 0.10, and SRMR ≤ 0.10 (Byrne, 2001; Kline, 2005). We found that the one-factor model exhibited a satisfactory fit to the data: $\chi^2$ (35) = 92.43, $p < 0.001$; GFI = 0.94, CFI = 0.93, RMSEA = 0.077, SRMR = 0.048. The factor loadings ranged between 0.46 and 0.66 ($ps < 0.001$). The confirmatory factor analysis thus indicated that the factor structure of the scale was stable across the different populations.

#### *Satisfaction with Life Scale*

The Satisfaction with Life Scale (SWLS, Diener et al., 1985) was administered to assess life satisfaction. The scale consists of five items, such as “I am satisfied with my life” and “In most ways my life is close to my ideal.” Participants are instructed to rate their agreement on a 7-point Likert-type scale ranging from 1 = strongly disagree to 7 = strongly agree. Higher scores reflect higher levels of life satisfaction. The SWLS has high internal consistency, test–retest reliability, and criterion-related validity (Diener et al., 1985; Kong et al., 2014a, 2014b, 2014c; Kong and You, 2013; Kong and Zhao, 2013; Song et al., 2013; Sun and Kong, 2013; Wang and Kong, 2014). In this study, the SWLS exhibited adequate reliability ($\alpha = 0.82$).

#### *Socioeconomic status scale*

To control for the effect of socio-demographic factors, we assessed participants' subjective socioeconomic status (SES) using a graphical representation of a ladder with 10 rungs (1 being the lowest rank; 10 being the highest rank) (Adler et al., 2000). Participants are instructed to rank their parents' income, education, and occupational prestige levels based on their adulthood (Adler et al., 2000). Previous studies have found that the subjective SES exhibits stronger relationships with stress and health-related factors than objective SES measures (Adler et al., 2000; Singh-Manoux et al., 2005).

#### *Wong and Law Emotional Intelligence Scale*

Emotional intelligence was assessed using the Wong and Law Emotional Intelligence Scale (WLEIS, Kong and Zhao, 2013), which has four subscales: Self Emotion Appraisals (SEA), Others' Emotion Appraisals (OEA), Regulation of Emotion (ROE), and Use of Emotion

(UOE). The scale consists of 16 items, such as "I am sensitive to the feelings and emotions of others" and "I am quite capable of controlling my own emotions." Participants are instructed to rate their agreement on a 7-point Likert-type scale ranging from 1 = strongly disagree to 7 = strongly agree. Higher scores reflect higher levels of emotional intelligence. The WLEIS has high internal consistency, test–retest reliability, and criterion-related validity (e.g., Bao et al., 2015; Kong and Zhao, 2013; Kong et al., 2015a; Wang and Kong, 2014). In this study, the WLEIS exhibited adequate reliability (Cronbach's $\alpha = 0.87$).

*NEO Personality Inventory*

The Revised NEO Personality Inventory (NEO-PI-R) is a 120-item self-report questionnaire based on the five-factor model (FFM) of personality (Costa and McCrae, 1992). 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 (Kong et al., 2015b,2015c). In this study, Cronbach's $\alpha$ of the NEO-PI-R scales ranged from 0.71 to 0.88, indicating that these five personality dimensions of NEO-PI-R exhibited adequate internal reliability.

*Image acquisition*

Image data were collected using a 3 T scanner (Siemens Magnetom Trio, A Tim System) with a 12-channel phased-array head coil at Beijing Normal University Imaging Center for Brain Research, Beijing, China. The resting-state scanning consisted of 240 contiguous EPI volumes (TR = 2000 ms; TE = 30 ms; flip angle = 90°; number of slices = 33; matrix = 64 × 64; FOV = 200 × 200 mm$^2$; acquisition voxel size = 3.1 × 3.1 × 3.6 mm$^3$). During the rs-fMRI scans, participants were instructed to close their eyes, remain motionless, and not think systematically, or fall asleep. For spatial registration, high-resolution T1-weighted images were then acquired with magnetization prepared gradient echo sequence (MPRAGE: TR/TE/TI = 2530/3.39/1100 ms; flip angle = 7°; acquisition matrix = 256 × 256). 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. One participant whose head motion was greater than 3.0 mm in any of the *x*, *y*, or *z* directions, or 3.0° of any angular motion throughout the rs-fMRI scan were excluded from further analyses. The preprocessing steps 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. Registration of each participant's high-resolution anatomical images to a common stereotaxic space (the Montreal Neurological Institute 152-brain template (MNI152) with a resolution of 2 × 2 × 2 mm$^3$) was accomplished using a two-step process (Andersson et al., 2007).

*ReHo–behavior correlation analysis*

ReHo was performed on a voxel-by-voxel basis by calculating Kendall's coefficient of concordance (KCC) of time series of each of the 26 neighbors surrounding the center voxel (Zang et al., 2004). A KCC value was then attributed to the central voxel representing the ReHo, and individual ReHo maps were obtained. A larger ReHo value for a given voxel indicates a higher local synchronization of rs-fMRI signals among neighboring voxels. Then, individual ReHo maps were registered to MNI152 standard space by applying the previously calculated transformation matrix for further groupwise analyses. For standardization purposes, the individual data were transformed to *Z* score (i.e., minus the global mean value and then divided by the standard deviation).

A growing body of evidence from lesion and neuroimaging studies has shown that resilience to stress implicates multiple regions including the amygdala, thalamus, hippocampus, insula, OFC, vmPFC, and ACC (Dedovic et al., 2009; Pitman et al., 2012; Reynaud et al., 2013; Shin and Liberzon, 2009; van der Werff et al., 2013). These regions might reflect individual differences in psychological resilience. Thus, we conducted a region of interest (ROI) correlation analysis to detect the brain regions whose ReHo values predict individual differences in psychological resilience. Age, sex, and SES were treated as the confounding covariates, and the score of psychological resilience was treated as the covariates of interest. The Wake Forest University (WFU) Pick Atlas (Maldjian et al., 2003) was used to define the ROIs including the ACC, OFC, vmPFC, insula, thalamus, hippocampus, and amygdala, based on the automated anatomical labeling (AAL) template. Multiple comparison correction was performed using the 3dClustSim program in AFNI (http://afni.nimh.nih.gov/pub/dist/doc/program_help/3dClustSim.html). The parameters were as follows: 10,000 simulations, 91 × 109 × 91 dimensions, 2 × 2 × 2 m$^3$, two-sided, FWHM = 6, with a combined mask of the ROIs. A corrected cluster threshold of $p < 0.05$ (single voxel $p < 0.005$, cluster size ≥ 35.5 voxels; 284 mm$^3$) was set.

Given the complex and dynamic nature of psychological resilience, it is possible that other regions are also related to psychological resilience. Thus, we also conducted a whole-brain correlation analysis to comprehensively explore the regions that are related to psychological resilience. Age, sex, and SES were treated as the confounding covariates, and the score of psychological resilience was treated as the covariates of interest. The parameters were as follows: 10,000 simulations, 91 × 109 × 91 dimensions, 2 × 2 × 2 m$^3$, two-sided, FWHM = 6, with a whole-brain gray matter mask. A corrected cluster threshold of $p < 0.05$ (single voxel $p < 0.005$, cluster size ≥ 52.4 voxels; 419.2 mm$^3$) was set. All significant correlations were presented in MNI coordinates.

*Prediction analysis*

To confirm the robustness of the relation between ReHo and behavioral performance, we conducted a machine-learning approach with balanced fourfold cross validation combined with linear regression (Qin et al., 2014; Supekar et al., 2013). After regressing out age, sex, and SES, residual scores were computed, and thus residual ReHo of the regions as an independent variable and residual psychological resilience as a dependent variable were treated as input to a linear regression algorithm. The $r_{(\text{predicted, observed})}$ was used to measure how well the independent variable predicts the dependent variable using a balanced fourfold cross-validation procedure. Data were divided fourfold such that the distributions of these variables were balanced across folds. Then a linear regression model was built threefold, leaving out onefold, and this model was then used to predict the data in the left-out fold (i.e., predicted values). This procedure was repeated four times to compute a final $r_{(\text{predicted, observed})}$ representing the correlation between the values predicted by the regression model and the observed values. Nonparametric testing approach was used to assess the statistical significance of the model. The empirical null distribution of $r_{(\text{predicted, observed})}$ was estimated by generating 1,000 surrogate data sets under the null hypothesis that there was no association between ReHo and behavioral performance. We generated each surrogate data set Di of size equal to the observed data set by permuting the labels on the observed data points (i.e., the score of psychological resilience). The $r_{(\text{predicted, observed})i}$ (i.e., $r_{(\text{predicted, observed})}$ of Di) was computed using the observed labels of Di and predicted labels using the fourfold-balanced cross-validation procedure described previously. This procedure produced a null distribution of $r_{(\text{predicted, observed})}$ for the regression model. The statistical significance ($p$ value) of the model was then determined by counting the number of $r_{(\text{predicted, observed})i}$ greater than

**Table 1**
Descriptive statistics for all the measures.

| | Minimum | Maximum | Mean | SD | Skewness | Kurtosis |
|---|---|---|---|---|---|---|
| Age | 18 | 25 | 21.58 | 1.01 | −0.16 | 0.67 |
| Family SES | 1 | 9 | 4.62 | 1.73 | 0.07 | −0.55 |
| Resilience | 30 | 58 | 44.30 | 5.30 | −0.21 | −0.32 |
| Life satisfaction | 6 | 35 | 20.00 | 5.35 | −0.14 | −0.37 |

$r_{(\text{predicted, observed})}$ and then dividing that count by the number of Di data sets (i.e., 1,000).

*Mediation analysis*

To test whether brain regions can reliably explain the relationships between psychological resilience and life satisfaction, we conducted a mediation analysis, using the PROCESS macro programmed by Hayes (2013). Variable *M* is a mediator if one predictor variable (*X*) significantly predicts M (Path a), *X* significantly predicts an outcome variable (*Y*) (Path c; representing the total effect), M significantly predicts *Y* (Path b) when controlling for *X*, and the effect of *X* on *Y* reduces significantly when M as well as *X* simultaneously predicts *Y* (Path c'; representing the direct effect). In order to test statistical significance of the indirect effect through M, bootstrapping tests were used. We used 5000 bootstrap samples to generate bootstrap confidence intervals (95%) for the indirect effects. An empirical 95% confidence interval (CI) does not include zero, indicating that the mediating effect is significant at the 0.05 level.

## Results

*ReHo–behavior correlation analysis*

Means, SDs, scoring range, skewness, and kurtosis 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).

To detect the brain regions whose ReHo values predict individual differences in psychological resilience, we conducted an ROI correlation analysis. The results revealed psychological resilience was negatively correlated with the ReHo in the right dorsal ACC (dACC; MNI: 12, 28, 32; $r = -0.28$; $z = -4.66$; cluster size = 1032; $p < 0.05$, SVC), right rostral ACC (rACC; MNI coordinate: 10, 46, 10; $r = -0.22$; $z = -3.53$; cluster size = 352; $p < 0.05$, SVC), left insula (MNI: −26, 24, 0; $r = -0.24$; $z = -3.80$; cluster size = 384; $p < 0.05$, SVC), and right insula (MNI: 34, 22, −4; $r = -0.22$; $z = -3.70$; cluster size = 288; $p < 0.05$, SVC) (Figs. 1 and 2, Table 2). No significant relationships were observed in the vmPFC, OFC, thalamus, hippocampus, and amygdala.

To explore whether there are other regions that are related to psychological resilience, we also conducted a whole-brain correlation analysis. The results revealed that psychological resilience had significant negative correlations with the ReHo in the right dACC (MNI: 12, 28, 32; $r = -0.29$; $z = -4.66$; cluster size = 1080; $p < 0.05$), left insula (MNI: −26, 24, 0; $r = -0.24$; $z = -3.80$; cluster size = 560; $p < 0.05$), and right insula (MNI: 34, 22, −4; $r = -0.24$; $z = -3.70$; cluster size = 496; $p < 0.05$). Although the size of the clusters exhibited small changes, these three significant regions were identical to those identified in the ROI analysis. No other significant relationships were observed.

*Prediction analysis*

To examine the robustness of the relation between ReHo and psychological resilience, we extracted the ReHo value of the clusters obtained in the ROI analysis and applied a balanced fourfold cross-validation approach combined with linear regression. We found that dACC ($r_{(\text{predicted, observed})} = 0.26$; $p < 0.001$), rACC ($r_{(\text{predicted, observed})} = 0.19$; $p < 0.001$), left insula ($r_{(\text{predicted, observed})} = 0.20$; $p < 0.001$), and right insula ($r_{(\text{predicted, observed})} = 0.18$; $p < 0.001$) reliably predicted individual differences in psychological resilience.

*Mediation analysis*

To identify the neural mechanisms that link psychological resilience and life satisfaction, we first performed a behavioral correlation analysis to replicate the previously reported association between two variables. The results revealed that psychological resilience was significantly correlated with life satisfaction ($r = 0.28$, $p < 0.001$). Furthermore, after controlling for age, sex, and family SES, psychological resilience explained the unique variance in life satisfaction (7.1%).

Next, we examined whether the regions related to psychological resilience are associated with life satisfaction. The results showed that the ReHo in only the right dACC covaried with life satisfaction ($r = -0.21$, $p = 0.004$, Bonferroni corrected). Furthermore, after controlling for age, sex, and family SES, the ReHo in dACC explained the unique variance in life satisfaction (3.8%). To examine the robustness of the relation between ReHo and life satisfaction, we also carried out a prediction analysis. We found that the ReHo in dACC reliably predicted individual differences in life satisfaction ($r_{(\text{predicted, observed})} = 0.17$, $p < 0.001$).

Furthermore, we performed a mediation analysis to test whether spontaneous brain activity of the dACC is able to mediate the effect of psychological resilience on life satisfaction. Age, sex, and SES were treated as the confounding factors. The effect of psychological resilience on life satisfaction was reduced, though significant ($\beta = 0.23$, $p < 0.001$) after the dACC was added as a mediator in the model. In addition, the total effect was significant ($\beta = 0.27$, $p < 0.001$). Bootstrap simulation (n = 5000) further confirmed that the indirect effects for life satisfaction (95% CI = [0.01, 0.08], $p < 0.05$) were significant, suggesting that the ReHo in the dACC mediated the effect of psychological resilience on life satisfaction (see Fig. 3).

In addition, previous studies have revealed the relation among personality dispositions, emotional intelligence, well-being, and resting state (Kong et al., 2015a,2015b); here we examined whether the effect of psychological resilience is independent from these factors. First, we tested the influence of emotional intelligence and Big Five personality traits on the neural correlates of psychological resilience. We found that, after controlling for emotional intelligence and Big Five personality traits (i.e., extraversion, neuroticism, agreeableness, conscientiousness, and openness to experience), the ReHo in the dACC ($r = -0.21$; $p < 0.001$), rACC ($r = -0.14$; $p = 0.026$), left insula ($r = -0.23$; $p < 0.001$), and right insula ($r = -0.20$; $p = 0.002$) was still related to psychological resilience, indicating its specificity to psychological resilience. Second, we tested the influence of emotional intelligence and Big Five personality traits on the association between the ReHo in the dACC and life satisfaction. After controlling for emotional intelligence and five basis personality traits, the correlation between the ReHo in the dACC and life satisfaction remained significant ($r = -0.14$; $p = 0.025$). Furthermore, we tested whether the mediating effect of the ReHo in the dACC on the relationship between psychological resilience and life satisfaction can be influenced by emotional intelligence and Big Five personality traits. We found that, after controlling for emotional intelligence and five basis personality traits, the mediating effect of the dACC remained significant (95% CI = [0.01, 0.09], $p < 0.05$), suggesting that the mediating effect of the dACC was not influenced by general personality dispositions.

## Discussion

The aim of the present study was to investigate the neural basis of psychological resilience during resting state and its association with life satisfaction in a large sample of healthy individuals. The

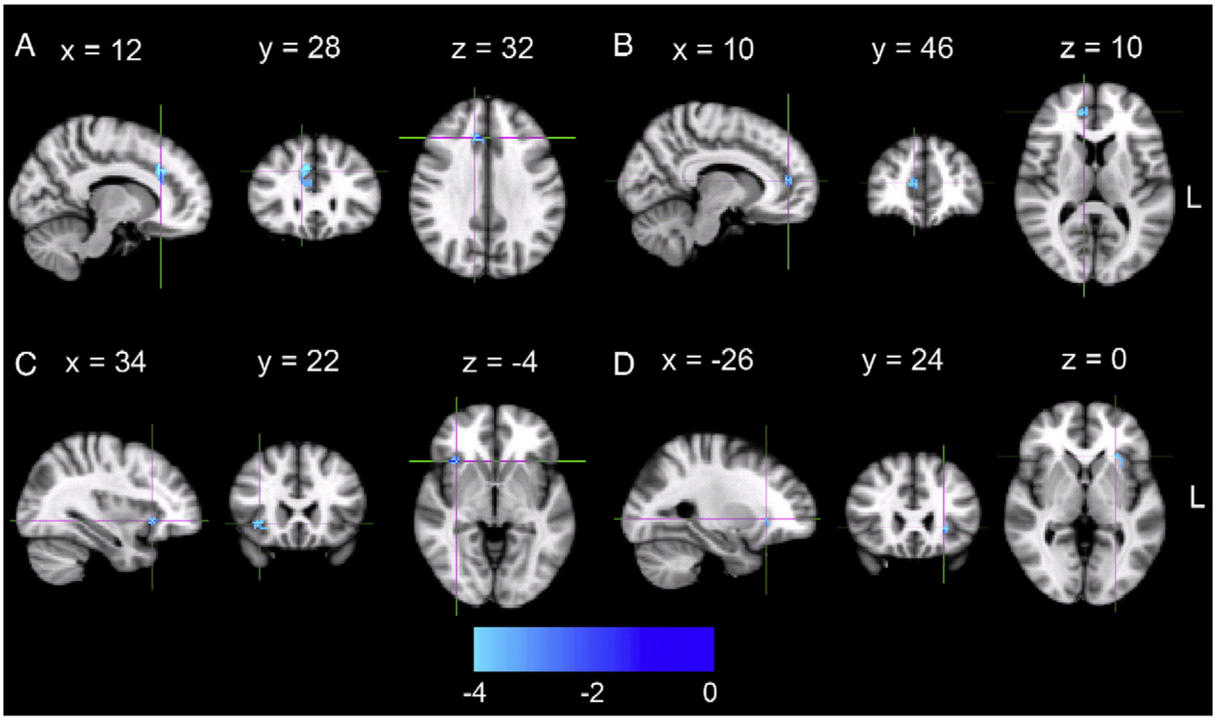


**Fig. 1.** Brain regions that negatively correlated with psychological resilience. The ReHo of the right dorsal anterior cingulate cortex (ACC) (A), right rostral ACC (B), right insula (C), and left insula (D) was negatively correlated with psychological resilience. All these correlation were based on whole-brain analysis. The coordinate is shown in the MNI stereotactic space.

ReHo–behavior analysis revealed that psychological resilience was negatively correlated with the ReHo in the bilateral insula, right dACC, and right rACC, suggesting a functional neural basis of psychological resilience. Further, after controlling for emotional intelligence and Big Five personality traits, the ReHo in these regions was still related to psychological resilience, indicating its specificity to psychological resilience. Crucially, the ReHo in the dACC mediated the effects of psychological resilience on life satisfaction. In addition, after controlling for emotional intelligence and five basis personality traits, the mediating effect of the dACC remained significant, suggesting that the mediating effect of the dACC was not influenced by general personality dispositions. Together, our findings provide the first evidence on spontaneous brain activity linking with individual differences in psychological resilience and highlight the potential role of the dACC in mediating the relation between resilience and life satisfaction.

The finding that psychological resilience is negatively correlated with the ReHo in the insula fits nicely with a previous fMRI study showing the role of the insula in psychological resilience in a healthy population (Waugh et al., 2008), and recent studies showing increased brain activity at rest in the insula in PTSD patients (Lui et al., 2009; Yan et al., 2013). In addition, the negative correlation between psychological resilience and the ReHo in the right dACC and rACC is also in line with recent studies showing increased brain activity at rest in the ACC in PTSD patients (Bing et al., 2013; Yan et al., 2013). Higher ReHo in the insula and ACC in low-resilient individuals, as well as PTSD patients, can be interpreted as the temporal synchronization of the neural activity in these regions. The increased ReHo has been considered as a compensatory mechanism to offset functional decrease or impairments in previous studies (e.g., Chen et al., 2012; Dai et al., 2012; Guo et al., 2012; Liang et al., 2011; Song et al., 2014; Zhang et al., 2012). This seems to fit well with the dysfunction of the insula and ACC in major depression disorder (Horn et al., 2010; Sprengelmeyer et al., 2011; van Tol et al., 2010), PTSD (Chen et al., 2006; Liberzon and Martis, 2006; Karl et al., 2006), and other anxiety disorders (Paulus and Stein, 2006; van Tol et al., 2010), all of which have been associated with impairments in psychological resilience (Hjemdal et al., 2011; Skrove et al., 2013). This putative explanation needs to be evaluated in future studies. In short, the present results are in line with the literature on patient populations, so our observation may be extended to patient groups.

**Table 2**
Brain regions correlating with psychological resilience.

| Region | Side | MNI coordinate | | | $Z$ | Cluster size ($mm^3$) |
|---|---|---|---|---|---|---|
| | | $x$ | $y$ | $z$ | | |
| *Negative correlation* | | | | | | |
| Dorsal ACC | R | 12 | 28 | 32 | 4.66 | 1032* |
| Rostral ACC | R | 10 | 46 | 10 | 3.53 | 352* |
| Insula | L | -26 | 24 | 0 | 3.80 | 384* |
| Insula | R | 34 | 22 | -4 | 3.70 | 288* |

Note: MNI = Montreal Neurological Institute; L = left; R = right. All $z$-scores reflect a ReHo threshold of $p < 0.005$ (uncorrected). * $p < 0.05$ corrected at the cluster level.

Previous rs-fMRI studies have reliably indicated that there is a canonical coherent network primarily comprising the ACC and bilateral insula (Seeley et al., 2007; Taylor et al., 2009). As this network is implicated in monitoring and/or generating autonomic responses to salient stimuli, it has been labeled as the salience network (SN; Seeley et al., 2007). This network also plays a key role in switching among the default mode network, the executive control network, and the external attention networks (Doucet et al., 2011; Sridharan et al., 2008). Prior studies have demonstrated alterations within the SN in anxiety disorders, especially PTSD, generalized anxiety disorder, and social anxiety disorder (Peterson et al., 2014; Sripada et al., 2012). The present finding of significant correlations between psychological resilience and the ReHo in the ACC and insula further supports the notion of a critical role of the SN in psychological resilience in a healthy population. The insula within the SN has been known to be involved in a wide range of functions including interoception, body awareness, emotional awareness, and stress responses (Craig, 2009; Critchley et al., 2004; Li et al., 2014; Tsakiris et al., 2007). Thus, the engagement of the insula might help individuals to improve accurate interoception and self-awareness including somatic and emotional awareness and thus lead to high levels of psychological resilience. The ACC within the SN has been known to be implicated in a

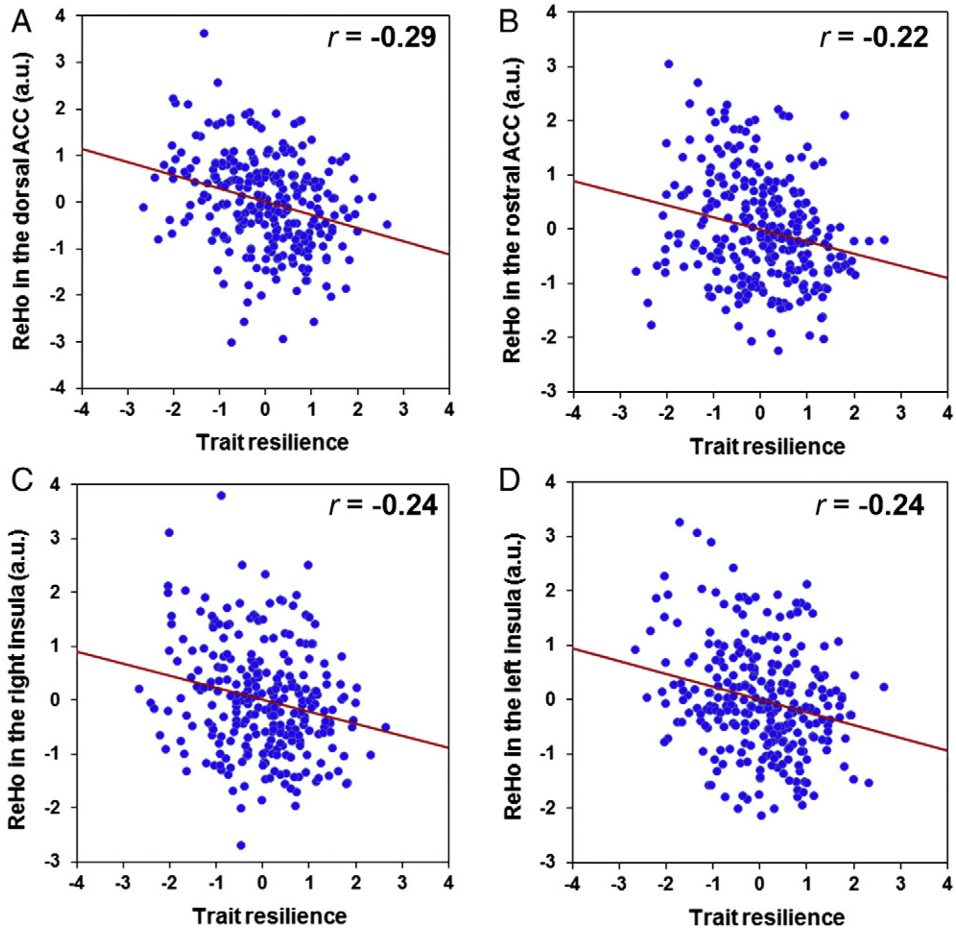


**Fig. 2.** Scatter plots depicting correlations between ReHo and psychological resilience. Scatter plots depicting correlations between ReHo of the right dorsal anterior cingulate cortex (ACC) (A), right rostral ACC (B), right insula (C), and left insula (D), and psychological resilience after adjusting for age, sex, and family SES.

wide range of emotional and cognitive functions such as executive functions, working memory, motor control, motivation, and regulation of emotion (Bush et al., 2000). A body of empirical research has differentiated the dACC and rACC, which are involved in cognitive and emotional processing, respectively (Bush et al., 2000; Davis et al., 2005). However, recent works seem to indicate that both subregions contribute to emotional processing (Etkin et al., 2011). Specifically, the dACC is involved in appraisal and expression of emotion, whereas the rACC is involved in regulation of emotion. Previous behavioral studies have found that psychological resilience is associated with flexible emotional responsiveness and flexible control in processing affective and non-affective material (Genet and Siemer, 2011; Waugh et al., 2011). Thus, the significant correlations in the ACC observed in this study might reflect its role in regulating cognitive, behavioral, and affective responses to stressors.

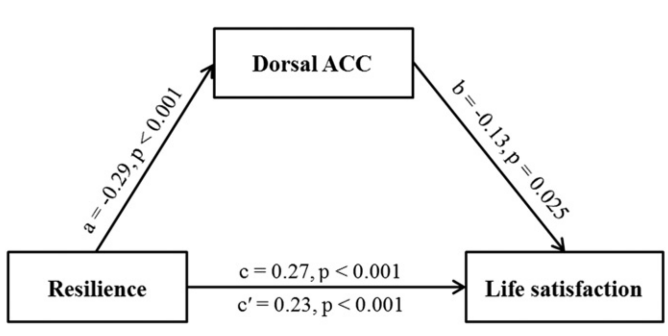


**Fig. 3.** Right dorsal anterior cingulate cortex mediates the influence of psychological resilience on life satisfaction. Depicted is the path diagram (including standard regression coefficients) of the mediation analysis demonstrating that psychological resilience affects life satisfaction through right dorsal anterior cingulate cortex.

Importantly, we found that the ReHo in the dACC mediated the effect of psychological resilience on life satisfaction. Previous studies have repeatedly reported that psychological resilience is strongly related to life satisfaction (Cohn et al., 2009; Mak et al., 2011). Furthermore, in our study psychological resilience accounted for the additional variance in life satisfaction (7.1%) above and beyond that of demographic factors including sex, age, and SES. Thus, psychological resilience is likely an important psychological resource for fostering an individual's positive well-being. In addition, several neuroimaging studies have demonstrated that the dACC is a core node of the neural network for life satisfaction (Gilleen et al., 2015; Kong et al., 2015a,2015b,2015c; Takeuchi et al., 2014). For example, in a normal population, measures related to life satisfaction were associated with spontaneous brain activity or regional gray matter volume of the dACC (Kong et al., 2015a,2015b,2015c; Takeuchi et al., 2014). Furthermore, in schizophrenia, impaired life satisfaction is associated with reduced dACC activity during reward processing (Gilleen et al., 2015). Given the association of the dACC with psychological resilience, the dACC apparently acts as a mediator of the relation between psychological resilience and life satisfaction.

Some limitations of the current study should be mentioned. First, because ReHo measures the local synchronization and may lead to additional smoothness, we re-estimated the smoothness with 3dFWHMx on the ReHo maps, and the estimated size of spatial smoothness was larger (origin: 6, 6, and 6 mm; new: 8.90 11.83, and 11.28 mm). Using the new smooth size for multiple comparison correction, no cluster survived the new criteria in the whole-brain analysis (minimally

1416 mm$^3$). In addition, only one cluster in the right dACC (the largest one in Table 2) survived in the ROI analysis (minimally 728 mm$^3$). This pattern is consistent with the study by Tian et al. (2012), suggesting that the smoothing by ReHo needs further statistical consideration in the future. Second, in light of the cross-sectional design, causal relationship between the ReHo and psychological resilience could not be addressed. Future studies may utilize longitudinal designs to tackle the causality of these factors. Third, the data primarily relied on self-report measures, although they were selected for their good psychometric properties. The use of multiple methods for evaluation (e.g., other-report) may minimize the influence of response bias. Finally, this study only found significant associations with the ACC and insula but not with the other regions especially the vmPFC and amygdala, which are believed to be important for resilience and well-being (Pitman et al., 2012; Shin and Liberzon, 2009; van der Werff et al., 2013). The present findings relied on exclusively the measure of ReHo of resting-state brain activity; therefore, the associations of psychological resilience with these regions might be reflected in other types of measures on resting-state brain activity (e.g., functional connectivity) and measures on the brain structure (e.g., cortical thickness and gray matter volume).

In conclusion, this study directly identified the associations between spontaneous brain activity in the insula and ACC within the SN and psychological resilience in a non-clinical sample of young adults, suggesting a functional neural marker for psychological resilience. Furthermore, this study highlighted the dACC within the SN as a neural substrate linking psychological resilience and life satisfaction. Finally, our finding may have clinical implications for providing potential biomarkers for the early detection of the functioning deterioration in resilience. Furthermore, beyond resilience-related behavioral interventions (e.g., Brunwasser et al., 2009), the neurofeedback training (e.g., Zoefel et al., 2011) of resilience can be developed to improve levels of health and well-being in both non-clinical and clinical populations.

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