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The Neural Basis of Independence Versus Interdependence Orientations: A Voxel-Based Morphometric Analysis of Brain Volume

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Abstract

Sociocultural research has established *independence* and *interdependence* as two fundamental ways of thinking about oneself and the social world. Recent neuroscience studies further demonstrate that these orientations modulate brain activity in various self- and socially related tasks. In the current study, we explored whether the traits of independence and interdependence are reflected in anatomical variations in brain structure. We carried out structural brain imaging on a large sample of healthy participants (n = 265) who also completed self-report questionnaires of cultural orientations. Voxel-based morphometry analysis demonstrated that a relative focus of independence (vs. interdependence) was associated with increased gray-matter volume in a number of self-related regions, including ventromedial prefrontal cortex, right dorsolateral prefrontal cortex, and right rostrolateral prefrontal cortex. These results provide novel insights into the biological basis of sociocultural orientations.

Keywords

independence orientation, interdependence orientation, gray-matter volume, voxel-based morphometry, open materials, open data

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People vary greatly in their ways of thinking about themselves and the social world around them. There is now a great deal of cross-cultural research indicating that the contrast between *independence* and *interdependence* is an important dimension distinguishing behaviors in different cultures and social contexts (Kitayama et al., 2014; Markus & Kitayama, 1991).[1] Independence, most prominent in Western cultures, is associated with an emphasis on personal agency and uniqueness from other people. In contrast, interdependence, most prominent in Eastern cultures, is associated with an emphasis on the relations among people and with the maintenance of collectivist values, emphasizing social harmony. The overarching independence-interdependence dimension is linked to cultural differences in various domains (e.g., Carpenter, 2000; Kitayama, Duffy, Kawamura, & Larsen, 2003). Furthermore, although the concept was initially developed from cross-cultural research, subsequent studies have indicated that independent versus interdependent orientations can also be treated as individual-level dispositional constructs within a single culture (e.g., Cross & Madson, 1997), and they can be temporally manipulated by priming (Gardner, Gabriel, & Lee, 1999).

With the emergence of sociocultural neuroscience in recent years, a growing literature shows that independent versus interdependent orientations modulate neural

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activity in various tasks. For example, Zhu, Zhang, Fan, and Han (2007) found that, compared with Western participants, Chinese participants had greater overlap in their neural representations of themselves and their mothers, consistent with an interdependent orientation toward incorporating close others into one's own self-concept. This overlap was centered on the ventromedial prefrontal cortex (vmPFC), an area typically associated with self-judgments (Northoff et al., 2006; Sui, Rotshtein, & Humphreys, 2013). Chiao et al. (2009) also found increased activity of the vmPFC during general (vs. contextual) self-judgments for participants who scored relatively higher on measures of independence than of interdependence. Although these studies provide valuable insight into the interaction of sociocultural orientations and brain function, they all employed functional MRI. Previous research in voxel-based morphometry has shown that experience shapes the structure of the brain, and proficiency in a certain domain of processing is typically associated with enlargement of relevant brain regions (May & Gaser, 2006). As suggested by Kitayama and Tompson (2010), repeated engagement with one's own culture may lead not only to functional changes in brain activity but also to anatomical changes in brain structure. To date, there have been several attempts to compare the structural brain characteristics of Easterners and Westerners. For example, Kochunov and colleagues (2003) have reported that, compared with English-speaking Caucasians, Chinese-speaking Asians had larger left middle frontal gyri, inferior middle temporal gyri, and right superior parietal lobules, but smaller left superior parietal lobules. Chee and colleagues (2011) have also reported higher cortical thickness and gray-matter density in young Chinese Singaporeans than in young non-Asian Americans in a number of regions, including bilateral ventrolateral and anterior medial prefrontal cortex, right supramarginal gyrus, superior parietal lobule, and middle temporal gyrus. These studies shed new light on how culture may shape the structural characteristics of the brain. However, these results were obtained from cross-cultural comparisons and thus might be attributed to factors other than the independence-interdependence orientations, such as other cultural values and environmental factors.

In the present study, we added to prior work by administering two widely used self-report measures of independent and interdependent orientations, namely Singelis's (1994) Self-Construal Scale and Singelis, Triandis, Bhawuk, and Gelfand's (1995) Individualism and Collectivism Scale, in a large sample of healthy Chinese participants, and we performed voxel-based morphometry analysis to examine the anatomical correlates of the profiles on these subjective measures. This study provided a direct examination of the relations between brain structure and independence-interdependence orientations.

Converging existing evidence from voxel-based morphometry and functional MRI studies led us to expect that individuals showing a relative focus of independence would have enhanced brain volume in the vmPFC. This hypothesis is in line with the findings of Chee et al.'s study (2011), which showed greater cortical thickness in the frontal regions in Americans than in Singaporeans. (However, it should be noted that cortical thickness and gray-matter volume are highly correlated but separate measures; Hutton, Draganski, Ashburner, & Weiskopf, 2009.) This hypothesis is also consistent with previous findings showing that increased activity in the vmPFC is associated with stronger self-bias in cognition (Sui et al., 2013). It has been argued that the vmPFC plays a central role in processing stimuli relevant to the self (Northoff et al., 2006; Sui, 2016). Additional evidence comes from neuropsychological studies demonstrating that lesions in the vmPFC result in impairments in self-referential memory (Philippi, Duff, Denburg, Tranel, & Rudrauf, 2012) and in self-matching, where participants match shapes to labels referring to the self and others (Sui, Enock, Ralph, & Humphreys, 2015). This neuropsychological evidence suggests that the vmPFC may play a necessary role in establishing and maintaining self-bias.

Method

Participants

Data were obtained from 265 young and healthy Chinese participants (128 females, 137 males; age: M = 23.01, SD = 2.69), all of whom were undergraduate or graduate students recruited from several universities in Haidian District, Beijing, through online advertisements. Participants were taking part in various neuroimaging studies, and anatomical images of their brains were acquired as part of the scanning protocols. Informed consent was obtained from all participants prior to the experiment according to procedures approved by the local ethics committee. Data were accumulated from December 2011 to July 2015, after which we decided that the sample size was adequate for the research problem. We were aiming for an effect size (r) of at least .20, which is commonly seen in voxel-based-morphometry studies such as ours. Using a voxel-wise threshold of $p < .005$, we expected the current sample size to yield approximately 90% statistical power at the voxel level.

Image acquisition

Participants were scanned using a Philips Achieva 3.0T TX system with a SENSE eight-channel head coil. A high-resolution T1-weighted image was acquired for each participant with 160 contiguous sagittal slices of 1-mm thickness and 8° flip angle. The sensitivity encoding (SENSE) parallel-imaging technique (Pruessmann, Weiger, Scheidegger, & Boesiger, 1999) was employed to reduce scan time. The SENSE acceleration factor was 2 for the anterior-posterior direction and 1.5 for the right-left direction. Repetition time was 8.2 ms, and echo time was 3.8 ms. The acquisition matrix was 256 voxels × 256 voxels × 160 voxels with a voxel size of 0.938 mm × 0.938 mm × 1 mm.

Measurement of independence-interdependence orientations

After the scanning session, participants completed two widely used measures of trait independence-interdependence. The Self-Construal Scale (Singelis, 1994) consists of 30 items, half of which measure independent self-construals (e.g., "I do my own thing, regardless of what others think"), while the other half measure interdependent self-construals (e.g., "I will sacrifice my self-interest for the benefit of the group I am in"). Participants rated the extent to which they agreed with each item using a 7-point Likert-type scale from 1, *strongly disagree*, to 7, *strongly agree*. In this study, the alpha coefficients for the independence and interdependence subscales were .75 and .75, respectively.

The Individualism and Collectivism Scale (Singelis et al., 1995) consists of 32 items belonging to four dimensions: vertical individualism (e.g., "Winning is everything"), horizontal individualism (e.g., "I often do 'my own thing'"), vertical collectivism (e.g., "I hate to disagree with others in my group"), and horizontal collectivism (e.g., "I like sharing little things with my neighbors"). Participants rated the extent to which they agreed with each item using a 7-point Likert-type scale from 1, *strongly disagree*, to 7, *strongly agree*. In this study, the alpha coefficients for vertical individualism, horizontal individualism, vertical collectivism, and horizontal collectivism were .69, .66, .65, and .70, respectively.

The independence and interdependence orientations were initially proposed to describe the contrast between Eastern and Western cultures. Later, there were debates regarding whether these orientations should be treated as a bipolar dimension or two separate dimensions (Brewer & Chen, 2007; Oyserman, Coon, & Kemmelmeier, 2002). In the field of cultural neuroscience, however, a great many of the existing studies took the unidimensional approach by contrasting Easterners and Westerners (e.g., Zhu et al., 2007), comparing participants primed with different cultural mind-sets (e.g., Sui & Han, 2007), or administering self-report measures and computing a composite score (e.g., Chiao et al., 2009).

Following Kitayama et al.'s (2014) recent work, we combined the unidimensional approach with a factor-analysis approach, calculating a composite score of independence-interdependence through the following steps. First, we computed the mean ratings of each subscale (independent self-construal, interdependent self-construal, vertical individualism, horizontal individualism, vertical collectivism, and horizontal collectivism). We then submitted these six indexes to a factor analysis, extracting factors with the principal-axis-factoring method and oblimin rotation with Kaiser normalization. Following Kaiser's rule (dropping all components with eigenvalues under 1.0) and visually inspecting the scree plot, we decided that a two-factor solution was most appropriate (see Table 1). In this solution, Factor 1 represented an interdependent orientation, and Factor 2 represented an independent orientation. Loadings of all indexes, with the exception of vertical individualism, were greater than .60 on the expected factor and lower than .30 on the other. Vertical individualism's loadings on both factors were lower than .30. The regression-based factor score was computed for each factor. Finally, a composite

Table 1. Factor Loadings for Six Measures Extracted From the Self-Construal Scale and Individualism-Collectivism Scale

Measure	Factor 1 (interdependent orientation)	Factor 2 (independent orientation)
Interdependent self-construal	**.88**	−.02
Vertical collectivism	**.78**	−.20
Horizontal collectivism	**.68**	.18
Vertical individualism	.24	.13
Independent self-construal	.09	**.79**
Horizontal individualism	−.05	**.63**

Note: Boldface highlights the important measures for each factor (measures loading more than .60 on the expected factor).

factor score was derived by subtracting the score for Factor 1 (the interdependence factor) from the score for Factor 2 (the independence factor); higher scores indicated more inclination toward independence relative to interdependence. This approach allowed us to control for the response bias to affirm cultural values (Kitayama, Park, Sevincer, Karasawa, & Uskul, 2009). Furthermore, scores derived from factor analysis accounted for measurement errors and differentiated item weights, which helps to tackle the lingering issue of the poor validity of self-reported measures in the field of independence-interdependence (Brewer & Chen, 2007; Oyserman et al., 2002), thus providing an edge over raw scale scores. In addition, results using separate factors of independence-interdependence were obtained, and analyses using raw scores of independence-interdependence are shown in the Supplemental Material available online.

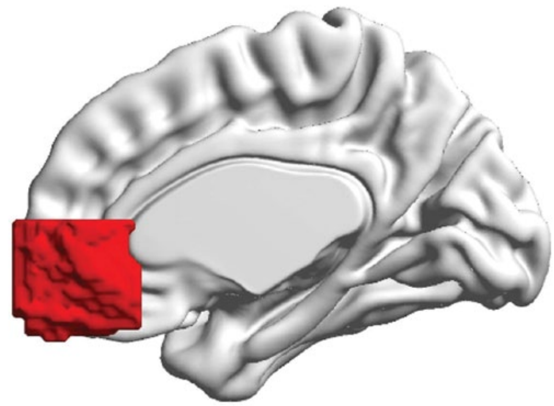

Fig. 1. Illustration of the anatomical mask of ventromedial prefrontal cortex (vmPFC), visualized with BrainNet Viewer (Xia, Wang, & He, 2013).

Image preprocessing

Images were preprocessed using Statistical Parametric Mapping (SPM) software (SPM8; Wellcome Department of Cognitive Neurology, London, United Kingdom; www.fil.ion.ucl.ac.uk/spm). Participants' T1-weighted images were examined individually, and the orientation and origin point were manually adjusted to match the template for better registration. The adjusted images were segmented into different tissue types, including gray matter, white matter, and cerebrospinal fluid, using SPM8's New Segmentation module. A study-specific template of gray matter was created using the diffeomorphic-anatomical-registration-through-exponentiated-lie (DARTEL) algorithm (Ashburner, 2007) implemented in SPM8 and then affine-registered to Montreal Neurological Institute (MNI) space. Individual segmented gray-matter images were nonlinearly warped to match the space of the DARTEL template and were modulated to preserve gray-matter volumes. Finally, the modulated images were smoothed with a Gaussian kernel of full width at half maximum equal to 4 mm.

Statistical analysis

Statistical analyses were performed on preprocessed gray-matter images using SPM8.

Region-of-interest (ROI) analysis. An anatomically defined mask of vmPFC was created using the Wake Forest University Pickatlas Toolbox (Maldjian, Laurienti, Kraft, & Burdette, 2003) by combining the labels of the bilateral medial frontal gyrus, cingulate region, and medial orbital-frontal gyrus in the 71-segmentation version of the Individual Brain Atlases Using Statistical Parametric Mapping (IBASPM71) software and then cropping to the following parameters: $x = -15$ mm to 15 mm, $y >$ 30 mm, and $z < 10$ mm. A visualization of this mask is shown in Figure 1.

We performed voxel-wise generalized linear modeling within the mask to identify regions in which gray-matter volume was significantly correlated with the composite score of independence-interdependence, controlling for global gray-matter volume, gender, and age. Because of a major update of the MRI scanner during the collection of the data, a dichotomous covariate representing data before and after the update was also included. Statistical maps were assessed at an uncorrected threshold of $p <$ .005, and clusters were considered significant if they passed a cluster-level threshold of $p < .05$ after family-wise-error correction using small-volume correction. Furthermore, clusters that passed a more liberal cluster-level threshold of $p < .05$, uncorrected, were considered marginally significant, and these are reported in detail in the Supplemental Material. Nonstationary extent correction (Hayasaka, Phan, Liberzon, Worsley, & Nichols, 2004) was applied during calculation of the cluster-level p value to address the issue of nonisotropic smoothness in the voxel-based-morphometry data. These analyses were performed again using the independence and interdependence factors as separate predictors in the generalized linear models. Contrasts for the two factors were examined separately.

Whole-brain analyses. To identify other regions in which gray-matter volume correlated with the independence-interdependence scores, we created a similar generalized linear model across the whole brain. A sample-specific gray-matter mask was created using the automatic optimal-thresholding method implemented in the masking toolbox in SPM8 (http://www0.cs.ucl.ac.uk/staff/g.ridgway/masking/). This approach has been shown to be superior in reducing the risk of false negatives relative to other commonly used approaches, such as absolute or relative threshold masking (Ridgway et al., 2009). Statistical maps were again assessed at an uncorrected threshold of $p < .005$, and clusters were considered significant if they passed a cluster-level threshold of $p < .05$ after familywise-error correction. Furthermore, clusters passing a more liberal cluster-level threshold of $p < .05$, uncorrected, were considered marginally significant, and these are reported in detail in the Supplemental Material. Nonstationary extent correction was applied during calculation of the cluster-level p value.

Scatterplots were also created for each significant cluster for demonstration purposes. For these plots, correlation coefficients and their 95% confidence intervals were calculated using the independence-interdependence scores and the peak gray-matter volume of the clusters, adjusted for global gray-matter volume, gender, and age.

As with the ROI analyses, the whole-brain analyses were performed again using the independence and interdependence factors as separate predictors in the generalized linear models. Contrasts for the two factors were examined separately.

Results

Table 2 presents age and independence-interdependence scores for each gender in the sample. There was no significant gender difference for the independence-interdependence scores, $t(263) = -0.43$, $p = .66$.

Table 2. Mean Age and Independence-Interdependence Score for the Sample

Variable	Total (n = 265)	Male (n = 137)	Female (n = 128)
Age	23.01 (2.69)	23.57 (2.45)	22.41 (2.82)
Independence-interdependence score	0.00 (1.04)	–0.001 (0.91)	0.001 (0.89)

Note: Standard deviations are given in parentheses.

Voxel-based-morphometry results: composite score

For the ROI analysis, a cluster was identified within the vmPFC mask as having gray-matter volume significantly positively correlated with trait independence, k = 195, Brodmann's area (BA) 10, p = .04, peak: x = 6, y = 69, z = −18, Z = 3.82 (Fig. 2). The stronger the participant's independence (relative to interdependence) orientation, the larger the size of his or her gray-matter volume in the vmPFC.

Results for the whole-brain voxel-based morphometric analysis are presented in Table 3 and in Figure 3. The analysis showed that the independence-interdependence score was positively correlated with the gray-matter volume in right dorsolateral prefrontal cortex (DLPFC; k = 427; BAs 9, 10, and 46; p = .02; peak: x = 48, y = 42, z = 21; Z = 4.66) and right rostrolateral prefrontal cortex (RLPFC; k = 351; BA 10; p = .02; peak: x = 31.5, y = 63, z = −3; Z = 4.64). Moreover, the greater trait independence,

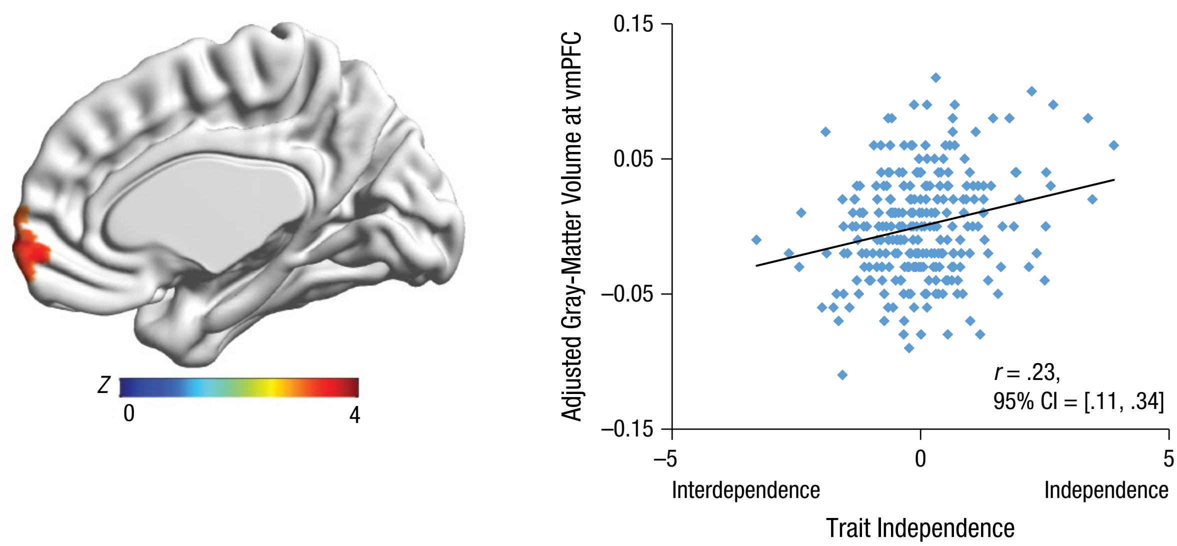

Fig. 2. Results of the region-of-interest analysis: scatterplot (with best-fitting regression line) showing the correlation between adjusted gray-matter volume in ventromedial prefrontal cortex (vmPFC) and trait independence. The brain image shows the cluster within vmPFC for which results are graphed. CI = confidence interval.

Table 3. Regions Where Gray-Matter Volume Was Significantly Positively Correlated With Trait Independence in the Whole-Brain Analysis

Region	Side	Brodmann's area	Cluster size: Number of voxels	Cluster size: Volume (mm^3)	Peak coordinates: *x*	Peak coordinates: *y*	Peak coordinates: *z*	Peak coordinates: *Z*
DLPFC	Right	9/10/46	427	1,441 mm^3	48	42	21	4.66
RLPFC	Right	10	351	1,185 mm^3	31.5	63	–3	4.64

Note: Statistical maps were assessed at an uncorrected threshold of $p < .005$; the two clusters were significant at $p < .05$, familywise-error-corrected, at the cluster level. Coordinates are given in Montreal Neurological Institute (MNI) space. DLPFC = dorsolateral prefrontal cortex; RLPFC = rostrolateral prefrontal cortex.

the larger the gray-matter volume found in right DLPFC and RLPFC. In addition, five clusters showed marginally significant positive correlations: left DLPFC; right fusiform and inferior temporal gyrus; vmPFC; left temporoparietal junction (TPJ), including superior, middle temporal, and postcentral gyrus; and a second cluster at right DLPFC (see Fig. S1a and Table S3 in the Supplemental Material).

For trait interdependence, two clusters were found covering the bilateral calcarine sulcus extending to the

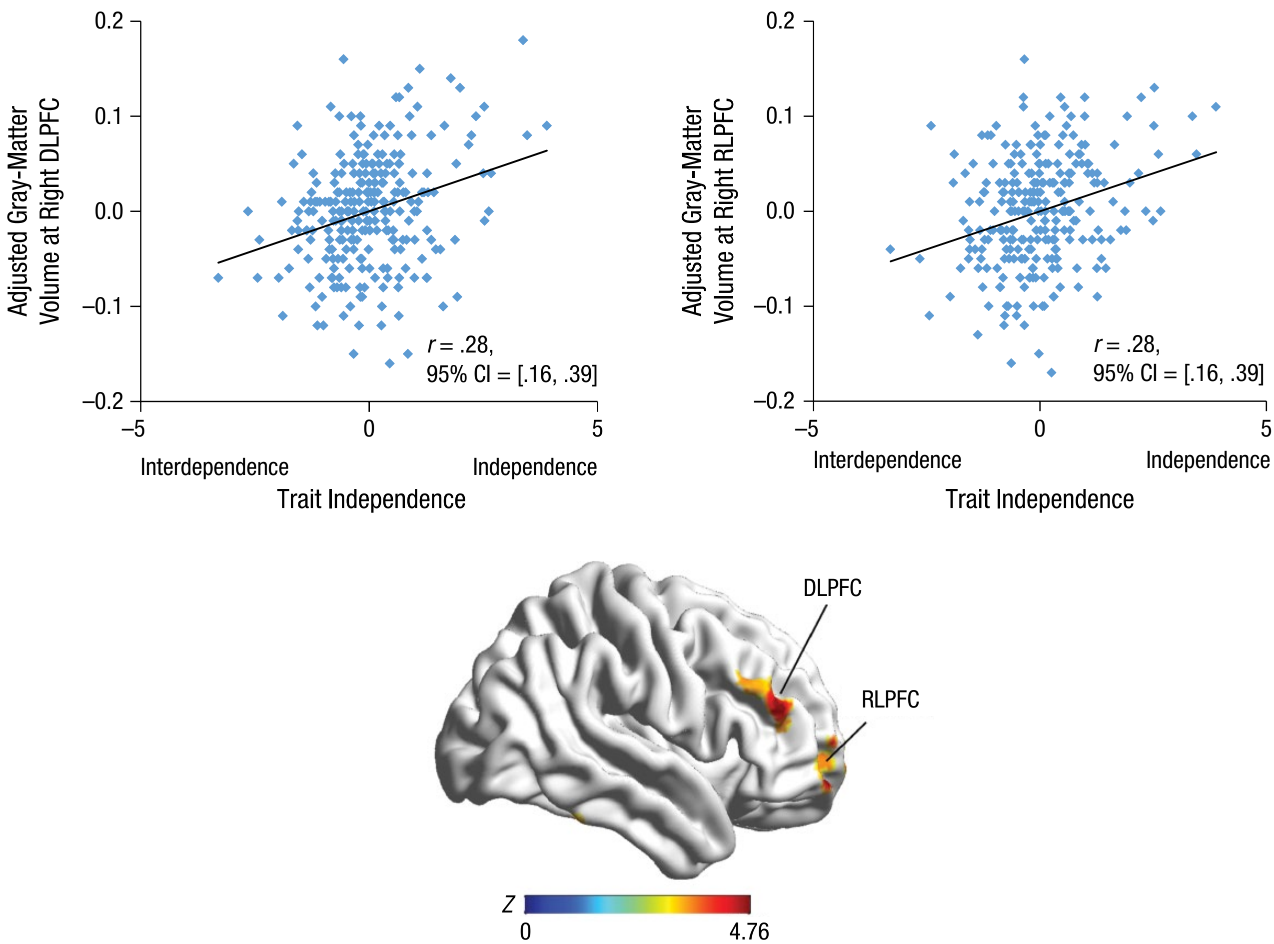

Fig. 3. Results of the whole-brain analysis: scatterplots (with best-fitting regression lines) showing the correlation between adjusted gray-matter volume in dorsolateral prefrontal cortex (DLPFC) and right rostrolateral prefrontal cortex (RLPFC), respectively, and trait independence. The brain image shows the clusters within DLPFC and RLPFC for which results are graphed. CI = confidence interval.

Table 4. Intercorrelations Among Regional Gray-Matter Volumes (Controlling for Global Gray-Matter Volume, Gender, Age, and MRI Update)

Region	2	3	4	5	6	7	8	9
1. vmPFC	.13* [.01, .25]	.25** [.13, .36]	.19** [.07, .30]	.13* [.01, .25]	.05 [–.07, .17]	.04 [–.08, .16]	–.17** [–.29, –.05]	–.08 [–.20, .04]
2. Right DLPFC	—	.26** [.14, .37]	.30** [.19, .41]	.06 [–.06, .18]	–.05 [–.17, .07]	.25** [.13, .36]	–.09 [–.21, .03]	–.02 [–.14, .10]
3. Right RLPFC		—	.22** [.10, .33]	.10 [–.02, .22]	–.01 [–.13, .11]	.20** [.08, .31]	–.04 [–.16, .08]	–.07 [–.19, .05]
4. Left DLPFC			—	.05 [–.07, .17]	–.04 [–.16, .08]	.23** [.11, .34]	.02 [–.10, .14]	–.02 [–.14, .10]
5. Right fusiform gyrus				—	.11† [–.01, .23]	.10 [–.02, .22]	–.08 [–.20, .04]	–.09 [–.21, .03]
6. Left postcentral gyrus					—	–.07 [–.19, .05]	–.09 [–.21, .03]	–.17** [–.29, –.05]
7. Right DLPFC 2						—	–.14* [–.26, –.02]	–.15* [–.27, –.03]
8. Left calcarine sulcus							—	.51** [.41, .60]
9. Right calcarine sulcus								—

Note: The values in brackets are 95% confidence intervals. DLPFC = dorsolateral prefrontal cortex; RLPFC = rostrolateral prefrontal cortex; vmPFC = ventromedial prefrontal cortex.
†$p < .10$. *$p < .05$. **$p < .01$.

lingual gyrus and precuneus (see Fig. S1b and Table S4 in the Supplemental Material), and these both showed marginally significant negative correlations with the independence-interdependence score.

Voxel-based-morphometry results: separate factor scores

In the ROI analysis, no cluster was found with a significant or marginally significant positive or negative correlation with regional gray-matter volume for either the independence or interdependence factor score. In the whole-brain analysis, for the independence factor score, no cluster was found with significant positive or negative correlation with regional gray-matter volume, but four clusters showed marginally significant positive correlations: a cluster covering middle occipital gyrus; a cluster covering left TPJ, including the superior, temporal, and postcentral gyrus; a cluster covering right fusiform gyrus; and a cluster covering left DLPFC (see the Supplemental Material for details). Furthermore, a cluster at right posterior superior frontal gyrus showed a marginally significant negative correlation. For the interdependence factor score, a cluster covering left calcarine sulcus extending to the lingual gyrus and precuneus showed significantly positive correlation (k = 893; BAs 18 and 30; p = .04; peak: x = −10.5, y = −63, z = 6; Z = 4.37). Additionally, a cluster covering right calcarine sulcus, a cluster covering right cerebellum, and a cluster covering left supramarginal gyrus showed marginally significant positive correlations. Three clusters showed significant negative correlations: two clusters covering bilateral DLPFC (right—k = 404; BAs 9, 10, and 46; p = .02; peak: x = 52.5, y = 27, z = 27; Z = 4.86; left—k = 390; BAs 10 and 46; p = .01, uncorrected; peak: x = −46.5, y = 36, z = 18; Z = 4.71) and one cluster covering right RLPFC (k = 393; BA 10; p = .01; peak: x = 28.5, y = 60, z = −9; Z = 4.61). Two additional clusters were identified as showing marginally significant negative correlations: a cluster covering left medial frontal gyrus, middle cingulate cortex, and supplementary motor area, and a cluster covering left DLPFC.

Intercorrelations of regional gray-matter volumes between the vmPFC and other regions, and the mediating role of independence-interdependence

Table 4 shows partial intercorrelations between gray-matter volumes at peak coordinates of the vmPFC and other clusters, after we controlled for global gray-matter volume, gender, and age. Gray-matter volume of the vmPFC was positively correlated with bilateral DLPFC, right RLPFC, and right fusiform gyrus, and negatively correlated with left calcarine sulcus, $|r|\text{s} > .12$, $p\text{s} < .05$.

Discussion

As predicted, individuals who expressed a greater relative focus of independence (vs. interdependence) had greater gray-matter volume in the vmPFC. Enlargement of a brain region is usually linked to proficiency in the relevant processing domain (May & Gaser, 2006). Previous functional neuroimaging studies have shown that vmPFC serves a critical role in self-related processing in a range of tasks (Sui, 2016), including perceptual matching (Sui et al., 2013), self-referential thinking, and memory (Northoff et al., 2006), and that the activity in vmPFC evoked by self-related processing is enhanced in individuals from independence-focused cultures relative to those from interdependence-focused cultures (e.g., Chiao et al., 2009, 2010; Sui & Han, 2007; Zhu et al., 2007). Therefore, our results are consistent with the theoretical view that trait independence (vs. interdependence) focuses more on the personal self (Markus & Kitayama, 1991), and these findings provide novel evidence that such broad sociocultural orientations are also reflected in anatomical features of the brain.

Besides the hypothesized results in vmPFC, we further found that independence-interdependence scores were significantly correlated with gray-matter volume in right DLPFC and right RLPFC. DLPFC has been argued to play a crucial role in creating and maintaining a sense of self-agency (e.g., Fink et al., 1999). According to this view, increased gray-matter volume in DLPFC linked to trait independence is consistent with more-independent individuals having a greater drive for personal agency (Shinobu Kitayama & Uchida, 2005). The function of RLPFC is even less well understood (Gilbert et al., 2006); however, there are reports that RLPFC is involved in processing self-generated information (Christoff, Ream, Geddes, & Gabrieli, 2003) and self-referential processing during retrieval from episodic memory (Sajonz et al., 2010). It is possible then that the tendency of independently oriented people to focus on the inner self (Markus & Kitayama, 1991) results in increased gray-matter volume in RLPFC. In sum, the results of the whole-brain analysis can also be explained through the personal-self account.

Notably, we also found that the gray-matter volume of the vmPFC was positively correlated with the gray-matter volume of the bilateral DLPFC. These results are in line with the theory of the self-attention network (Humphreys & Sui, 2016), which proposes that the functional coupling between vmPFC and DLPFC is linked to participants having to effect greater attentional control over biases to self-related stimuli compared with other stimuli. This idea is also supported by Northoff (2016), who suggests that these functional neural couplings reflect the interaction between internal self-specificity and external stimuli. If this theory is correct, the current results can be interpreted as showing that people with a relative focus of independence have a strengthened self-attention network. Future work might focus on the relationship between independence-interdependence and the functional coupling between vmPFC and DLPFC using the resting-state network or self-related tasks.

Beyond these significant results, some regions also showed marginally significant results. For example, we found increased gray-matter volume in relation to trait independence in right fusiform gyrus, which is a key region in processing faces and is especially sensitive to self-face identity (Ma & Han, 2012). Furthermore, Sui, Chechlacz, Rotshtein, and Humphreys (2015) found that reduced gray-matter volume in the right fusiform cortex of neuropsychological patients was associated with reduced self-bias; these authors proposed that these regions contained self-related memories. In contrast, a relative focus of interdependence was associated with increased gray-matter volume bilaterally in the calcarine sulcus extending to lingual gyrus. Because it is a visual region, the results for this area might be linked with previous studies showing that people with an interdependence focus (e.g., East Asians) and independence focus (e.g., Westerners) are different in their scope of visual attention. For example, East Asians may be more likely to perceive visual scenes as a whole, and their attention may be more evenly distributed between objects and background (Nisbett, Peng, Choi, & Norenzayan, 2001). However, it should be noted that these results showed only marginal significance. Future research may provide clarification by examining the relationship between independence-interdependence and the activity of these regions when performing the related behavioral tasks (e.g., a face-processing task for the fusiform gyrus or an attention task for the calcarine sulcus).

When the independence and interdependence orientations were examined separately, most of the significant results re-emerged for the interdependence score—and a cluster in the calcarine sulcus, which was only marginally significant in the unidimensional analysis, also reached significance—whereas the independence score was only marginally significant. The pattern of weaker results for the independence score was also observed in Ray et al. (2009), in which only interdependent self-construal, but not independent self-construal, predicted medial prefrontal cortex and posterior cingulate cortex's relative activations in self-referential versus mother-referential judgments. One possibility is that the self-reported measures for independence may be noisier. For example, in Ray et al. (2009), the independent subscale had an alpha of .53, and in our study, the vertical-individualism subscale loaded poorly on both the interdependence and independence factors, which left only two indicators for the independence factor. Although the independence and interdependence orientations were initially proposed as a contrast between Eastern and Western cultures, there have been debates on whether independence and interdependence should be treated as one bipolar dimension or two separate construals (Brewer & Chen, 2007; Oyserman et al., 2002). Nevertheless, our results are in line with those of previous cultural neuroscience studies, in which a unidimensional approach was predominantly taken and the links between the relative focus of independence and activities of self-related regions were reported. Also, using a relative score could control for the response-bias artifacts of affirming cultural values, which could thus lead to a clearer result.

One limitation of the current study is that the analyses are correlational in nature, and a longitudinal design is needed to determine the causal direction between independent and interdependent traits and changes in brain structure. Further, the results of the present study may also reflect the influences of environmental or genetic factors. There has been emerging evidence for the correlations between the independence-interdependence orientations and certain genotypes (e.g., Chiao & Blizinsky, 2010). Future research could pursue these correlations to establish the link among genes, the brain, and culture. Furthermore, our approach of treating independence-interdependence as an individual-differences variable within a single culture, while allowing us to control for confounds such as language, might also have limited the range of distribution of the traits in our sample. Clearly, a cross-cultural analysis would be helpful to test this. Actually, some of the regions reported here were also identified in Chee et al.'s (2011) comparison between young Easterners and Westerners. Nevertheless, our results provide novel evidence that there are anatomical variations of brain structure underlying the sociocultural orientations of independence and interdependence, even within a single culture.

Action Editor

Eddie Harmon-Jones served as action editor for this article.

Author Contributions

F. Wang developed the study concept and design with K. Peng and J. Sui. Data were collected by teams from K. Peng and J. Sui's laboratory. F. Wang analyzed and interpreted the data under the supervision of J. Sui. F. Wang drafted the manuscript. All authors discussed the manuscript. J. Sui and G. W. Humphreys provided critical revisions. All authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797616689079

Open Practices

Behavioral data and Statistical Parametric Mapping (SPM) results for this study have been made publicly available via the Open Science Framework and can be accessed at https://osf.io/p6jfq/. All materials have been made publicly available via the Open Science Framework and can be accessed at https://osf.io/vhme2/. The complete Open Practices Disclosure for this article can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797616689079. This article has received badges for Open Data and Open Materials. More information about the Open Practices badges can be found at http://www.psychologicalscience.org/publications/badges.

Note

1. In social psychology and cross-cultural psychology, various related terms, such as *independent-interdependent self-construals* or *individualism-collectivism*, have been used. In the current article, we follow Kitayama et al. (2014) in using the term *independence-interdependence* to refer to these general orientations.

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