Interdependent Self-Construal Predicts Increased Gray Matter Volume of Scene Processing Regions in the Brain

Qinggang Yu[1]
Anthony P. King[1]
Carolyn Yoon[1]
Israel Liberzon[2]
Richard J. Davidson[3]
Shinobu Kitayama[1]

[1]University of Michigan
[2]Texas A&M College of Medicine
[3]University of Wisconsin -- Madison

All correspondence regarding this article should be addressed to Qinggang Yu (qinggang@umich.edu) at Department of Psychology, University of Michigan, 530 Church St, Ann Arbor, MI 48109

Abstract

Interdependent self-construal (SC) is thought to lead to a more holistic cognitive style that emphasizes the processing of the background scene of a focal object. At present, little is known about whether the structural properties of the brain might underlie this functional relationship. Here, we examined the gray matter (GM) volume of three cortical regions involved in scene processing -- a cornerstone of contextual processing. Study 1 tested 78 European American non-student adults and found that interdependent (vs. independent) SC predicts higher GM volume in the parahippocampal place area (PPA), one of the three target regions. Testing both European American and East Asian college students (total N = 126), Study 2 replicated this association. Moreover, the GM volume of all the three target regions was greater for East Asians than for European Americans. Our findings suggest that there is a structural neural underpinning for the cultural variation in cognitive style.

Keywords: Self-construal, parahippocampal place area, cultural difference, voxel-based morphometry, scene processing

Interdependent Self-Construal Predicts Increased Gray Matter Volume of Scene Processing Regions in the Brain

For a long time, the study of ethnic and racial variations in brain volume has carried racist overtones (Gould et al., 1996). It is only over the last decade that researchers began linking brain differences to the meanings and practices of different cultural groups (Kitayama et al., 2017; Park & Huang, 2010; Yu et al., 2019). In this new approach, the analytic focus shifted from the prior emphasis on total brain volume to the volume of specific regions recruited to perform specific tasks more common in some cultures than in others. The key working assumption has been that the brain regions recruited repeatedly by the tasks emphasized in any given culture may increase in volume, controlling for the total brain size or volume (Kitayama et al., 2017; Maguire et al., 2000; Yu et al., 2019). In the current work, we built on recent work in cultural psychology and tested the link between the axis of independent vs. interdependent self-construal (SC) that permeates known cultural variation and the volume of specific brain regions.

The cultural psychological research has shown substantive psychological differences, including cognitive differences, between European Americans and East Asians (Markus & Kitayama, 1991; Nisbett et al., 2001). Moreover, this work has linked these differences to the construal of the self as independent or interdependent (Cohen & Kitayama, 2019; Kitayama & Uskul, 2011). Specifically, people engaged in cultures emphasizing interdependent SC, such as East Asians, are more holistic in cognition than people engaged in cultures emphasizing independent SC, such as European Americans. Thus, for example, East Asians allocate more attention to the context (e.g., visual background) while viewing a focal object (Kitayama et al., 2003; Masuda & Nisbett, 2001). At present, however, little is known about whether the relationship between the SCs and holistic cognition manifests in structural neural correlates of holistic cognition.

The present study aimed to fill this gap in two ways. First, we tested the association between interdependent (vs. independent) SC and the gray matter (GM) volume in three cortical regions uniquely involved in scene perception (Epstein & Baker, 2019; Epstein & Kanwisher, 1998), and hence critical for contextual processing. Second, we examined whether East Asians show greater GM volume in these cortical regions than European Americans.

Self-Construal, Cognitive Style, and Visual Processing

People endorsing independent SC prioritize their self-interests and personal goals (over social expectations) and pursue what they want (Markus & Kitayama, 1991). They thus are more likely to allocate greater attention to focal objects relevant to their personal goals than to the contextual surroundings (Kühnen & Oyserman, 2002; Nisbett et al., 2001; Oyserman & Lee, 2008). Conversely, people endorsing interdependent SC prioritize social norms over self-interest and goals (Markus & Kitayama, 1991). They tend to be more attentive to the contextual surrounding and the relationship between the focal objects and the context. In social settings, they may be vigilant of the expectations of others and the norms of the situations (Iyengar & Lepper, 1999; Kitayama et al., 2004). This tendency to holistically allocate more attention to context extends to social cognition (Morris & Peng, 1994) and non-social perception (Kitayama et al., 2003; Nisbett & Masuda, 2003).

Recent research on culture and cognition has employed neural indicators of holistic cognition and linked them to independent and interdependent SC. Goto et al. (2010) indexed holistic cognition with N400, an electrocortical indicator of expectation violation (Kutas & Hillyard, 1980; Rabovsky et al., 2018). N400 was assessed while subjects were viewing an object (e.g., crab) superimposed on a contextual scene that is either congruent (e.g., beach) or incongruent (e.g., parking lot) with the object. They were to make a judgment about the object while ignoring the scene. Thus, the magnitude of N400 in response to objects in incongruent contextual scenes indicates spontaneous attention to the context. The researchers found that this N400 effect decreased as a function of independent SC. Further, as may be expected, the N400 effect was significant for Asian Americans, yet negligible for European Americans. In another study, the same group of researchers (Goto et al., 2013) carried out a similar study with a different set of stimuli and found that the magnitude of N400 for objects in an incongruent context increased as a function of interdependent SC. As may also be expected, the N400 effect was again significant for Asian Americans, yet negligible for European Americans.

A similar question has been addressed by Na and Kitayama (2011), who tested the degree to which personality traits are automatically inferred from another's behavior. This effect, called the spontaneous trait inference (Winter & Uleman, 1984), results from focused attention to the target person at the expense of her surrounding context. Hence, the spontaneous trait inference effect may also increase/decrease as a function of independent/interdependent SC. Na and Kitayama (2011) used N400 to index spontaneous trait inference and found that the magnitude of this effect decreased (thus showing greater contextual attention) as a function of interdependent (relative to independent) SC. Again, the spontaneous trait inference, robust among European Americans, was negligible among Asian Americans. Altogether, these studies are consistent with the hypothesis that holistic cognitive tendencies either increase as a function of interdependent SC or decrease as a function of independent SC.

Structural Neural Correlates of Holistic Visual Processing in the Brain

The three N400 studies reviewed above suggest that the processing of contextual elements in relevant scenes (e.g., visual backgrounds and social contexts) is more automatic and potentially more efficient for those known to be higher in interdependent SC or lower in independent SC. Since this processing involves specific anatomical regions of the brain, we may reasonably ask whether SCs are linked systematically to the structural properties of these regions. Recent work (Kitayama et al., 2017, 2020; Wang et al., 2017; Yu et al., 2019) focused on one structural property (GM volume) and showed that interdependent (vs. independent) SC predicts *decreased* GM volume of certain prefrontal regions linked to the maintenance of a clear sense of the self and the identification of personal preferences and goals (Northoff & Bermpohl, 2004; O'Doherty, 2011), as well as *increased* GM volume of the temporoparietal junction, which is critical for perspective-taking (Saxe & Kanwisher, 2003). These patterns align with the findings that interdependent SC is linked to *suppressed* personal goal pursuit (Heine et al., 1999; Kitayama & Park, 2014) and *increased* perspective-taking (Atkins et al., 2016; Wu & Keysar, 2007). Extending this work, we tested whether interdependent (vs. independent) SC predicts GM volume of several cortical regions involved in the processing of visual scenes that typically constitute visual contexts for focal objects. Given that interdependent SC is linked to more frequent and elaborate contextual processing, it is likely associated with *increased* GM volume of these regions.

Visual scenes receive selective processing in a cortical network including three regions, parahippocampal place area (PPA), retrosplenial complex/medial place area (RSC/MPA), and occipital place area (OPA). Previous neuroimaging work showed that all three regions respond preferentially to visual scenes (e.g., landscapes or cityscapes) as opposed to focal objects (Epstein, 2008; Epstein & Baker, 2019; Epstein & Kanwisher, 1998), suggesting that they may be involved in the encoding of contextual information. In addition, lesions (or "virtual lesions" induced by transcranial magnetic stimulation) of these three regions are associated with impairment in both visual scene identification and visuospatial processing (Aguirre & D'Esposito, 1999; Ganaden et al., 2013; Ino et al., 2007).

It is worth noting that there have been a few studies using functional MRI to compare brain activations between East Asians and European Americans when viewing visual stimuli (Goh et al., 2007, 2010; Gutchess et al., 2006; Jenkins et al., 2010). Consistent with East Asians being more holistic or less analytic than European Americans, these studies found that East Asians showed reduced activation in the object-processing areas of the brain during visual perception, although cultural difference in activation of PPA was not reliably identified. However, previous studies did not test the association between the SCs and brain activations. Moreover, the focus has been exclusively on the PPA, rather than the other scene-processing regions, and none of them tested GM volume. Our study here aimed to fill these gaps.

The present study thus set out to test if interdependent (vs. independent) SC predicts greater GM volume in PPA, MPA, and OPA. In Study 1, we tested European American non-student adults from a national sample of the U.S. In Study 2, we tested an undergraduate student sample including both European Americans and East Asian-born Asians. The latter sample enabled us to examine whether East Asians show greater GM volume in the specific regions of interest than European Americans.

Study 1

Method

Participants. Participants were drawn from the Midlife in the United States (MIDUS) project, a national longitudinal study on health and well-being (http://www.midus.wisc.edu). In particular, the participants were from the MIDUS "Refresher" study, which was designed to replenish the original MIDUS baseline cohort. The "Refresher" study tested a national probability sample of 3,577 participants who were recruited through random digit dialing, as well as a separate sample of 508 African Americans from Milwaukee. The study administered a series of questionnaires, including the Singelis self-construal scale (Singelis, 1994), which is of interest in the present study. One hundred thirty-eight participants from the "Refresher" study later participated in the "Refresher" Neuroscience study, in which they completed various cognitive and emotional tasks and underwent psychophysiological assessments and MRI scanning of the brain. Among the 138 participants, 11 were not eligible for MRI scanning due to failure to meet inclusion criteria (e.g., no history of neurological disorders, no magnetic metal or medical devices in the body, no claustrophobia, ability to lie down on one's back for two hours). For the remaining 127 participants, one was excluded due to missing SC data, and another was excluded due to left-handedness. Among the remaining 125 participants, 78 were European Americans (38 females and 40 males) and of interest in the present study. The average age was 49.01 years, with ages ranging between 27 and 76 years. All participants provided informed consent before the study procedures. Data and brain images are publicly available from the MIDUS website upon request.

Self-construal scale. The Singelis self-construal (SC) scale (Singelis, 1994) was used to assess the SC of participants. SC was assessed using a scale consisting of 10 items measuring independent SC and 12 items measuring interdependent SC. Sample items for independent SC included “I enjoy being unique and different from others in many respects” and “Being able to take care of myself is a primary concern for me.” Sample items for interdependent SC included “I often have the feeling that my relationships with others are more important than my own accomplishments” and “I will sacrifice my self-interest for the benefit of the group I am in.” Participants rated each item on a 7-point Likert scale (1 – strongly agree, 7 – strongly disagree). The scores were then reversed. Thus, a higher score reflects a stronger endorsement of both SCs. The internal consistencies of independent and interdependent SC were adequate ($\alpha = 0.64$ and $\alpha = 0.65$, respectively).

Image acquisition. Structural scan was acquired using a 3 T scanner (MR750 GE Healthcare, Waukesha, WI). A three-dimensional magnetization-prepared rapid gradient-echo sequence (Mugler & Brookeman, 1990) was used to acquire a T1-weighted anatomical image (repetition time = 8.2 ms, echo time = 3.2 ms, flip angle = 12 degrees, field of view = 256 mm, 256 x 256 matrix, 160 1mm axial slices per volume, inversion time = 450 ms).

Image pre-processing and measurement. Structural images were pre-processed and analyzed using voxel-based morphometry (VBM) (Ashburner & Friston, 2000) implemented in the Statistical Parametric Mapping software (SPM; Wellcome Department of Cognitive

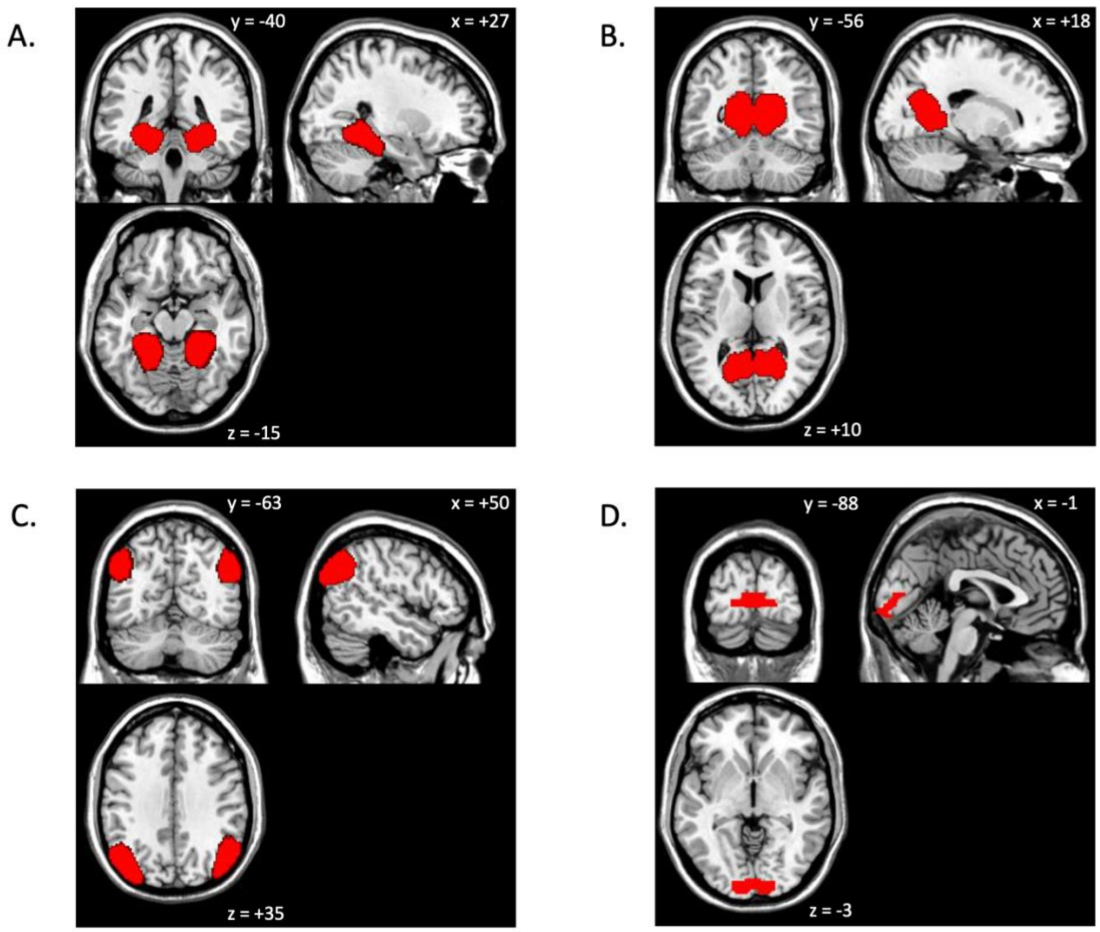
Neurology, London, UK). VBM has been commonly used in the past to examine structural properties of the brain in relation to culture and culturally-related variables (Kitayama et al., 2017, 2020; Wang et al., 2017; Yu et al., 2019). First, each structural image was visually inspected for its orientation and origin point, and it was adjusted to match the template better if necessary. The images were then segmented into different tissue classes – GM, white matter (WM), and cerebrospinal fluid (CSF) based on prior probability templates. After this, the "Diffeomorphic Anatomical Registration through Exponentiated Lie" (DARTEL) algorithm (Ashburner, 2007) was used to create a sample-specific template of GM, which was affine-registered to the Montreal Neurological Institute (MNI) space. All the segmented GM images were then nonlinearly warped to match the space of the DARTEL template. Modulation was performed to retain the original GM volume by multiplying the warped tissue probability map by the Jacobian determinant of the warp. Lastly, the modulated images were smoothed with a 10-mm full-width half-maximum Gaussian kernel. The total GM, WM, and CSF volume for all participants were calculated by multiplying the total number of voxels of each tissue type by the voxel size. Total brain volume (TBV) was subsequently calculated by summing the total GM volume and total WM volume.

Region of interest definition. Because the scene-processing regions (PPA, MPA, and OPA) are functionally defined and have no clear-cut anatomical boundaries, we constructed our scene-processing regions of interest (ROIs) based on previous work that functionally identified those regions. In particular, we used the maximum-probability ROI map of scene-selective regions from Zhen et al. (2017), which includes the definitions of PPA, MPA, and OPA in MNI space based on functional brain activation data (a contrast of scene vs. object) of a sample of 202 subjects (see Zhen et al. for more details). To verify the specificity of the effects of SC and culture on scene-processing regions, we also included a "control region" in the present analysis. In particular, we used the primary visual cortex (V1). The V1 ROI was constructed with the WFU

PickAtlas toolbox (Maldjian et al., 2003), defined anatomically as the Brodmann area 17, and further dilated by one voxel. We used the PPA, MPA, OPA, and V1 ROI (Fig. 1) to carry out small volume correction in our structural image analysis.

Figure 1

The regions of interest (ROIs) for Studies 1 and 2.



Note. A. Parahippocampal place area (PPA). B. Retrosplenial cortex/medial place area (RSC/MPA). C. Occipital place area (OPA). D. Primary visual cortex (V1). Within each sub-figure, the ROI is plotted from a coronal (top left), sagittal (top right), and axial (bottom left) view.

Statistical analysis. To test our predictions, we carried out voxel-level analysis in the framework of general linear model on the pre-processed GM images. All voxels with a GM value smaller than 0.2 (of a maximum value of 1) were first excluded to retain only the homogenous voxels. Nonstationary cluster extent correction was also applied to correct for nonisotropic smoothness of VBM data (Hayasaka & Nichols, 2004). Because previous work has demonstrated correlations between holistic cognitive tendencies and independent SC, interdependent SC, or the difference score (interdependent SC - independent SC) (Goto et al., 2010; Lewis et al., 2008; Na & Kitayama, 2011), we tested all three indices of SC. We used the multiple regression design and included independent SC, interdependent SC, or the difference score as the regressor in three separate models. Age, sex, and TBV were included as covariates in these models. We first carried out ROI analysis, using the ROI masks for small volume correction. We tested whether the GM volume within these ROIs showed (1) *positive* correlation with interdependent SC, (2) *negative* correlation with independent SC, or (3) *positive* correlation with the difference score. Statistical inferences were made at the voxel level for all ROI analyses. The threshold of significance was set at $p < .05$ family-wise error (FWE) corrected at the voxel level. Because three separate models were run with the three SC scores, we further corrected for multiple-comparison with Bonferroni correction and set the threshold of significance at $p < .0167$ (generated by 0.05 divided by 3). We then carried out exploratory whole-brain analyses to see if there were any additional effects. The threshold of significance was set at $p < .05$ (FWE-corrected) at the voxel-level.

Results

Questionnaire data. We found that there was no difference between interdependent and independent SC among European American non-student adults (*M*s = 5.00 and 5.03, respectively; $t(77) = .295$, $p = .769$).

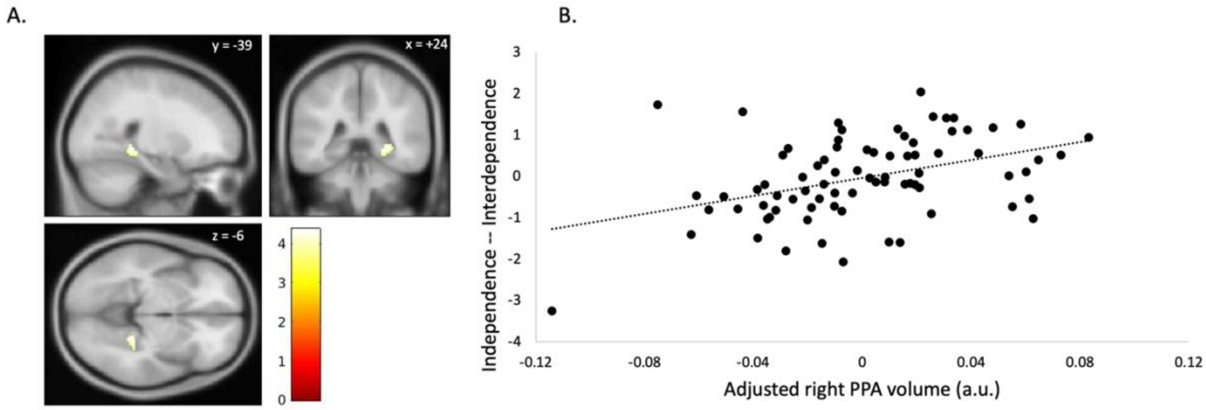
Correlation between SC and GM volume of the scene-processing regions. We found that the difference score (interdependent - independent SC) was positively correlated with the GM volume within the right PPA (peak voxel MNI coordinates 24, -39, -6; Z value = 4.14; cluster size = 230; peak-level p = .004, FWE-corrected). Fig. 2-A shows the significant voxels within the right PPA region. To illustrate the relationship, we extracted the GM value of the significant voxels and plotted it as a function of the difference score (Fig. 2-B). The voxel-level relationship remained significant after excluding the subject generating one apparent outlier (more than 3 SD below the mean for both variables) in the bottom left corner (peak voxel MNI coordinates 24, -39, -6; Z value = 3.48; cluster size = 4; peak-level p = .041, FWE-corrected). Thus, individuals who were more interdependent relative to independent showed greater GM volume within the right PPA[1]. There was no significant correlation between the difference score and the GM volume within MPA or OPA. In addition, we did not detect a significant correlation between interdependent SC itself and the GM volume within the scene-processing regions, or between independent SC itself and the GM volume within the scene-processing regions. Lastly, no effect of the SCs was observed at the GM volume within the control region, V1.

It is unclear whether the greater GM volume as a function of the difference score was due to an increased GM thickness, an increased GM surface area, or a combination of both. Because VBM is an intensity-based measure and it itself cannot inform this question, we used surface-based morphometry, Freesurfer, to test thickness and surface area separately as a function of the difference score (see Supplementary materials).

[1] When we tested all the 125 subjects of the current sample (including the additional 47 subjects who are racial minorities, primarily African Americans), the result did not change. The difference score was positively correlated with the GM volume within the right PPA (peak voxel MNI coordinates 24, -40, -9; Z value = 4.14; cluster size = 203; peak-level p = .004, FWE-corrected).

Figure 2

ROI analysis of the correlation between PPA gray matter (GM) volume and the difference score (interdependent SC - independent SC) in Study 1.



Note. A. Cluster that shows a significant positive correlation between the difference score and GM volume within the PPA ROI. The color bar indicates the *t* score of the significant voxels. B. An illustrative scatterplot on right PPA GM volume (significant voxels) and the difference score. Right PPA GM volume was adjusted by regressing out the effect of covariates.

Whole-brain analysis. We then carried out whole-brain analyses exploring additional brain regions of which the GM volume was *positively* correlated with interdependent SC (Table S1), *negatively* correlated with independent SC (Table S2), or *positively* correlated with the difference score (Table S3). Although there were some voxels that were significant at the uncorrected level ($p < .001$), they did not survive the FWE correction[2]. Hence, no further interpretation is generated.

Study 2

[2] Prior work (Kitayama et al., 2017, 2020; Yu et al., 2019; Wang et al., 2017), including some that have used the dataset of Study 2 here, found that interdependent SC inversely predicts GM volume in OFC, and independent SC inversely predicts GM volume in TPJ. However, these results did not replicate with the current MIDUS sample in Study 1. The comparatively smaller size of this sample might account for this.

The purpose of Study 2 was to replicate the initial evidence linking SC to the PPA GM volume using a separate sample. We also tested whether the GM volume of the scene-processing regions showed a cross-cultural variation suggested by prior evidence (e.g., Kitayama et al., 2003; Masuda & Nisbett, 2001). We anticipated that the GM volume of PPA, MPA, and OPA would be greater for East Asians than for European Americans.

Method

Participants. We tested 132 healthy right-handed undergraduate students at the University of Michigan. Sixty-six of them (45 females and 21 males) were European Americans born and raised in the U.S., with an average age of 20.2 years and ages ranging between 18 and 23. The remaining 66 participants (40 females and 26 males) were East Asian-born Asians with an average age of 21.2 years and aged ranging between 18 and 27. They had been in the U.S. for less than ten years at the time of the study. All these participants were part of a larger participant pool (n = 635) that had been built for research on genetics, cultural psychology, and cultural neuroscience. We excluded six participants, three in each cultural group, from the structural brain analysis due to poor image quality that prevents optimal segmentation of GM and WM, leaving us with 126 participants. Existing studies using the same structural brain dataset have been published (Kitayama et al., 2020; Yu et al., 2019). Data and raw structural brain images of this sample are available at: https://osf.io/wpfuv/?view_only=7bf64f11dc124901866a0ea5b102149e. This study was approved by the Internal Review Board of the University of Michigan.

Self-construal scale. As in Study 1, the Singelis SC scale (Singelis, 1994) was used to assess the SC. Unlike in Study 1, the full 30-item scale was used in Study 2, with 15 items measuring independent SC and 15 items measuring interdependent SC. Participants rated each item on a 7-point Likert scale (1 – strongly disagree, 7 – strongly agree). Internal consistencies for independent and interdependent SCs were adequate for European American participants (α

= 0.65 and α = 0.62, respectively) and East Asian participants (α = 0.68 and α = 0.72, respectively).

Image acquisition. Scanning was performed using a 3 T scanner (Phillips Medical Systems, Andover, MA). A high-resolution T1-weighed anatomical image was acquired from all participants (echo time = 4.6 ms, repetition time = 9.8 ms, 256 × 200 matrix, flip angle = eight degrees, field of view = 256 × 256 × 180 (mm), 180 contiguous 1mm sagittal slices per volume).

Image pre-processing and ROI definition. The procedures were identical to those of Study 1. It should be noted that, unlike Study 1, Study 2 included both European American and East Asian samples. These two groups are known to vary in head shape (Zilles et al., 2001), calling for extra caution in normalizing the brains. One possible approach is to normalize European Americans' and East Asians' brains to their corresponding group-specific templates, thus minimizing normalization error. This approach, however, can severely bias the ROI analysis because the ROI masks of the present study, defined in MNI space from a prior study (Zhen et al., 2017), will be mapped on different anatomical structures between brains normalized to the different templates. We thus adopted the SPM-DARTEL approach (Ashburner, 2007) as in Study 1, which creates a shared sample-specific GM template. This template is thus intermediate between a Caucasian template and an East Asian template. This procedure is designed to reduce the normalization error when individual segmented GM images are warped to match the template in MNI space and has been used in previous studies examining GM volume among cross-cultural samples (Huang et al., 2019; Kitayama et al., 2020; Yu et al., 2019).

Statistical analysis. We first aimed to replicate the correlation between PPA GM volume and the SC score in the ROI analyses. The procedures and the threshold for statistical significance were identical to those of Study 1. We then tested the cultural difference of GM volume within PPA, MPA, OPA, and V1. We used the two-sample *t*-test design and tested the contrast: East Asians - European Americans. The same ROIs of these regions were used for small volume correction, and the same set of covariates was used, as in the other analyses. Statistical inferences were made at the voxel level for all ROI analyses. The threshold of significance was set at $p < .05$ (FWE-corrected at the voxel level). Lastly, whole-brain analyses were conducted to explore other brain regions of which the GM volume was (1) *positively* correlated with interdependent SC, (2) *negatively* correlated with independent SC, or (3) *positively* correlated with the difference score. Whole-brain analysis was also conducted to see if any additional brain regions showed greater GM volume among East Asians than among European Americans. Note that a similar cross-cultural comparison was included in a previous study (Yu et al., 2019). The threshold of significance was set at $p < .05$ (FWE-corrected) at the voxel-level.

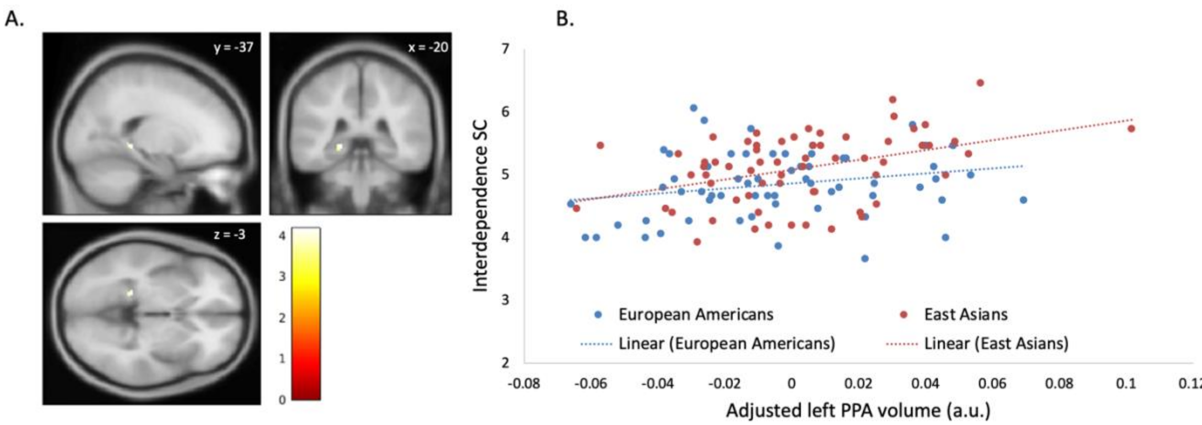
Results

Questionnaire Data. East Asians were significantly more interdependent in their SC than European Americans (*M*s = 5.10 and 4.85, respectively; $t(124) = -2.565$, $p = .012$). However, East Asians and European Americans were no different in the independent SC (*M*s = 4.83 and 4.87, respectively; ($t(124) = .380$, $p = .705$). In addition, for East Asians, the average score was higher for interdependent SC than for independent SC ($t(62) = 2.490$, $p = .015$). There was no such difference for European Americans ($t(62) = -.160$, $p = .873$).

Correlation between SC and GM volume of the scene-processing regions. Across the cultural groups, interdependent SC was associated with greater GM volume within the left PPA (peak voxel MNI coordinates -20, -37, -3; *Z* value = 4.02; cluster size = 48; peak-level $p = .007$, FWE-corrected) (Fig. 3). As in Study 1, the correlation was only detected at PPA, but not at MPA and OPA. In addition, we did not detect a significant correlation between independent SC and the GM volume within the scene-processing regions, or between the difference score and the GM volume within the scene-processing regions. Lastly, there was no effect of the SCs at the GM volume within the control region, V1.

Figure 3

ROI analysis of the correlation between PPA GM volume and interdependent SC in Study 2.

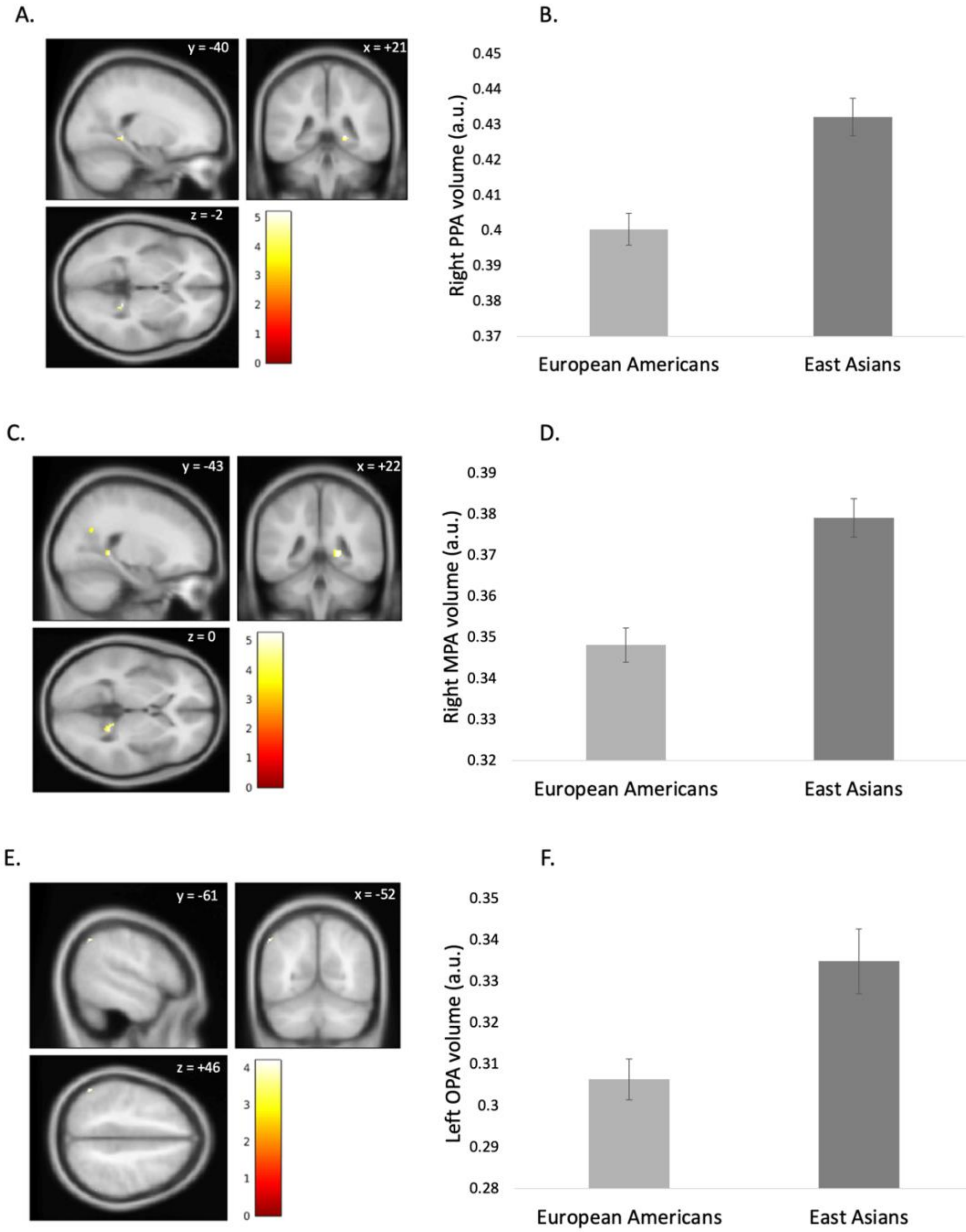


Note. A. Cluster that shows a significant positive correlation between interdependent SC and GM volume within the PPA ROI. The color bar indicates the *t* score of the significant voxels. B. Scatterplot on left PPA GM volume (significant cluster) and interdependent SC as a function of culture. Left PPA GM volume was adjusted by regressing out the effect of covariates.

Cultural Difference in GM volume of the scene-processing regions. East Asians showed greater GM volume within the right PPA compared to European Americans (peak voxel MNI coordinates 21, -40, -2; Z value = 4.91; cluster size = 31; peak-level $p < .001$, FWE-corrected) (Fig. 4). East Asians also showed greater GM volume within the right MPA compared to European Americans (Cluster 1: peak voxel MNI coordinates 21, -42, 0; Z value = 4.97; cluster size = 106; peak-level $p < .001$, FWE-corrected. Cluster 2: peak voxel MNI coordinates 24, -61, 27; Z value = 3.93; cluster size = 18; peak-level $p = .011$, FWE-corrected) (Fig. 4). Moreover, East Asians showed greater GM volume within bilateral OPA compared to European Americans (Cluster 1: peak voxel MNI coordinates -52, -61, 46; Z value = 4.05; cluster size = 19; peak-level $p = .006$, FWE-corrected. Cluster 2: peak voxel MNI coordinates -50, -58, 51; Z value = 3.82; cluster size = 2; peak-level $p = .015$, FWE-corrected. Cluster 3: peak voxel MNI coordinates 57, -54, 46; *Z* value = 3.70; cluster size = 3; peak-level *p* = .022, FWE-corrected) (Fig. 4). Lastly, East Asians did not show greater GM volume within V1, the control region.

Figure 4

ROI analysis of cultural difference in Study 2.



Note. A. Cluster that shows significant cultural difference in the GM volume within the PPA ROI. Color bar indicates the *t* score of the significant voxels. B. Mean GM volume of the cluster as a function of culture. Error bar represents +/- 1 standard error. C and D show the same information for MPA, and E and F for OPA.

Whole brain analysis. In terms of the correlation with the SCs, there were, as in Study 1, some voxels that were significant at the uncorrected level ($p < .001$), but they did not survive the FWE correction (see Table S4-6). Hence, no further interpretation is carried out. There was significant cultural difference such that East Asians showed greater GM volume in bilateral middle temporal gyrus and temporal pole, bilateral supramarginal gyrus extending to occipitoparietal regions and bilateral sensorimotor cortex, and retrosplenial region (see Table S7)[3].

Discussion

The contribution of the current work is two-fold. First, we showed that interdependent (vs. independent) SC reliably predicts increased GM volume in the PPA. We found this association among European American and East Asian undergraduates, as well as European American non-student adults, underscoring the robustness and generalizability of the association. This finding extends earlier work linking holistic cognition to interdependent (vs. independent) SC (Goto et al., 2010, 2013; Na & Kitayama, 2011) by showing that there is a close relationship between the mode of daily operation and the working of the brain. It also adds further evidence to the robust relationship between SC and regional GM volume (Kitayama et al., 2017, 2020; Yu et al., 2019; Wang et al., 2017).

Second, we also showed that GM volume in the three scene-processing regions (PPA, MPA, and OPA) is greater among East Asians than European Americans. This finding contributes to an emerging body of work documenting cultural variation in the cortical volume of various brain regions, including prefrontal regions (Yu et al., 2019) and TPJ (Kitayama et al., 2020), among others (Chee et al., 2010; Huang et al., 2019; Tang et al., 2018). Ours is the first to show that the cultural effect extends to scene processing regions (Epstein, 2008; Epstein &

[3] There are also a few regions that showed greater GM volume among European Americans than East Asians. They include anterior prefrontal cortex (and orbitofrontal cortex) and the visual association area. This pattern has been reported in a prior study (Yu et al., 2019).

Baker, 2019), consistent with the hypothesis that culture can influence basic cognitive processing, including the spatial extent of attention.

The present work raises two important sets of questions for future work. First, our data are clear that PPA GM volume is related to interdependent (vs. independent) SC. However, there were some variations regarding which subscale of SC shows this association. Whereas the difference score between interdependent and independent SC predicted the PPA GM in Study1, it was interdependent SC that predicted the PPA GM volume in Study 2. Curiously, similar patterns have been observed in studies utilizing an EEG-based measure (N400) of holistic attention (Goto et al., 2010, 2013; Lewis et al., 2008; Na & Kitayama, 2011). The variations here could be due to nuanced processes by which specific forms of SC are related to holistic cognition. First, interdependent SC may foster cognitive attunement to contextual stimuli. Second, independent SC may inhibit this contextual attunement by motivating a more focused pursuit of personal goals and a narrower focus on goal-related objects. Third, both of these processes could be involved in different proportions under different circumstances or for different groups that vary in age, culture, and many other variables. Future work should zero in on these specific mechanisms.

Second, whereas Study 2 shows clear cultural differences in all three of the scene processing regions tested (PPA, MPA, and OPA), the relationship with SC was evident only for PPA in both Studies 1 and 2. Why might the association with SC be limited to PPA? Among the three regions, only PPA is functionally connected to an action-related brain region (the caudate) (Nasr & Rosas, 2016). Moreover, retinotopic mapping shows that PPA specializes in the upper visual field (which includes scenes in the distance and, by extension, supposedly broad social and non-social contexts, rather than immediate scenes such as the “landscape” on the table or at one’s feet) (Silson et al., 2015). In combination, PPA may be particularly attuned to SC to help navigate actions vis-à-vis a broad context. Once activated, PPA might subsequently implicate the remaining two regions. This putative causal sequence (SC → PPA → MPA/OPA) would imply that the association with SC is easier to find for PPA than for the remaining two regions (Kenny & Judd, 2014).

Some limitations of the current work should be acknowledged. First, the data of the present study are correlational. We hypothesize that interdependent SC fosters holistic cognitive tendency and hence leads to increased GM volume in scene-selective regions. However, an alternative possibility could be that variation in GM volume in scene-processing region results from certain genetic predisposition, and this variation, in turn, leads to cultural difference or SC-related difference in cognitive style. Therefore, the directionality of this link is currently speculative and needs to be confirmed by additional causal evidence. Second, the current work focused on the morphometry, that is, the GM volume. Our study did not test whether these scene-processing regions are activated differently as a function of culture or SC. Therefore, we cannot directly inform functional consequences of the change in GM volume, such as the efficiency or competence of contextual processing, and how it may relate to the SC or the cultural differences in cognitive style. Future cross-cultural studies assessing both the structural aspect and the functional aspect (activation and connectivity) of scene-selective regions will better elucidate the neural underpinnings of cultural influences on cognitive style.

These limitations notwithstanding, the current work provides the first evidence that the cortical volume of the scene-processing network shows a substantial cultural variation. Moreover, SC is likely implicated in the etiology of this variation. Our work thus underscores the possibility that culture goes deep under the skin and is eventually “embrained.”

Acknowledgment

This work was supported by a grant from the National Science Foundation (BCS 0717982 and SES 1325881)

References

Aguirre, G. K., & D'Esposito, M. (1999). Topographical disorientation: A synthesis and taxonomy. *Brain*, *122*(9), 1613–1628. https://doi.org/10.1093/brain/122.9.1613

Ashburner, J. (2007). A fast diffeomorphic image registration algorithm. *NeuroImage*, *38*(1), 95–113. https://doi.org/10.1016/j.neuroimage.2007.07.007

Ashburner, J., & Friston, K. J. (2000). Voxel-Based Morphometry—The Methods. *NeuroImage*, *11*(6), 805–821. https://doi.org/10.1006/nimg.2000.0582

Atkins, D., Uskul, A. K., & Cooper, N. R. (2016). Culture shapes empathic responses to physical and social pain. *Emotion*, *16*(5), 587–601. https://doi.org/10.1037/emo0000162

Chee, M. W. L., Zheng, H., Goh, J. O. S., Park, D., & Sutton, B. P. (2010). Brain Structure in Young and Old East Asians and Westerners: Comparisons of Structural Volume and Cortical Thickness. *Journal of Cognitive Neuroscience*, *23*(5), 1065–1079. https://doi.org/10.1162/jocn.2010.21513

Cohen, D., & Kitayama, S. (2019). *Handbook of Cultural Psychology: Second Edition*. Guilford Press. https://www.guilford.com/books/Handbook-of-Cultural-Psychology/Cohen-Kitayama/9781462536238

Epstein, R. (2008). Parahippocampal and retrosplenial contributions to human spatial navigation. *Trends in Cognitive Sciences*, *12*(10), 388–396. https://doi.org/10.1016/j.tics.2008.07.004

Epstein, R., & Baker, C. I. (2019). Scene Perception in the Human Brain. *Annual Review of Vision Science*, *5*(1), 373–397. https://doi.org/10.1146/annurev-vision-091718-014809

Epstein, R., & Kanwisher, N. (1998). A cortical representation of the local visual environment. *Nature*, *392*(6676), 598–601. https://doi.org/10.1038/33402

Ganaden, R. E., Mullin, C. R., & Steeves, J. K. E. (2013). Transcranial Magnetic Stimulation to the Transverse Occipital Sulcus Affects Scene but Not Object Processing. *Journal of Cognitive Neuroscience*, *25*(6), 961–968. https://doi.org/10.1162/jocn_a_00372

Goh, J. O., Chee, M. W., Tan, J. C., Venkatraman, V., Hebrank, A., Leshikar, E. D., Jenkins, L., Sutton, B. P., Gutchess, A. H., & Park, D. C. (2007). Age and culture modulate object processing and object—Scene binding in the ventral visual area. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(1), 44–52. https://doi.org/10.3758/CABN.7.1.44

Goh, J. O., Leshikar, E. D., Sutton, B. P., Tan, J. C., Sim, S. K. Y., Hebrank, A. C., & Park, D. C. (2010). Culture differences in neural processing of faces and houses in the ventral visual cortex. *Social Cognitive and Affective Neuroscience*, *5*(2–3), 227–235. https://doi.org/10.1093/scan/nsq060

Goto, S. G., Ando, Y., Huang, C., Yee, A., & Lewis, R. S. (2010). Cultural differences in the visual processing of meaning: Detecting incongruities between background and foreground objects using the N400. *Social Cognitive and Affective Neuroscience*, *5*(2–3), 242–253. https://doi.org/10.1093/scan/nsp038

Goto, S. G., Yee, A., Lowenberg, K., & Lewis, R. S. (2013). Cultural differences in sensitivity to social context: Detecting affective incongruity using the N400. *Social Neuroscience*, *8*(1), 63–74. https://doi.org/10.1080/17470919.2012.739202

Gould, S. J., Gold, S. J., & Gould, T. A. A. P. of Z. S. J. (1996). *The Mismeasure of Man*. W. W. Norton & Company.

Gutchess, A. H., Welsh, R. C., Boduroĝlu, A., & Park, D. C. (2006). Cultural differences in neural function associated with object processing. *Cognitive, Affective, & Behavioral Neuroscience*, *6*(2), 102–109. https://doi.org/10.3758/CABN.6.2.102

Hayasaka, S., & Nichols, T. E. (2004). Combining voxel intensity and cluster extent with permutation test framework. *NeuroImage*, *23*(1), 54–63. https://doi.org/10.1016/j.neuroimage.2004.04.035

Heine, S. J., Lehman, D. R., Markus, H. R., & Kitayama, S. (1999). Is there a universal need for positive self-regard? *Psychological Review*, *106*(4), 766–794. https://doi.org/10.1037/0033-295X.106.4.766

Huang, C.-M., Doole, R., Wu, C. W., Huang, H.-W., & Chao, Y.-P. (2019). Culture-Related and Individual Differences in Regional Brain Volumes: A Cross-Cultural Voxel-Based Morphometry Study. *Frontiers in Human Neuroscience*, *13*. https://doi.org/10.3389/fnhum.2019.00313

Ino, T., Doi, T., Hirose, S., Kimura, T., Ito, J., & Fukuyama, H. (2007). Directional Disorientation Following Left Retrosplenial Hemorrhage: A Case Report with FMRI Studies. *Cortex*, *43*(2), 248–254. https://doi.org/10.1016/S0010-9452(08)70479-9

Iyengar, S. S., & Lepper, M. R. (1999). Rethinking the value of choice: A cultural perspective on intrinsic motivation. *Journal of Personality and Social Psychology*, *76*(3), 349–366. https://doi.org/10.1037/0022-3514.76.3.349

Jenkins, L. J., Yang, Y.-J., Goh, J., Hong, Y.-Y., & Park, D. C. (2010). Cultural differences in the lateral occipital complex while viewing incongruent scenes. *Social Cognitive and Affective Neuroscience*, *5*(2–3), 236–241. https://doi.org/10.1093/scan/nsp056

Kenny, D. A., & Judd, C. M. (2014). Power Anomalies in Testing Mediation. *Psychological Science*, *25*(2), 334–339. https://doi.org/10.1177/0956797613502676

Kitayama, S., Duffy, S., Kawamura, T., & Larsen, J. T. (2003). Perceiving an Object and Its Context in Different Cultures: A Cultural Look at New Look. *Psychological Science*, *14*(3), 201–206. https://doi.org/10.1111/1467-9280.02432

Kitayama, S., & Park, J. (2014). Error-related brain activity reveals self-centric motivation: Culture matters. *Journal of Experimental Psychology: General*, *143*(1), 62–70. https://doi.org/10.1037/a0031696

Kitayama, S., Snibbe, A. C., Markus, H. R., & Suzuki, T. (2004). Is There Any “Free” Choice?: Self and Dissonance in Two Cultures. *Psychological Science*, *15*(8), 527–533. https://doi.org/10.1111/j.0956-7976.2004.00714.x

Kitayama, S., & Uskul, A. K. (2011). Culture, Mind, and the Brain: Current Evidence and Future Directions. *Annual Review of Psychology*, *62*(1), 419–449. https://doi.org/10.1146/annurev-psych-120709-145357

Kitayama, S., Yanagisawa, K., Ito, A., Ueda, R., Uchida, Y., & Abe, N. (2017). Reduced orbitofrontal cortical volume is associated with interdependent self-construal. *Proceedings of the National Academy of Sciences*, *114*(30), 7969–7974. https://doi.org/10.1073/pnas.1704831114

Kitayama, S., Yu, Q., King, A. P., Yoon, C., & Liberzon, I. (2020). The gray matter volume of the temporoparietal junction varies across cultures: A moderating role of the dopamine D4 receptor gene (DRD4). *Social Cognitive and Affective Neuroscience*, *15*(2), 193–202. https://doi.org/10.1093/scan/nsaa032

Kühnen, U., & Oyserman, D. (2002). Thinking about the self influences thinking in general: Cognitive consequences of salient self-concept. *Journal of Experimental Social Psychology*, *38*(5), 492–499. https://doi.org/10.1016/S0022-1031(02)00011-2

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*(4427), 203–205. https://doi.org/10.1126/science.7350657

Lewis, R. S., Goto, S. G., & Kong, L. L. (2008). Culture and Context: East Asian American and European American Differences in P3 Event-Related Potentials and Self-Construal. *Personality and Social Psychology Bulletin*, *34*(5), 623–634. https://doi.org/10.1177/0146167207313731

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. J., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi

drivers. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(8), 4398–4403.
Maldjian, J. A., Laurienti, P. J., Kraft, R. A., & Burdette, J. H. (2003). An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *NeuroImage*, *19*(3), 1233–1239. https://doi.org/10.1016/S1053-8119(03)00169-1
Markus, H. R., & Kitayama, S. (1991). Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review*, *98*(2), 224–253. https://doi.org/10.1037/0033-295X.98.2.224
Masuda, T., & Nisbett, R. E. (2001). Attending holistically versus analytically: Comparing the context sensitivity of Japanese and Americans. *Journal of Personality and Social Psychology*, *81*(5), 922–934. https://doi.org/10.1037/0022-3514.81.5.922
Morris, M. W., & Peng, K. (1994). Culture and cause: American and Chinese attributions for social and physical events. *Journal of Personality and Social Psychology*, *67*(6), 949–971. https://doi.org/10.1037/0022-3514.67.6.949
Mugler, J. P., & Brookeman, J. R. (1990). Three-dimensional magnetization-prepared rapid gradient-echo imaging (3D MP RAGE). *Magnetic Resonance in Medicine*, *15*(1), 152–157. https://doi.org/10.1002/mrm.1910150117
Na, J., & Kitayama, S. (2011). Spontaneous Trait Inference Is Culture-Specific: Behavioral and Neural Evidence. *Psychological Science*, *22*(8), 1025–1032. https://doi.org/10.1177/0956797611414727
Nasr, S., & Rosas, H. D. (2016). Impact of Visual Corticostriatal Loop Disruption on Neural Processing within the Parahippocampal Place Area. *The Journal of Neuroscience*, *36*(40), 10456–10471. https://doi.org/10.1523/JNEUROSCI.0741-16.2016
Nisbett, R. E., & Masuda, T. (2003). Culture and point of view. *Proceedings of the National Academy of Sciences*, *100*(19), 11163–11170. https://doi.org/10.1073/pnas.1934527100
Nisbett, R. E., Peng, K., Choi, I., & Norenzayan, A. (2001). Culture and systems of thought: Holistic versus analytic cognition. *Psychological Review*, *108*(2), 291–310.
Northoff, G., & Bermpohl, F. (2004). Cortical midline structures and the self. *Trends in Cognitive Sciences*, *8*(3), 102–107. https://doi.org/10.1016/j.tics.2004.01.004
O’Doherty, J. P. (2011). Contributions of the ventromedial prefrontal cortex to goal-directed action selection. *Annals of the New York Academy of Sciences*, *1239*(1), 118–129. https://doi.org/10.1111/j.1749-6632.2011.06290.x
Oyserman, D., & Lee, S. W. S. (2008). Does culture influence what and how we think? Effects of priming individualism and collectivism. *Psychological Bulletin*, *134*(2), 311–342. https://doi.org/10.1037/0033-2909.134.2.311
Park, D. C., & Huang, C.-M. (2010). Culture Wires the Brain: A Cognitive Neuroscience Perspective. *Perspectives on Psychological Science*, *5*(4), 391–400. https://doi.org/10.1177/1745691610374591
Rabovsky, M., Hansen, S. S., & McClelland, J. L. (2018). Modelling the N400 brain potential as change in a probabilistic representation of meaning. *Nature Human Behaviour*, *2*(9), 693–705. https://doi.org/10.1038/s41562-018-0406-4
Saxe, R., & Kanwisher, N. (2003). People thinking about thinking people: The role of the temporo-parietal junction in “theory of mind.” *NeuroImage*, *19*(4), 1835–1842. https://doi.org/10.1016/S1053-8119(03)00230-1
Silson, E. H., Chan, A. W.-Y., Reynolds, R. C., Kravitz, D. J., & Baker, C. I. (2015). A Retinotopic Basis for the Division of High-Level Scene Processing between Lateral and Ventral Human Occipitotemporal Cortex. *Journal of Neuroscience*, *35*(34), 11921–11935. https://doi.org/10.1523/JNEUROSCI.0137-15.2015

Singelis, T. M. (1994). The measurement of independent and interdependent self-construals. *Personality and Social Psychology Bulletin*, *20*(5), 580–591. https://doi.org/10.1177/0146167294205014

Tang, Y., Zhao, L., Lou, Y., Shi, Y., Fang, R., Lin, X., Liu, S., & Toga, A. (2018). Brain structure differences between Chinese and Caucasian cohorts: A comprehensive morphometry study. *Human Brain Mapping*, *39*(5), 2147–2155. https://doi.org/10.1002/hbm.23994

Wang, F., Peng, K., Chechlacz, M., Humphreys, G. W., & Sui, J. (2017). The Neural Basis of Independence Versus Interdependence Orientations: A Voxel-Based Morphometric Analysis of Brain Volume. *Psychological Science*, *28*(4), 519–529. https://doi.org/10.1177/0956797616689079

Winter, L., & Uleman, J. S. (1984). When are social judgments made? Evidence for the spontaneousness of trait inferences. *Journal of Personality and Social Psychology*, *47*(2), 237–252. https://doi.org/10.1037/0022-3514.47.2.237

Wu, S., & Keysar, B. (2007). The Effect of Culture on Perspective Taking. *Psychological Science*, *18*(7), 600–606. https://doi.org/10.1111/j.1467-9280.2007.01946.x

Yu, Q., Abe, N., King, A., Yoon, C., Liberzon, I., & Kitayama, S. (2019). Cultural variation in the gray matter volume of the prefrontal cortex is moderated by the dopamine D4 receptor gene (DRD4). *Cerebral Cortex*, *29*(9), 3922–3931. https://doi.org/10.1093/cercor/bhy271

Zhen, Z., Kong, X.-Z., Huang, L., Yang, Z., Wang, X., Hao, X., Huang, T., Song, Y., & Liu, J. (2017). Quantifying the variability of scene-selective regions: Interindividual, interhemispheric, and sex differences. *Human Brain Mapping*, *38*(4), 2260–2275. https://doi.org/10.1002/hbm.23519

Zilles, K., Kawashima, R., Dabringhaus, A., Fukuda, H., & Schormann, T. (2001). Hemispheric Shape of European and Japanese Brains: 3-D MRI Analysis of Intersubject Variability, Ethnical, and Gender Differences. *NeuroImage*, *13*(2), 262–271. https://doi.org/10.1006/nimg.2000.0688

Supplementary materials

Interdependent Self-Construal Predicts Increased Gray Matter Volume of Scene Processing Regions in the Brain

Qinggang Yu[1]
Anthony P. King[1]
Carolyn Yoon[1]
Israel Liberzon[2]
Richard J. Davidson[3]
Shinobu Kitayama[1]

[1]University of Michigan
[2]Texas A&M College of Medicine
[3]University of Wisconsin -- Madison

All correspondence regarding this article should be addressed to Qinggang Yu (qinggang@umich.edu) at Department of Psychology, University of Michigan, 530 Church St, Ann Arbor, MI 48109

A. Freesurfer Analysis on Thickness and Surface Area

VBM is an intensity-based measure and it itself cannot inform whether the variation in cortical volume is driven by variation in cortical thickness, or by variation in cortical surface area. Although this is secondary to our main research question, here we tested whether the associations with cortical volume identified in the main study can be identified with cortical thickness or cortical surface area itself, using a surface-based morphometry technique – Freesurfer (Dale et al., 1999).

Methods

The T1-weighted anatomical brain images of the subjects in Study 1 and 2 were processed with Freesurfer 6.0 (Martino Imaging Centre). Each image was pre-processed by running the “recon-all” command with the default setting. The processing pipeline included motion correction, intensity non-uniformity correction, transformation to a Talairach-like space, intensity normalization, skull stripping, segmentation, cortical surface registration, and cortical parcellation. The “recon-all” command was run with the “-qcache” flag so that the subjects’ data were resampled onto the fsaverge (the Freesurfer average subject) and were smoothed at various full-width half-maximum (FWHM).

We first tested the subjects in Study 1. In the main study, we found that the difference score between interdependent self-construal (SC) and independent SC predicts increased gray matter (GM) volume of the parahippocampal place area (PPA). Here, and examined whether the difference score (interdependent SC - independent SC) predicts increased cortical thickness or increased cortical surface area at the PPA, after controlling for age and sex. Intracranial volume was additionally controlled in the analysis of surface area. We then tested the subjects in Study 2. In the main study, interdependent SC predicted increased GM volume of PPA. In addition, East Asians showed greater GM volume in PPA, MPA, and OPA. Here, we examined whether the same patterns could be identified with cortical thickness or cortical surface area.

To carry out Freesurfer group analysis on thickness and surface area, we ran the "mri_preproc" command (cached in data smoothed with 10mm FWHM, same as in the SPM analysis) followed by the "mri_glmfit" command, which fits general linear model (GLM) at each surface vertex. The cortical thickness and cortical surface area were modeled as a function of the SC score or the cultural group, plus the covariates. The statistical inference was then carried out at the cluster level using the "mri_glmfit-sim" command, which performed cluster-wise correction of multiple-comparison using the Monte Carlo simulation (Hagler et al., 2006). The cluster forming threshold at the vertex-level was set at $p < .001$. Statistical significance was set at $p < .05$ cluster-wise.

Results

Study 1. We found that the difference score (interdependent SC - independent SC) was positively associated with the cortical surface area of the right PPA (peak vertex coordinates in MNI space 31, -37, -13; number of vertices of the significant cluster = 420; cluster-wise $p = .014$). All brain regions that pass the cluster-forming threshold are shown in Fig. S1-A, and the significant cluster was shown in Fig. S1-B. There was no significant relationship, however, between the difference score and the cortical thickness of the PPA.

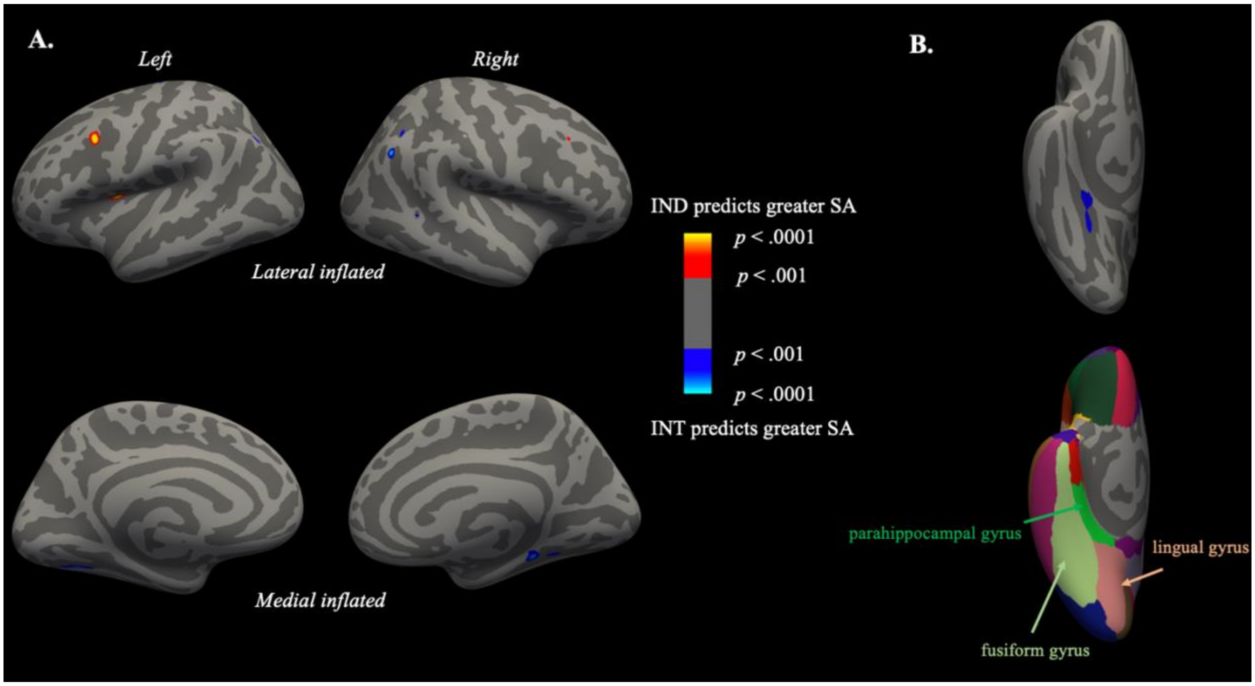


Fig S1. A. The brain regions that showed a significant correlation (p < .001 uncorrected) with the difference score (interdependent (INT) SC - independent (IND) SC), both positively (in blue) and negatively (in red), controlling for age, sex, and intracranial volume. B. The top panel shows the cluster located at the right PPA of which the surface area (SA) was positively correlated with the difference score. The bottom panel shows the label of the anatomical regions at which the significant cluster rests on, based on the Desikan-Killiany parcellation (Desikan et al., 2006). The inflated cortical surface was shown from a ventral view.

Study 2. We did not find either a significant relationship between the interdependent SC and the cortical surface area of the PPA, or a significant relationship between the interdependent SC and the cortical thickness of the PPA. Likewise, we did not find evidence that the cortical thickness of the scene-processing regions itself or the cortical surface area of the scene-processing regions itself was greater among East Asians than among European Americans.

References

Dale, A. M., Fischl, B., & Sereno, M. I. (1999). Cortical surface-based analysis. I. Segmentation and surface reconstruction. *NeuroImage*, *9*(2), 179–194. https://doi.org/10.1006/nimg.1998.0395

Desikan, R. S., Ségonne, F., Fischl, B., Quinn, B. T., Dickerson, B. C., Blacker, D., Buckner, R. L., Dale, A. M., Maguire, R. P., Hyman, B. T., Albert, M. S., & Killiany, R. J. (2006). An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. *NeuroImage*, *31*(3), 968–980. https://doi.org/10.1016/j.neuroimage.2006.01.021

Hagler, D. J., Saygin, A. P., & Sereno, M. I. (2006). Smoothing and cluster thresholding for cortical surface-based group analysis of fMRI data. *NeuroImage*, *33*(4), 1093–1103. https://doi.org/10.1016/j.neuroimage.2006.07.036

B. Tables on the Whole Brain Analysis with SPM

Table S1. Regions in which the gray matter (GM) volume was positively correlated with the interdependent self-construal (SC) in Study 1 (cluster size > 10)

Region (Brodmann's area)	MNI coordinates			Z-value	Cluster size	Voxel-level *p-value* (uncorrected)
	x	y	z			
Right supramarginal gyrus (40)	48	-30	42	4.26	301	< 0.001
Left visual association area (18)	-32	-88	-10	3.77	520	< 0.001
Left visual association area (19)	-50	-75	10	3.64	124	< 0.001

Table S2. Regions in which the GM volume was negatively correlated with the independent SC in Study 1 (cluster size > 10)

Region (Brodmann's area)	MNI coordinates			Z-value	Cluster size	Voxel-level *p-value* (uncorrected)
	x	y	z			
Right parahippocampal gyrus (36)	24	-38	-8	3.22	34	< .001

Table S3. Regions in which the GM volume was positively correlated with the difference score (interdependent SC - independent SC) in Study 1 (cluster size > 10)

Region (Brodmann's area)	MNI coordinates x	y	z	Z-value	Cluster size	Voxel-level *p*-value (uncorrected)
Right parahippocampal gyrus (36)	24	-39	-6	4.14	556	< .001
Left hippocampus	-22	-40	2	3.30	42	< .001

Table S4. Regions in which the GM volume was positively correlated with the interdependent SC in Study 2 (cluster size > 10)

Region (Brodmann's area)	MNI coordinates x	y	z	Z-value	Cluster size	Voxel-level *p*-value (uncorrected)
Left parahippocampal gyrus (36)	-21	-34	-3	4.06	381	< .001

Table S5. Regions in which the GM volume was negatively correlated with the independent SC in Study 2 (cluster size > 10)

Region (Brodmann's area)	MNI coordinates x	y	z	Z-value	Cluster size	Voxel-level *p*-value (uncorrected)
Right angular gyrus (39)	52	-48	33	3.85	367	< .001
Left inferior frontal gyrus (45)	-44	29	10	3.48	75	< .001
Left angular gyrus (39)	-62	-58	22	3.25	21	< .001

Table S6. Regions in which the GM volume was positively correlated with the difference score (interdependent SC - independent SC) in Study 2 (cluster size >= 10)

Region (Brodmann's area)	MNI coordinates x	y	z	Z-value	Cluster size	Voxel-level *p*-value (uncorrected)
Left parahippocampal gyrus (36)	-20	-33	-3	3.46	61	< .001
Left hippocampus	-16	-39	6	3.27	10	< .001
Right angular gyrus (39)	57	-46	30	3.26	38	< .001

Table S7. Regions in which East Asians had greater GM volume than European Americans (cluster size > 10)

Region (Brodmann's area)	MNI coordinates x	y	z	Z-value	Cluster size	Voxel-level *p*-value (FWE-corrected)
Right middle temporal gyrus (21)	51	-10	-29	7.30	3590	< 0.001
Left middle temporal gyrus (21)	-56	-9	-27	6.83	2027	< 0.001
Right primary motor cortex (4)	64	-3	28	6.59	2920	< 0.001
Left supramarginal gyrus (40)	-63	-30	43	5.29	274	0.001
Left temporal pole (38)	-39	3	-27	5.12	130	0.002
Right temporal pole (38)	52	20	-26	5.11	84	0.002
Left somatosensory cortex (1)	-66	-18	21	4.72	35	0.012
Right retrosplenial cortex (30)	20	-40	0	4.99	66	0.004
Right somatosensory cortex (1)	52	-25	49	4.65	59	0.016
Right premotor cortex (6)	16	-7	70	4.79	76	0.009
Left premotor cortex (6)	-46	-6	31	4.72	35	0.012
Right inferior frontal gyrus (44)	60	17	24	4.72	36	0.012
Left inferior temporal gyrus (20)	-52	-33	-21	4.70	83	0.013
Left supramarginal gyrus (40)	-39	-51	57	4.55	12	0.024
Left premotor cortex (6)	-16	-3	72	4.55	19	0.025