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Accessible cultural mind-set modulates default mode activity: Evidence for the culturally situated brain

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Self-construal priming modulates human behavior and associated neural activity. However, the neural activity associated with the self-construal priming procedure itself remains unknown. It is also unclear whether and how self-construal priming affects neural activity prior to engaging in a particular task. To address this gap, we scanned Chinese adults, using functional magnetic resonance imaging, during self-construal priming and a following resting state. We found that, relative to a calculation task, both interdependent and independent self-construal priming activated the ventral medial prefrontal cortex (MPFC) and the posterior cingulate cortex (PCC). The contrast of interdependent vs. independent self-construal priming also revealed increased activity in the dorsal MPFC and left middle frontal cortex. The regional homogeneity analysis of the resting-state activity revealed increased local synchronization of spontaneous activity in the dorsal MPFC but decreased local synchronization of spontaneous activity in the PCC when contrasting interdependent vs. independent self-construal priming. The functional connectivity analysis of the resting-state activity, however, did not show significant difference in synchronization of activities in remote brain regions between different priming conditions. Our findings suggest that accessible collectivistic/individualistic mind-set induced by self-construal priming is associated with modulations of both task-related and resting-state activity in the default mode network.

Keywords: Culture; Self-construal priming; Resting state; Default mode; fMRI.

Recent cultural neuroscience research provides evidence that the functional organization of the human brain is sensitive to sociocultural experiences (Han & Northoff, 2008; Han et al., 2013; Kitayama & Uskul, 2011). One line of cultural neuroscience research focuses on differences in brain activity between two cultural groups. For example, Zhu, Zhang, Fan, and Han (2007) first reported that the ventral medial prefrontal cortex (vMPFC) engaged in personality trait judgments of oneself (Kelley et al., 2002) is also involved in making judgments about the personality traits of a close other (e.g., one's mother) among

Chinese but not English speaking Westerners. Ma et al. (in press) also found that the vMPFC activity related to reflection on one's own social, mental, and physical attributes was greater in Danes than in Chinese. In contrast, reflection on one's own social attributes (e.g., nationality and occupation) produced stronger activity in the temporoparietal junction (TPJ) in Chinese than in Danes. The vMPFC (Chiao et al., 2009; Ma et al., in press) and TPJ activity (Ma et al., in press; Sul, Choi, & Kang, 2012) involved in self-referential processing were associated with a measure of a cultural value of interdependence of self-construal. Moreover,

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the cultural group difference in the TPJ activity underlying self-reflection of one's social attributes was mediated by a measure of interdependence of self-construal (Ma et al., in press). These findings of cultural group differences in brain activity indicate that chronic cultural experiences shape the functional organization of human brains and provide neural bases for the proposition that Westerners in individualistic cultural contexts view the self as an autonomous entity separating from others, whereas East Asians in collectivistic cultural contexts have a strong sense of self as connected to or interdependent with others (Markus & Kitayama, 1991, 2010).

Another line of cultural neuroscience research examines the effect of cultural mind-set priming on human brain activity involved in multiple cognitive processes. This line of research is based on the hypotheses that individuals can acquire multiple sets of cultural knowledge and exposure to cultural symbols may activate specific cultural knowledge and result in mind-sets and behaviors that are consistent with that culture (Hong, Morric, Chiu, & Benet-Martinez, 2000). Moreover, depending on the context, functional organization in line with either an individualistic or a collectivistic cultural mind-set is possible within individuals and across societies (Oyserman, 2011; Oyserman & Sorensen, 2009). Consistent with these hypotheses, behavior studies have shown that cultural priming affects visual and auditory perception (Kühnen & Oyserman, 2002; Lin & Han, 2009; Oyserman, Sorensen, Reber, & Chen, 2009), self-face recognition (Sui & Han, 2007), memory (Kühnen & Oyserman, 2002; Ng & Lai, 2009, 2011; Oyserman et al., 2009), complex problem solving (Oyserman et al., 2009), and attribution (Hong et al., 2000). The effects of cultural value (e.g., self-construal) priming on behavioral performances were observed in both Chinese participants (Lin & Han, 2009; Sui & Han, 2007) and American participants (Kühnen & Oyserman, 2002; Oyserman et al., 2009), suggesting that cultural priming exhibit effects on behavioral performances regardless the participants' chronic cultural values. Moreover, size and direction of cultural priming effects match those demonstrated in comparisons between different cultural groups (see Oyserman, Coon, & Kemmelmeier, 2002; Oyserman & Lee, 2008a, 2008b for reviews).

Following these behavioral findings, a number of neuroimaging studies examined whether priming manipulations that prime accessible individualistic or collectivistic mind-set modulate brain activity involved in a specific cognitive process. Sui and Han (2007) reported the first functional magnetic resonance imaging (fMRI) evidence that independent vs. interdependent self-construal priming among Chinese

induced stronger right frontal activity engaged in recognition of one's own face. A following event related potential (ERP) research further showed that priming an interdependent self-construal reduced a frontal activity to one's own face in British participants whereas priming an independent self-construal in Chinese participants suppressed the frontal activity to a friend's faces (Sui, Hong, Liu, Humphreys, & Han, in press). Ng, Han, Mao and Lai (2010) showed that cultural mind-set priming also modulated the default mode activity along the midline cortical structure in bicultural individuals (i.e., students from Hong Kong). Watching Western cultural icons increased, whereas watching Chinese cultural icons decreased, the differential activity in the vMPFC to self vs. others in a following task requiring personality trait judgments. Similarly, Harada, Li, and Chiao (2010) found that priming bicultural individuals with independent self-construals enhanced activity in the dorsal region of MPFC (dMPFC) during implicit evaluation of father-relevant information. Chiao et al. (2010) also found that priming individualism by asking Asian-American students to consider their differences from family and friends increased activation in the vMPFC and posterior cingulate cortex (PCC) during general relative to contextual self-judgments. In contrast, priming collectivism, by asking participants to consider their similarities to family and friends, increased MPFC and PCC activity during contextual relative to general self-judgments.

Priming collectivistic/individualistic mind-set also modulates neural substrates of low-level perceptual/sensorimotor processing. Lin, Lin, and Han (2008) reported ERP evidence that the independent self-construal priming among Chinese resulted in enlarged occipital activity to local than global targets of visual stimuli whereas the interdependent self-construal priming led to a reverse modulation of the occipital activity. Obhi et al. (2011) recorded motor-evoked potentials elicited by transcranial magnetic stimulation during an action observation task in which Canadians were presented with either interdependent (e.g., unique, distinguished) or independent (e.g., together, integrate) self-construal prime words. They found that, relative to a no-priming baseline condition, interdependent self-construal priming increased motor cortical responses whereas independent self-construal priming did not.

Taken together, the previous brain imaging findings provide strong evidence for dynamic influence of cultural mind-set on neural activities underlying multiple psychological processes. These findings uncover causal relationships between cultural values and neurocognitive processes and suggest a neurobiological basis by which people acculturate to novel

environments. However, to date, we have known surprisingly little about the neural correlates of cultural mind-set priming itself. In addition, it is unclear whether and how cultural mind-set priming modulates the resting-state activity that underlies internal modes of cognition. This issue is particularly important because the resting-state activity along the cortical midline structure is associated with self-related processing (Schneider et al., 2008) and may interact with task-induced activity (Northof Duncan, & Hayes, 2010) to provide a neural basis for any ongoing task-related processes. It is also unclear how to integrate work assuming that effects are mediated by self-construal with work that does not make this prediction. The strongest prediction from cultural mind-set priming research is that currently activated mind-set will affect functional organization and that effects found when groups are compared are due to the average increased likelihood that individualistic vs. collectivistic mind-set will be salient in one group vs. another.

The current work investigated the neural mechanisms of accessible cultural mind-set by scanning Chinese adults, using fMRI, during self-construal priming, and a following resting-state. The self-construal priming procedure asked participants to circle the singular ("I," "me," "mine," independent self-construal) or plural ("we," "our," "us," interdependent self-construal) pronouns in essays printed on a piece of paper (e.g., Gardner, Gabriel, & Lee, 1999). We used a modified self-construal priming task inside a fMRI scanner that required participants to read sentences of an essay shown on a screen and to indicate whether target words (singular pronouns ("I," "me," "mine" during independent self-construal priming), plural pronouns ("we," "our," "us" during interdependent self-construal priming), or "people" during a control priming) were shown in each sentence by a button press. In the first session of this study we employed a block design to record blood oxygen level dependent (BOLD) signals while participants performed different priming tasks that were intervened with calculation tasks that provided a baseline condition. Contrasts between priming and calculation tasks revealed neural activity common for the priming procedure and contrasts between different priming tasks identified neural activity that was specifically associated with independent or interdependent self-construal priming.

In the second session of this study, we scanned participants during the priming procedure and a following resting state. We were particularly interested in whether the resting-state activity in the midline cortical structure is modulated by self-construal priming because brain regions such as the MPFC and PCC are engaged in self-referential processing (Craig et al.,

1999; Han et al., 2008, 2010; Johnson et al., 2002; Kelley et al., 2002; Ma & Han, 2011; Northoff et al., 2006) and show strong baseline metabolic activity at rest (Raichle et al., 2001). To obtain an estimate of the nature of these effects, analysis of the effect of self-construal priming on the resting-state brain activity focused on both the local synchronization of spontaneous fMRI signals and the synchronization of remote brain regions. Regional homogeneity (ReHo) was calculated to examine the similarity of dynamic fluctuations of voxels within a given cluster (Long et al., 2008; Zang, Jiang, Lu, He, & Tian, 2004; Zou, Wu, Stein, Zang, & Yang, 2009). Functional connectivity (Biswal, Zerrin Yetkin, Haughton, & Hyde, 1995; Greicius, Krasnow, Reiss, & Menon, 2003, 2009) was calculated to estimate the synchronization between remote brain regions during the resting state. These analyses allowed us to examine whether accessible individualistic vs. collectivistic cultural mind-set affects synchronization of spontaneous BOLD activity in a local region and between distant regions and whether effects are moderated by independent or interdependent self-construals.

METHODS

Participants

Eighteen Chinese university students (nine males, nine females; 19–23 years, mean age \pm SD = 22.2 \pm 1.1) participated in the study as paid volunteers. All subjects were right-handed, had normal or corrected-to-normal vision, and reported no history of neurological and psychiatric disorders. The study was approved by the ethic committee at the Department of Psychology, Peking University. Written informed consent was obtained prior to the study.

Stimuli, procedure, and measures

Participants were asked to complete self-construal scale (SCS, Singelis, 1994; 5-point response, 1 = strongly disagree, 5 = strongly agree) before fMRI scanning. The SCS includes 12 items assessing interdependent self-construal (e.g. "I have respect for the authority figures with whom I interact"; "Even when I strongly disagree with group members, I avoid an argument") and 12 items assessing independent self-construal ("I'd rather say 'no' directly than risk being misunderstood," "My personal identity independent of others, is very important to me"). Scores were summed so that responses ranged from 12 to 60.

Twelve short essays were used in a modified self-construal priming task during fMRI scanning. Each essay consisted of six sentences with four sentences containing target words. The target words were plural pronouns (“we,” “our,” or “us”) in four essays for the interdependent self-construal priming, singular pronouns (“I,” “me,” “mine”) in four essays for the independent self-construal priming, and “people” in four essays for the control priming. Sentence length was matched across essays.

There were two fMRI sessions in the current study, as illustrated in Figure 1a. A block design was used in the first fMRI session that consisted of two scans to examine the brain activity associated with the priming task. Each scan consisted of six blocks. Each block started with a 4 s instruction that designated a target. The six sentences that together formed an essay were presented in order on the screen. Each sentence, subtended a visual angle of $19.8^\circ \times 2.1^\circ$ (width \times height) at a viewing distance of 80 cm, was presented for 4 s and was followed by a 2 s interval during which participants had to indicate whether a target word was present by a button press using the left or right index finger. Two successive blocks were intervened with a 20 s calculation task that consisted of a 4 s instruction and 4 trials. On each trial during the calculation task, an equation (e.g., $(7 + 8) \times 3$) was presented for 3 s followed by a 1 s interval. Participants had to judge whether each calculation would produce an odd

or even number by a button press. The essays used for and the order of different self-construal priming was counterbalanced across participants.

In the second fMRI session, three scans were conducted to examine the effect of self-construal priming on the resting-state activity. As illustrated in Figure 1b, each scan started with a 20 s calculation task of 4 trials. Participants were then shown an essay that consisted of 27 sentences with target words (i.e., plural pronouns, singular pronouns, or “people”) in 18 sentences. Participants were asked to read each sentence carefully. Participants were then asked to take a 7 minute rest during which they were instructed to keep their eyes open and try not to think of anything particular. The order of different priming conditions was pseudo-randomized and counterbalanced across participants in both fMRI sessions.

After scanning, participants were asked to rate the degree of wakefulness (1 = slightly sleepy, 9 = extremely wakeful) during the resting state of each condition.

Imaging parameters and data analysis

Image acquisition was conducted on a 3T (Tim Trio Siemens) scanner with a standard head coil. Functional images were acquired by using T2-weighted, gradient-echo, echo-planar imaging (EPI) sequences

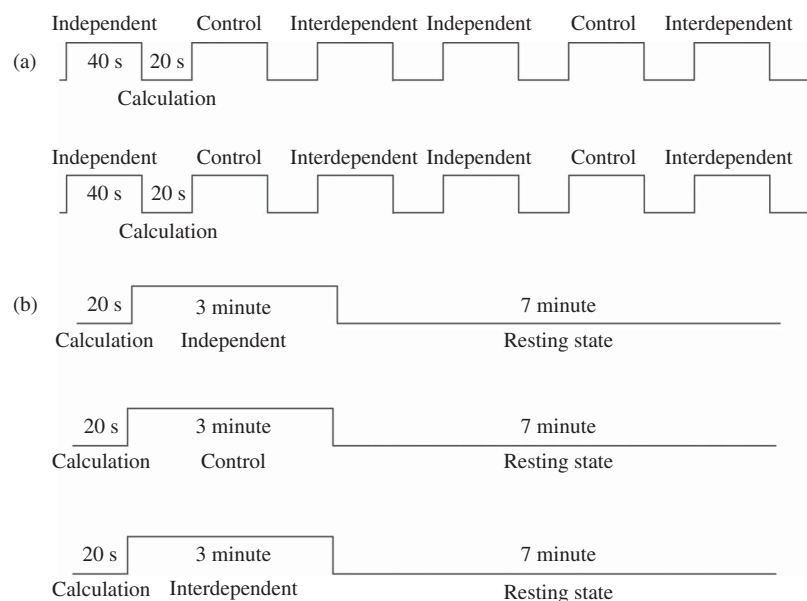


Figure 1. Illustration of the design of our study. (a) The first fMRI session consisted of two scans of 6 blocks. Self-construal and control priming tasks that were intervened by calculation tasks. (b) The second fMRI session consisted of three scans. Each scan started with a 4-trial calculation task followed by a priming task and a resting state. The order of different priming conditions was pseudo-randomized and counterbalanced across participants in both fMRI sessions.

sensitive to BOLD contrast (repetition time (TR) = 2000 ms; echo time (TE) = 30 ms; flip angle = 90°; field of view (FOV) = 224 × 224; 64 × 64 matrix; 32 slices; 1.00 mm gap between slices; 3.44 × 3.44 × 3.99 mm voxels). A high-resolution anatomical T1-weighted image was acquired for each participant (TR = 2600 ms; TE = 3.02 ms; FA = 8°; FOV = 224 × 224; 256 × 256 matrix; 176 slices; 1.00 mm gap between slices; size = 1.00 × 1.00 × 1.00 mm voxels).

Functional images were preprocessed using SPM8 software (the Wellcome Trust Centre for Neuroimaging, London, UK). Head movements were corrected within each run, and six movement parameters (translation: x, y, z and rotation: pitch, roll, yaw) were extracted for further analysis in the statistical model. The anatomical image was coregistered with the mean realigned functional image and then was normalized to the standard Montreal Neurological Institute (MNI) template. The functional images were resampled to 2 × 2 × 2 mm³ voxels, normalized to the MNI space using the parameters of anatomical normalization and then spatially smoothed using an isotropic of 8 mm full-width half-maximum (FWHM) Gaussian kernel.

A general linear model (GLM) was applied to the fMRI data in the first session. Parameter estimations were conducted by convolving the images in the design matrix with a hemodynamic response function. To examine the neural activity underlying priming, the contrasts between each priming condition and the calculation condition were calculated. To assess the neural activity that distinguished different priming conditions, we also calculated the contrasts between two priming conditions. Random-effect analyses were then conducted based on statistical parameter maps from each participant to allow population inference. Significant activations were identified using a threshold of $p < .005$, $k > 50$, uncorrected.

ReHo was calculated to assess similarity of a given voxel to its nearest neighbors on time sequences (Zang et al., 2004) during the rest state. ReHo is indexed by a Kendall's coefficient of concordance (KCC, Kendall & Gibbons, 1990) ranged from 0 to 1 and calculated as follows:

$$W = \frac{\sum (R_i)^2 - n(\bar{R})^2}{\frac{1}{12}K^2(n^3 - n)}, \quad \text{where } \bar{R} = \frac{1}{n} \sum_{i=1}^n R_i,$$

W is the KCC among given voxels; K is the number of time series within a measured cluster (here $K = 27$, one given voxel plus the number of its neighbors); n is the number of ranks (here $n = 210$); R_i is the sum rank of the clustered voxels of the i th time point.

Preprocessing of raw data for ReHo was the same as mentioned earlier except that, after normalization, the functional images were corrected for the linear trend and temporally band-pass filtered (0.01–0.08 Hz) to reduce the high-frequency physiological noise, such as respiration. Then, the individual ReHo map was performed by calculating the KCC of each voxel within the whole brain using the Resting-State fMRI Data Analysis Toolkit (REST, <http://www.restfmri.net>). Standardized map was obtained by dividing a whole-brain mean KCC value from the individual ReHo map. It was then smoothed with a Gaussian kernel (FWHM = 4 mm) for further group analysis.

We first tested whether the resting-state regional homogeneity was different between the brain regions that differentiated between different priming tasks. We then extracted the ReHo value of each voxel within a region of interest (ROI) and calculated the mean, individual by individual. The ROIs of ReHo were then subjected to t -test between two priming conditions. We also conducted the whole-brain analysis to further confirm the ROI results and to explore any other brain regions linked to the resting-state differences. Random-effects analyses were performed on the individual ReHo maps of different conditions. Significant activations were identified using a threshold of $p < .005$, $k > 50$, uncorrected.

Similar to the previous research (Biswal et al., 1995; Greicius et al., 2003; Yan et al., 2009), functional connectivity during the resting state was computed using Pearson correlation analyses embedded also in the REST package. This analysis required to defined seed areas. Thus we defined the seed areas in the brain regions that differentiated between the priming and calculation tasks and that differentiated between different priming tasks. We first calculated the functional connectivity between a seed area and other brain regions during the resting state after each priming task. Correlation coefficient maps for each participant were generated by calculating the correlation of time courses of the BOLD in the seed area and voxels in the whole brain. The correlation coefficient maps from each individual were converted to a normal distribution using Fisher's z -transform. To estimate functional connectivity patterns at the group level, one-sample t -tests were performed on the individual z maps using SPM for each seed regions. Similar to the previous work (Yan et al., 2009), the within-condition statistic threshold was set at $|t| > 4.71$ ($p < .0005$ for $df = 17$) and cluster number $k > 50$ corrected for multiple comparisons. We then conducted random-effect analysis using the same threshold to assess difference in the resting-state functional connectivity between two priming conditions.

RESULTS

Behavioral performance and self-construal measurement

Response accuracy to identify target words was high during the priming tasks (Table 1). There was no significant difference in response accuracy between different priming conditions ($p > .3$), suggesting comparable attentiveness to different priming tasks. Self-reported degree of wakefulness was above the midpoint and did not differ significantly across after different priming conditions ($ps > 0.3$). Questionnaire measurement of independent and of interdependent self-construal showed that each was above the midpoint and the interdependence score was significantly higher than the independence score ($M = 43.6 \pm 3.3$ vs. 40.4 ± 3.9 , $t(1, 17) = 2.59$, $p = .019$). Rating scores of interdependence and independence were not correlated with each other ($r = 0.021$, $p > .5$).

Neural activity associated with self-construal priming

Analysis of the data in the first fMRI session showed that, relative to the calculation task, the self-construal and control priming tasks significantly activated the MPFC and the PCC (Figure 2). The MNI coordinates of the activations are listed in Table 2. A direct comparison between interdependent vs. independent self-construal priming tasks showed greater activations in the dMPFC, left middle frontal cortex,

TABLE 1
Effect of priming on percent accuracy and wakefulness score

| | Mean (SD) | | |
|-------------------|---------------|---------------|-------------|
| | Session 1 | Session 2 | Wakefulness |
| Priming condition | | | |
| Independent | 99.07% (1.54) | 97.94% (2.74) | 6.33 (1.56) |
| Interdependent | 99.07% (1.44) | 98.56% (2.08) | 6.22 (1.78) |
| Control | 98.38% (2.34) | 97.74% (3.27) | 6.11 (1.56) |

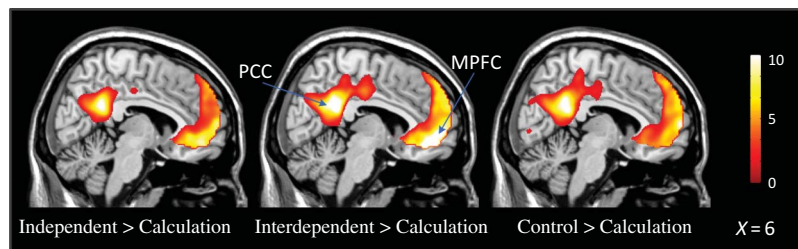


Figure 2. The results of whole-brain analyses that contrasted interdependent/independent/control priming tasks with the calculation task in the first fMRI session. All contrasts showed significant activation in the medial prefrontal cortex and the posterior cingulate cortex. Scale bar indicates t -values.

TABLE 2
Brain regions showing increased activity in the priming vs. calculation tasks

| Brain region | MNI coordinates | | | | Size | t-value |
|------------------------------|-----------------|-----|-----|-----|----------|---------|
| | BA | x | y | z | (voxels) | |
| Independent > Calculation | | | | | | |
| Medial frontal gyrus | 32 | 10 | 60 | 8 | 827 | 10.42 |
| Posterior cingulate | 23 | 4 | −48 | 24 | 427 | 10.93 |
| L Superior temporal gyrus | 21 | −52 | −4 | −10 | 252 | 9.15 |
| Interdependent > Calculation | | | | | | |
| Medial frontal gyrus | 32 | 6 | 44 | −10 | 2258 | 12.84 |
| Posterior cingulate | 23 | 4 | −44 | 24 | 913 | 14.68 |
| L Middle temporal gyrus | 22 | −68 | −34 | 2 | 904 | 12.68 |
| R Middle temporal gyrus | 21 | 52 | 2 | −24 | 212 | 10.90 |
| R supramarginal gyrus | 39 | 46 | −54 | 28 | 196 | 12.16 |
| Control > Calculation | | | | | | |
| Medial frontal gyrus | 10 | 6 | 62 | 8 | 268 | 10.27 |
| Posterior cingulate | 23 | 4 | −46 | 24 | 664 | 11.50 |
| R supramarginal gyrus | 39 | 46 | −54 | 28 | 188 | 11.70 |

Note: Threshold: $p < .005$, uncorrected, $k > 50$ (only for brain regions reach $p < .05$, FWE corrected with $k > 100$ are listed here).

left ventrolateral frontal cortex, and right cerebellum (Figure 3a, Table 3). A direct comparison of the control vs. independent self-construal priming tasks showed increased activations in the dMPFC, left middle frontal cortex, left insula, and right cuneus (Figure 3b). We also calculated the contrasts between other two priming tasks but did not find significant activations.

To assess individual differences in the brain activity related to the priming tasks, we calculated parameter estimates of signal intensity in the brain regions in which activations were significantly different between the interdependent and independent self-construal priming tasks. Then, we conducted regression analyses including independent and interdependent self-construal scores and found that activity in the dMPFC (0/30/32) and in the left ventrolateral frontal cortex (-24/54/12) were negatively correlated with independent self-construal score

TABLE 3

Differences in brain activations between priming conditions

| Brain region | BA | MNI coordinates | | | Size (voxels) | t-value |
|-------------------------------|-------|-----------------|-----|-----|------------------|---------|
| | | x | y | z | | |
| Interdependent > Independent | | | | | | |
| Medial frontal gyrus | 32 | 12 | 32 | 34 | 102 | 4.91 |
| L middle frontal gyrus | 10 | −24 | 54 | 12 | 131 | 6.00 |
| L middle frontal gyrus | 9 | −36 | 22 | 34 | 66 | 5.11 |
| R anterior cerebellum | \ | 26 | −44 | −26 | 82 | 5.42 |
| R posterior cerebellum | \ | 22 | −60 | −36 | 144 | 5.02 |
| Control > Independent | | | | | | |
| Medial superior frontal gyrus | 8 | 0 | 38 | 52 | 95 | 5.04 |
| L middle frontal gyrus | 10 | −24 | 48 | 30 | 59 | 4.92 |
| L insula | 13/38 | −38 | 4 | 14 | 80 | 5.56 |
| R cuneus | 19 | 18 | −90 | 30 | 83 | 4.65 |

Note: Threshold: $p < .005$, uncorrected, $k > 50$.

(Table 4). Participant with higher independent self-construal scores showed weaker activity in the dMPFC and left ventrolateral frontal cortex during both interdependent and independent self-construal priming tasks. Figure 3c and d illustrate the correlation

TABLE 4

Brain activation correlated with independent self-construal score

| Correlation $r(p)$ | Priming condition | | |
|-----------------------------------|-------------------|----------------|----------------|
| | Independent | Interdependent | Control |
| dMPFC | -0.652 (0.003) | -0.558 (0.016) | -0.541 (0.020) |
| Left ventrolateral frontal cortex | -0.670 (0.002) | -0.640 (0.004) | -0.635 (0.005) |

between the brain activity associated with the interdependent priming task and independent self-construal score. Similar analysis of the left middle frontal activity (-36/22/34) did not showed significant correlation with the independent or interdependent self-construal scores ($ps > 0.1$).

Regional homogeneity during the resting state

We first conducted whole-brain analyses of ReHo maps to examine whether self-construal priming modulated the local synchronization of spontaneous fMRI signals. This revealed significantly increased ReHo in the dMPFC, left middle frontal cortex, and cingulate gyrus, after interdependent compared to independent self-construal priming (Figure 4a,

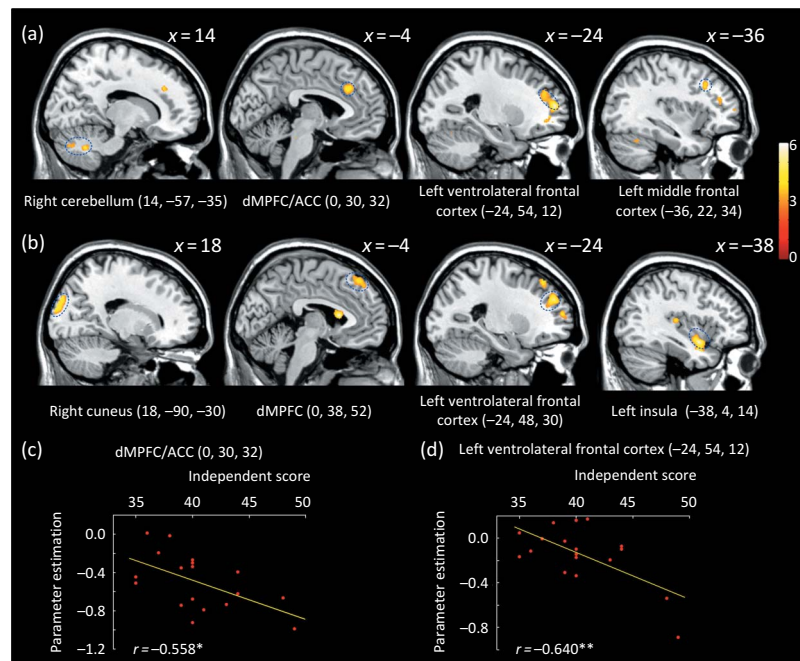


Figure 3. The results of whole-brain analyses of the data in the first fMRI session. Significant activations observed in the contrast of (a) interdependent vs. independent self-construal priming and (b) control priming vs. independent self-construal priming. Scale bar indicates t -values. Scatter diagrams show correlations between and activity in the dMPFC/ACC (c) and left ventrolateral frontal cortex (d). X-axial is individual's independent score; estimation of signal intensity (y-axial) is plotted against independent score. Asterisks indicate significant correlation, $*p \leq .05$, $**p \leq .01$.

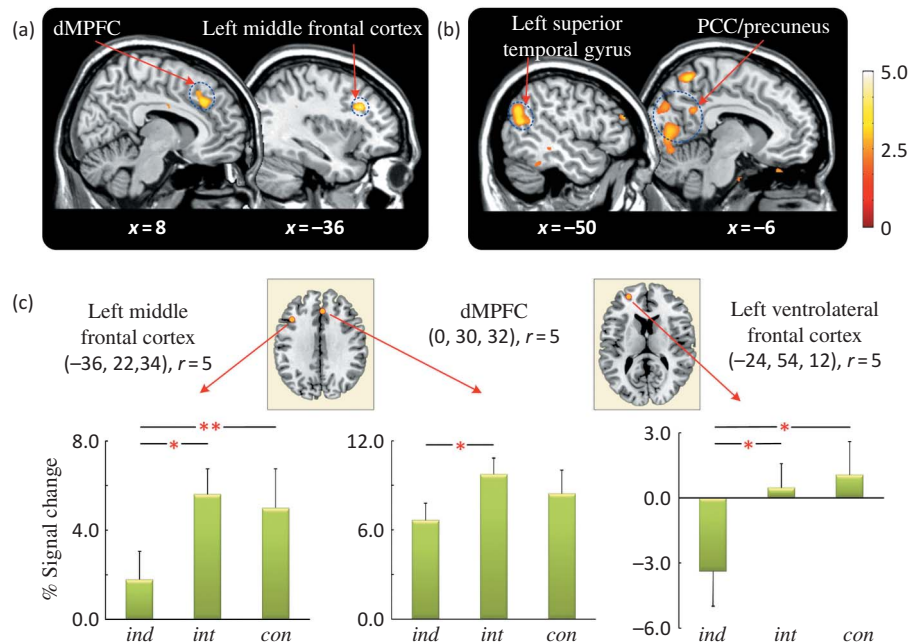


Figure 4. The results of resting-state regional homogeneity. (a) Increased regional homogeneity was observed in the dMPFC and left middle frontal cortex after interdependent vs. independent priming. (b) Increased regional homogeneity was observed in the PCC/precuneus and left superior temporal gyrus after independent vs. interdependent priming. (c) Regional homogeneity during the resting state in the brain regions that showed significant activations during the priming tasks. ROIs were defined in the contrast of interdependent vs. independent self-construal priming in the first fMRI session. The percentage of ReHo value change (y axis) is plotted against priming conditions in the second fMRI session (x axis). Asterisks indicate significant differences between the two conditions. ind = independent; int = interdependent; con = control.

Table 5). Similarly, significantly increased ReHo in the dMPFC and left middle frontal cortex was found after the control compared to independent self-construal priming. In contrast, significantly increased ReHo in the PCC, precuneus, left lingual gyrus, and left superior temporal gyrus was found after the independent relative to interdependent self-construal priming (Figure 4b).

To test whether the priming tasks influenced the resting-state ReHo in the brain regions that showed significant activations during the priming tasks, we conducted ROI analyses to calculate the ReHo values in spheres with a 5 mm radius that centered at $0/30/32$ (dMPFC), $-36/22/34$ (left middle frontal cortex), and $-24/54/12$ (left ventrolateral frontal cortex). We then compared the ReHo values in these brain regions between each two priming conditions. Paired *t*-tests showed greater ReHo values after the interdependent relative to independent self-construal priming in the dMPFC ($t = 2.417, p = .027$), left middle frontal cortex ($t = 3.412, p = .003$), and left ventrolateral frontal cortex ($t = 2.383, p = .029$, Figure 4c). Moreover, the ReHo values in the left middle frontal cortex ($t = 2.338, p = .032$) and left ventrolateral frontal cortex ($t = 2.329, p = .032$) were

larger after the control priming compared to the independent self-construal priming. There was no significant difference in ReHo values between interdependent self-construal priming and the control priming ($ps > 0.3$).

Functional connectivity during the resting state

To assess the effect of self-construal priming on the synchronization of remote brain regions during the resting state, we calculated functional connectivity maps during the resting state. We selected three seed areas (spheres with a 5 mm radius) in the default network that significantly differentiated between the priming and calculation tasks (e.g., the vMPFC ($8/54/4$) and PCC ($4/-46/24$)) and between interdependent and independent self-construal priming tasks (e.g., the dMPFC ($0/30/32$)). The whole-brain analysis based on the seed region of vMPFC showed that, during the resting state after all the three priming conditions, the vMPFC activity was positively correlated with those in the PCC ($-1, -47, 30$), dMPFC ($0, 32, 22$), bilateral superior frontal gyrus ($\pm 22, 36$,

TABLE 5
Differences in ReHo during the resting state between each two priming conditions

| Brain region | MNI coordinates | | | | Size (voxels) | t-value |
|-------------------------------|-----------------|-----|-----|-----|------------------|---------|
| | BA | x | y | z | | |
| Interdependent > Independent | | | | | | |
| Medial frontal gyrus | 32 | 8 | 30 | 36 | 85 | 4.11 |
| Cingulate gyrus | 24 | -6 | -8 | 46 | 78 | 4.01 |
| L Middle frontal gyrus | 9 | -36 | 24 | 30 | 55 | 4.60 |
| Independent > Interdependent | | | | | | |
| Cuneus/Posterior cingulate | 19/18 | 2 | -60 | 8 | 631 | 3.79 |
| L precuneus | 7 | -10 | -58 | 62 | 69 | 4.25 |
| L lingual gyrus | 18 | -18 | -66 | -2 | 91 | 3.58 |
| L superior temporal gyrus | 39 | -50 | -62 | 18 | 110 | 4.21 |
| L supramarginal gyrus | 40 | -58 | -54 | 34 | 69 | 4.00 |
| R precuneus | 7 | 8 | -62 | 62 | 249 | 4.59 |
| Control > Independent | | | | | | |
| Medial superior frontal gyrus | 32 | -4 | 4 | 52 | 104 | 3.51 |
| L middle frontal gyrus | 9/46 | -44 | 26 | 26 | 97 | 3.77 |
| Interdependent > Control | | | | | | |
| L middle frontal gyrus | 8 | -30 | 18 | 44 | 91 | 4.96 |
| L cerebellum | \ | -16 | -44 | -40 | 91 | 3.66 |
| R cerebellum | \ | 10 | -62 | -44 | 196 | 3.70 |
| R insula | 13 | 40 | 12 | 0 | 180 | 4.88 |
| Control > Interdependent | | | | | | |
| Medial superior frontal gyrus | 10 | -6 | 62 | 26 | 74 | 3.72 |
| L precentral gyrus | 4/3 | -42 | -20 | 68 | 286 | 4.68 |
| R inferior frontal gyrus | 9 | 62 | 6 | 26 | 62 | 4.50 |
| R middle temporal gyrus | 39 | 56 | -68 | 34 | 66 | 5.15 |
| R superior occipital gyrus | 19 | 38 | -82 | 32 | 252 | 4.83 |
| R postcentral gyrus | 4/6 | 54 | -24 | 54 | 285 | 4.70 |
| R lingual gyrus | 18 | 10 | -84 | -2 | 414 | 4.19 |

Note: Threshold: $p < .005$, corrected at cluster level of $k > 50$.

42), bilateral inferior parietal cortex ($\pm 51, -62, 36$), and bilateral middle temporal gyrus ($\pm 56, 0, -21$), but negatively correlated with those in the bilateral inferior frontal gyrus ($\pm 43, 5, 30$) and bilateral supra-parietal gyrus ($\pm 46, -32, 43$, Figure 5). The PCC activity was positively correlated with those in the vMPFC (0, 42, -10), dMPFC (1, 46, 32), bilateral superior frontal gyrus ($\pm 24, 36, 42$), bilateral inferior parietal gyrus ($\pm 41, -66, 40$), and bilateral middle temporal gyrus ($\pm 54, -12, -18$). However, the PCC activity was negatively correlated with those in the bilateral inferior frontal gyrus ($\pm 51, 10, 12$), bilateral supra-parietal

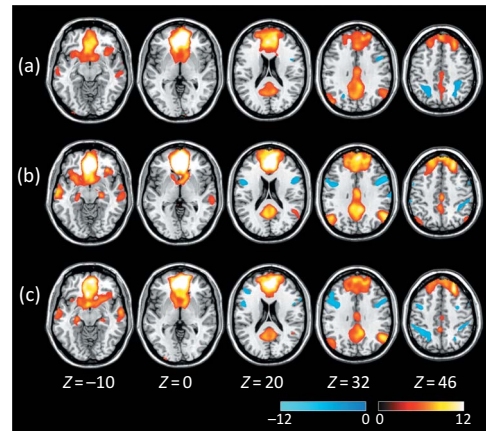


Figure 5. Functional connectivity map based on the vMPFC seed area (8/54/4, $r = 5$) during the resting state. (a) Resting state after independent self-construal priming. (b) Resting state after interdependent self-construal priming. (c) Resting state after control priming. Red regions indicate positive functional connectivity and blue regions indicate negative functional connectivity. Scale bar indicates correlation coefficients. There was no significant difference between any two conditions.

gyrus ($\pm 58, -32, 36$), and medial frontal gyrus (6, 11, 50). Activity in the dMPFC was positively correlated with those in the vMPFC ($-2, 46, 2$), the PCC (0, -24, 32), bilateral superior frontal gyrus ($\pm 30, 42, 36$), and bilateral insula ($\pm 34, 14, -2$). We compared the resting-state functional connectivity among these brain regions between any two priming conditions but did not find significant differences.

To further test whether the resting-state functional connectivity between the seed regions was associated with self-construals, we calculated the strength of functional connectivity between the vMPFC and dMPFC/PCC for each participant. Then, we conducted a correlation analysis and found that the strength of functional connectivity between the vMPFC and dMPFC after the control priming was positively correlated with the interdependent self-construal score ($r = 0.476$, $p = .046$, Figure 6). In addition, the strength of functional connectivity between the vMPFC and the PCC after the control priming was positively correlated with the independent self-construal score ($r = 0.712$, $p = .001$). Similar analyses failed to show significant correlation between self-construal score and the functional connectivity after the independent and interdependent self-construal priming ($ps > 0.2$). These results suggest that, after the control priming, individuals with greater interdependent self-construals showed stronger functional connectivity between the vMPFC and dMPFC and individuals with greater independent self-construals showed stronger functional connectivity between the vMPFC and PCC during the resting state.

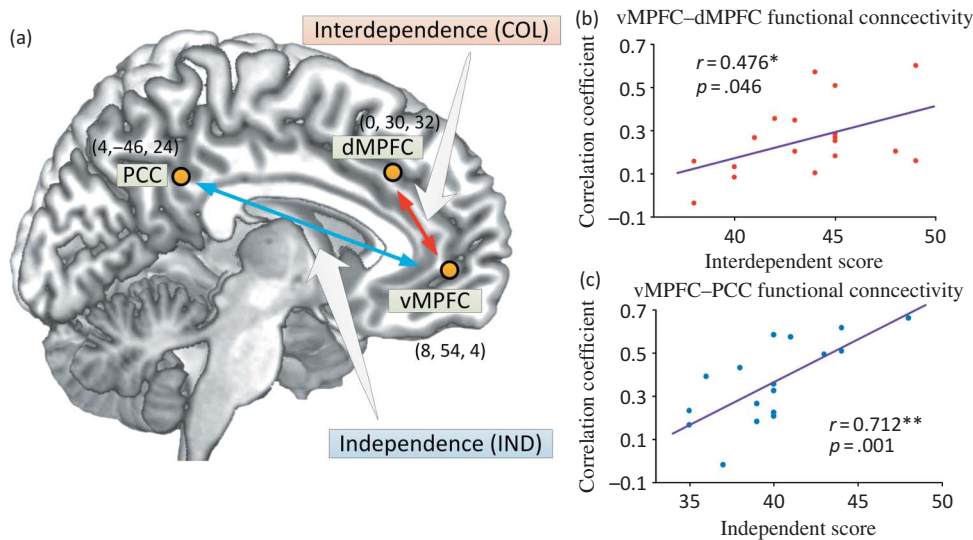


Figure 6. The results of resting-state functional connectivity after control priming. (a) Illustration of three key brain regions involved in the functional connectivity analysis. (b) Correlation between interdependent self-construal score (COL) and vMPFC–dMPFC functional connectivity during the resting state. (c) Correlation between independent self-construal score (IND) and vMPFC–PCC functional connectivity during the resting state.

DISCUSSION

Given the increasing evidence for the effects of cultural mind-set priming on behavioral performance (Oyserman, 2011; Oyserman & Lee, 2008a, 2008b) and brain activity involved in multiple cognitive processes (Han & Northoff, 2008; Han et al., 2013), it is crucial to uncover the neural correlates of cultural mind-set priming itself. The current work contributed in a number of ways to understanding of the neural correlates of a particular cultural mind-set priming procedure as compared to a control condition.

First, our fMRI results showed evidence that the self-construal priming procedure was associated with modulations of neural activity in the midline cortical structure. Relative to a calculation task, both interdependent and independent self-construal priming tasks significantly activated the MPFC and PCC. These activations were not specific to self-construal priming because the control priming that required identification of “people” also activated the similar brain regions compared to the calculation task. However, we did find brain activations that differentiated between the interdependent and independent self-construal priming tasks. Specifically, the interdependent self-construal priming task-induced greater activity in the dMPFC and left middle frontal cortex compared to the independent self-construal priming task. These effects cannot be explained by task difficulty because neither response accuracy nor wakefulness differed across self-construal or control priming tasks. The effect of

semantic processing on neural activity related to the priming tasks was kept minimal since sentences used in different priming tasks were counterbalanced across participants. The dMPFC is a key node of the default mode network and is activated during person perception (Han, Jiang, Humphreys, Zhou, & Cai, 2005; Mitchell, Heatherton, & Macrae, 2002) as well as during interference of others’ mental states (Amodio & Frith, 2006; Gallagher, Happe’, Brunswick, Fletcher, & Frith, 2000). The lateral frontal cortex is also engaged in representing context information and guiding executive behaviors (Figner et al., 2010; Koechlin, Ody, & Kouneiher, 2003). Thus our fMRI results are consistent with the idea that accessible collectivistic mind-set enhances attention to others and social contexts relative to accessible individualistic mind-set.

The dMPFC and ventrolateral frontal activities during the priming procedure varied significantly across participants who differed in self-construal scores, with lower activity among those scoring higher in independence and no effect of interdependent self-construal score. The previous research found that, relative to those from collectivistic cultural contexts, individuals from individualistic cultural contexts showed stronger neural activity to self-related information (e.g., one’s own face, Sui, Liu, & Han, 2009; one’s own personality traits, Ma et al., in press) but weaker activity in response to information of others (e.g., personality traits, Zhu et al., 2007). Moreover, priming bicultural individuals with individualistic vs. collectivistic cultural values also increased the neural activity related

to others (Ng et al., 2010), but decreased the neural activity linked to general relative to contextual self-judgments (Chiao et al., 2010). Consistent with the previous neuroimaging findings, our fMRI results indicate that individuals with stronger independent self-construals were less influenced by the priming procedure to activate the brain regions engaged in the processing of others' mind or contextual information. These neuroimaging findings together provide a neuroscience account of the difference in self-construals between Western and East Asian cultures (Markus & Kitayama, 1991, 2010) and of the different effect of cultural mind-set priming across individuals.

The second contribution of the current study is to uncover the effect of accessible cultural mind-set on the resting-state activity. The ReHo analysis showed that the anterior and posterior regions of the midline cortical structure significantly differentiated between the resting-state activity after the interdependent and independent self-construal priming tasks. Relative to the independent self-construal priming, the interdependent self-construal priming significantly increased the ReHo in the dMPFC. The ROI analysis further confirmed that the interdependent vs. independent self-construal priming induced greater resting-state ReHo value in the dMPFC that showed increased activity during the interdependent self-construal priming procedure. In contrast, the independent self-construal priming led to increased ReHo in the PCC during the resting state after the priming procedure. Thus interdependent and independent self-construal priming respectively enhanced the local synchronization of spontaneous activity in voxels within the anterior and posterior clusters in the midline cortical structure. These results showed the first evidence that making collectivistic/individualistic cultural mind-set accessible modulates the resting-state activity following the prime in a way that may be associated with a specific mind-set.

This variation in resting-state activity as a function of self-construal priming implicates a neural mechanism for the effect of cultural mind-set priming on brain activity observed in previous studies. For example, the increased ReHo in the dMPFC, a brain region engaged in person perception (Han et al., 2005; Mitchell et al., 2002), and inference of others' mental states (Amodio & Frith, 2006; Gallagher et al., 2000) during the resting state after the interdependent self-construal priming may facilitate mental readiness for attention to contextual information and thus resulted in enhanced neural representation of others (Ng et al., 2010) and faster behavioral responses to context-dependent targets (Kühnen & Oyserman, 2002; Lin et al., 2008; Oyserman et al., 2009). In contrast, the

increased ReHo in the PCC, a brain region involved in episodic memory (Hassabis, Kumaran, & Maguire, 2007), and self-reflection (Johnson et al., 2002) during the resting state after the independent self-construal priming may promote a mental readiness state for self-focusing and thus enhance neural representation of the self (Ng et al., 2010; Sui & Han, 2007). Recent studies also reported that the PCC was activated during mentalizing others' mind (e.g., Lombardo et al., 2010; Spunt, Satpute, & Lieberman, 2011). Thus an alternative account is that the increased PCC ReHo might reflect enhanced processing of others' mind during the resting state. However, if this were the case, one would expect that the effect on PCC ReHo would be stronger after the interdependent than independent self-construal priming, but this contradicts with our results.

Functional connectivity analysis showed similar coherent activity among the brain regions in the default mode network during the resting state after the self-construal and control priming tasks. This is consistent with the findings of the previous research (Fox et al., 2005; Greicius et al., 2003). We did not find evidence for different modulations of synchronization between remote brain regions during the resting state after the interdependent and independent self-construal priming procedure. These results suggest that synchronization of spontaneous neural activity in remote brain regions may be less sensitive to cultural mind-set priming than synchronization of spontaneous neural activity in a local brain region. However, we did find that chronic self-construal was associated with functional connectivity between brain regions in the default mode network in the control condition. The coherent activity between the vMPFC and dMPFC was stronger in those with greater interdependent self-construal scores whereas the coherent activity between the vMPFC and PCC was stronger in those with greater independent self-construal scores. These results were not observed if either collectivistic or individualistic mind-set had been primed. Thus while self-construal matters, it matters only if individualistic or collectivistic mind-set is not cued by an immediate context. Or, put another way, it is possible that the long-range functional connectivity between brain regions is shaped by chronic cultural experiences that produce a dominant self-construal in an individual but connectivity is also sensitive to immediate experience as reflected in cultural mind-set priming.

Taken together, our findings provide neuroimaging evidence that cultural mind-set priming modulates both task-related and subsequent resting-state activity in the default mode network. These modulations may provide a neural basis for the effects of

accessible collectivistic and individualistic mind-sets. The culture-as-situated-cognition model proposes that cognitive styles are not fixed across situations (Oyserman, 2011; Oyserman et al., 2009). Instead, cognitive processes are situationally malleable so that individuals are able to use collective or individual mind-sets depending on psychologically meaningful features of immediate situations. Our neuroimaging suggest that the variation of local synchronization of spontaneous neural activity in the anterior (e.g., dMPFC) and posterior (e.g., PCC) regions in the mid-line cortical structure may provide a potential neural mechanisms underlying the effect of mind-sets. The increased local synchronization in the dMPFC induced by an accessible collectivistic mind-set may set the mind to a connecting and relating style whereas the increased local synchronization in the PCC induced by an accessible individualistic mind-set may set the mind to a separating and pulling apart style. These neuroimaging results lend support to the proposal that the working cultural mind-set is malleable, rather than fixed, and varies as a function of situation (Oyserman et al., 2009).

Our recent research showed evidence that the effect of self-construal priming may depend upon individuals' mind-set formed during long-term, chronic cultural adaptation (Sui et al., in press). The current work only tested Chinese participants who showed a tendency of interdependent self-construal. Thus it is not surprising that the control priming task, similar to the interdependent self-construal priming task, induced increased dMPFC activity and increase ReHo in the dMPFC compared to the independent self-construal priming task. Future research should test participants from other cultures that are dominated by independent self-construals to examine whether self-construal priming produces variations of the resting-state activity similar to what we observed here.

In summary, our neuroimaging findings demonstrate modulations of the neural activity in the default mode network after priming cultural mind-set. Our findings provide novel insight into how cultural mind-set priming dynamically alters the resting-state brain activity that serves as a neural basis for cognitive and affective tasks. These modulations of the neural activity in the default mode network as a result of priming may be associated with other effects of individualistic and collectivistic mind-set on affect, cognition, and behavior. While we used only one mind-set priming task, prior neuroscience research using a variety of priming and cross-group comparisons provide converging evidence of effects, implying that the identified processes may explain how accessible cultural

mind-sets ready the brain to act in support of doing in context.

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