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# Neural differences in the processing of semantic relationships across cultures

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**The current study employed functional MRI to investigate the contribution of domain-general (e.g. executive functions) and domain-specific (e.g. semantic knowledge) processes to differences in semantic judgments across cultures. Previous behavioral experiments have identified cross-cultural differences in categorization, with East Asians preferring strategies involving thematic or functional relationships (e.g. cow-grass) and Americans preferring categorical relationships (e.g. cow-chicken). East Asians and American participants underwent functional imaging while alternating between categorical or thematic strategies to sort triads of words, as well as matching words on control trials. Many similarities were observed. However, across both category and relationship trials compared to match (control) trials, East Asians activated a frontal-parietal network implicated in controlled executive processes, whereas Americans engaged regions of the temporal lobes and the cingulate, possibly in response to conflict in the semantic content of information. The results suggest that cultures differ in the strategies employed to resolve conflict between competing semantic judgments.**

**Keywords:** cognition; culture; executive function; fMRI; semantic

## INTRODUCTION

In recent years, influences of culturally based ideas and practices on cognitive behaviors of individuals have been established in a number of domains, including memory, attention and social judgments (Markus and Kitayama, 1991; Kitayama *et al.*, 2003; for reviews see Nisbett *et al.*, 2001; Nisbett and Masuda, 2003). Although there are many dimensions along which cultural groups will differ, one dimension that has received a large amount of attention involves the difference between so-called independent cultures (hypothesized to be predominant in Western nations such as America), which are associated with preferential processing of individual objects and their attributes, and interdependent cultures (hypothesized to be predominant in East Asian cultures including Japan, China and Korea), which are associated with preferential processing of contextual relationships among objects in a wider attentional field (Hofstede, 1980; Markus and Kitayama, 1991; Nisbett *et al.*, 2001). In particular, several studies have observed differences among participants from American and East Asian cultures in situations where independent and interdependent cognitive styles are placed in conflict or opposition to one another (Masuda and Nisbett, 2001; Norenzayan *et al.*, 2002; Kitayama *et al.*, 2003). Whereas some of these differences stemming from cultural contexts seem domain-specific (e.g. tendency to attend to contextual features in a visual scene), some data reveal cultural differences in controlled processes and executive function as a function of task familiarity or fluency (e.g. Hedden *et al.*, 2008), which may indicate domain-general influences of culture. In the present study, we investigate the extent to which cultural influences are present in executive processes when interference occurs between different types of well-learned semantic knowledge. Because it involves well-learned crystallized representations, the domain of semantic knowledge, which includes one's store of factual knowledge as well as the organizational structure and interconnections amongst concepts (e.g. categorical hierarchies and functional relationships), provides an important test of the ways in which executive functions may interact with culturally grounded associations. It may be the case that cultures similarly engage controlled processes and executive function to resolve semantic interference across tasks. In this case, different cultural groups would engage similar cognitive processes, but do so under different circumstances (i.e. for the semantic task that they find relatively more difficult). However, it could be the case that individuals from different cultural backgrounds access distinct pools of semantic knowledge or differ in the processes recruited to resolve interference. The present study evaluates the possible mechanisms through which cultural ideas and practices may contribute to resolving interference during a semantic association task.

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Cultural ideas and practices undoubtedly guide what semantic information is learned (Yoon *et al.*, 2004), and cultural contexts also impact how semantic information is used and organized (Chiu, 1972; Choi *et al.*, 1997; Nisbett *et al.*, 2001; Ji *et al.*, 2004). On average, there is a tendency for individuals from different cultural groups to exhibit variations in their preference for or the ease with which they use particular semantic strategies, with Americans tending to exhibit a preference for organizing information by taxonomic categories and East Asians tending to display a preference for organizing information by thematic or functional relationships (Chiu, 1972; Ji *et al.*, 2004; Unsworth *et al.*, 2005; Gutchess *et al.*, 2006b). For example, when presented with word triplets such as *seagull-squirrel-tree* and asked to select the two words that go together, Americans tended to select the seagull and the squirrel, and provided reasons appealing to the category level (e.g. 'they're both animals'). East Asians, on the other hand, tended to select the squirrel and the tree, and their reasons appealed to the functional relationship (e.g. 'the squirrel climbs the tree') (Chiu, 1972; Ji *et al.*, 2004). Individuals from different cultural contexts also differ in the use of semantic information in explicit memory (Gutchess *et al.*, 2006b). To organize information in memory, older Americans used a categorization-based strategy more than older Chinese while younger adults did not differ across cultures on the task (although it is important to note that a strategy relying on functional relationships was not readily supported by the task). These findings may suggest that prolonged immersion in a particular cultural context enhances the influence of culturally specific ideas and practices on cognitive strategies (Gutchess *et al.*, 2006b).

The results of the Gutchess *et al.* (2006b) memory study may also suggest that applying a strategy that is not generally solicited by one's cultural surroundings may require additional cognitive effort, such that older adults who have reduced levels of attentional capacity are limited in their ability to apply a strategy that is less familiar. Neuroimaging methods are one promising approach to assess cultural differences in the cognitive demands of different strategies. On a line judgment task (Kitayama *et al.*, 2003) known to be sensitive to cultural influences on performance for relative (i.e. matching the length of a line relative to the surrounding context) *vs* absolute judgments (i.e. matching the length of a line regardless of the surrounding context), Hedden and colleagues (2008) found that participants engaged a frontal-parietal system subserving controlled processing and executive function for judgments using the culturally non-preferred strategy (relative for Americans; absolute for East Asians). Of interest, the same network was engaged for the non-preferred task by both East Asian and American individuals, even though the strategy being applied differed across cultural groups. This effect emerged despite equivalent behavioral performance on the fMRI task across cultures, indicating that the neural markers of difficulty may be more sensitive than the behavioral indices for this task. The use of neuroimaging not only provides converging evidence for cultural influences on the ease or difficulty of applying particular strategies, but also offers insights into the level at which cultural contexts operate. The observation of a frontal-parietal network (Hedden *et al.*, 2008), also identified by Nan and colleagues (2008) on a comparison of culturally familiar *vs* unfamiliar music, indicates that cultural groups likely differ primarily in the engagement of top-down control strategies (for review and discussion, see Ketay *et al.*, 2009). These findings complement those of prior studies, which identified cross-cultural differences in brain regions associated with domain-specific processes that may be modulated by attentional processes (Gutchess *et al.*, 2006a; Goh *et al.*, 2007).

In the present study, we employed fMRI methods to compare the contribution of domain-specific (i.e. unique to categorical or relational judgments) and domain-general (i.e. executive function or otherwise shared across tasks) processes in resolving semantic interference across cultural groups. East Asians and Americans made categorical or relational semantic judgments while inhibiting the other type of judgment. Based on previous comparisons of taxonomic and thematic categorization in mono-cultural samples, cultural contexts could influence activation observed in a right-lateralized network (including regions of the insula, middle frontal gyrus, precuneus, cuneus and post-central gyrus) that becomes more engaged during taxonomic than thematic categorization (Kotz *et al.*, 2002; Sachs *et al.*, 2008a, b). The right precuneus reflected greater priming effects for taxonomic relationships whereas distinct regions of right middle frontal gyrus and the anterior cingulate responded to thematic priming (Sachs *et al.*, 2008b). These regions may therefore respond to differences in the salience and relative difficulty in processing different types of semantic associations. One study (Sachs *et al.*, 2008a) directly compared selection of taxonomic *vs* thematic relationships using verbal stimuli and found a strikingly similar pattern of neural activity across the tasks. Another study using pictorial stimuli identified differences in occipital, temporal and parietal regions (Kalenine *et al.*, 2009). Notably, all of these results were based solely on Western populations.

Because individuals from different cultural contexts vary in their tendency to apply categorical strategies (Chiu, 1972; Ji *et al.*, 2004; Unsworth *et al.*, 2005; Gutchess *et al.*, 2006b), we expected that East Asians and Americans would differ in the effort required to process different types of semantic associations in our study. The behavioral studies employed in cross-cultural research (e.g. Ji *et al.*, 2004) typically require participants to use one strategy on a given trial while inhibiting another strategy, which increases the interference and competition between semantic knowledge. The fMRI studies to date (using mono-cultural samples) generally did not pit these strategies against each other, and instead have only one plausible pairing (e.g. car-garage-eraser). In cases where both taxonomic and thematic pairings were available, participants were free to select either strategy (Sachs *et al.* 2008a). Thus, a stronger test of differences in categorical and relational processing will allow the two processes to compete with each other, and require participants to sometimes use a non-preferred strategy over a preferred one. To the extent that cultural influences on semantic processing are domain-general (Hedden *et al.*, 2008), we expected to observe a pattern of activation in a frontal-parietal network associated with attentional control such that regions within this network would respond to the conflict between categorical and thematic semantic relationships. Based on the literature on semantic processing (e.g. Sachs *et al.*, 2008b), this network may be more right-lateralized for conflict arising from non-preferred judgments. Alternatively, to the extent that cultural influences are domain-specific, we predicted that cultures would differ in the engagement of temporal regions during the access of semantic knowledge or that the cultures would differ in the processes recruited to resolve interference.

## METHODS

Twenty college students (ages 18–26 years, $M = 20.6$ years), 10 East Asians (5 female) and 10 Americans (6 female) of Caucasian ethnicity participated in the experiment. East Asians were of heterogeneous origin (including mainland China, Hong Kong, Taiwan, and South Korea), had emigrated to the USA <7-years-ago ($M = 5.3$ years), and were proficient in English as demonstrated by performance on the English-language Nelson-Denny Reading Comprehension subtest (Americans: $M = 35.5$, s.d. $= 1.8$; Asians: $M = 33.4$, s.d. $= 4.0$, $t(18) = 1.51$, $p = 0.15$). Participants completed other individual differences measures of cultural identification, including an acculturation questionnaire (Suinn *et al.*, 1992) and the self-reliance, concern for ingroup, and distance from ingroup subscales of a questionnaire measure of individualism/collectivism (Triandis *et al.*, 1988).

During scanning, participants made judgments about word triads, using a task adapted from Chiu (1972) and Ji *et al.* (2004). On each trial (see Figure 1), participants made a button press to indicate which two of three words (e.g. panda, banana, monkey) matched one another, based on the classification rule for that trial. For 'category' trials, participants selected the two words that were categorically related (e.g. panda and monkey) whereas for the 'relationship' trials, participants selected the two words that shared a functional relationship (e.g. banana and monkey). As a control condition, participants selected the two words that were identical on 'match' trials (e.g. flower, paper, paper). Stimuli were selected on the basis of prior categorization work (Chiu, 1972; Ji *et al.*, 2004; Yoon *et al.*, 2004) and pre-tested to eliminate triads that were overly ambiguous or heavily biased toward either the category or relational choice. Across participants, word triads were counterbalanced to appear in either the category or relational rule instruction. Trials were presented in a blocked design, with each block lasting 27.75 s (15 TRs) and consisting of eight trials (3.2 s each) from one condition preceded by the rule (2.15 s) for that block.

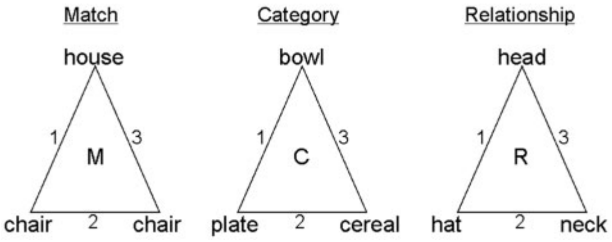

**Fig. 1** Example stimuli for each of three trial types. According to the rule for that trial block, participants pressed a button corresponding to one of the numbered lines to identify a particular type of relationship (e.g. for the 'category' trial, participants should press '1' to indicate that 'bowl' and 'plate' share a categorical relationship). Trials were presented in blocks of eight trials from a single condition, and each stimulus contained a centrally presented letter (M for match, C for category, or R for relationship) as reminder of the response rule for that block.

A 1.5-T General Electric Signa MR scanner with a whole-head coil was used to acquire BOLD fMRI data with a sequential spiral-in/spiral-out acquisition sequence. Twenty-three 5-mm oblique slices were acquired ($\mathrm{TR} = 1850$ ms, $\mathrm{TE} = 40$ ms, flip angle $= 70^\circ$, $64 \times 64$ matrix, field of view $= 240$ mm) for 180 scans and five discarded acquisitions in each of two runs. Data were screened for artifacts and preprocessed, including motion-correction, normalization to the Montreal Neurological Institute (MNI) template, and smoothing with a 6 mm kernel.

We conducted whole-brain analyses of fMRI data using SPM2 (Wellcome Trust Centre for Neuroimaging, London, UK). For the first-level analysis, we created contrasts for each participant to compare the conditions of interest and pooled these at the second level to compare cultural groups using random-effects analyses. The first set of analyses compared Task (collapsed across the two semantic conflict types, category and relationship) to control (match) to assess cultural differences and similarities in the neural activity underlying strategic semantic judgments. We also compared activations across the cultural groups during each of the two different types of semantic conflict trials (category or relationship) *vs* control (match) trials. For example, greater activity for East Asians rather than Americans was identified using the contrast of Asian-Americans (category-match). For all analyses, we used a voxel-level threshold of $p < 0.005$ in combination with an extent threshold of 79 voxels to achieve an overall $p$-value of <0.05 (using the cluster extent thresholding script available at: http://www2.bc.edu/∼slotnics/scripts.htm). Patterns of activity were extracted from significant clusters with MarsBaR (Brett, 2002) using the peak voxel as a region of interest, to illustrate the nature of the cultural differences across conditions. ROIs, as in Figure 3, are used to illustrate the nature of the effect and thus are drawn from the same contrast that originally identified the region. Activity in representative ROIs were tested for correlations with scores on individual difference measures. Six ROIs, drawn from middle frontal, cingulate, angular and insula gyri regions listed in Table 2, were selected on the basis of theoretical interest. Note that the regions were selected on the basis of subtractions that were independent of the measures tested for correlations (Vul *et al.*, 2009).

## RESULTS

Behavioral data showed no significant cultural differences in accuracy or reaction time (RT) for any condition. Although RT did not significantly differ across conditions ($t = 1.67$, $p = 0.11$), each group displayed higher accuracy rates ($t = 4.96$, $p < 0.001$) in the relational condition (East Asians: accuracy $M = 0.79$ s.d. $= 0.11$, RT $M = 1945$ s.d. $= 217$; Americans: accuracy $M = 0.79$ s.d. $= 0.11$, RT $M = 1942$ s.d. $= 142$) than in the categorical condition (East Asians: accuracy $M = 0.71$ s.d. $= 0.09$, RT $M = 1901$ s.d. $= 207$; Americans: accuracy $M = 0.70$ s.d. $= 0.10$, RT $M = 1908$ s.d. $= 190$). The relatively low accuracy rates may be attributable to the fact that many of the word triads were selected to exclude high-association categories or relationships and that each triad included both a categorical and relational pair, thereby potentially invoking inhibition of the non-relevant dimension during each block of trials. One indication that the cultural groups may differ in their preference for certain strategies was a stronger relationship for the Americans ($r = -0.83$) than the East Asians ($r = -0.23$) between accuracy and RT for the category trials (Fisher's $r$- to -$Z$ transformation: $Z = 1.76$, $p < 0.05$, one-tailed). The faster RTs paired with higher levels of accuracy indicate greater fluency with the category task for the Americans than East Asians. However, the groups did not differ in the correlation between accuracy and RT for the relationship condition (Americans: $r = -0.56$; East Asians: $r = -0.57$; $Z = 0.01$, $p > 0.05$). Both groups were near ceiling in the 'matching' control condition (East Asians: accuracy $M = 0.99$ s.d. $= 0.02$, RT $M = 1152$ s.d. $= 137$; Americans: accuracy $M = 0.99$ s.d. $= 0.01$, RT $M = 1091$ s.d. $= 99$).

The first set of brain analyses collapsed across the two semantic conflict conditions (category and relationship) to contrast the strategy-based tasks against the control task (match). Both East Asians and Americans activated an extensive network including frontal, temporal and parietal regions (see Figure 2, Table 1, panel A). This suggests that both cultures engage several of the same semantic and attentional top-down processes when making difficult semantic judgments as opposed to match judgments.

Despite the substantial overlap across cultural groups seen in the above comparison, a number of circumscribed differences emerged across the two cultures. During semantic conflict trials, relative to match trials, East Asian participants engaged more regions associated with attention and top-down task control than Americans, including middle frontal gyrus, superior parietal cortex and insula (see Table 1, panel B). In contrast, Americans activated temporal lobe regions more than East Asians, as well as a region of the cingulate (see Table 1, panel C).

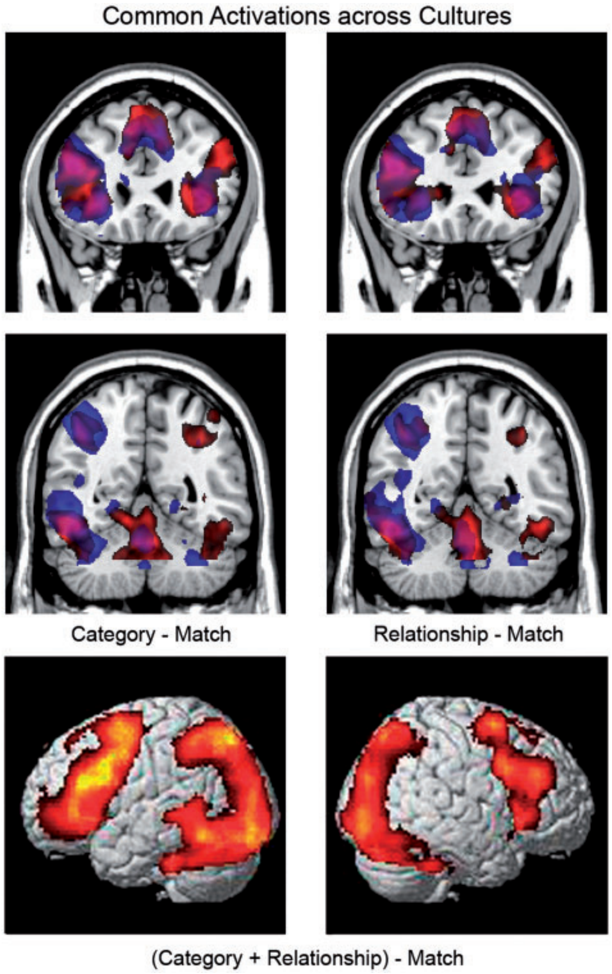

**Fig. 2** Similarity of semantic processing across cultures and tasks. The top and middle panels illustrate the overlap between East Asians' activations (displayed in red) and Americans' activations (displayed in blue) for both category-match and relationship-match contrasts. In addition, note the similarity in the regions engaged by both tasks. Each image is thresholded at $p < 0.005$ and images are displayed at $y = +26$ (top row) and $-52$ (second row). The bottom panel displays the activations across both groups for both strategic judgments [(category + relationship) − match], with more extensive activation in the left hemisphere than in the right. Images are overlaid on a single-subject canonical anatomical image.

The second set of analyses compared regions differentially engaged across cultures for each of the specific tasks, category *vs* match and relational *vs* match. Overall, East Asian participants evinced greater levels of activation than Americans on both types of semantic conflict tasks (see Table 2). Similar to the regions that emerged in the comparison of strategic tasks to control, East Asian participants engaged middle frontal gyrus and the insula, as well as the angular gyrus, more than Americans for the contrast of category-match. For the comparison of relationship—match, East Asians engaged angular, middle frontal, middle temporal and post-central gyri more than

**Table 1** Comparison of strategy-based (category and relationship) *vs* control (match) tasks: commonalities and differences across cultural groups

| Region | BA | Coordinates of activation peak | | | Number of voxels | *t*-value |
|---|---|---|---|---|---|---|
| | | *x* | *y* | *z* | | |
| *(A) Commonalities: [(category + relationship) − match]* | | | | | | |
| L inferior temporal | 37 | −46 | −52 | −16 | 62 817 | 14.86 |
| Brainstem | N/A | −4 | −26 | −20 | | 14.60 |
| L inferior frontal | 48 | −46 | 26 | 22 | | 14.04 |
| L caudate | N/A | −18 | −4 | 20 | | 12.82 |
| L putamen | N/A | −18 | 0 | 10 | | 12.66 |
| L superior parietal | 7 | −30 | −62 | 50 | | 12.61 |
| L inferior frontal | 44 | −48 | 12 | 24 | | 12.51 |
| R insula | 47 | 38 | 24 | −4 | | 12.23 |
| R cerebellum | N/A | 4 | −70 | −32 | | 11.10 |
| L hippocampus | N/A | −28 | −32 | 0 | | 11.01 |
| *(B) Asian-American [(category + relationship) − match]* | | | | | | |
| R angular gyrus | 7 | 36 | −70 | 54 | 324 | 4.14 |
| R middle occipital | 19 | 32 | −66 | 32 | | 3.85 |
| R middle frontal | 9 | 38 | 16 | 60 | 253 | 4.57 |
| R precentral | 6 | 46 | −4 | 62 | | 4.41 |
| R middle frontal | 6 | 38 | 6 | 60 | | 4.25 |
| L cerebellum | N/A | −12 | −58 | −12 | 170 | 8.05 |
| L lingual gyrus | 17 | −4 | −76 | −6 | | 3.28 |
| L cerebellum | N/A | −4 | −74 | −16 | | 3.04 |
| R middle temporal | 20/21 | 48 | −6 | −24 | 138 | 4.22 |
| R middle temporal | 21 | 56 | −6 | −22 | | 4.18 |
| R middle frontal | 10 | 40 | 60 | 10 | 132 | 4.18 |
| R postcentral | 43 | 58 | −6 | 28 | 89 | 4.82 |
| R superior parietal | 7 | 24 | −58 | 44 | 86 | 3.57 |
| R precuneus | 7 | 14 | −68 | 44 | | 3.51 |
| R insula | 47 | 34 | 26 | 2 | 85 | 4.62 |
| *(C) American-Asian [(category + relationship) − match]* | | | | | | |
| R superior temporal | 38 | 48 | 12 | −12 | 147 | 4.45 |
| R cingulate | 32 | 14 | 10 | 46 | 101 | 3.99 |
| R cingulate | 24 | 6 | 8 | 46 | | 3.91 |
| L cingulate | 24 | −2 | 12 | 42 | | 3.02 |
| L superior temporal | 22 | −68 | −42 | 16 | 88 | 4.08 |
| L superior temporal | 42 | −60 | −40 | 18 | | 3.53 |

For each region of activation, local maxima at least 8 mm apart are displayed, and a maximum of 10 peaks are displayed for the common regions and three for the group differences. Labels correspond to the peak activated voxel.

**Table 2** Cultural differences in category and relational tasks, relative to the control task

| Region | BA | Coordinates of activation peak | | | Number of voxels | *t*-value |
|---|---|---|---|---|---|---|
| | | *x* | *y* | *z* | | |
| *(A) Asian-American: category-match* | | | | | | |
| R angular gyrus | 7 | 40 | −64 | 50 | 277 | 4.40 |
| R angular gyrus | 7 | 36 | −72 | 54 | | 4.06 |
| R inferior parietal | 40 | 44 | −54 | 42 | | 3.79 |
| R middle frontal | 9 | 38 | 14 | 58 | 137 | 4.18 |
| R middle frontal | 6 | 38 | 6 | 60 | | 3.67 |
| R superior frontal | 6 | 28 | 6 | 64 | | 3.18 |
| R middle frontal | 10 | 40 | 60 | 10 | 136 | 4.47 |
| R insula | 47 | 36 | 24 | 0 | 99 | 4.54 |
| *(B) American-Asian: category-match* | | | | | | |
| R cingulate | 32 | 12 | 10 | 46 | 225 | 4.56 |
| L cingulate | 24 | −2 | 12 | 42 | | 3.69 |
| R middle frontal | 46 | 32 | 40 | 28 | 150 | 4.93 |
| R middle frontal | 46 | 34 | 48 | 30 | | 3.55 |
| R superior temporal pole | 38 | 50 | 12 | −12 | 80 | 4.08 |
| *(C) Asian-American: relationship-match* | | | | | | |
| R angular gyrus | 7 | 36 | −70 | 56 | 215 | 4.02 |
| R superior parietal | 7 | 32 | −70 | 48 | | 3.90 |
| R superior occipital | 7 | 28 | −70 | 38 | | 3.61 |
| R middle frontal | 9 | 38 | 14 | 60 | 167 | 4.67 |
| R precentral | 6 | 46 | −4 | 62 | | 3.84 |
| R middle frontal | 6 | 38 | 4 | 66 | | 3.59 |
| R postcentral | 43 | 60 | −2 | 26 | 111 | 4.17 |
| R inferior frontal | 6 | 52 | 8 | 18 | | 3.16 |
| R middle frontal | 10 | 36 | 54 | 6 | 104 | 3.86 |
| R middle temporal | 21 | 56 | −6 | −20 | 98 | 4.45 |
| *(D) American-Asian: relationship-match* | | | | | | |
| R insula | 48 | 46 | 12 | −10 | 144 | 4.47 |

A maximum of three local maxima at least 8 mm apart are displayed per region of activation, and labels correspond to the peak activated voxel.

Americans, although the cultural differences in middle temporal and postcentral regions were primarily driven by Americans' tendency to deactivate the regions during strategic tasks relative to the control task.[1] Americans engaged several regions to a greater extent than East Asians in the contrast of category-match, including cingulate gyrus, superior temporal pole and middle frontal gyrus. However, only the insula was more engaged by Americans in the contrast of relationship-match, and this resulted primarily from East Asians' deactivation during strategic tasks compared to control.[1] See Figure 3 for representative activations.

Our analysis approach was adopted in light of the substantial similarity in the regions engaged by the relationship and category tasks, as seen in the comparison of Tables 1 and 2. In direct comparisons of the relationship and category tasks across cultures, only one region, the mid-cingulate (peak voxel 12, −18, 32), emerged in the interaction contrast of Asian-American (category-relationship). No additional regions were present for the same subtraction in Americans-Asians. Given the similarity in behavioral performance and neural overlap across tasks, an analysis approach comparing cultural differences in preferred and non-preferred tasks was inappropriate. While a number of regions exhibited apparent cultural differences in the comparison of putatively non-preferred or preferred tasks,[2] highly similar regions emerged across subtractions for both non-preferred and preferred tasks (e.g. right middle frontal gyrus appeared in a subtraction of Asians-Americans for non-preferred tasks: Asian (category-match)-American (relationship-match) as well in a subtraction of preferred tasks: Asian (relationship-match)-American (category-match), with virtually identical peaks

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[1] Results available from the authors.

[2] Results available in Supplementary Table 1.

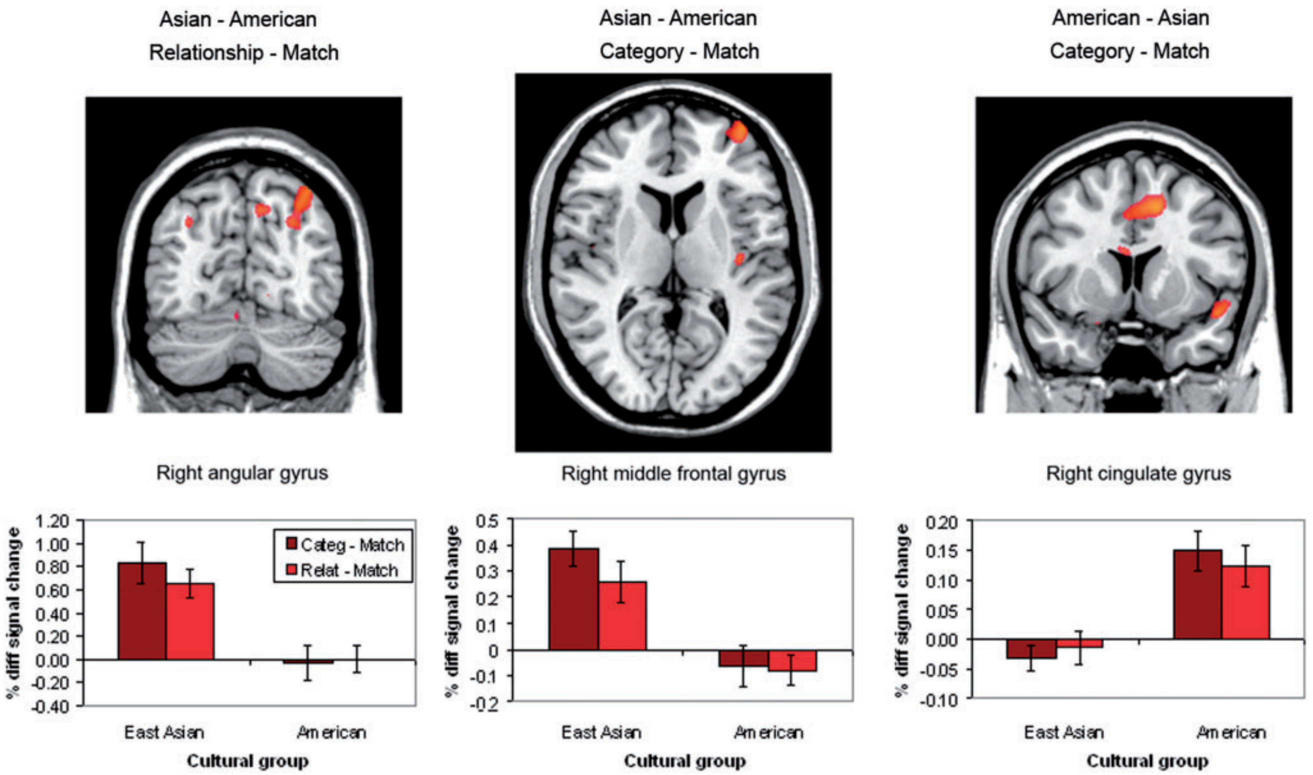

**Fig. 3** Cultural influences on category and relationship judgments. Differences between East Asians and Americans on either the category or relationship task relative to the control match task are depicted for angular gyrus (36, −70, 56), middle frontal gyrus (40, 60, 10), and cingulate gyrus (12, 10, 46). Note that many of the cultural differences extend to both semantic tasks (category and relationship), although are highlighted for the peak for a single condition in the figure.

(38, 14, 60 *vs* 38, 16, 60). This pattern indicates that the observed cultural differences are best thought of as main effects of culture on semantic processing rather than interactions of culture and task preference, a pattern that is also apparent in Figure 3. These findings indicate that cultural differences in categorical and relational processing occurred within the context of more robust cultural differences across strategic tasks compared to the matching control. For example, East Asians engaged angular gyrus and middle frontal gyrus more than Americans in the comparison of category-match as well as relationship-match. The overlap in the regions engaged for both trial types indicates that similar strategies are engaged to resolve both types of semantic conflict, whether it is making a categorical judgment when in conflict with a relational judgment or making a relational judgment when in conflict with a categorical judgment.

In order to further investigate the relationship between brain and behavior, we correlated the activity in selected regions of interest with participants' scores on questionnaire and performance measures.[3] To investigate the potential contribution of language fluency to the pattern of results, we correlated scores on the reading scale with neural activity and found that scores on the reading test were selectively correlated with engagement of right insula (46, 12, −10) for the subtractions of category-match ($r = 0.56$, $p < 0.02$) and relationship-match ($r = 0.54$, $p < 0.02$). East Asians' acculturation scores were negatively related ($r = -0.81$, $p < 0.005$) to the engagement of right middle frontal gyrus (36, 54, 6), indicating that the region was most strongly engaged for participants who identified the least with American values and culture (this relationship remained when language-related items were excluded from the acculturation scale). On the other hand, the right middle frontal region was positively correlated with scores on the self-reliance subscale for Americans for both the category-match judgments ($r = 0.72$, $p < 0.02$) and relationship-match judgments ($r = 0.65$, $p < 0.05$). No additional significant correlations were observed between the questionnaire measures and ROIs.

## DISCUSSION

The present study reveals that, despite many neural similarities, cultural context influences individuals to differentially engage neural regions in order to resolve conflict during semantic tasks. To select the word pair associated either relationally or categorically, both types of semantic connections are likely evaluated. East Asians tended to resolve this conflict by engaging top-down controlled processes, mediated by frontal-parietal networks. Americans engaged

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[3] Activity in ROIs was not significantly correlated with accuracy on category or relationship trials.

regions related to the processing of semantic information, such as temporal lobe regions, as well as some regions relating to top-down conflict detection and monitoring, such as the cingulate gyrus. The finding that each culture displayed a distinct pattern of activation, in addition to a larger set of common activations, indicates that cultural contexts may influence processes related to semantic conflict between taxonomic and thematic representations. The fact that these regions differed across cultural groups, but emerged across the category and relationship trials within a culture, could reflect the fact that each trial included possible responses from both semantic dimensions. Thus, both modes of processing were likely activated within a given trial; what differs is presumably how each culture copes with overcoming that conflict.

This similarity in activation across tasks may reflect the task design, in which both the relational and categorical conditions contained distracting stimuli that likely invoked semantic processing of the opposing type. As found in the comparison of both strategy-based tasks (category and relationship) to control (match) trials, cultural groups differ in the way that they respond to the presence of semantic conflict in the task. Furthermore, the use of a block design prevented the separate examination of correct and erroneous trials, which could have masked some potential cultural differences. However, given the constrained nature of the stimulus set and the corresponding limitation on the number of possible trials, a block design was necessary to maximize our power to detect potential group differences in BOLD signal (Birn *et al.*, 2002).

Cultural differences in the engagement of distinct neural regions suggest that East Asian and American individuals differed primarily in the engagement of domain-specific processes. This is in contrast to previous results identifying cultural differences primarily in domain-general processes. A study examining perceptual judgments with this same sample revealed that culturally non-preferred strategies engaged top-down control and executive processes (Hedden *et al.*, 2008; Nan *et al.*, 2008), subserved by a frontal-parietal network (Corbetta and Shulman, 2002; Wager and Smith, 2003; Collette *et al.*, 2006), more than culturally preferred strategies. In the present study, making strategic decisions about categorical or relational semantic information (when in direct conflict with the other type of judgment) engaged this network robustly across both cultural groups. Indeed, a striking finding is the remarkable extent of overlap between the two kinds of semantic conflict task across groups, as can be readily seen in Figure 2. However, differences did emerge in the engagement of this network across cultures, not between type of semantic conflict task, but rather between either types of semantic conflict *vs* simple matching. East Asians activated a region of Brodmann's area (BA) 7 with a peak in the angular gyrus for both category and relationship judgments more than Americans. Superior parietal cortex (BA 7), where the peak of our angular gyrus activation lies, emerged in a meta-analysis as a region consistently implicated in executive processes across a range of tasks (Wager and Smith, 2003). A number of frontal regions contributed to executive function (Wager and Smith, 2003; Badre and Wagner, 2004) including regions in BA 9, 46 and 10, which differed across cultures in the present study. These results underscore the contribution of selective attention and executive function to the ability to select an appropriate strategy to make semantic judgments while inhibiting other types of semantic information. However, note that some regions typically implicated in semantic competition, such as left inferior prefrontal cortex (Thompson-Schill and Botvinick, 2006; Badre and Wagner, 2007) did not differ between cultures. In terms of cultural differences, regions similar to our findings, including the insula, middle frontal and angular gyri, also emerged during the processing of unfamiliar styles of Eastern music compared to familiar Western styles (Nan *et al.*, 2008). These regions responded to the high selective attention demands of processing unfamiliar music, further suggesting that these regions are recruited for demanding tasks that require controlled processing. Future studies that explicitly manipulate the demands to resolve semantic competition will be necessary to fully characterize the nature of cultural differences in these processes.

In addition to the focus on perceptual versus semantic contexts, one crucial difference between the current design and that of Hedden and colleagues (2008) that could explain our finding that cultural differences were no stronger for non-preferred tasks compared to preferred tasks (e.g. preferred relationship competing with non-preferred category for Americans), lies in the control, or baseline, condition used in each experiment. In Hedden *et al.* (2008), the baseline included stimuli for which the same response was correct when using both preferred and non-preferred strategies for each culture; hence, the two response rules were congruent with one another but, crucially, the baseline condition invoked processing of the same response rules invoked in the experimental condition. In the current study, the baseline (match) condition involved stimuli that entirely removed the semantic processing requirement present in the experimental conditions and instead required a judgment on the basis of perceptual identification. This may have contributed substantially to the overarching similarity between the category and relationship conditions relative to baseline in this study, despite the fact that both studies used stimuli in the experimental conditions that invoked conflict between preferred and non-preferred rule sets. As this account would suggest, we found that category and relational judgments differed little in the neural regions engaged but that differences across cultures emerged for both tasks, indicating that the precise demands of the specific task may be less important than the comparison of multiple semantic dimensions on each trial.

To further examine this possibility, we explored activation in the current task within a mask based on the 11 ROIs identified in the study by Hedden and colleagues (2008) as regions that exhibited responses to task conflict in their interaction analysis of culture × task × difficulty. When applied to the current data, activation was observed in these ROIs within both cultures for both strategic semantic tasks relative to the match condition; however, activation in these ROIs did not differ across cultures. This supports the findings of Hedden and colleagues (2008) in that the same regions are invoked by both cultures in a domain-general manner (e.g. during semantic conflict), but suggests that the inability of the present task to separate semantic conflict from semantic processing in the *absence* of conflict may have limited our ability to elicit cultural differentiation in these regions. These findings also correspond to the work of Sachs *et al.* (2008a), who found overlapping activations during the processing of taxonomic (categorical) or thematic (relational) semantic relationships when participants engaged in one of the processes but did not need to inhibit the other process.

In addition to the contribution of the angular and middle frontal gyrus as part of an attentional network, the regions have specific functions within the domain of semantic knowledge (Binder *et al.*, 2009). The angular gyrus contributes to the integration of information and concept retrieval (Binder *et al.*, 2009); in terms of semantic interference, it is engaged during inhibition of alternate meanings of homophones (Hoenig and Scheef, 2009). Middle frontal gyrus has been associated with tasks requiring more extensive search of lexical or categorical knowledge during semantic tasks (Grabowski *et al.*, 1998; Kotz *et al.*, 2002), consistent with our postulation that the region responds to conflict between competing semantic representations. The correlation of the right middle frontal gyrus with acculturation scores for the East Asian sample could reflect the extent of competition present between distinct sets of lexical knowledge. The precise contribution of the distinct subregions of middle frontal gyrus, and the ways in which cultures differ in the underlying processes, requires further exploration in future studies. Regions of middle frontal gyrus emerged prominently across multiple comparisons, with East Asians engaging regions of BA 9, 6 and 10 more than Americans, but Americans activating a region in BA 46 more than East Asians. Overall, the tendency for East Asians to engage these regions more than Americans suggests that the cultures differ in their preferred strategies for dealing with conflict, with East Asians possibly engaging in an effortful strategy to inhibit irrelevant information.

The Americans, on the other hand, may respond more to the conflict between the content of competing representations. Americans engaged the cingulate more than East Asians during strategic tasks, although this cultural difference only reached significance for the comparison of category-match. The cingulate responds under conditions of lexical and semantic ambiguity and during the successful selection of relevant semantic relationships (Copland *et al.*, 2007; Sass *et al.*, 2009). The activation in our study likely reflects the controlled demands of the selection task, with Americans attending to the diverging content of the semantic relationships of the word pairs. Americans also tended to activate the right temporal pole and to deactivate middle temporal gyrus during relationship judgments. These regions are strongly implicated in conceptual and semantic knowledge, contributing to the integration and retrieval of concepts (Binder *et al.*, 2009). The temporal poles contribute to the access of semantic knowledge (Lambon Ralph *et al.*, 2009) and left middle temporal cortex is involved in the storage of properties and features of objects (Martin, 2007). Cultural differences in the engagement of middle temporal gyrus have been identified during consideration of object properties (Gutchess *et al.*, 2006a). The emergence of this region is consistent with the idea that conflict may arise for Americans during the consideration of specific semantic relationships, rather than at the level of strategy selection.

In addition to the specific locations of activation differences, the overwhelmingly right-lateralized pattern of activity for cultural differences (see Tables 1, panels B and C, and 2) could reflect the effects of task difficulty. Whereas semantic and language-based tasks tend to predominantly engage left hemisphere regions (Martin, 2007; Binder *et al.*, 2009; Mahon and Caramazza, 2009), the cultural differences observed here emerged primarily in the right hemisphere. Two lines of evidence support the claim that right hemisphere regions can be recruited in response to cognitively demanding situations. Previous studies have interpreted the emergence of a right lateralized network during the processing of taxonomic categories as reflecting greater task effort (Kotz *et al.*, 2002; Sachs *et al.*, 2008a, b). In addition, Western-trained musicians activated several right-hemisphere regions, including ones overlapping with regions observed in the current study, when processing unfamiliar Eastern music compared to familiar Western music (Nan *et al.*, 2008). The convergence between regions implicated in the processing of unfamiliar music and our results indicate that these right-hemisphere regions are engaged when less familiar modes of processing require more effort.

One caveat is that these results could reflect the contribution of language rather than of cultural differences in modes of thought. While language is a large component of culture and can shape thought to some extent (Boroditsky, 2001; Ji *et al.*, 2004), culture encompasses other factors that do not rely on language, such as attentional lenses, strategies for information processing, and the concept of oneself, particularly in relation to others. Because the tasks in the present study draw on semantic knowledge, which is heavily based in language, the tendency for East Asians to engage more regions for both category and relationship judgments could reflect the fact that this sample was tested in their non-native language and thus experienced greater difficulty. However, the activity of only a single region, the right insula, was correlated with a measure of reading proficiency, indicating that language fluency is not likely a major contributor to the engagement of widespread neural regions. In addition, behavioral performance (including RTs, which might reflect speed of semantic accessibility) did not differ across the groups, contradicting an explanation that the results solely reflect language proficiency, although this pattern does not preclude the possibility that the cultural groups relied on distinct strategies. Another consideration is the fact that the majority of the East Asian participants were native speakers of character-based languages, which tend to engage right hemisphere regions to a greater extent than do English or other alphabetical languages (Tan *et al*., 2001; Dong *et al*., 2005). Although we cannot rule out these possibilities, previous research suggests that neural activations differ relatively little across testing languages, particularly when participants have a high level of English fluency, as would be true of our sample drawn from a selective college in the USA (Chee *et al*., 2000; Fu *et al*., 2002; Perani and Abutalebi, 2005). In addition, the heterogeneity of our East Asian sample, drawn from multiple nationalities with different linguistic backgrounds, likely reduced the contribution of native language to neural activation patterns. While further research is needed to disentangle the contributions of language and culture to neural activation patterns, Ji and colleagues (2004) found that preferences for category or relational strategies extended across testing languages and multiple testing environments, although the testing language may reduce the magnitude of cultural differences in some cases.

The lack of cultural differences in behavioral performance is also surprising, given the results of previous studies (Chiu, 1972; Ji *et al*., 2004). It is possible that the emphasis on speed during the time-limited trials, the blocked design, or the use of verbal, as opposed to pictorial, stimuli impacted participants' performance, although we did find a stronger relationship between RTs and accuracy for the Americans than the East Asians on the category trials, indicating the Americans' greater relative ease with this trial type. Notably, individual difference measures related to cultural identity, acculturation measures for the East Asian participants and a self-reliance subscale emphasizing independence for Americans, correlated with the engagement of right middle frontal gyrus, indicating that neural activity is related to specific dimensions of cultural identity. Moreover, previous studies have also identified cultural differences in neural activity in the absence of behavioral differences (e.g. Gutchess *et al*., 2006a; Hedden *et al*., 2008), suggesting that neural measures may be more sensitive than behavioral measures. Another advantage is that cultural differences in brain activity, thought to reflect differences in strategy or required effort, can to be interpreted in light of equivalent behavioral performance, rather than potentially reflecting differences in task performance.

In conclusion, our results are consistent with findings of cultural differences in higher-order processes, such as attentional modulation, reported in some other studies of neural differences across cultures (see reviews by Han and Northoff, 2008 and Ketay *et al*., 2009). We observed that similar regions associated with executive control were engaged across cultures during semantic processing. However, when cultural differences were observed, they were present in neural regions distinct to each cultural group, with East Asians activating frontal-parietal regions indicating executive control and selective attention and Americans engaging the cingulate and temporal regions, perhaps indicating selection and conflict monitoring corresponding to the content of semantic information. One of the most striking findings was the overwhelming extent of common areas of activation related to difficult semantic judgments, such that the cultural differences must be considered in the context of cultural commonalities. Nevertheless, the present results suggest that culture can influence the regions engaged during semantic processes, likely reflecting the approach that individuals from a particular cultural background adopt to resolve conflict between simultaneous semantic representations.

## SUPPLEMENTARY DATA

Supplementary data are available at *SCAN* online.

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