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Culturally non-preferred cognitive tasks require compensatory attention: A functional near infrared spectroscopy (fNIRS)investigation

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Culturally non-preferred cognitive tasks require compensatory attention: a functional near infrared spectroscopy (fNIRS) investigation

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Abstract Previous work shows that as compared to European Americans, Asians are more holistic (or less focused) in perceptual processing. Drawing on this evidence, we expected that extra attention control would be recruited to perform focused processing for Asians and holistic processing for European Americans. Eight Asian American and 13 European American young adults judged whether a given framed-line was the same in length as the framed-line shown on the previous trial on the basis of either an absolute or relative criterion. Their brain activities were monitored with functional near infrared spectroscopy. As predicted, Asian Americans showed an increased activation in the parietal regions during the absolute (vs. relative) task, whereas European Americans showed an increased activation in the same regions during the relative (vs. absolute) task. No comparable pattern was observed for performance. The current work provides further evidence for compensatory attention that is engaged during culturally non-preferred tasks.

Keywords Culture · Framed-line task · Holistic vs. analytic attention · fNIRS

Previous research shows that individuals with varying cultural backgrounds exhibit divergent patterns of cognitive and perceptual processing (Nisbett et al. 2001). Specifically, individuals from East Asian cultures are more holistic in attention.

When looking at a focal object, they tend to attend holistically to a larger context in which the object is embedded. In contrast, those from European American cultures are more analytic. Their attention is more narrowly focused on the focal object and they are thus relatively oblivious to a larger context that surrounds the object. It has been theorized that this perceptual difference stems from a broader cultural difference in social orientation (Markus and Kitayama 1991; Varnum et al. 2010). East Asians tend to be more interdependent and, as a consequence, they are likely to be more attentive to the social context, whereas European Americans tend to be more independent and, as a consequence, they are likely to be more attentive to specific objects that are relevant to their personal goals and concerns. These social differences are considered to extend to non-social perceptual domains.

The effect of culture on attention has been demonstrated with several different methodologies. Masuda and Nisbett (2001) presented participants with animated vignettes of naturalistic scenes (e.g., an underwater scene with fish swimming) and asked them to recall what they saw in each scene. They observed that East Asians remembered contextual information both earlier and better than European Americans did. In another study, participants were shown slightly different versions of the same scenery (e.g., an airport scene with different buildings and planes) and asked to detect the differences between the scenes. As may be expected, East Asians were more sensitive than European Americans to the differences that existed in the context (Masuda and Nisbett 2006). Still another study showed a comparable cultural difference in the patterns of eye movement. East Asians tend to show more saccades to the background of a naturalistic scene as compared to European Americans, who tend to show saccades more focused on the central, focal object (Chua et al. 2005). Further evidence for the thesis that, as compared to Asians, European Americans are perceptually more focused on a central object comes from a recent event-related potential (ERP) study (Kitayama and Murata 2013). In this study, participants were asked to detect an infrequent target (i.e., a coffee mug of a distinct color in the background of a naturalistic scene) in an oddball paradigm while their brain activity was monitored with electroencephalogram (EEG). An ERP component indicative of focused attention to the detected target (late positivity or slow wave) was more pronounced for European Americans than for Asians.

The cultural difference in holistic attention has also been demonstrated with geometric configurations as stimuli. In a series of studies, Kitayama et al. (2003, 2009) presented participants with a vertical line embedded in a square frame and asked them to draw a vertical line in a new blank square frame of varying size. The participants were told that the line must be identical to the first line in terms of either absolute length (absolute task) or its proportion to the frame size (relative task). The absolute task requires the participants to ignore the square frame while attending to the focal line, whereas the relative task requires them to take into account the size of the square frame. This test (called the framed line test, or FLT) enables the researcher to examine the relative ease of ignoring or incorporating contextual information in the judgment of line length. As may be predicted from the hypothesis that Asians are more holistic compared to European Americans, East Asians are more accurate in the relative task than in the absolute task, but this difference is either reversed (Kitayama et al. 2003) or eliminated (Kitayama et al. 2009) i n European Americans.

The hypothesis that culture influences the relative ease of either ignoring or incorporating contextual information in perceptual judgment has also received support in a functional magnetic resonance imaging (fMRI) study by Hedden et al. (2008). Both East Asian and European American participants performed a modified FLT while their brain activities were monitored. Unlike the original FLT (Kitayama et al. 2003), which involved the reproduction of a line embedded in a blank square of different sizes, Hedden et al. used a matching version of FLT, which involved matching judgments of consecutively presented framed-lines in terms of either the absolute or relative criterion. Hidden et al. found no performance difference in terms of either accuracy or response time across the two cultural groups. Importantly, however, the pattern of brain activity indicative of attention control depended on both task type and culture. They observed a substantial increase of neural activity in the bilateral frontal and parietal regions of the brain during the culturally non-preferred task, namely, during the absolute task for Asian participants and the relative task for European American participants, respectively. The frontal and parietal regions are thought to mediate cognitive control over working memory and attention (Badre and Wagner 2004; Smith and Jonides 1999; Wager and Smith 2003). Accordingly, the evidence suggests that the culturally non-preferred tasks required compensatory engagement of sustained attentional control to achieve the same degree of behavioral performance.

The Hedden et al. (2008) study suggests that cultural influences extend to specific brain mechanisms involved in perceptual processing. Given the paucity of such investigations in this area, we decided to replicate and extend Hedden et al.'s (2008) findings by using a different brain imaging method, functional near-infrared spectroscopy (fNIRS). fNIRS measures changes in hemodynamic response, specifically oxy- (HbO) and deoxy-(Hb) species of hemoglobin (Hoshi et al. 2001; Villringer and Chance 1997; Kovelman et al. 2009). When a brain region is activated and thus oxygen is consumed, the supply of oxygenated blood to the region increases so as to compensate for the oxygen consumption at the region. Thus, the relative increase of oxygenated hemoglobin concentrations in the region (as indexed by HbO) is a reliable indicator of the activity of the region. Unlike HbO, the deoxygenated hemoglobin concentrations (Hb) tend to remain relatively stable. fNIRS has several advantages in its cost, portability, and greater ecological validity. Whereas fMRI requires more restrictive positions for participants to be scanned, fNIRS allows normal upright postures with negligible physical/motor constraints. Given previous evidence documenting close relations between body posture and vertical perception (Bohmer et al. 1996; Riccio et al. 1992), it would seem particularly desirable to repeat the matching version of the FLT procedure (which involves the size judgment of vertical lines) with fNIRS. One weakness of fNIRS is its relatively crude spatial resolution of 2–3 cm and its limitation to cortical measurements. However, the reduced spatial resolution does not affect our study as our regions of interest extend broadly to both frontal and parietal cortices, encompassing both the middle frontal gyrus and spatially extensive regions of the inferior parietal lobule (Hedden et al. 2008).

Method

Participants

Eight Asian American (3 female, 5 male; mean age 20.8, range 19–27) and 13 European American (8 female, 5 male; mean age 29.6, range 18–23) undergraduate students at the University of Michigan participated in the experiment. Written informed consent was obtained from each participant after the nature of the study had been fully explained. All participants were right-handed and had normal or corrected-to-normal vision. No participant reported any prior histories of neurological or psychiatric disorders, and none were using medication at the time of testing. The treatment of all participants and experimental procedures were in full compliance with the ethical guidelines of the Institutional Review Boards of the University of Michigan Medical School.

Procedure and stimuli

Upon arrival in the lab, participants were seated in a comfortable chair in a dimly lit room. After the experimenter provided general instructions for the task and described the fNIRS recording procedure, the 36-channel fNIRS probe-set was placed on the participant's head. Participants were then asked to perform a blocked-design FLT adapted from Hedden et al. (2008). The presentation of stimuli and the recording of behavioral responses were controlled by E-prime software (Psychology software Tools, Inc.). Each stimulus was presented on iMac "Core 2 Duo" 3.06 (2009 model) with a 27-inch screen placed 60 cm in front of the participants.

The experiment began with a 33-s lead-in-time, during which the physiological baseline of each participant's hemodynamic response was recorded. Participants were then given instructions for the absolute and relative tasks. They were told that they would be shown a series of lines embedded in square frames. In the absolute task, participants were to judge whether the stimulus line matched the line shown on the previous trial in terms of the absolute length. They were to ignore the squares that surrounded the stimulus lines. In the relative task, participants were to judge whether the square and line combination of each stimulus matched the proportional scaling of the preceding combination. They were given several practice trials for each task. Next, they performed four sessions of FLT in a counter-balanced order (either absolute → relative → absolute → relative or relative → absolute → relative → absolute).

Each session consisted of eight blocks with five trials in each, resulting in a total of 40 trials per session. At the beginning of each session, participants were told which judgment criterion (absolute or relative) they were to use in the session. Each of the eight blocks included in the session began with the presentation of a fixation point (a white circle) for 15 s. Participants were then presented with a series of five framed-lines. Each framed-line was presented for 1 s, with an inter-stimulus interval of 3 s. Participants were asked to observe the first framed-line. In the next trial, they were to judge whether a given framed-line was the same or different from the immediately preceding one on the basis of either the absolute or relative criterion.

The stimuli included square frames of four different sizes (2.3, 3.0, 3.8, 4.6 cm) that surrounded a line that varied in length relative to the height of each frame (23, 37, 67, 87 %).

Two of the four framed-lines were the same as the preceding ones, while the remaining two were different from the latter, in accordance with the pertinent judgment criterion (see Fig. 1 for sample trials). The same and different framed-lines were presented in a quasi-random order. Participants reported their matching judgment by pressing either the "F" key with the left index finger or the "J" key with the right index finger. The assignment of the keys to the "same" and "different" responses was randomized across participants. Each session lasted a maximum of 5 min. Participants were given a short break between sessions.

fNIRS data acquisition and analyses

Participants' hemodynamic responses were recorded using a Hitachi ETG-4000 with 36 channels (Hitachi Medical Co., Tokyo, Japan). The lasers were factory set to 690 and 830 nm, and the inter-optode distance was 3 cm. The sampling rate was set at 10 Hz. There was a total of three probe-holders. Each probe-holder contained 5 lasers and 4 detectors arranged into a 3 × 3 array corresponding to 12 channels (Fig. 2; see also Kovelman et al. 2009 for more detailed description of the apparatus, imaging and analytical procedures). Once the participant was comfortably seated, one probe-holder was placed in the center of the frontal lobe. The remaining two probe-holders were placed on the left and right parietal sides of the participant's head, respectively, following the 10/10 system. The probe-holders were anchored at the Fpz frontal coordinate and at the T7/T8 temporal 10–10 coordinates, respectively. Fpz was located at the middle frontal gyrus (Brodman's

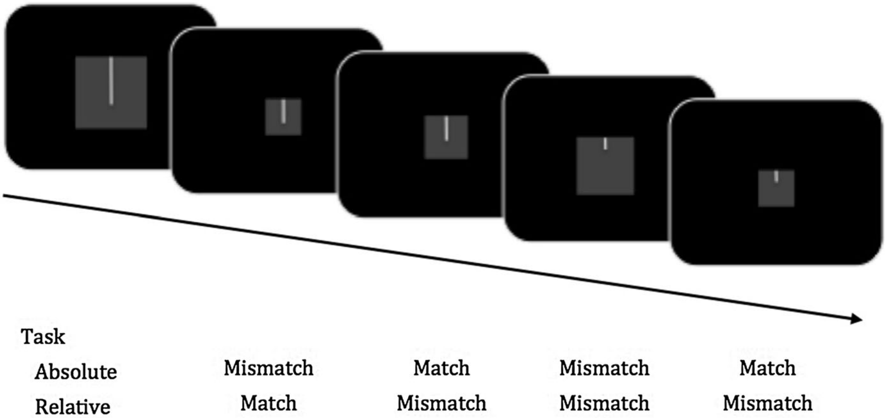


Fig. 1 Examples of stimuli used in the FLT. Each stimulus consisted of a *white line* embedded in a *gray square*. In the absolute task, participants judged whether the line in the current stimulus matched the line in the most recently presented line in terms of absolute length; in the relative task, participants judged whether the line-to-square proportion matched the proportion in the most recently presented stimuli, regardless of the size of the *square*

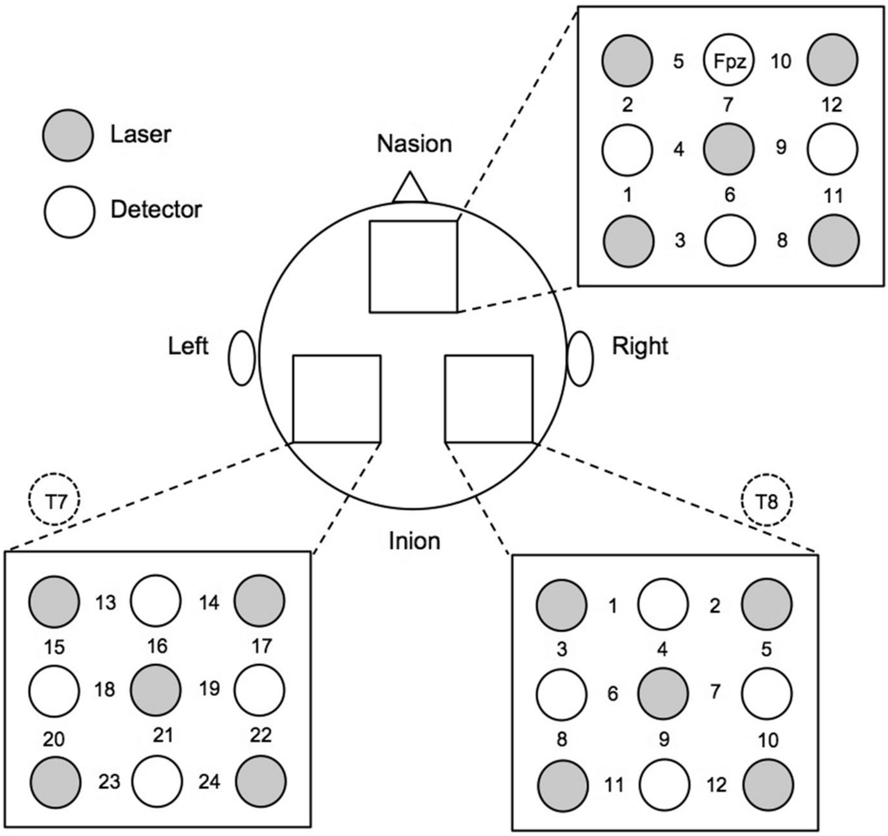


Fig. 2 Location of the optodes placed in the frontal and parietal areas in both hemispheres. The distance between each laser and the corresponding detector was set at 3 cm. Fpz was located between channel 5 and 10. T7/T8 positions, at 3 cm to the front of the bottom row of optodes, served as anchor points for the *left* and *right* 3 × 3 optode arrays

area: BA 10) and the channels in the frontal probe-holder were placed over the frontal gyrus. T7/T8 was located at the superior temporal gyrus (BA 22) and the channels in the parietal probe-holders were placed over the inferior parietal lobule (BA 40) (cf. Okamoto et al. 2004). Digital photographs were taken of the array positioning prior to and after the recording session to record any changes in the array positioning during testing.

The fNIRS data were exported and analyzed with MATLAB-based software developed by Drs. Mark Shalinsky and Laura-Ann Petitto.[1] The software operates in line with diffuse optical imaging principles (Boas et al. 2004; Huppert et al. 2009), and has been validated in previous fNIRS studies (e.g., Kovelman et al. 2009, 2011, 2012, 2014; Shalinsky et al. 2009). fNIRS data was then high-pass

[1] We thank Dr. Laura Ann Petitto for making this software available to us, for details see Kovelman et al. 2009).

filtered at 0.5 Hz to remove physiological noise (especially heart rate). Each participant's hemodynamic response was baseline-corrected by subtracting the mean intensity of the optical signal recorded during the 15 s from the overall hemodynamic activity. The modified Beer-Lambert equation (mBL; Delpy et al. 1988) was used to convert wavelength data to oxy- and deoxy-hemoglobin concentrations (designated as HbO and Hb, respectively, see Huppert et al. 2009, for details). Following the conversion, the time course data (all channels, all conditions) for each participant were plotted in Matlab and visually inspected for motion artifacts and signal quality; blocks containing signal changes that occurred too rapidly to be physiological (3 s or less) were removed across all channels from further analyses. We included all channels in the analyses for all participants. Finally, the peak HbO and minimum Hb signal intensity value for each task was calculated for each participant. As an estimation of cerebral blood volume, the percentage signal of HbO and Hb was then calculated (see Kovelman et al. 2009 for more details).

To investigate cultural differences in the HbO activation across the two tasks, we conducted 2 Culture (Asian American vs. European American) × 2 Task (Absolute vs. Relative) repeated-measures analysis of variance (ANOVA)s on the peak HbO value for each of the 36 channels tested, with one between-subjects factor (Culture) and one within-subjects factor (Task). To confirm that HbO activation occurred relative to the corresponding Hb level, we conducted pairwise t-tests on the HbO versus Hb values for each significant region of interest (ROI), cultural group, and task.

Results

Behavioral data

A culture × task ANOVA on response time showed a main effect of Culture, $F(1, 19) = 8.69$, $p < 0.01$, $\eta_p^2 = 0.31$. Consistent with the patterns found in previous cross-cultural work (e.g., Kitayama and Park 2014; Kitayama et al. 2003; Masuda and Nisbett 2001), Asian Americans responded faster ($M = 790.3$ ms, $SE = 85.8$) than European Americans ($M = 1111.9$ ms, $SE = 67.3$). This cultural difference, however, was not dependent on task type. The analysis on accuracy revealed a significant main effect of Task, $F(1, 19) = 11.95$, $p < 0.01$, $\eta_p^2 = 0.39$, indicating a higher accuracy for the relative task than the absolute task (*M*s = 80.0 % and 66.6 %, *SE*s = 4.7 and 4.2 for the relative and absolute tasks, respectively). This was the case for both cultural groups. No other effect approached statistical significance, *F*s < 2.5.

fNIRS data

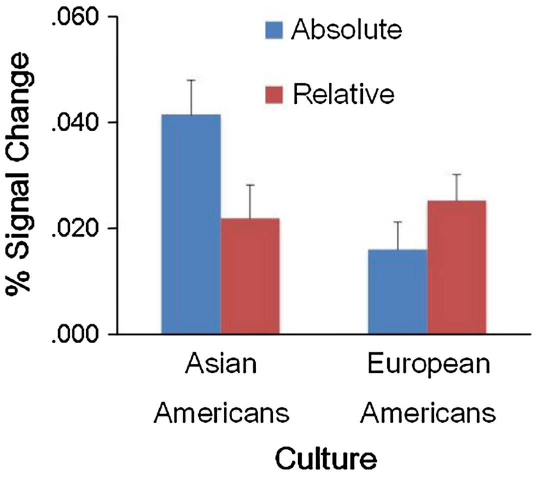
Table 1 shows the peak HbO means from all 36 channels. The peak HbO value for each channel was submitted to a 2 culture × 2 task ANOVA. The analysis revealed a significant interaction between culture and task in eight channels in the bilateral

Table 1 Mean percent signal change of HbO for each channel in the absolute and the relative tasks for Asian Americans and European Americans

Task	Asian American		European American		Culture × task interaction
	Absolute Mean (SE)	Relative Mean (SE)	Absolute Mean (SE)	Relative Mean (SE)	*F*
Frontal channel 1 (BA8/9)	0.029 (0.191)	0.015 (0.284)	0.213 (0.152)	0.306 (0.227)	0.784
Frontal channel 2 (BA9)	0.019 (0.084)	0.028 (0.059)	0.122 (0.067)	0.100 (0.047)	0.746
Frontal channel 3 (BA8)	0.025 (0.006)	0.019 (0.008)	0.018 (0.005)	0.020 (0.006)	1.380
Frontal channel 4 (BA9)	0.021 (0.006)	0.017 (0.007)	0.018 (0.005)	0.021 (0.005)	0.985
Frontal channel 5 (BA10)	0.020 (0.010)	0.037 (0.010)	0.036 (0.008)	0.042 (0.008)	0.831
Frontal channel 6 (BA8/9)	0.024 (0.007)	0.023 (0.008)	0.019 (0.006)	0.020 (0.006)	0.048
Frontal channel 7 (BA9/10)	0.025 (0.009)	0.030 (0.010)	0.031 (0.007)	0.036 (0.008)	0.002
Frontal channel 8 (BA8)	0.020 (0.005)	0.019 (0.009)	0.017 (0.004)	0.018 (0.007)	0.084
Frontal channel 9 (BA9)	0.047 (0.017)	0.049 (0.017)	0.019 (0.013)	0.024 (0.014)	0.154
Frontal channel 10 (BA10)	0.020 (0.011)	0.026 (0.010)	0.031 (0.009)	0.033 (0.008)	0.035
Frontal channel 11 (BA8/9)	0.023 (0.441)	0.019 (0.800)	0.465 (0.352)	0.830 (0.638)	0.644
Frontal channel 12 (BA9)	0.031 (0.022)	0.028 (0.018)	0.052 (0.018)	0.054 (0.015)	0.132
Right channel 1 (BA40)	0.030 (0.006)	0.019 (0.007)	0.019 (0.005)	0.020 (0.006)	2.509
Right channel 2 (BA22)	0.046 (0.006)	0.022 (0.008)	0.016 (0.005)	0.031 (0.006)	22.314**
Right channel 3 (BA40)	0.011 (0.006)	0.017 (0.007)	0.016 (0.005)	0.018 (0.005)	0.284
Right channel 4 (BA22/21)	0.038 (0.007)	0.019 (0.007)	0.015 (0.005)	0.021 (0.006)	8.097**
Right channel 5 (BA22)	0.029 (0.007)	0.021 (0.008)	0.016 (0.006)	0.021 (0.006)	1.442
Right channel 6 (BA22)	0.018 (0.006)	0.018 (0.007)	0.015 (0.005)	0.20 (.0005)	0.251
Right channel 7 (BA21)	0.034 (0.007)	0.024 (0.006)	0.017 (0.005)	0.027 (0.005)	5.094*
Right channel 8 (BA39)	0.012 (0.007)	0.017 (0.005)	0.014 (0.006)	0.021 (0.004)	0.011
Right channel 9 (BA21)	0.018 (0.006)	0.019 (0.007)	0.020 (0.005)	0.027 (0.005)	0.309
Right channel 10 (BA37)	0.011 (0.005)	0.029 (0.008)	0.017 (0.004)	0.025 (0.006)	0.929
Right channel 11 (BA39)	0.016 (0.008)	0.015 (0.007)	0.027 (0.006)	0.028 (0.006)	0.068
Right channel 12 (BA37)	0.021 (0.005)	0.023 (0.008)	0.022 (0.004)	0.031 (0.007)	0.343
Left channel 13 (BA22)	0.051 (0.009)	0.041 (0.010)	0.022 (0.007)	0.036 (0.008)	3.069
Left channel 14 (BA40)	0.040 (0.007)	0.017 (0.007)	0.015 (0.006)	0.025 (0.006)	14.353**
Left channel 15 (BA22)	0.044 (0.007)	0.029 (0.007)	0.014 (0.006)	0.024 (0.006)	6.127*
Left channel 16 (BA22/21)	0.047 (0.008)	0.022 (0.007)	0.014 (0.006)	0.024 (0.005)	8.144*
Left channel 17 (BA40)	0.035 (0.010)	0.015 (0.009)	0.018 (0.008)	0.022 (0.007)	4.808*
Left channel 18 (BA21)	0.036 (0.006)	0.033 (0.008)	0.016 (0.005)	0.027 (0.006)	2.293
Left channel 19 (BA22)	0.048 (0.010)	0.023 (0.008)	0.016 (0.008)	0.016 (0.008)	3.946
Left channel 20 (BA37)	0.051 (0.013)	0.032 (0.009)	0.016 (0.010)	0.021 (0.007)	0.936
Left channel 21 (BA21)	0.054 (0.008)	0.027 (0.007)	0.018 (0.006)	0.025 (0.006)	6.117*
Left channel 22 (BA39)	0.026 (0.007)	0.012 (0.009)	0.017 (0.006)	0.018 (0.007)	3.426
Left channel 23 (BA37)	0.045 (0.011)	0.030 (0.007)	0.014 (0.008)	0.018 (0.005)	1.154
Left channel 24 (BA39)	0.037 (0.008)	0.016 (0.006)	0.026 (0.006)	0.024 (0.006)	2.635

Two-way ANOVAs * $p < 0.05$, ** $p < 0.01$

Fig. 3 Mean percent signal changes during the absolute and the relative task from the eight parietal channels in which the Culture × Task interactions were significant (channel 2, 4, 7, 14, 15, 16, 17, and 21). *Error bars* indicate standard errors



parietal regions (Right channels 2, 4, 7 and Left channels 14, 15, 16, 17, 21).[2] When the same analysis was performed on the minimal value of Hb from all the channels, the culture × task interaction did not prove significant in any channel.

To understand the overall pattern of the culture × task interaction across these eight channels, the peak HbO values from these eight channels were collapsed to yield the mean peak HbO value for each task. These means were submitted to a 2 culture × 2 task ANOVA. As expected, a significant culture × task interaction was observed, $F(1, 19) = 22.89$, $p < 0.00$, $\eta_p^2 = 0.55$. European Americans showed greater activity during the relative task than during the absolute task, $F(1, 12) = 10.64$, $p < 0.01$, $\eta_p^2 = 0.47$. In contrast, Asian Americans showed greater activity during the absolute task than during the relative task, $F(1, 7) = 9.86$, $p < 0.05$, $\eta_p^2 = 0.59$. This pattern is illustrated in Fig. 3. As can be seen, the cultural difference was significant in the absolute task, with Asian Americans showing greater activity than European Americans, $F(1, 19) = 11.03$, $p < 0.01$, $\eta_p^2 = 0.37$. There was no significant cultural difference in the relative task.

To validate the observed change in hemodynamic response for the eight critical channels where a significant culture × task interaction was observed, we examined whether the peak HbO was in fact higher than the minimum Hb change. The peak HbO value and the minimum HbO value were statistically compared through pair-wise t-tests for each of the eight channels. As shown in Table 2, the peak HbO value was significantly greater than the minimum Hb value in all eight channels ($p < 0.05$). In addition, we visually inspected the hemodynamic response for each of the eight channels. Figure 4 shows a representative pattern of hemodynamic change. Specifically, it shows the block average of HbO and Hb time course for hemodynamic response across participants and conditions in Left channel 21. The HbO concentration level began to increase several seconds after the onset of each

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[2] Because the data collection of the frontal brain region was unsuccessful from three participants (one Asian American and two European American participants), the data from 18 participants were analyzed for the brain activity in this region.

Table 2 Mean percent signal change for eight channels (channel 2, 4, 7, 14, 15, 16, 17, and 21) in the absolute and the relative tasks for Asian Americans and European Americans

Culture	Asian American						European American					
Task	Absolute			Relative			Absolute			Relative		
	HbO Mean (SE)	Hb Mean (SE)	t	HbO Mean (SE)	Hb Mean (SE)	t	HbO Mean (SE)	Hb Mean (SE)	t	HbO Mean (SE)	Hb Mean (SE)	t
Channel 2	0.046 (0.008)	−0.024 (0.010)	4.307**	0.022 (0.010)	−0.014 (0.004)	3.692**	0.016 (0.004)	−0.007 (0.002)	4.505**	0.031 (0.005)	−0.010 (0.003)	6.197**
Channel 4	0.038 (0.010)	−0.022 (0.010)	3.455*	0.019 (0.007)	−0.014 (0.004)	3.386*	0.015 (0.003)	−0.006 (0.002)	5.696**	0.021 (0.006)	−0.008 (0.003)	5.909**
Channel 7	0.034 (0.009)	−0.021 (0.009)	3.639**	0.024 (0.006)	−0.015 (0.007)	3.068*	0.017 (0.004)	−0.011 (0.005)	5.094**	0.027 (0.005)	−0.014 (0.005)	7.077**
Channel 14	0.040 (0.008)	−0.019 (0.009)	3.495*	0.017 (0.004)	−0.019 (0.006)	4.193**	0.015 (0.005)	−0.010 (0.002)	4.605**	0.025 (0.007)	−0.010 (0.003)	4.696**
Channel 15	0.044 (0.011)	−0.017 (0.008)	3.988**	0.029 (0.009)	−0.028 (0.009)	3.362*	0.014 (0.003)	−0.014 (0.004)	6.03**	0.024 (0.005)	−0.016 (0.005)	6.857**
Channel 16	0.047 (0.013)	−0.024 (0.010)	3.443*	0.022 (0.005)	−0.018 (0.007)	3.989**	0.015 (0.002)	−0.012 (0.003)	7.536**	0.024 (0.006)	−0.014 (0.004)	4.916**
Channel 17	0.035 (0.013)	−0.015 (0.010)	2.389*	0.015 (0.008)	−0.014 (0.005)	3.593**	0.018 (0.006)	−0.006 (0.001)	3.438**	0.023 (0.007)	−0.008 (0.002)	3.892**
Channel 21	0.054 (0.013)	−0.019 (0.008)	3.693**	0.027 (0.009)	−0.016 (0.008)	5.127**	0.018 (0.003)	−0.009 (0.002)	8.277**	0.025 (0.004)	−0.008 (0.002)	6.897**

Pair-wise t-tests for HbO versus Hb values, * $p < 0.05$, ** $p < 0.01$)

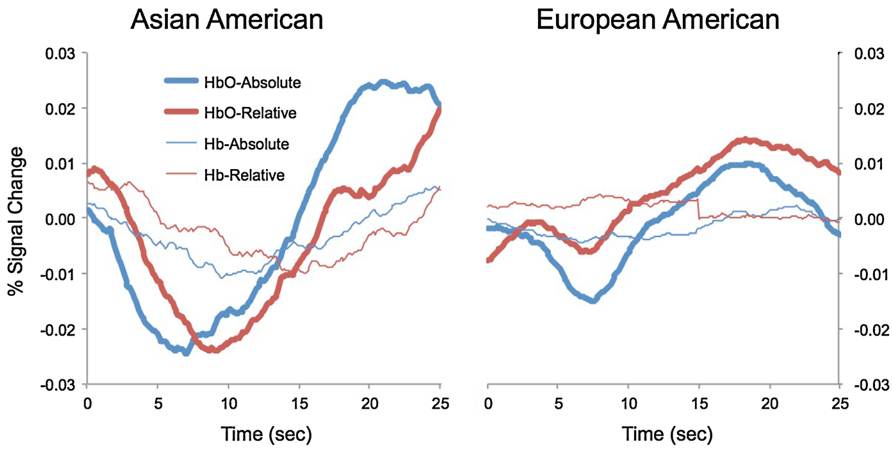

Fig. 4 Representative time course of signal change of HbO and Hb throughout a task period (Left channel 21, signal averaged across blocks)

block and reached its peak towards the end of the block. Consistent with prior fNIRS findings (Huppert et al. 2009), we observe relatively smaller magnitude in percent signal change in Hb response.

Discussion

Over the last two decades, numerous studies have documented cultural variations in perceptual and cognitive processes (Kitayama and Uskul 2011). One robust finding is that as compared to European American cultures, Asian cultures foster a more holistic mode of perceptual and cognitive processing (Nisbett et al. 2001). While people are likely capable of performing all cognitive tasks regardless of culture, culturally non-preferred tasks may be relatively more demanding to perform. For such tasks, compensatory attention control may be recruited to achieve the same level of performance.

Following earlier behavioral work by Kitayama et al. (2003, 2009), as well as its neuroimaging extension by Hedden et al. (2008), we found that Asian Americans show an increased parietal activity while completing a task that requires them to ignore contextual information. This finding is consistent with the hypothesis that, because Asian Americans automatically and habitually allocate processing resources to the context, it takes additional effort for them to disengage these resources away from the context. In contrast, European Americans show an increased parietal activity during the performance of a task that requires them to incorporate contextual information. This finding supports the hypothesis that, because European Americans automatically and habitually focus processing resources to a focal object, it takes additional effort for them to shift the resources to the context. Importantly, no corresponding effects of culture were observed for either accuracy or response time.

Previous behavioral studies (Kitayama et al. 2003) found a reliable cultural difference in behavioral performance (i.e., accuracy) using FLT. Similar to the present findings, European Americans were relatively better in the absolute task than in the relative task, while Asians were relatively better in the relative task than in the absolute task. In these experiments, however, the dependent variable involved reproducing a given line in terms of either absolute length or relative length, whereas the present study used a matching procedure. Given that the matching operation may be less demanding than reproduction, it may be easier to achieve the comparable level of behavioral performance by the use of compensatory attention in the matching task than in the reproduction task. The pattern shown in Fig. 3 is consistent with our claim that individuals expend extra attention control to compensate for the difficulty of performing culturally non-preferred tasks.

It is of note that Hedden et al. (2008) found evidence for the compensatory engagement of attention control in both frontal and parietal regions. In contrast, the current work found such evidence only for the parietal regions. It is possible that the optodes for the frontal area might not have been sufficient to cover the relevant frontal regions. It is also possible that, in the FLT task used, attentional control was likely exercised on the contextual square that surrounded a target line. Because spatial processing is often linked closely to parietal regions (Heilman and Van Den Abell 1980; Shulman et al. 2010), the evidence for the compensatory attention hypothesis in the FLT might be especially strong in these regions.

The fact that compensatory attention control is spontaneously engaged during culturally non-preferred tasks suggests that the perceptual and cognitive propensities fostered by different cultures are likely fully automatized (Bargh and Ferguson 2000). These propensities are thus quickly initiated, and once initiated, they may not be easily suspended or terminated. As a result, if they are not suitable for the task at hand, their operation must be compensated for only after it is completed.

The principle of compensatory attention control should be extended to other important effects of culture. First and foremost, it will be important to see if the current pattern of compensatory attention is observed in eye movement (Chua et al. 2005). Might a similar set of compensatory brain mechanisms be required when Asians try to shift their eyes away from distracting contextual stimuli to a central figural object? Or might these mechanisms be engaged when European Americans try to find certain contextual elements while looking at the central figural object?

Similar questions should be explored with respect to non-perceptual effects. For example, recent evidence suggests that dispositional attributions for another person's behavior are more habitual and automatic for European Americans than for Asians (Na and Kitayama 2011). We might expect, then, that European Americans would engage compensatory attention control when trying to propose situational explanations for the behavior. This effect, however, might not be observed for Asians. Likewise, it has been suggested that European Americans are attuned closely to their positive attributes (called self-enhancement), but Asians are attuned more to their shortcomings (called self-criticism, Kitayama et al. 1997). It might be the case, then, that European Americans engage compensatory attention control when they are asked to think critically of their shortcomings and weaknesses, but Asians might do so when asked to think optimistically of attributes they can feel proud of. While only future work can settle any of these questions, this work will be greatly facilitated with the method utilized in the current research.

One shortcoming of the current study is that the sample size was small. It is encouraging that we could confirm the earlier finding with this small number of participants. Nevertheless, more detailed, nuanced analyses involving individual difference variables including independent versus interdependent self-construal or acculturation would require a larger sample size. Another shortcoming is that, again due to the small sample size, it was not possible to carry out any detailed analyses on acculturation history or ethnic identity among our Asian American participants. Future work should extend the current paradigm to Asians in Asia as well as Asian immigrants in the U.S. It is also important to examine how the culturally contingent perceptual and cognitive tendencies are acquired by assessing the developmental time course (Duffy et al. 2009; Imada et al. 2013).

To conclude, cultural psychology has evolved to be a powerful source of insight into human psychological processes (Heine 2012; Kitayama and Cohen 2007). The current work has added to this literature by suggesting that neuroimaging methods such as fNIRS, fMRI, and EEG offer substantial promise in identifying new phenomena, highlighting hitherto unknown aspects in each phenomenon, and in shedding new light on underlying mechanisms. Because culture can be best seen as a macroscopic, collective phenomenon, it may seem paradoxical to argue that one can learn about culture by studying the brain. Nevertheless, our data shows that the nature of culture is reflected in the ways in which neural mechanisms are shaped and organized within the brain of each individual member (Kitayama and Uskul 2011).

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References

Badre, D., & Wagner, A. D. (2004). Selection, integration, and conflict monitoring; assessing the nature and generality of prefrontal cognitive control mechanisms. *Neuron, 41*(3), 473–487.

Bargh, J. A., & Ferguson, M. L. (2000). Beyond behaviorism: On the automaticity of higher mental processes. *Psychological Bulletin, 126*(6), 925–945.

Boas, D. A., Chen, K., Grebert, D., & Franceschini, M. A. (2004). Improving the diffuse optical imaging spatial resolution of the cerebral hemodynamic response to brain activation in humans. *Optical Letters, 29*(13), 1506–1508.

Bohmer, A., Mast, F., & Jarchow, T. (1996). Can a unilateral loss of otolithic function be clinically detected by assessment of the subjective visual vertical? *Brain Research Bulletin, 40*(5–6), 423–427.

Chua, H. F., Boland, J. E., & Nisbett, R. E. (2005). Cultural variation in eye movements during scene perception. *Proceedings of the National Academy of Sciences of the United States of America, 102*(35), 12629–12633.

Duffy, S., Toriyama, R., Itakura, S., & Kitayama, S. (2009). The development of culturally-contingent attention strategies in young children in the U.S. and Japan. *Journal of Experimental Child Psychology, 102*, 351–359.

Delpy, D. T., Cope, M., van der Zee, P., Arridge, S., Wray, S., & Wyatt, J. (1988). Estimation of optical pathlength through tissue from direct time of flight measurement. *Physics in Medicine & Biology*, *33*(12), 1433–1442. doi:10.1088/0031-9155/33/12/008.

Hedden, T., Ketay, S., Aron, A., Markus, H. R., & Gabrieli, J. D. (2008). Cultural influences on neural substrates of attentional control. *Psychological Science, 19*(1), 12–17.
Heilman, K. M., & Van Den Abell, T. (1980). Right hemisphere dominance for attention: The mechanism underlying hemispheric asymmetries of inattention (neglect). *Neurology, 30*(3), 327–330.
Heine, S. J. (2012). *Cultural psychology* (2nd ed.). New York, NK: WW Norton & Company.
Hoshi, Y., Kobayashi, N., & Tamura, M. (2001). Interpretation of near-infrared spectroscopy signals: A study with a newly developed perfused rat brain model. *Journal of Applied Physiology, 90*(5), 1657–1662.
Huppert, T. J., Diamond, S. G., Franceschini, M. A., & Boas, D. A. (2009). HomER: A review of time-series analysis methods for near-infrared spectroscopy of the brain. *Applied Optics, 48*(10), D280–D298.
Imada, T., Carlson, S. M., & Itakura, S. (2013). East-West cultural differences in context-sensitivity are evident in early childhood. *Developmental Science, 16*(2), 198–208. doi:10.1111/desc.12016.
Kitayama, S., & Cohen, D. (2007). *Handbook of cultural psychology*. New York: Guilford Press.
Kitayama, S., Duffy, S., Kawamura, T., & Larsen, J. T. (2003). Perceiving an object and its context in different cultures: A cultural look at new look. *Psychological Science, 14*(3), 201–206. Kitayama, S., Markus, H. R., Matsumoto, H., & Norasakkunkit, V. (1997). Individual and collective processes in the construction of the self: Self-enhancement in the United States and self-criticism in Japan. *Journal of Personality and Social Psychology, 72*(6), 1245–1267.
Kitayama, S., & Murata, A. (2013). Culture modulates perceptual attention: An event-related potential study. *Social Cognition*, *31*(6), 758–769.
Kitayama, S., & Park, J. (2014). Error-related brain activity reveals self-centric motivation: Culture matters. *Journal of Experimental Psychology: General, 143*(1), 62–70. doi:10.1037/a0031696.
Kitayama, S., Park, H., Servincer, A. T., Karasawa, M., & Uskul, A. K. (2009). A cultural task analysis of implicit independence: Comparing North America, West Europe, and East Asia. *Journal of Personality and Social Psychology, 97*(2), 236–255.
Kitayama, S., & Uskul, A. (2011). Culture, mind, and the brain: Current evidence and future directions. *Annual Review of Psychology, 62*, 419–449.
Kovelman, I., Shalinsky, M. H., Berens, M. S., & Petitto, L. A. (2014). Words in the bilingual brain: An fNIRS brain imaging investigation of lexical processing in sign-speech bimodal bilinguals. *Frontiers in Human Neuroscience, 8*, 606.
Kovelman, I., Shalinsky, M. H., White, K. S., Schmitt, S. N., Berens, M. S., Paymer, N., & Petitto, L. (2009). Dual language use in sign-speech bimodal bilinguals: fNIRS brain-imaging evidence. *Brain and Language, 109*(2–3), 112–123.
Markus, H. R., & Kitayama, S. (1991). Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review, 98*, 224–253.
Masuda, T., & Nisbett, R. E. (2001). Attending holistically versus analytically: Comparing the context sensitivity of Japanese and Americans. *Journal of Personality and Social Psychology, 81*(5), 922–934.
Masuda, T., & Nisbett, R. E. (2006). Culture and change blindness. *Cognitive Science, 30*, 381–399. Na, J., & Kitayama, S. (2011). Trait-based person perception is culture-specific: Behavioral and neural evidence. *Psychological Science, 22*(8), 1025–1032.
Na, J., & Kitayama, S. (2012). Will people work hard on a task they choose? Both culture and social-eyes priming matter. *Journal of Experimental Social Psychology, 48*(1), 284–290.
Nisbett, R. E., Peng, K., Choi, I., & Norenzayan, A. (2001). Culture and systems of thought: Holistic versus analytic cognition. *Psychological Review, 108*(2), 291–310.
Okamoto, M., Dan, H., Sakamoto, K., Takeo, K., Shimizu, K., Kohno, S., Oda, I., Isobe, S., Suzuki, T., Kohyama, K., & Dan, I. (2004). Three-dimensional probabilistic anatomical cranio-cerebral correlation via the international 10-20 system oriented for transcranial functional brain mapping. *Neuroimage*, *21*(1), 99–111.
Riccio, G. E., Martin, E. J., & Stoffregen, T. A. (1992). The role of balance dynamics in the active perception of orientation. *Journal of Experimental Psychology: Human Perception and Performance, 18*(3), 624–644.
Shalinsky, M. H., Kovelman, I., Berens, M. S., & Petitto, L. A. (2009). Exploring cognitive functions in babies, children & adults with near infrared spectroscopy. *Journal of Visualized Experiments,*. doi:10.3791/1268.

Shulman, G. L., Pope, D. L., Astafiev, S. V., McAvoy, M. P., Snyder, A. Z., & Corbetta, M. (2010). Right hemisphere dominance during spatial selective attention and target detection occurs outside the dorsal frontoparietal network. *The Journal of Neuroscience*, *30*(10), 3640–3651.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science, 283*, 1657–1661.

Varnum, M. E. W., Grossmann, I., Kitayama, S., & Nisbett, R. E. (2010). The origin of cultural differences in cognition: The social orientation hypothesis. *Current Directions in Psychological Science*, *19*(1), 9–13.

Villringer, A., & Chance, B. (1997). Non-invasive optical spectroscopy and imaging of human brain function. *Trends in Neurosciences, 20*(10), 435–442.

Wager, T. D., & Smith, E. E. (2003). Neuroimaging studies of working memory: A meta-analysis. *Cognitive, Affective & Behavioral Neuroscience, 3*(4), 255–274.