

Temperament trait of sensory processing sensitivity moderates cultural differences in neural response

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This study focused on a possible temperament-by-culture interaction. Specifically, it explored whether a basic temperament/personality trait (sensory processing sensitivity; SPS), perhaps having a genetic component, might moderate a previously established cultural difference in neural responses when making context-dependent vs context-independent judgments of simple visual stimuli. SPS has been hypothesized to underlie what has been called inhibitedness or reactivity in infants, introversion in adults, and reactivity or responsiveness in diverse animal species. Some biologists view the trait as one of two innate strategies—observing carefully before acting vs being first to act. Thus the central characteristic of SPS is hypothesized to be a deep processing of information. Here, 10 European-Americans and 10 East Asians underwent functional magnetic resonance imaging while performing simple visuospatial tasks emphasizing judgments that were either context independent (typically easier for Americans) or context dependent (typically easier for Asians). As reported elsewhere, each group exhibited greater activation for the culturally non-preferred task in frontal and parietal regions associated with greater effort in attention and working memory. However, further analyses, reported here for the first time, provided preliminary support for moderation by SPS. Consistent with the careful-processing theory, high-SPS individuals showed little cultural difference; low-SPS, strong culture differences.

Keywords: culture; sensory processing sensitivity; attention; gene × environment interaction; highly sensitive person

INTRODUCTION

Are some people less influenced by their cultural context than others? This study examined a possible culture-by-temperament interaction. Specifically, we explored whether an established cultural difference in perceptual judgments may be weaker for individuals with a particular temperament trait involving the processing of sensory information. The focal trait is thought to cause individuals' perceptual judgments to be based more directly on the actual stimuli. This trait presumably has a strong genetic component, although it may require the presence of particular environmental influences for expression. We were in a strong position to test this potential interaction because the focal cultural difference—context dependent vs context independent—is well supported in diverse previous research and has recently been demonstrated to be linked to differences in brain response (Han and Northoff, 2008; Hedden *et al.*, 2008). Furthermore, the focal temperament trait—sensory processing sensitivity (SPS)—has a well-established questionnaire measure for adults (Aron and Aron, 1997). Indeed, in the Hedden *et al.* neuroimaging study of culture differences,

participants completed the SPS questionnaire. However, the relation of SPS scores to the imaging results was not analyzed as part of that research report. Thus, this article reports for the first time a further analysis of the Hedden *et al.* data that tests the interaction of SPS with culture in predicting differences in neural response. In addition to an initial examination of the specific role of this particular temperament trait and this particular cultural difference, the present study may also bear to some extent on the larger question of gene × culture interaction (and more generally, gene × environment interaction).

Cultural context and the neural substrates of perceptual judgments

Research on social cognition differentiates cultural contexts that emphasize ideas and practices of interdependence (e.g. East Asian cultural contexts in China, Japan and Korea) vs ideas and practices of independence [e.g. Western cultural contexts, in North America and Western Europe (Markus and Kitayama, 1991; Triandis, 1995)]. These cultural differences were originally considered in terms of social relations. However, subsequent research has shown that they also apply to performance on simple perceptual judgments. Specifically, people from East Asian cultural contexts perform better on tasks with interdependent (*relative* or context

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dependent) demands, and people from Western cultural contexts perform better on tasks with independent (*absolute* or context independent) demands (Kitayama *et al.*, 2003). These findings suggest that culture influences perception in a fundamental way (Nisbett *et al.*, 2001).

Based on this idea, Hedden *et al.* (2008) used functional magnetic resonance imaging (fMRI) to examine where in the brain cultural context alters processing of simple perception under relative *vs* absolute judgment conditions. Specifically, they scanned samples of East Asian and American participants comparing neural responses of individuals from the two cultural groups when making judgments of line lengths either relative to a surrounding context or when ignoring the surrounding context.

The findings of Hedden *et al.* (2008) were that cultural differences in the preferred and encouraged judgment style robustly influenced brain function, reversing the relation between task and activation across a widespread brain network. On average, individuals who have habitually engaged in American cultural contexts exhibited greater activation during the culturally non-preferred relative task, whereas, on average, individuals who have habitually engaged in East Asian cultural contexts exhibited greater activation during the culturally non-preferred absolute task. This interaction between culture and task preference yielded statistically significant interactions on activation in 11 brain regions identified via a whole-brain analysis. In addition, magnitudes of activation for culturally preferred and non-preferred tasks varied as a function of a person's degree of culture-typical identity (i.e. those with stronger identification with their cultural context showed stronger effects). Such a convergence between overall differences and individual differences in the degree of such effects is thought to provide particularly strong support for a brain-behavior relation (Kosslyn *et al.*, 2002; Omura *et al.*, 2005).

The results of Hedden *et al.* (2008) were most interpretable as an average increased need for sustained attentional control during tasks requiring a processing style for which individuals are less culturally prepared. The large majority of culturally influenced activation differences were in frontal and parietal regions that regularly exhibit greater activation for more demanding tasks, and are therefore thought to mediate cognitive control over working memory and attention (Badre and Wagner, 2004; Smith and Jonides, 1999; Wager and Smith, 2003). Regions activated by the culturally non-preferred task condition (context independent for East Asians, context dependent for Americans) exhibited substantial similarity across groups, with no above-threshold voxels differing between groups. This suggests that the same attentional control network is engaged by individuals in each cultural context. However, the conditions requiring such attentional control are moderated by what individuals have been prepared for by their particular cultural contexts.

SPS

SPS is a temperament/personality trait characterized by sensitivity to both internal and external stimuli, including social and emotional cues. The standard measure of SPS in adults is the Highly Sensitive Person Scale (HSP Scale). The HSP Scale was initially derived from characteristics identified in lengthy interviews, and then systematically demonstrated to have high levels of reliability, and of convergent, discriminant, and construct validity using a variety of methods and across diverse populations (Aron and Aron, 1997). Items include being bothered by intense stimuli; aware of subtleties; more affected by caffeine, pain, and being rushed; having a faster startle response; being more aware of others moods; and performing worse when observed (presumably due to over arousal from processing too much information).

SPS is probably innate to some degree, or largely, in that it is closely related behaviorally to traits such as introversion, neuroticism, shyness, and behavioral inhibition. All of these involve the observable behavior of failing to act as soon as others, which has been assumed in humans to be due variously to low sociability, low approach, low positive affect, or high anxiety. Each of these has been shown to be partly heritable and may share some underlying genetic basis. Furthermore, the SPS concept adopts the view from biology that most species have evolved two 'personality' types. Initially these were seen as shy *vs* bold (Wilson *et al.*, 1993), 'uptight' *vs* 'laid back' (Suomi, 1999), or non-aggressive *vs* aggressive (Korte *et al.*, 2005). Meanwhile the trait has been identified in over 100 different species (Wolf *et al.*, 2008), and understanding of it has evolved such that the current terms for it are responsive (Wolf *et al.*, 2008) or sensitive (Sih and Bell, 2008). The trait is now thought to represent one of two underlying strategies. One is 'pause before acting' in order to allow neural processes to assess survival-related subtleties in the environment. The other is 'act first' in order to respond quickly to opportunities. For example, there are two types of fruit flies, sitters and rovers, representing two strategies of locating food (Renger *et al.*, 1999). Rovers use the strategy of high motor activity, but sitters have more elaborate neural networks, suggesting that the behavioral inhibition of these fruit flies is indeed related to more extensive processing of the environment.

At the other end of the species spectrum, rhesus monkeys have been divided into two types (Sumoi, 1999), and when the reactive or 'up tight' individuals have been cross-fostered with skilled mothers, they have been observed to become the leaders of their troops. Presumably, the successful reactive types are utilizing some deeper processing of social cues.

Ellis *et al.* (2005) have theorized that interactions such as the one Sumoi found, which are also being found in humans (e.g. Aron *et al.*, 2005; Boyce *et al.*, 1995; Gannon *et al.*, 1989—for a review, see Belsky and Pluess, 2009), are explained by a single gene creating a 'biological sensitivity to context.' This putative 'plasticity' gene allows individuals to adapt soon after birth to either very stressful or very

supportive environments by becoming more sensitive. Such sensitivity is an advantage in both of these environmental extremes, whereas sensitivity is not activated in a more neutral environment, where it might be a liability.

Belsky and Pluess (2009) present evidence for a similar plasticity resulting from several candidate genes, so that the more such genes an individual carries, the greater might be the person's 'differential susceptibility to environmental influences'. In all cases, the identified genes, formerly seen as only risk factors, have been found to result in better than average functioning if a child with that gene has been exposed to a supportive, enriching environment.

However this trait is understood, several well-established theories view it as a neutral trait having survival advantages in some situations but not others, and involving a more thorough processing of stimuli. The latter is further supported by recent neuroimaging findings that those high in SPS pay greater attention to subtle changes in visual scenes (Jagiellowicz *et al.*, 2010). In animals this trait predicts differences in a wide range of behaviors, such as feeding, harm avoidance, mating, affiliating, and seeking higher status, also supporting the idea that it has a broad effect on perception and behavior. The two strategies appear to have evolved because they each can succeed in different but normal variations in habitat (Sih and Bell, 2008; Wilson, *et al.*, 1993).

The various theories about the trait studied here provide us with a new way of understanding long established views of human personality variations. For example, introverts have been found to have a greater awareness of subtle stimuli, more attentional vigilance (Koelega, 1992), greater sensory reactivity (Doucet and Stelmack, 1997, 2000; Stelmack, 1990), and a 'reflective' cognitive style as evidenced by pausing longer after a punished trial and showing more learning from it (Patterson and Newman, 1993). Hence sensitivity to stimuli would seem to underlie at least some types of introversion. As for shyness, a series of studies (Aron *et al.*, 2005) found support for a model in which the interaction of SPS and a troubled childhood predicted negative affect (neuroticism), which in turn predicted shyness. Those findings suggest that shyness, like 'uptightness' in monkeys, may arise from an interaction with environment but is not the complete explanation for pausing or withdrawing behavior.

In the case of behavioral inhibition, the behaviorally inhibited child is observed to be slow but accurate at tasks (Kagan *et al.*, 1964). High behavioral inhibition is usually interpreted as a greater sensitivity to punishment or threat (Carver and White, 1994), the result of an especially active behavioral inhibition system (BIS), rather than a greater sensitivity to all stimuli. In contrast, Gray (1991) originally posited that the BIS provides a better explanation for many behaviors associated with introversion. One reason was that he thought pausing behaviors (behavioral inhibition) were best explained by a need to allow time to process stimuli further rather than by low sociability (Gray, 1981,

1985). Hence as originally conceived, greater behavioral inhibition was associated with a strategy of taking time to process stimuli more thoroughly, especially in novel situations, whether these situations involve threatening stimuli or not. That is, while the point is often missed, Gray (1981, p. 270) did not view behavioral inhibition as only a greater awareness of the threat of punishment, saying such an explanation for behavioral inhibition would be 'tortuous, assuming it to be viable at all'. Obviously one cannot detect a threat of punishment and choose to focus only on that before one has processed all that is occurring, and that processing is more or less thorough depending upon one's typical processing style. Indeed Gray's revised model (Gray and McNaughton, 2000) makes the BIS, with its careful processing of a situation, a mediator between the urge to proceed, coming from the behavioral activation system, and the urge to flee coming from the fear system in the amygdala.

In sum, it would seem that a possibly innate preference to process information more thoroughly may be the best underlying explanation for most of the pausing behaviors associated with human personality. If such a preference exists as a trait, those high in it should process stimuli more elaborately (Aron and Aron, 1997) and/or pay more attention to stimuli in all cultural contexts, a characteristic that should make their perceptual judgments relatively less influenced by the cultural contexts to which they have been exposed.

The present research

The present study investigated whether the role of independent *vs* interdependent cultural context in moderating perceptual judgments of relative *vs* absolute stimuli is indeed less influential for individuals high in SPS. That is, do individuals high in SPS process sensory information especially thoroughly and carefully, so that they are more directly responsive to the actual stimuli and relatively less affected than others by their cultural context?

To begin to answer that question, we focused here specifically on how SPS may moderate the results obtained by Hedden *et al.* (2008), using the data from that study, which found average cultural differences in neural activation in attentional regions when making relative *vs* absolute perceptual judgments. Would those differences be relatively less for individuals high in SPS?

METHODS

Participants

Twenty participants (aged 18–26 years; 11 female), 10 East Asians recently in the USA and 10 Americans of Western-European ancestry, completed relevant questionnaires and underwent fMRI scanning. Participants from each culture were equated on baseline measures of reading comprehension, $t(18) = 1.51$, $P = 0.15$; and speed of

processing, $t(18) = 0.44$, $P = 0.66$. (See Hedden *et al.*, 2008, for more details.)

Questionnaire measures

We assessed SPS with an 11-item, short version of the HSP Scale (Aron and Aron, 1997), as described above. (Example item: 'Are you made uncomfortable by loud noises'; all items rated on the standard 7-point scale from 1 = not at all to 7 = extremely). It was necessary to use shortened scales to assess most variables in order to minimize the overall time demands on the participants. The particular 11 items used here were selected because in previous studies with large samples, they had particularly high correlations with the overall scale total. (The full 11 items of the SPS measure and the items in the brief introversion and neuroticism scales are included in the supplementary appendix 1.) Cronbach's α in the present study is 0.82 (α for the full 27 item version in previous studies with large samples have typically been ~ 0.85).

As controls, we assessed two personality variables often correlated with SPS, introversion/extraversion and neuroticism (negative affectivity) using a short set of items employed in some previous studies (e.g. Aron and Aron, 1997; Aron *et al.*, 2005): introversion/extraversion with two items (e.g. 'Do you like to meet strangers?') and neuroticism (negative affectivity) with three items (e.g. 'Are you a tense or worried person by nature?'). Because scores on the neuroticism measure were strongly skewed, to meet assumptions of normality in the regression analyses the neuroticism scores were square-root transformed prior to including them in the various analyses. (However, the same analyses using the original untransformed scores yielded nearly identical results.)

We assessed culture-specific identity with two 10-item standard measures: Americans completed an independence questionnaire (e.g. 'I am not to blame if one of my family members fails'; Triandis *et al.*, 1988); East Asians, an acculturation questionnaire (e.g. 'How well do you fit when with other Asians of your same ethnicity?'; Suinn *et al.*, 1992). [See Hedden *et al.* (2008), for more details on the culture-specific identity scales used with this sample.] To permit us to control for culture-specific identity in analyses including participants from both cultural groups, we created an overall variable using scores standardized within each group and combined so that higher scores meant greater interdependence.

Design and stimuli

Participants were scanned while making judgments regarding line lengths (Figure 1) in an adaptation for the scanner of the Kitayama *et al.* (2003) paradigm. In a 2×2 design, stimuli were judged under either relative (attending to context) or absolute (ignoring context) instructions, and in which the judgments to be made were either congruent (easy) or incongruent (difficult).

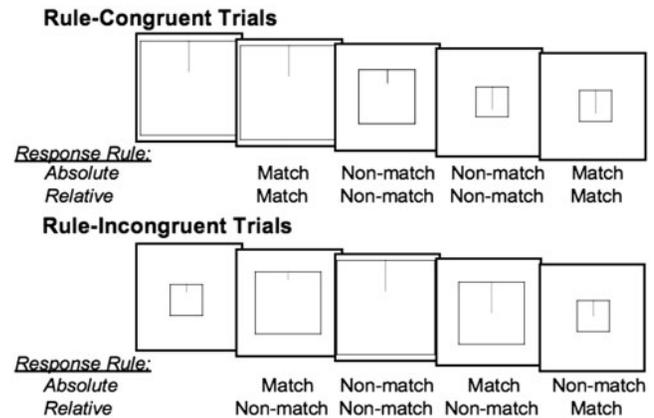


Fig. 1 The task consisted of judging stimuli depicting a vertical line inside a box. In the relative instruction condition, participants judged whether each box and line combination matched the proportional scaling of the preceding combination; in the absolute-instruction condition, participants judged whether each line matched the previous line, regardless of the size of the accompanying box. In each block of trials, either both instructions led to the same matching response (congruent condition) or both instructions typically led to opposing responses (incongruent condition).

Scanning

Functional data were acquired using a 1.5-T General Electric Signa MR scanner paired with a whole-head coil and using sequential spiral in-out acquisition sequences for measurement of blood oxygen level-dependent (BOLD) effects (TR = 1850 ms, TE = 40 ms, flip angle = 70°, 64 × 64 matrix, FOV = 240 mm, 235 mm oblique slices). Images were screened for artifacts, motion-corrected, normalized to the MNI template, and smoothed at 6 mm. Statistical analyses were conducted using SPM2 (Wellcome Department of Imaging Neuroscience, London) and associated scripts.

Attention ROI composite

As reported in detail by Hedden *et al.* (2008), whole-brain analyses were first conducted on the three-way interaction of culture (American vs East Asian) × instruction (absolute vs relative) × congruency (incongruent vs congruent) to locate regions demonstrating activation differences across task and culture (whole-brain corrected $P \leq 0.05$ threshold, achieved with $P \leq 0.005$ and cluster size ≥ 49 for normalized, resliced voxels). This contrast identified regions that (i) exhibited greater activation in Americans than East Asians during the relative-incongruent than the relative-congruent task conditions (the Americans' non-preferred task version), and/or (ii) exhibited greater activation in East Asians than Americans during the absolute-incongruent than absolute-congruent task conditions (the East Asians' non-preferred task version). The incongruent vs congruent contrasts showed that both groups exhibited widespread bilateral activations during the culturally non-preferred task that were greater than the activations found in the other group for the same task—that is, the culturally preferred

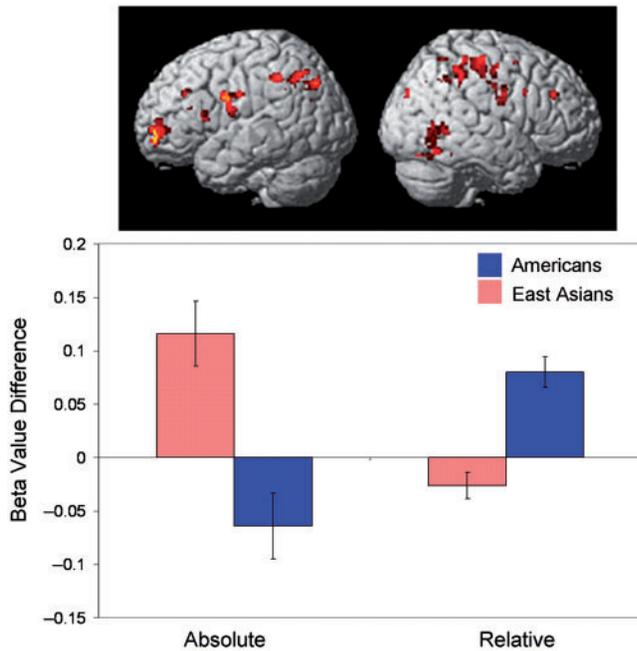


Fig. 2 Brain regions identified from the contrast analysis of the non-preferred task versions (culture × instruction × congruency interaction; uncorrected threshold of $P < 0.005$, cluster size = 49). The bar graph displays beta-value difference scores (incongruent minus congruent) from a composite score computed as the weighted (by cluster size) mean across 11 ROIs identified from the three-way interaction. Difference scores are shown as a function of instruction (absolute vs relative) and culture (American vs East Asian). Adapted from results reported in Hedden *et al.* (2008).

version for the latter group (culture × instruction × congruency interaction). These activations were primarily concentrated in prefrontal and parietal areas known to support sustained attentional control (e.g. Wager and Smith, 2003). There were no significant differential activations in occipital cortex, where early visual processes are subserved by primary and secondary visual cortices (see Figure 2).

Next, Hedden *et al.* (2008) treated clusters of activation identified in the interaction analyses as ROIs. Within each instruction condition (absolute or relative), activation differences (incongruent minus congruent) were highly intercorrelated across these ROIs (Cronbach's $\alpha = 0.97$ for the absolute task; 0.90 for the relative task), indicating strong functional coactivation. Importantly, this allowed the calculation of a summary activation measure for each instruction condition. Weighted means (weighted by cluster size) of the activation differences were computed across the 11 ROIs identified by the contrast for the non-preferred task.

In the present report, we extended this analysis, using this same 11-ROI composite, but examining for the first time the relation of SPS to the focal interaction with cultural context.

RESULTS

Table 1 displays means and standard deviations for the questionnaire variables by group. There were no significant differences between groups on any of these variables. Table 1 also displays correlations among these variables overall

Table 1 Overall correlations and means by group for questionnaire variables

Variable	SPS	<i>I</i>	<i>N</i>
SPS			
Introversion (<i>I</i>)	0.28		
Neuroticism (<i>N</i>)	0.32	0.55**	
Interdependent orientation ^a	-0.04	-0.12	0.02
East Asians (<i>N</i> = 10)			
M	4.04	3.35	3.70
s.d.	0.69	1.20	1.61
Americans (<i>N</i> = 10)			
M	3.51	3.85	3.23
s.d.	0.83	1.36	1.51

** $p < 0.01$.

^aCorrelations with interdependent orientation were computed using scores from different scales that were separately standardized within each group to a mean of 0 and a s.d. of 1.

Note: No differences between groups on these variables were significant.

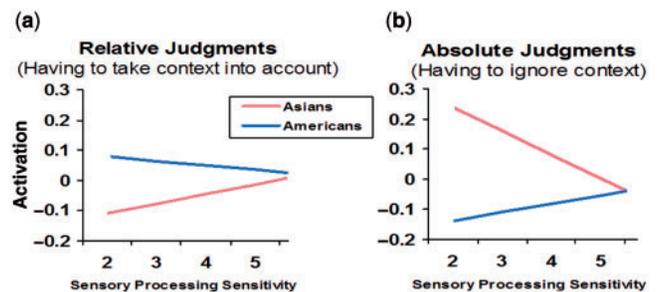


Fig. 3 Regression lines for each cultural group showing neural activity (weighted mean response in the 11-ROI composite) as a function of SPS scores. (a) Relative task. (b) Absolute task. Three-way regression interaction (SPS × culture × task type contrast), $t(12) = 2.35$, $P = 0.02$.

(there were no significant differences between groups in correlations). No correlations with SPS were significant.

For the relative task (i.e. for the contrast of relative incongruent minus relative congruent), on the 11-ROI composite, among East Asians, those scoring higher in SPS had more activation ($r = 0.43$); among Americans, those scoring higher on SPS had somewhat less activation ($r = -0.15$); these patterns were significantly different; $t(12) = 1.77$, $P = 0.05$, interaction $\beta = -1.38$. See Figure 3a. (All analyses were hierarchical regressions, treating SPS as a continuous variable, and controlling for gender, introversion, neuroticism and cultural identification. Analyses not controlling for these variables yielded the same pattern and, due to increased *df*, generally slightly more significant results. Parallel analyses of covariance treating SPS as a dichotomous variable also yielded virtually identical results. *P*-levels for *t*-values for predicted effects are one-tailed.)

For the absolute task (i.e. for the contrast of absolute incongruent minus absolute congruent) on the 11-ROI composite, among East Asians, those scoring higher in SPS had less activation ($r = -0.40$); among Americans, those scoring higher on SPS had somewhat more activation ($r = 0.22$);

Table 2 Means for dichotomized SPS \times cultural context \times relative vs absolute task interaction predicting activation in 11-ROI composite

	Low SPS		High SPS	
	Relative	Absolute	Relative	Absolute
East Asians	-0.04	1.75	0.03	0.01
Americans	-0.69	0.97	-0.06	0.06

Note: All means are adjusted for the covariates included in the analysis (gender, introversion, neuroticism and interdependent orientation). Three-way interaction, $F(1,12) = 6.45$, $P = 0.03$.

these patterns were significantly different; $t(12) = 2.00$, $P = 0.04$, interaction $\beta = 1.52$. See Figure 3b.

Crucially, the three-way regression interaction (SPS \times culture \times task type contrast) was strong and very clearly significant; $t(12) = 2.35$, $P = 0.02$. This is illustrated by comparing Figure 3a and b. The three-way interaction can also be seen in Table 2, displaying the pattern of means from the parallel mixed model analysis of covariance treating SPS as a dichotomous variable (three-way interaction $F(1,12) = 6.45$, $P = 0.03$).

Also, as can be seen from Table 2, high SPS individuals showed no significant difference in activation within the composite of attention ROIs between the absolute and relative conditions; SPS \times condition interaction $F(1,12) = 2.13$, $P = 0.17$. These results suggest that high SPS was associated with not being influenced by the absolute and relative instructions. Such a lack of influence is most readily interpreted as a tendency to deeply process all stimuli components to an equivalent extent, regardless of condition.

DISCUSSION

The present data suggest that some categories of individuals are less influenced by their cultural context than others. Specifically, this study provides suggestive evidence for a culture-by-temperament interaction in which an established cultural difference, that of taking context into account in perceptual judgments, is weaker for individuals high in SPS. We have suggested that a trait-based strategy of processing all stimuli more thoroughly than those without the trait may cause perceptual judgments to be based more directly on the actual stimuli. Here, we report for the first time an analysis testing the interaction of SPS with culture in predicting cultural differences in neural response.

The Hedden *et al.* (2008) findings suggested that cultural influences on brain functions engaged by perceptual tasks involving making absolute judgments vs making relative judgments occur primarily during late-stage attentional processing rather than early-stage perceptual processing. The conceptual model of SPS suggests that those high in the trait should process stimuli more elaborately and/or pay more attention to stimuli, regardless of cultural context. Therefore, individuals high in SPS should be less likely to

exhibit cultural differences in a perceptual processing task because they are more likely to be highly attentive to all aspects of a stimulus, a model supported by the present results.

Furthermore, individuals high in SPS would be expected to show little difference between activations invoked by the processing of absolute and relative stimuli, again because they are highly (and equivalently) engaged by multiple aspects of the stimuli in both conditions. Two aspects of the results support this possibility. Individuals high in SPS showed little difference between the level of activation in the composite of attention ROIs during the absolute and relative conditions, and had activation levels that did not significantly differ across congruent and incongruent conditions. Both of these findings held across the cultural groups.

The moderating influence of SPS was also independent from an individual's affiliation with his or her culture (as measured by the standardized measure of culture-specific identity), as indicated by the low correlation of SPS with interdependent orientation, $r = -0.04$. Additionally, there were not significant differences on SPS across the cultural groups. These results suggest that the shifts in activation attributable to SPS are not simply a reflection of other cultural tendencies, as might be expected if, for instance, East Asian cultural practices tended to foster a greater incidence of high SPS individuals.

A possible alternative explanation arises from potential cultural differences in the social value accorded to highly sensitive individuals (Chen *et al.*, 1992) such that the trait may be relatively positively valued in Chinese cultural contexts but relatively negatively valued in North American cultural contexts. A role for this factor in shaping cultural differences in brain response to perceptual judgments cannot be ruled out (and would be of interest in its own right if true). However, it seems an unlikely explanation for the present results because one would expect those with lower status-sensitive people in a North American cultural context—to be more, not less attentive to cultural context, which is not the pattern found. Thus, any such effects would seem to work for the opposite results of those observed here.

This is of course only a first study, with a very small N , and with very specific operational definitions. On the one hand, we would emphasize that significant results were obtained in spite of only 10 participants in each cultural group, and using a continuous measure for the moderator variable (which also lowers power). Thus, a significant regression interaction under these conditions necessarily represents a substantial effect size that is highly likely to be replicated in future, larger samples. (Also, supporting the strength of these findings is that they were obtained for a set of ROIs independently identified for a different purpose, no issues of multiple comparisons were involved, and results remained significant whether or not controlling for various potentially confounding variables.) On the other hand, the relatively small N makes it difficult to be confident that results may

not in some way be sample specific, so that any conclusions must be taken as highly preliminary and only as suggestive. Future directions would certainly include replication of these novel results with larger *N*s. (Larger samples would also permit more fine grained analyses.) Other crucial future directions include using different paradigms and different cultural variations (such as cultures focusing more or less on social hierarchy), as well as additional approaches for assessing the focal temperament trait, the strategy of pausing to observe (such as using genetic methods or subjects from a longitudinal study that began with infant observations). Finally, understanding of the more general possibility of culture × temperament interactions would be advanced by considering interactions with other temperament traits.

Nevertheless, the present results are provocative in testing for the first time the possibility of substantial temperament by culture interactions, and doing so in a neuroimaging context. The neuroimaging data reported here are significant both for suggesting directions for advancing knowledge of brain function and because they offer a uniquely powerful implicit measure of traits previously studied only by self-report, such as SPS. It is a measure likely to be minimally influenced by response biases, language, and related artifacts. In sum, we believe the present results, although highly preliminary, provide some direct support for the first time for culture × temperament interaction and for the role of SPS in particular, as well as laying a strong foundation and model for the emerging field of cultural neuroscience.

SUPPLEMENTARY DATA

Supplementary data are available at SCAN online.

REFERENCES

- Aron, E.N., Aron, A. (1997). Sensory-processing sensitivity and its relation to introversion and emotionality. *Journal of Personality and Social Psychology*, 73, 345–68.
- Aron, E.N., Aron, A., Davies, K.M. (2005). Adult shyness: the interaction of temperamental sensitivity and an adverse childhood environment. *Personality and Social Psychology Bulletin*, 31(2), 181–97.
- Badre, D., Wagner, A.D. (2004). Selection, integration, and conflict monitoring: assessing the nature and generality of prefrontal cognitive control mechanisms. *Neuron*, 41, 473–87.
- Belsky, J., Pluess, M. (2009). Beyond diathesis stress: differential susceptibility to environmental influences. *Psychological Bulletin*, 135, 885–908.
- Boyce, W.T., Chesney, M., Alkon, A., et al. (1995). Psychobiologic reactivity to stress and childhood respiratory illnesses: results of two prospective studies. *Psychosomatic Medicine*, 57, 411–22.
- Carver, C.S., White, T.L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS Scales. *Journal of Personality and Social Psychology*, 67(2), 319–33.
- Chen, X.Y., Rubin, K.H., Sun, Y.R. (1992). Social reputation and peer relationships in Chinese and Canadian children: a cross-cultural study. *Child Development*, 63, 1336–43.
- Doucet, C., Stelmack, R.M. (1997). Movement time differentiates extraverts from introverts. *Personality and Individual Differences*, 23(5), 775–86.
- Doucet, C., Stelmack, R.M. (2000). An event-related potential analysis of extraversion and individual differences in cognitive processing speed and response execution. *Journal of Personality and Social Psychology*, 78(5), 956–64.
- Ellis, B.J., Essex, M.J., Boyce, W.T. (2005). Biological sensitivity to context: II. Empirical explorations of an evolutionary-developmental theory. *Development and Psychopathology*, 17(2), 303–28.
- Gannon, L., Banks, J., Shelton, D. (1989). The mediating effects of psychophysiological reactivity and recovery on the relationship between environmental stress and illness. *Journal of Psychosomatic Research*, 33, 165–75.
- Gray, J.A. (1981). A critique of Eysenck's theory of personality. In: Eysenck, H.J., editor. *A Model for Personality*. New York: Springer, pp. 246–76.
- Gray, J.A. (1985). Issues in the neuropsychology of anxiety. In: Ruma, A.H., Maser, J.D., editors. *Anxiety and disorder*. Hillsdale, NJ: Earlbaum, pp. 5–25.
- Gray, J.A. (1991). The Neuropsychology of temperament. In: Strelau, J., Angleitner, A., editors. *Explorations in Temperament: International Perspectives on Theory and Measurement*. New York: Plenum Press, pp. 105–28.
- Gray, J.A., McNaughton, N. (2000). *The Neuropsychology of Anxiety: An Enquiry into the Functions of the Septo-Hippocampal System*, 2nd edn, Oxford: Oxford University Press.
- Han, S., Northoff, G. (2008). Culture-sensitive neural substrates of human cognition: a transcultural approach. *Nature Reviews Neuroscience*, 9, 646–54.
- Hedden, T., Ketay, S., Aron, A., Markus, H., Gabrieli, J.D.E. (2008). Cultural influences on neural substrates of attentional control. *Psychological Science*, 19, 13–7.
- Jagiellowicz, J., Xu, X., Aron, A., et al. (2010). The trait of sensory processing sensitivity and neural responses to changes in visual scenes. *Social Cognitive and Affective Neuroscience*, doi:10.1093/scan/nsq001 [Epub ahead of print].
- Kagan, J., Rosman, B.L., Day, D., Albert, J., Phillips, W. (1964). Information processing in the child: significance of analytic and reflective attitudes. *Psychological Monographs: General and Applied*, 78, 1–37.
- 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, 201–6.
- Koelega, H.S. (1992). Extroversion and vigilance performance: 30 years of inconsistencies. *Psychological Bulletin*, 112(2), 239–58.
- Korte, S.M., Koolhaas, J.M., Wingfield, J.C., McEwen, B.S. (2005). The Darwinian concept of stress: Benefits of allostasis and costs of allostatic load and the trade-offs in health and disease. *Neuroscience and Biobehavioral Reviews*, 29, 3–38.
- Kosslyn, S.M., Cacioppo, J.T., Davidson, R.J., et al. (2002). Bridging psychology and biology: The analysis of individuals in groups. *American Psychologist*, 57, 341–51.
- Markus, H., Kitayama, S. (1991). Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review*, 98, 224–53.
- Nisbett, R.E., Peng, K., Choi, I., Norenzayan, A. (2001). Culture and systems of thought: holistic versus analytic cognition. *Psychological Review*, 108, 291–310.
- Omura, K., Aron, A., Canli, T. (2005). Variance maps as a novel tool for localizing regions of interest in imaging studies of individual differences. *Cognitive, Affective, and Behavioral Neuroscience*, 5, 252–61.
- Patterson, C.M., Newman, J.P. (1993). Reflectivity and learning from aversive events: Toward a psychological mechanism for the syndromes of disinhibition. *Psychological Review*, 100, 716–36.
- Renger, J., Yao, W.-D., Sokolowski, M., Wu, C.-F. (1999). Neuronal polymorphism among natural alleles of a cGMP-dependent kinase gene, *foraging*, in *Drosophila*. *Journal of Neuroscience*, 19, RC28, 1–8.
- Sih, A., Bell, A.M. (2008). Insights for behavioral ecology from behavioral syndromes. *Advances in the Study of Behavior*, 38, 227–81.
- Smith, E.E., Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science*, 283, 1657–61.

- Stelmack, R.M. (1990). Biological basis of extraversion: psychophysiological evidence. *Journal of Personality*, 58(1), 293–311.
- Suinn, R.M., Ahuna, C., Khoo, G. (1992). The Suinn-Lew Asian self-identity acculturation scale: concurrent and factorial validation. *Educational and Psychological Measurement*, 52, 1041–6.
- Suomi, S.J. (1999). Attachment in rhesus monkeys. In: Cassidy, J., Shaver, P.R., editors. *Handbook of Attachment*. New York: Guilford Press, pp. 181–98.
- Triandis, H.C. (1995). *Individualism and collectivism*. Boulder, CO: Westview Press.
- Triandis, H.C., Bontempo, R., Villareal, M.J., Asai, M., Lucca, N. (1988). Individualism and collectivism: cross-cultural perspectives on self-ingroup relationships. *Journal of Personality and Social Psychology*, 54, 323–38.
- Wager, T.D., Smith, E.E. (2003). Neuroimaging studies of working memory: a meta-analysis. *Cognitive Affective Behavioral Neuroscience*, 3, 255–74.
- Wilson, D.S., Coleman, K., Clark, A.B., Biederman, L. (1993). Shy–bold continuum in pumpkinseed sunfish (*Lepomis gibbosus*): an ecological study of a psychological trait. *Journal of Comparative Psychology*, 107, 250–60.
- Wolf, M., van Doorn, G.S., Weissing, F.J. (2008). Evolutionary emergence of responsive and unresponsive personalities. *Proceeding of the National Academy of Sciences*, 105, 15825–15830.