Age and culture modulate object processing and object–scene binding in the ventral visual area

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Behavioral differences in the visual processing of objects and backgrounds as a function of cultural group are well documented. Recent neuroimaging evidence also points to cultural differences in neural activation patterns. Compared with East Asians, Westerners' visual processing is more object focused, and they activate neural structures that reflect this bias for objects. In a recent adaptation study, East Asian older adults showed an absence of an object-processing area but normal adaptation for background areas. In the present study, 75 young and old adults (half East Asian and half Western) were tested in an fMR-adaptation study to examine differences in object and background processing as well as object–background binding. We found equivalent background processing in the parahippocampal gyrus in all four groups, diminished binding processes in the hippocampus in elderly East Asians and Westerners, and diminished object processing in elderly versus young adults in the lateral occipital complex. Moreover, elderly East Asians showed significantly less adaptation response in the object areas than did elderly Westerners. These findings demonstrate the malleability of perceptual processes as a result of differences in cohort-specific experiences or in cultural exposure over time.

Extensive behavioral studies suggest that in visual processing, collectivist experiences bias East Asians to attend to contextual information, whereas individualistic experiences bias Westerners to process objects preferentially (Chua, Boland, & Nisbett, 2005; Nisbett & Masuda, 2003; Nisbett & Miyamoto, 2005; Nisbett, Peng, Choi, & Norenzayan, 2001). These effects of culture on cognitive function have been demonstrated across many domains, including perceptual processing, semantic organization, memory, reasoning, and neural function. At the perceptual level, Chua et al. (2005) found that, when viewing complex scenes, East Asians made more saccades to the background contexts, whereas Westerners fixated faster and longer on central objects. In studies on semantic organization, East Asians were found to associate images of people on the basis of functional relationships (such as grouping together a mother and her child because of the maternal relationship), whereas Westerners based their associations on physical features and categorical membership (such as grouping together a woman and a man because they were both adults) (Chiu, 1972; Ji, Zhang, & Nisbett, 2004). In a memory study, Masuda and Nisbett (2001) demonstrated

that East Asians were less likely to recognize target objects that they had previously encoded if the objects' background had changed, in contrast with Westerners, whose object memory was less affected by background changes. Most recently, Gutchess, Welsh, Boduroğlu, and Park (2006), using stimuli similar to those used by Masuda and Nisbett, observed cultural differences in the ventral visual cortex as well as in areas associated with semantic processing of objects. Westerners who encoded complex pictures containing a central object against a background showed more engagement of bilateral middle temporal, right superior temporal, and left superior parietal regions (areas important for object and semantic processing) than East Asians. In contrast, East Asians, when processing backgrounds, showed greater engagement of left occipital and fusiform areas, which are implicated in structural, perceptual analyses (Joseph & Gathers, 2003).

In the present study, we used the adaptation paradigm developed by Goh et al. (2004) to investigate how culture might interact with age differences in processing objects and backgrounds as well as contextual binding of objects to backgrounds. In Goh et al.'s study, young adults

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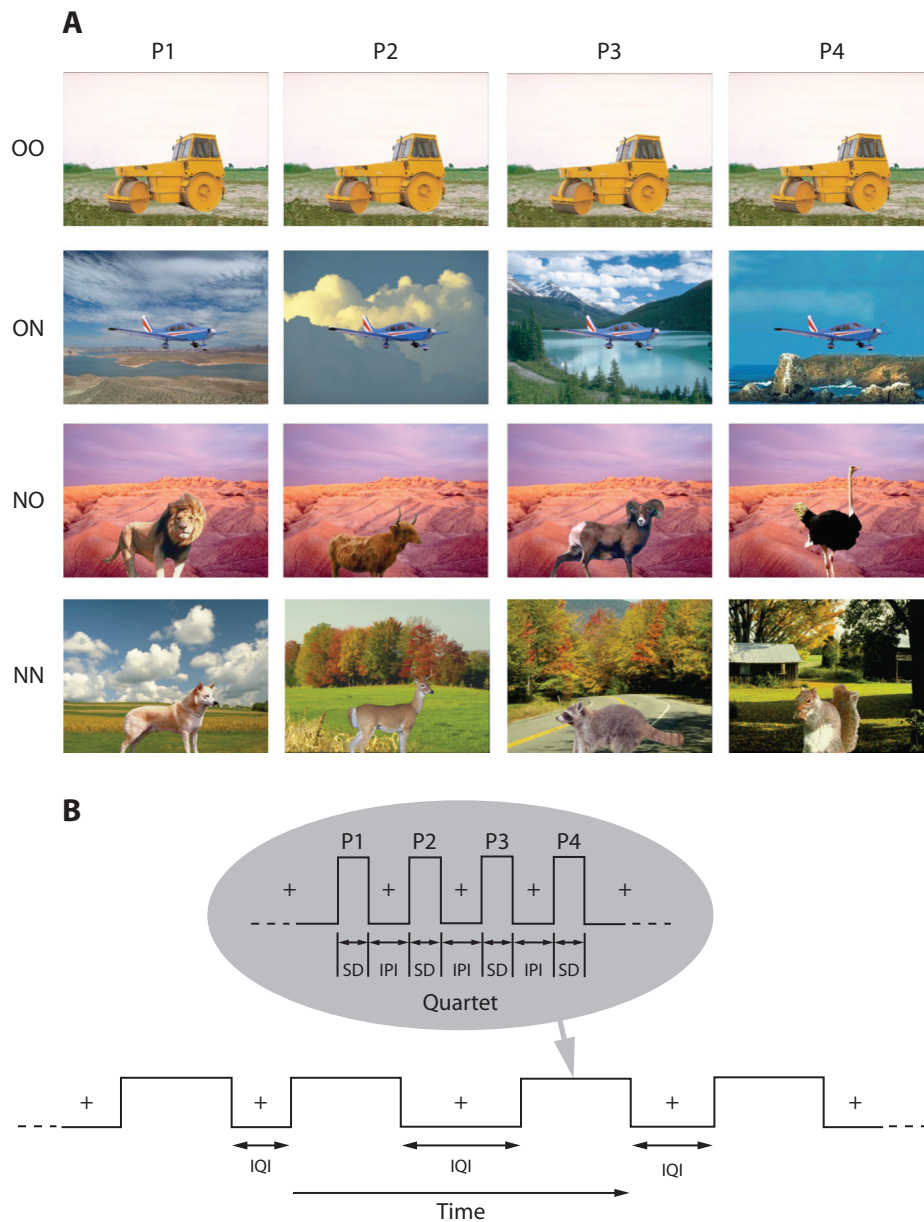
Figure 1. Hybrid block/event-related fMRI experiment consisting of quartets of picture stimuli. (A) The four quartet conditions: four repeated objects and scenes (OO: old object, old scene); four novel scenes with a repeated object (ON: old object, new scene); four novel objects within a repeated scene (NO: new object, old scene); and four novel objects with four novel scenes (NN: new object, new scene). (B) Picture stimulus duration (SD) was 1.5 sec, with an interpicture interval (IPI) of 250 msec and mean interquartet interval (IQI) of 9 sec. A fixation cross was shown during the intervals when no picture was displayed.

were presented with quartets of pictures in which either the central object or the background of the picture varied (Figure 1), and the attenuation of the blood oxygen level dependent (BOLD) signal that occurred upon repetition of elements of the pictures was measured (see Grill-Spector & Malach, 2001). In conditions in which the object was repeated and the background changed, the BOLD response diminished, relative to when both the object and the background were changed, in the lateral occipital complex (LOC) in both hemispheres (Grill-Spector, Kourtzi, & Kanwisher, 2001; Malach et al., 1995). This suggests that these areas were engaged for processing objects and that they showed an adapted response as the objects repeated across the quartets. Similarly, when the object changed and the background was held constant, bilateral parahippocampal place areas (PPA) showed adaptation, suggesting that these areas were specialized for background processing (Epstein, Graham, & Downing, 2003; Epstein &

Kanwisher, 1998). Finally, Henke, Weber, Kneifel, Wieser, and Buck (1999) demonstrated that binding areas in bilateral parahippocampal gyrus (separate from the PPA) and right hippocampus showed adaptation when both elements were repeated but not when both were varied, suggesting that these areas were important for contextually binding a target object to a scene; this was the first study that showed binding-related processing when subjects passively viewed scenes rather than when they actively attempted to bind scene elements.

Aging is consistently associated with poorer episodic memory related to binding deficits at encoding (Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, & D'Esposito, 2000; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Park, Puglisi, & Sovacool, 1984; Spencer & Raz, 1995). Chee et al. (2006) tested a sample of older adults using the Goh et al. (2004) paradigm to investigate the neural correlates of these binding deficits characteristic of aging. When compared with the data from young adults in Goh et al.'s study, the data from the Chee et al. study showed greatly reduced binding activity in older adults in the medial temporal regions and, surprisingly, the total absence of object processing adaptation in the LOC. In contrast, the background processing areas in the parahippocampal regions showed similar magnitudes of adaptation responses for old and young adults. In follow-up experiments, object processing adaptation in the LOC was demonstrated again when older adults were instructed to attend to the central object in the scene, as well as when the older adults viewed the object alone without a background. Thus the nonrecruitment of the LOC when the older adults passively viewed complex pictures appears to represent a perceptual bias driven by age-related changes in visual attention (Madden & Langley, 2003; Maylor & Lavie, 1998; McCarley, Mounts, & Kramer, 2004; Milham et al., 2002; Pringle, Irwin, Kramer, & Atchley, 2001).

It is noteworthy that the subjects in both Goh et al. (2004) and Chee et al. (2006) were Singaporeans of Chinese heritage. Both behavioral and imaging data suggest a bias in Westerners to process objects within the background, which raises the question of whether the loss of object sensitivity in older Chinese adults reflects a culturally biased visual perceptual processing in East Asians that is exacerbated by changes in visual attention with age.

To evaluate the neural correlates of cultural differences in perceptual processing as a function of age, we tested 38 young and elderly Western subjects (not of Asian descent) using the Goh et al. (2004) paradigm and contrasted the data from these subjects with the data from the young and elderly East Asians who participated in the Goh et al. and Chee et al. (2006) studies. We hypothesized that due to prolonged experience within an object-biased culture, elderly Westerners would show greater engagement of object-processing areas than did the elderly East Asians from the Chee et al. study. Specifically, we expected the elderly Westerners to show greater object-processing activity in the lateral occipital areas than the elderly East Asians. We also predicted, on the basis of behavioral findings of cross-cultural differences, that older Westerners would show less activity in the background processing areas than older East Asians. Finally, with regard to the extensive literature documenting behavioral and functional deficits in binding with age in Westerners, we expected both elderly East Asians and elderly Westerners to show deficits in binding reflected by reduced binding-related activity, relative to young adults, in the hippocampal and parahippocampal regions.

METHOD

Subjects

Thirty-eight right-handed volunteers, including 19 young Westerners (12 males and 7 females ranging in age from 19 to 27 with a mean age of 21.7 years) and 19 elderly Westerners (14 females and 5 males, ranging in age from 60 to 78 with a mean age of 68.1 years) from the United States, gave informed consent to participate in this study. Subjects were screened for significant illnesses and contraindications for fMRI scanning. Data from our previous study of Singaporean subjects were included for comparison across cultures. These subjects included 20 young East Asians (13 females and 7 males ranging in age from 20 to 24 with a mean age of 21.3 years) and 17 elderly East Asians (11 females and 6 males ranging in age from 60 to 75 with a mean age of 66.7 years). All subjects had normal vision or vision corrected to the acuity of 20/30 on the Snellen chart. Subjects underwent neuropsychological testing (see Table 1), and they also took the WAIS–R Comprehension test, which is a culturally appropriate measure of verbal intelligence with different versions for East Asians and Westerners (Gong, 1983; Wechsler, 1981). There were no significant differences across age [$F(1,69)$ = 0.003, n.s.] or culture [$F(1,69)$ = 0.032, n.s.] in subjects' performance on this test, indicating that subjects were comparable in this measure of general intelligence.

There were, however, significant effects of age in several tests involving speed of processing and working memory; this result is consistent with the notion that aging is associated with slowing (Madden & Langley, 2003; Salthouse, 1996). In contrast, there was no effect of culture on performance in these speeded working memory tests. There was an effect of age on the Mini-Mental State Exam (MMSE) [$F(1,69)$ = 11.34, $p < .01$], but the mean scores were still well within the population norm for elderly subjects, with all of the older subjects scoring 27 or greater (Crum, Anthony, Bassett, & Folstein, 1993). It is important to note that the MMSE scores did not differ across cultures between subjects within the same age group. There was a main effect of culture in the pattern-matching task [$F(1,69)$ = 4.29, $p < .05$] and an interaction of age with culture in the digit symbol task [$F(1,69)$ = 7.00, $p < .05$] (see Hedden et al., 2002).

Stimuli

In this fMRI experiment, full color pictures of 200 objects and 200 place scenes were used (Figure 1A; described in more detail in Goh et al., 2004) to compose picture stimuli of objects placed within congruent background scenes. Pictures were presented in quartets, which resulted in four experimental conditions: (1) four repeated object and scene pairs (OO: old object, old scene); (2) repeated objects within four novel scenes (ON: old object, new scene); (3) four novel objects within repeated scenes (NO: new object, old scene); and (4) four novel object and scene pairs (NN: new object, new scene). The objects subtended visual angles of approximately 0.5º × 1.0º (minimum) to 2.5º × 5.5º (maximum) from each of their centers, while background scenes subtended a visual angle of approximately 4.6º × 6.3º from the fixation point.

Each picture within a quartet was presented for 1.5 sec and separated from the next picture by an interpicture interval of 250 msec (fixation; see Figure 1B). Quartets were pseudorandomly presented such that a given condition did not occur more than three times consecutively. Quartets were also separated by interquartet intervals of

Table 1
Means (and Standard Deviations) for Demographic Information and Neuropsychological Test Scores
of Young and Elderly Westerners and East Asian Subjects

| | Westerners | | | | East Asians | | | | F Values | | |
| | Young (12 males, 7 females) | | Elderly (5 males, 14 females) | | Young (7 males, 13 females) | | Elderly (7 males, 10 females) | | | | Age × Culture |
	M	SD	M	SD	M	SD	M	SD	Culture	Age	
Age (years)	21.73	1.98	68.1	5.53	21.3	1.11	66.65	4.00	–	2,709.5**	–
Years of education	15.26	1.38	15.75	2.97	14	1.45	12.5	2.54	17.9**	–	–
Pattern matching	36.13	7.39[†]	21.15	4.78	39.94	5.50	22.7	4.40	4.29*	154.94**	–
Dot comparison	16.07	1.87[†]	9.4	2.64	16.61	3.01	7.8	3.24	–	138.98**	–
WAIS–R Digit–Symbol	72.93	9.36[†]	53.1	11.41	82.72	8.66	50	11.21	–	116.46**	7.00**
WAIS–R Information	22.93	3.47[†]	20.2	4.03	20.22	4.39	17.7	4.68	6.90*	7.02*	–
WAIS–R Comprehension	22.93	4.04[†]	21.05	3.53	21.28	3.72	23.05	4.88	–	–	–
Mini-Mental State Exam	29.6	0.51[†]	29	1.12	29.39	0.92	28.3	1.38	–	11.34**	–
WMS–III Forward Spatial Span	10.14	2.19[‡]	8.45	1.76	10.22	1.80	8.3	2.11	–	11.76**	–
WMS–III Backward Spatial Span	9.71	1.49[‡]	7.45	1.64	9.67	1.68	7.45	1.85	–	23.15**	–
WAIS–III Forward Digit Span	11	1.63[‡]	10	2.85	12.39	2.38	10.5	1.85	–	5.15*	–
WAIS–III Backward Digit Span	9.71	1.38[‡]	6.7	2.49	9.22	2.44	6.4	1.90	–	23.25**	–

Note—Only significant F values are reported for the main effects of culture and age, and the interaction between age and culture. Tests are complete for all elderly subjects and all young East Asians and data are missing for some young Westerners.   [†]$n = 15$.   [‡]$n = 7$.   *$p < .05$.   **$p < .01$.

6, 9, or 12 sec with a mean separation of 9 sec. The jittered intervals were necessary for effective estimation of BOLD responses to the stimuli in this rapid, event-related fMRI design (Dale, 1999).

Functional brain images were acquired as each subject viewed the picture stimuli over a course of four experimental runs that lasted 348 sec each. Each run comprised 20 quartets (5 from each condition), which were preceded and followed by periods of fixation that lasted 30 sec to allow for better estimation of baseline BOLD responses. Each subject therefore viewed a total of 20 quartets of each experimental condition across the four runs.

Imaging Protocol

fMRI experiments were conducted at the Cognitive Neuroscience Laboratory in Singapore and the University of Illinois at Urbana-Champaign. Both sites used identical 3.0T Allegra scanners (Siemens) and personnel worked closely together to be certain that protocols at the two sites were identical. Critical analyses of fMRI signal, noise, and stability were performed; they showed a high reliability across sites (Sutton et al., 2007).[1] For the experimental task, 116 functional scans were acquired in each run using a gradient-echo EPI sequence with TR of 3 sec, FOV 19.2 × 19.2 cm, and a 64 × 64 matrix. Thirty-six oblique axial slices, 3 mm thick (0.3 mm gap) and approximately parallel to the AC–PC line, were acquired. High-resolution coplanar T2 anatomical and 3-D MPRAGE anatomical images were also acquired for image coregistration of the functional slices into 3-D space. Stimuli were projected onto a screen at the back of the magnet while participants viewed the screen using a mirror.

Image Data Analysis

Functional images were processed using Brain Voyager 2000 4.9 and Brain Voyager QX 1.3 (Brain Innovation, Maastricht) customized with in-house scripts. Gaussian smoothing in the spatial domain was applied using a FWHM kernel of 8 mm. Functional data were then resampled into 1 × 1 × 1 mm resolution per voxel. For each of the four subject groups, the data were analyzed using a general linear model (GLM) comprising seven finite impulse response predictors for each of the four experimental conditions (OO, ON, NO, and NN). Thus we modeled the evolution of the BOLD response time course over 21 sec (seven scans) from stimulus onset. Subsequent contrast analyses of imaging data considered only the fourth predictor (9 sec from onset) for each condition, as this was identified as the peak response within the estimated BOLD response time course across all four groups of subjects (data available upon request). This analysis resulted in a statistical map containing parameter estimates for each predictor in every voxel of the 3-D functional brain data.

Conjunction Analysis

As in Goh et al. (2004), we used a conjunction analysis along with a region of interest (ROI) approach to identify and evaluate BOLD responses in object, background, and binding processing regions. For the conjunction analysis, we first computed voxel maps containing t values of each contrast (see below) of parameter estimates obtained from the GLM analysis. Then, for each voxel, we compared the relevant contrasts and entered the least significant t value into a new statistical voxel map only if all the contrasts in consideration were positive. Using this approach, we defined (1) object-processing voxels as those that showed adaptation responses when objects were repeated regardless of background repetition (OO < NN; OO < NO; ON < NN; ON < NO); (2) background-processing voxels as those that showed adaptation responses when backgrounds were repeated regardless of object repetition (OO < NN; OO < ON; NO < NN; NO < ON); and (3) binding-processing voxels as those that showed adaptation responses only when both object and background were repeated, with the additional requirement that the adaptation responses be greater than the sum of partial adaptation to either object or background repetition alone (OO < NN; OO < ON; OO < NO; [OO < NN] < [ON < NN] + [NO < NN]). Note that because we were considering adaptation responses, the contrasts are described as attenuations in signal, rather than increases (as is more typical).

Next, the object, background, and binding ROIs were defined as contiguous voxels (the smallest ROI cluster consisted of 105 voxels) that showed the respective significant conjunctions at a statistical threshold of $p < .001$ (uncorrected), except when the ROI was in the hippocampus, where a reduced threshold of $p < .005$ was used (congruent with procedures used by others: Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Ojemann et al., 1997). These ROIs were identified separately for the data from the East Asian group and that from the Western group. Examination of the peak Talairach coordinates of these functional ROIs in young and elderly Westerners (see Table 2) showed that they were comparable with those of the East Asians (Chee et al., 2006).[2]

Adaptation Magnitude Analysis

To characterize the effects of age and culture on the visual processing of objects, background scenes, and contextual binding, we evaluated group differences in adaptation magnitude in each

Table 2
Peak Talairach Coordinates of the Object, Background, and Object–Background Binding ROIs Identified Using the Conjunction Analysis for Young and Elderly Westerners

Brain Region	Brodmann's Area	x	y	z	t Value
Young Subjects					
Object Processing					
(NN > OO and NN > ON and NO > OO and NO > ON)					
R inferior occipital gyrus	19	30	−85	−2	4.96
L inferior occipital gyrus	19	−42	−73	−5	4.64
R fusiform gyrus	37	45	−67	−2	4.52
L fusiform gyrus	20	−39	−40	−14	5.16
Background Scene Processing					
(NN > OO and NN > NO and ON > OO and ON > NO)					
R parahippocampal gyrus	36	18	−39	−4	6.79
L parahippocampal gyrus	36	−22	−43	−5	5.73
R lingual gyrus	19	13	−68	−6	4.52
L lingual gyrus	19	−12	−71	−11	4.07
R posterior cingulate	29	10	−48	8	5.34
L posterior cingulate	29	−11	−48	7	6.47
L cuneus	18	−6	−92	9	4.21
Object and Background Scene Binding					
(NN > OO and NO > OO and ON > OO and					
[NN − OO] > [NN − ON] + [NN − NO])					
R hippocampus	35	33	−19	−11	4.00
R parahippocampal gyrus	37	29	−49	−11	6.86
L parahippocampal gyrus	36	−27	−27	−14	4.66
R lingual gyrus	18	12	−88	−2	4.17
L fusiform gyrus	37	−30	−70	−11	3.97
R occipito-parietal sulcus	19	49	−73	12	3.11
L occipito-parietal sulcus	19	−36	−79	19	4.61
Elderly Subjects					
Object Processing					
(NN > OO and NN > ON and NO > OO and NO > ON)					
L inferior occipital gyrus	19	−45	−74	−5	4.17
R fusiform gyrus	19	48	−65	−2	3.72
L fusiform gyrus	37	−39	−43	−17	3.85
Background Scene Processing					
(NN > OO and NN > NO and ON > OO and ON > NO)					
R parahippocampal gyrus	36	24	−44	−8	4.15
R lingual gyrus	19	20	−70	−11	4.17
L lingual gyrus	19	−21	−67	−11	4.31
R middle occipital gyrus	18	30	−80	16	4.28
L middle occipital gyrus	18	−36	−80	10	4.64
Object and Background Scene Binding					
(NN > OO and NO > OO and ON > OO and					
[NN − OO] > [NN − ON] + [NN − NO])					
R fusiform gyrus I	37	33	−37	−13	4.56
R fusiform gyrus II	19	30	−67	−8	3.48
L fusiform gyrus	37	−36	−43	−15	4.32
R occipito-parietal sulcus	19	33	−73	22	3.45
L occipito-parietal sulcus	19	−33	−70	28	3.44

of the functional ROIs as defined above (see Epstein, Higgins, & Thompson-Schill, 2005, for a similar approach). We reasoned that the difference in BOLD responses elicited by the relevant pairs of conditions for each functional ROI would give a measure of the integrity of function of that region, with larger adaptation indicating better functional integrity than weak or absent adaptation. In the object-processing regions, adaptation magnitude was indexed by the difference between ON and NN responses; in the background-processing regions, by the difference between NO and NN responses; and in the binding regions, by the difference between OO and NN responses. Note that these ROI were already identified as being involved in object, background, and binding processing, respectively. Thus, the resulting contrast values within each ROI reflect the degree of attenuation in response to the relevant repeated picture component (object, background, or the associations between them) relative to when no component was repeated (NN). The ROI masks that characterized the locus of each functional region for East Asians and Westerners were applied to each of the respective individual subjects. The individual measures of magnitude of adaptation for each ROI were determined and the data obtained were subsequently grouped according to age and culture.

RESULTS

We characterized the interaction between age and culture group using an ANOVA of the adaptation magnitude data from all four groups for each ROI (see Figure 2). In the object–background binding regions, we observed main effects of age in the right parahippocampal gyrus [$F(1,71) = 9.86$, $p < .001$] and right hippocampus [$F(1,71) = 4.13$, $p < .05$] (Figure 2A). There was no significant interaction of age with culture, suggesting that reduction in contextual binding is an age-related change that is independent of culture.

In the background-processing regions, there were no significant differences in adaptation response across all four groups in either the right or left parahippocampal gyrus, suggesting that background processing was preserved across both age and culture (Figure 2B).

Of particular interest, the analysis of object-processing regions showed evidence for a reduction of response with age in both left [$F(1,71) = 11.24$, $p < .01$] and right [$F(1,71) = 10.85$, $p < .01$] lateral occipital regions (Figure 2C). There was also a marginally significant interaction of age with culture in the right lateral occipital region [$F(1,71) = 3.22$, $p < .08$]. This interaction was predicted, and a planned comparison of this effect in this ROI revealed a highly significant difference in object-processing adaptation magnitudes between young and elderly East Asians [$t(35) = 3.65$, $p < .001$] but not in young and elderly Westerners [$t(36) = 1.11$, n.s.]. Moreover, the elderly East Asians showed significantly lower object-processing adaptation than did elderly Westerners [$t(34) = 2.86$, $p < .05$], whereas there was no significant difference between young East Asians and young Westerners [$t(37) = 0.01$, n.s.]. The same comparisons in the left lateral occipital region yielded significant differences as a function of age for both Westerners [$t(36) = 1.99$, $p < .05$] and East Asians [$t(35) = 2.76$, $p < .01$], with no evidence of an interaction [$F(1,71) = 0.07$, n.s.]. Overall, the analysis suggests that object processing in the lateral occipital regions is attenuated in elderly Westerners in the left but not the right LOC, and greatly attenuated in elderly East Asians in both hemispheres.

DISCUSSION

The present study makes three major points with respect to neurocognitive processes associated with aging and culture; each point addresses a different area of ventral visual cortex. The pattern of results observed demonstrates that (1) decreases in neural binding processes are manifested cross-culturally in elderly adults; (2) neural
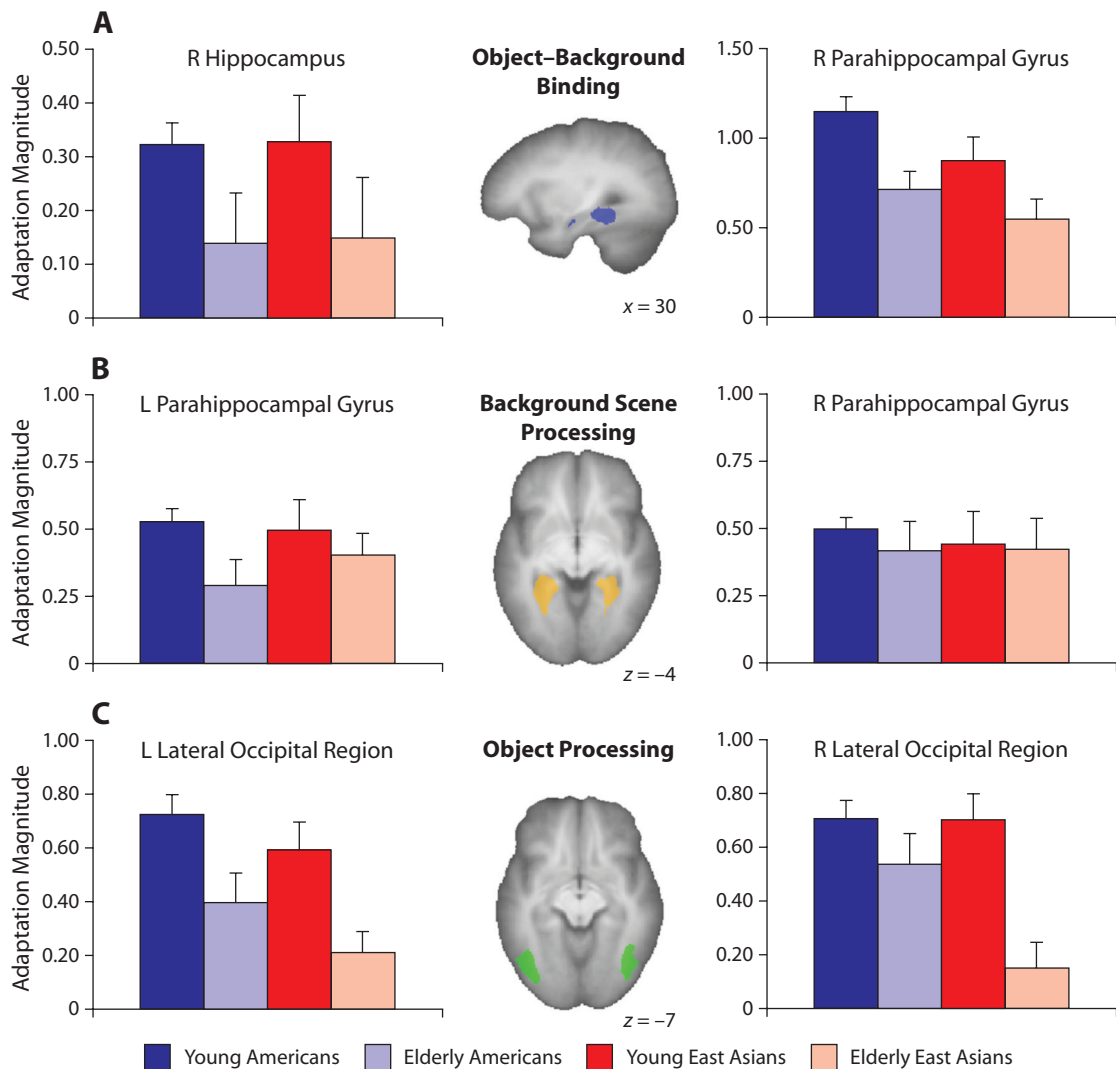
Figure 2. Mean magnitude of adaptation in young East Asians, young Westerners, elderly East Asians, and elderly Westerners. (A) Responses in hippocampal (left panel) and parahippocampal (right panel) binding regions. (B) Responses in left and right parahippocampal areas engaged in background processing. (C) Responses in left and right lateral occipital complex engaged in object processing. Standard error bars are shown.

processing of background scenes in complex pictures is unaffected by age or culture; and (3) object-processing regions decline with age, disproportionately in East Asians. Each result is discussed in turn.

Binding Mechanisms Across Age and Cultural Group

The finding that, during passive viewing of pictures, both elderly East Asians and elderly Westerners showed decreased binding in the right hippocampus and right parahippocampal gyrus compared with young adults suggests that experience (in the form of cultural exposure, for example) may play only a relatively modest role in moderating the binding process and that biological mechanisms associated with the aging process may play a larger role in decreasing older adults' ability to engage medial temporal structures for binding to the same degree that young adults

do. Studies have shown that the hippocampus and entorhinal cortex undergo atrophy with age and that this atrophy can be related to poorer memory performance (Rodrigue & Raz, 2004; Rosen et al., 2003). The loss of neural tissue available for processing contextual binding may diminish the quality of the representations of associative information that are encoded and subsequently accessed. The finding of this reduced binding in older adults replicates the results of Mitchell, Johnson, Raye, Mather, and D'Esposito (2000), in which an intentional encoding task was used. The results of the present study and those in Chee et al. (2006) extend this finding to a passive viewing task.

Age, Cultural Group, and the Processing of Background Context

We found little evidence that neural areas that are specialized for background scene processing differ as a func-

tion of age or culture, although some further exploration resulted in some marginally significant effects in the expected direction. We noted that the background adaptation response in the left parahippocampal gyrus was slightly lower for elderly Westerners than for young Westerners [$t(36) = 1.62$, $p = .06$] and young East Asians [$t(37) = 1.37$, $p = .09$], whereas there was no significant contrast between elderly East Asians compared with young Westerners [$t(34) = 1.02$, n.s.] and young East Asians [$t(35) = 0.72$, n.s.]. This finding is consistent with the notion of preserved background processing in elderly East Asians. That the relatively equivalent background processing across groups in this study may result from effective processing of contextual information in complex scenes by older adults.

There is considerable evidence that older adults buttress their memory for complex pictures by using contextual information when it is present in pictures that are sufficiently rich in meaning and detail (Park, Puglisi, & Smith, 1986; Park, Smith, Morrell, Puglisi, & Dudley, 1990; Smith, Park, Cherry, & Berkovsky, 1990). It is possible that further exploration of neural processing of context will demonstrate age differences in this mechanism in cases in which the contextual information is less meaningful or more poorly integrated with the target. In particular, a large number of findings suggests that older adults remember contextual information associated with words or abstract pictures less well than young adults do (Park et al., 1990; Smith et al., 1990). It may also be that pronounced cultural differences in the neural processing of background information will similarly emerge under more demanding conditions, accentuating the expected bias for East Asian cultural groups to show a preferential processing of background detail relative to Western groups.

Age, Culture, and Object Processing

In the present study, we found evidence for diminished object processing in the LOC in older adults from both cultures, as reported initially by Chee et al. (2006). Perhaps the most important finding from the present study is that elderly Westerners showed significantly greater object-processing adaptation in the LOC than did elderly East Asians, who showed almost no adaptation whatsoever. This finding provides neuroimaging evidence for cultural biases in perceptual processing of objects and is in agreement with Gutchess et al. (2006), who reported greater neural engagement for object-processing regions in Westerners than in East Asians in a picture recognition task, albeit for young adults in both cases. Although the stimuli used in this study were similar to those used by Gutchess et al., the present study differed in that we used a passive viewing task and an adaptation paradigm as opposed to a directed incidental encoding task.

Perhaps because the present paradigm is comparatively subtle, cultural differences became apparent only in older subjects who had had more exposure to their respective cultural environments than the young subjects had had. This is a plausible explanation, since there is substantial evidence that neuro-anatomical changes in the brain are related to

the length of time individuals spend being engaged in specific behavioral practices and sensory environments. In a structural MRI study, posterior hippocampal volume was positively correlated with spatial navigation experience in London taxicab drivers versus controls (Maguire et al., 2003). Recently, Schneider et al. (2005) also showed that the volume of Heschl's gyrus was positively correlated with musical experience in professional musicians versus nonmusicians. Likewise, compelling evidence for functional changes in relation to experience is clearly seen in the functional specialization of brain regions for letter and number recognition in human subjects (Polk & Farah, 1995; Polk et al., 2002; Puce, Allison, Asgari, Gore, & McCarthy, 1996). We posit that culturally distinct behaviors and thought can also be construed as differences in specific experiences that affect neural function. An alternate explanation to the cultural experience hypothesis is that Asian society is changing rapidly and that the young Singaporeans (all of Chinese descent) have internalized Western values to the point that they no longer display behavioral patterns characteristic of Asian cultures. Even if this is the case, the results clearly demonstrate systematic differences between Eastern and Western subjects, with a bias toward more processing of object information in elderly Westerners, a finding in agreement with the cultural/cognitive framework proposed by Nisbett and Masuda (2003).

Conclusion

In summary, the present findings suggest that age alone cannot explain the reduced expression of object-processing regions in elderly East Asians and that the functional engagement of neural areas, such as the LOC, can be modified through experience. The most plausible basis for the difference, based on the burgeoning literature in cultural psychology, appears to be that visual experience is biased by cultural factors. Future research is needed to more specifically determine differences in neural circuitry that vary as a function of experience, with cultural differences playing a plausible role in shaping processes that are both perceptual, as in the present study of object and scene processing during passive viewing, as well as strategic, as reported by Gutchess et al. (2006).

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NOTES

1. Magnet comparability was assessed by human and phantom experiments. Comparability of the BOLD responses was addressed by scanning two subjects (who were not part of the main study) repeatedly at both sites on a motor and visual task (McGonigle et al., 2000). Fifteen runs of each task at each site were performed. Voxel-by-voxel whole brain ANOVA and ICC analyses using task, subject, and scanner sites as factors were performed on the data; these analyses indicated high reliability across sites. Specifically, task and subject accounted for a much greater proportion of the variance in the data than did site.

2. The ROI were identified separately across groups, since a complete, whole-group GLM required a data set that required a large amount of computer memory, which the current software does not allow. We identified the ROI by analyzing the East Asians and Westerners as separate groups. We also performed the analysis by considering four groups across age and culture. Although there were slight differences in peak voxel locations, the results were largely similar across groups. We report here only the former analysis, since it allows us to identify and examine the BOLD responses in the object-processing ROI in the elderly East Asians, which is absent when analyzing that data set alone.