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The neural correlates of memory encoding and recognition for own-race and other-race faces

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ABSTRACT

People are generally better at recognizing faces from their own race than from a different race, as has been shown in numerous behavioral studies. Here we use event-related potentials (ERPs) to investigate how differences between own-race and other-race faces influence the neural correlates of memory encoding and recognition. ERPs of Asian and Caucasian participants were recorded during the study and test phases of a Remember–Know paradigm with Chinese and Caucasian faces. A behavioral other-race effect was apparent in both groups, neither of which recognized other-race faces as well as own-race faces; however, Caucasian subjects showed stronger behavioral other-race effects. In the study phase, memory encoding was assessed with the ERP difference due to memory (Dm). Other-race effects in memory encoding were only found for Caucasian subjects. For subsequently "recollected" items, Caucasian subjects showed less positive mean amplitudes for own-race than other-race faces indicating that less neural activation was required for successful memory encoding of own-race faces. For the comparison of subsequently "recollected" and "familiar" items, Caucasian subjects showed similar brain activation only for own-race faces suggesting that subsequent familiarity and recollection of own-race faces arose from similar memory encoding processes. Experience with a race also influenced old/new effects, which are ERP correlates of recollection measured during recognition testing. Own-race faces elicited a typical parietal old/new effect, whereas old/new effects for other-race faces were prolonged and dominated by activity in frontal brain regions, suggesting a stronger involvement of post-retrieval monitoring processes. These results indicate that the other-race effect is a memory encoding- and recognition-based phenomenon.
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1. Introduction

It is easier to recognize own-race faces than those of another race. This so-called other-race effect (also known as the own-race bias, cross-race effect, other-ethnicity effect, same-race advantage) is well-documented in behavioral research (e.g., Meissner & Brigham, 2001; Valentine, 1991) and in research on the neural correlates of perception (e.g., Gajewski, Schlegel, & Stoerig, 2008; Stahl, Wiese, & Schweinberger, 2008; Tanaka & Pierce, 2009; Wiese, Stahl, & Schweinberger, 2009). Although the other-race effect is rooted in differences in memory performance, systematic assessments of the neural correlates of memory processes are comparatively rare (Golby, Gabrieli, Chiao, & Eberhardt, 2001; Lucas, Chiao, & Paller, 2011; Stahl, Wiese, & Schweinberger, 2010). The present study uses event-related potentials (ERPs) to determine how lifelong experience with a race optimizes memory encoding and the subsequent recognition of faces from that race.

1.1. Memory processes underlying the other-race effect

Several behavioral studies have shown that own-race faces are more accurately recognized than other-race faces (e.g., Meissner & Brigham, 2001; Valentine, 1991). Recent studies have used specific tasks to refine these results and draw inferences about the two independent components of processing thought to underlie recognition memory: recollection and familiarity (Jacoby, 1991; Mandler, 1980; see Yonelinas, 2002, for a review). *Recollection* corresponds to the retrieval of specific, meaningful information about a studied face and its learning context. In this case, the subject remembers not just the face, but also such information as where the person was last seen or what the person's name is. *Familiarity* lacks the retrieval of such episodic details and arises instead from identifying a global similarity between a seen face and information stored in memory. In this instance, the subject knows that he or she has seen the person, but cannot recall any additional contextual information.

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Various experimental paradigms are used to measure recollection and familiarity. The one most often used is the Remember–Know procedure (Tulving, 1985). Participants are asked to indicate the reasons for classifying a previously studied item as "old." If aspects from the study episode are recalled together with the item, participants shall judge this item as "remembered." If participants feel that the item is old but do not remember any details from the study phase, they are asked to judge it as "known." "Remember" responses indicate recollection-based retrieval and "know" responses familiarity-based retrieval.

Previous research has suggested that both recollection and familiarity are influenced by the race of a face. Studies using Remember–Know tasks have shown that the own-race advantage results from higher "remember" hit rates for own-race as compared to other-race faces and thus from more accurate recollection-based processing of studied faces (Horry, Wright, & Tredoux, 2010; Marcon, Susa, & Meissner, 2009; Meissner, Brigham, & Butz, 2005). These studies have also reported fewer false alarms for own-race than for other-race faces. Familiarity has been linked to false alarm rates in Remember–Know tasks (Diana, Reder, Arndt, & Park, 2006), and it is thus likely that familiarity processes are enhanced for own-race faces as well. This influence of familiarity is only seen in false alarms but not in hit rates.

Previous behavioral other-race studies have also suggested that the other-race effect is an encoding-related phenomenon because superior and more detailed memory encoding facilitates the recognition of own-race faces (Marcon et al., 2009; Meissner et al., 2005). This is in accordance with studies on the Remember–Know procedure, which have shown that recollection, as compared to familiarity, is influenced by a deeper (i.e., generative or semantic) memory encoding (e.g., Yonelinas, 2002).

1.2. Theoretical accounts of the other-race effect in memory

Different theories have been put forward to account for the other-race effect in memory. Two different, but not mutually exclusive perspectives shall be briefly considered.

Perceptual expertise accounts (Meissner & Brigham, 2001; Rossion & Michel, 2011; Valentine, 1991) propose that the other-race effect is based on perceptual mechanisms that develop with increasing experience. Greater experience with own-race faces leads to better, more efficient memory processes for own-race faces only (Michel, Caldara, & Rossion, 2006; Michel, Rossion, Han, Chung, & Caldara, 2006; Tanaka, Kiefer, & Bukach, 2004). Supporting evidence for this view includes the intensification of the other-race effect from childhood to adult age (Chance, Turner, & Goldstein, 1982), the attenuation or even reversal of the other-race effect when children are adopted in an other-race environment (Bar-Haim, Ziv, Lamy, & Hodes, 2006; Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005), and the disappearance of the other-race effect after intensive other-race training (Goldstein & Chance, 1985; Tanaka & Pierce, 2009). Furthermore, the diagnostic information used to individuate faces differs within a race (Furl, Phillips, & O'Toole, 2002) and can only be learned over time (Hills & Lewis, 2006). Finally, the perceptual processing advantages that characterize own-race face recognition are similar to the processes that experts exhibit for the recognition of objects in their domain of expertise (Bukach, Gauthier, & Tarr, 2006; Scott, Tanaka, Sheinberg, & Curran, 2006, 2008).

In contrast to expertise-based interpretations, *socio-cognitive accounts* seek the origin of the other-race effect primarily in the social lives of humans but also suggest the influence of some expertise factors (Hugenberg, Young, Bernstein, & Sacco, 2010). They assume that poor recognition of other-race faces is caused by motivational and/or attentional factors that overemphasize the race (or group membership) of faces at the expense of their individuality. In-group/out-group differences (Sporer, 2001), situational contexts (Hugenberg, Miller, & Claypool, 2007; Wilson & Hugenberg, 2010), or racial biases (Levin, 2000) can lead to preferences in such processes as the individuation of own-race faces or the categorization of other-race faces, which can cause other-race effects in memory performance. Results of a recent study, however, did not support these assumptions (Rhodes, Lie, Ewing, Evangelista, & Tanaka, 2010). In accordance with behavioral studies of the other-race effect (see Section 1.1), socio-cognitive accounts attribute the other-race effect to differences in memory encoding (Hugenberg et al., 2010).

1.3. Electrophysiological correlates of memory processes

The present report focuses on three memory-related ERPs: difference due to memory (Dm), the parietal old/new effect, and the late-frontal old/new effects. All ERPs are commonly measured as difference waves between experimental conditions (e.g., "remember" minus "know", "remember" minus new). As compared to the parietal and late frontal old/new effects, research on the Dm showed less consistent results with regard to its time course, scalp distributions, and task sensitivities.

A Dm reflects the encoding of new representations into long-term memory and, in most studies on face recognition, is characterized by a central–parietal positivity between 300 and 1000 ms in the study phase of an experiment (e.g., Sommer, Schweinberger, & Matt, 1991; Yovel & Paller, 2004). The central–parietal scalp topography is consistent with prefrontal, medial-temporal, and parietal areas that have been identified as brain regions generating subsequent memory effects in fMRI studies (Kim, 2011; Spaniol et al., 2009). Dms are obtained by sorting ERPs recorded in the study episode according to the participant's memory judgments in the subsequent recognition test. In most studies on face recognition, faces that were correctly recognized in the test phase (i.e., old hits) elicited more positive activity over central–parietal regions than faces that were subsequently forgotten (i.e., old items incorrectly judged as "new," e.g., Sommer et al., 1991). In most Remember–Know studies, test items that were subsequently judged as "remembered" were found to show a greater central–parietal positivity during the study phase than test items that were subsequently judged as "known" (e.g., Friedman & Johnson, 2000; Yovel & Paller, 2004). A recent study found differences in Dms for own-race and other-race faces (Lucas et al., 2011). The Dm between subsequently, correctly recognized and subsequently forgotten items was larger for own-race than other-race faces.

Each of the two retrieval processes underlying recognition memory, familiarity and recollection (Jacoby, 1991; Mandler, 1980; Yonelinas, 2002), has been associated with characteristic ERPs measured by differences between successfully recognized old and correctly rejected new items in the test phase. The parietal old/new effect is a parietal positivity between 500 and 800 ms that is considered an index of recollection because it varies with the recollection of information from the study episode (Curran, 2000; Curran & Hancock, 2007; Rugg & Curran, 2007; Yovel & Paller, 2004). It is most likely generated in the parietal cortex (Spaniol et al., 2009).[1] A few studies have provided evidence for the influence of increased experience on the parietal old/new effect. Stahl et al. (2010) found

[1] The FN400, a frontal positivity between 300 and 500 ms, is thought to reflect processes of familiarity (see Rugg and Curran, 2007, for a review). It distinguishes hits from correct rejections without being influenced by the recollection of details from the study episode (e.g., Curran, 2000; Curran and Hancock, 2007; Rugg and Curran, 2007). In the present study, we did not find a significant FN400 and thus restrict our report to the parietal and late-frontal old/new effects.

larger old/new effects (400–600 ms) for own-race faces than for other-race faces. Similarly, a study on the own-age bias (Wiese, Schweinberger, & Hansen, 2008), which is thought to be based on similar mechanisms as the other-race effect, found that young participants had larger old/new effects (400–600 ms) for young faces as compared to old faces. Finally, a similar result was found in our previous study on car expertise, in which the magnitude of the parietal old/new effect increased with the level of car expertise (Herzmann & Curran, 2011).

Late-frontal old/new effects are characterized by a frontal positivity and onset times later than 800 ms (Cruse & Wilding, 2009; Friedman & Johnson, 2000; Hayama, Johnson, & Rugg, 2008; Ranganath & Paller, 2000), although some effects were observed starting as early as 500 ms (Friedman & Johnson, 2000). Late-frontal old/new effects are thought to be generated in the prefrontal cortex (Cruse & Wilding, 2009). Wilding and Rugg (1996) have proposed that these old/new effects reflect the engagement of post-retrieval processes that are activated whenever the outcome of the retrieval search is ambiguous or causes uncertainty (Rugg, Otten, & Henson, 2002). They could thus be expected to be more prevalent when subjects are retrieving information about other-race faces.

1.4. The present study

The present study investigated the neural correlates that underlie superior memory performance for own-race as compared to other-race faces. We measured ERPs indicative of memory encoding and recognition while Asian and Caucasian participants studied and recognized pictures of Chinese and Caucasian faces in a modified version of the Remember–Know procedure (Woodruff, Hayama, & Rugg, 2006; Yonelinas, Otten, Shaw, & Rugg, 2005). We conducted between-group analyses across Asian and Caucasian subjects. In addition, we calculated separate within-group analyses to better compare our results with previous ERP studies that included only one group (i.e., Caucasian subjects; Lucas et al., 2011; Stahl et al., 2010).

Considering previous reports (Hugenberg et al., 2010; Marcon et al., 2009; Meissner et al., 2005) that have attributed the other-race effect to processing differences during memory encoding, we would predict to find other-race effects only in the Dm, the ERP correlate of successful memory encoding. However, other studies (Herzmann & Curran, 2011; Stahl et al., 2010; Wiese et al., 2008) reported also modulations of retrieval-related ERPs. We therefore expected to observe other-race effects also in the parietal and late-frontal old/new effects, the ERP correlates of retrieval.

In addition to other-race effects in memory-related ERPs, we measured the P100, N170, P200, and N250 in order to replicate findings from previous studies on perceptual ERPs (e.g., Brebner, Krigolson, Handy, Quadflieg, & Turk, 2011; Gajewski et al., 2008; Herrmann et al., 2007; Lucas et al., 2011; Stahl et al., 2008, 2010; Tanaka & Pierce, 2009; Wiese et al., 2008, 2009).

2. Materials and methods

2.1. Participants

Thirty-two Caucasian undergraduates (59% females) and 25 international students from East-Asian countries[2] (64% females) gave informed consent to participate in the study,[3] which was approved by the Institutional Review Board of the University of Colorado at Boulder. Participants received partial course credit or payment of $15 per hour for their participation. All subjects were right-handed and had normal or corrected-to-normal visual acuity. Caucasian subjects had never lived in an Asian country, whereas Asian participants had lived in the USA for an average of 2.3 years (SD = 1.6 years). Asian participants (M = 23.0 years, SD = 3.2 years, range 18–29) were significantly older than Caucasian participants (M = 19.7 years, SD = 1.4 years, range 18–24), $t(55) = 4.8$, $p < .001$. However, this small age difference likely had no impact on the results of this experiment (Hildebrandt, Sommer, Herzmann, & Wilhelm, 2010).

2.2. Stimuli and apparatus

Stimuli (Fig. 1) consisted of 320 unfamiliar Caucasian (Color FERET database, Phillips, Moon, Rizvi, & Rauss, 2000) and 320 unfamiliar Chinese faces (CAS-PEAL database, Gao et al., 2004). Female and male faces were represented equally in both stimulus sets. All faces showed neutral or weakly smiling expressions. None had extraneous features like beards or glasses. Because the CAS-PEAL database consists of only gray-scale photographs, all pictures were converted to gray-scale and then fitted into a vertical ellipse of 170 pixels × 255 pixels (3.2° × 5° of visual angle) that extended up to the hairline. All pictures were equated for luminance and spatial frequency using the SHINE toolbox (Willenbockel et al., 2010) for MATLAB. Stimuli were shown on a uniform gray background at a viewing distance of one meter on a 17-in. flat-panel LCD monitor (Dell Professional P170S, refresh rate 60 Hz). Stimulus presentation and EEG recording were time-locked to the refresh point.

2.3. Procedure

The experiment consisted of eight study blocks followed immediately by their corresponding recognition blocks. Equal numbers of Chinese and Caucasian faces were presented intermixed in all blocks. Forty targets had to be memorized in each study block. In the subsequent recognition block, the 40 studied faces were randomly presented with 40 new, unfamiliar distracters. Face stimuli were randomly assigned as either targets or distracters for each participant. Short breaks were allowed within study blocks, between study and recognition blocks, and within recognition blocks to allow the participants to rest their eyes. Longer breaks were allowed before each new study block.

Each trial in the study blocks started with the presentation of a fixation cross for 200 ms, followed by the presentation of a target for 2 s. Inter-stimulus intervals were 1 s. Participants were instructed to look carefully at the targets and try to memorize them for the recognition block; no overt response was required. Each trial in the recognition blocks started with the presentation of a fixation cross for 200 ms, followed by a target or a distracter for 1.5 s. Participants were asked to withhold their response until the five response options appeared on the screen 1.5 s after target onset. This was done to minimize movement-related artifacts. After 1.5 s had passed, a horizontal, four-point rating scale and an additional square appeared on the screen below the stimulus. The rating scale consisted of four squares labeled "definitely unfamiliar," "maybe unfamiliar," "maybe familiar," and "definitely familiar." The additional square was labeled "recollect" (following Woodruff et al., 2006). For half of the participants, the following response button assignment was used: "recollect" – right index finger, "definitely familiar" – left index finger, "maybe familiar" – left middle finger, "maybe new" – left ring finger, and "definitely new" – left pinky. For the other half of the participants this assignment was reversed. Participants used a computer keyboard to make their responses. The interval between the response and the next fixation cross was 1 s. One study phase lasted about 2 min and one test phase about 10 min.

Before the experiment, participants received instructions and eight practice trials for "recollect" and "familiar" memory judgments. Recollection was explained as consciously remembering specific details of the appearance of a face or of the experience learning it in the study phase: something else that happened in the room, what the participants were thinking or doing, an association that came to mind, or what came just before or after that item. In the case that they did not recollect a face, they were asked to rate the familiarity. They were told to use "definitely familiar" or "maybe familiar" if they believed that they had seen the face in the study phase but could not consciously remember anything particular about its appearance or the experience learning it. "Maybe unfamiliar" or "definitely unfamiliar" were to be used if they did not recognize the item from the study phase. Participants were encouraged to make their responses according to their first impression, without time limit.

2.4. Performance measurement

For recognition memory performance, we considered percent of hits, percent of false alarms, the area below the receiver operating characteristic (ROC) curve ($P(A)$, Green & Swets, 1966), response bias c_a, and d' of "recollect" and "familiar" responses. ROC curves were computed from all five possible response bins, with "recollect" responses treated as reflecting higher confidence than "definitely familiar" responses. We interpret raw "recollect" judgments as corresponding to recollection. The raw "familiar" condition (i.e., "maybe familiar" and "definitely familiar") cannot be taken as a direct reflection of dual-process familiarity because these responses are contingent upon non-recollection. We thus calculated the independent remember/know (IRK) estimate of familiarity (IRK = $F/(1 - R)$, where F refers

[2] The Asian group consisted of 13 participants from China, 5 from Taiwan, 3 from Japan, 2 from Korea, 1 from Vietnam, and 1 from the Philippines.

[3] To rule out that differences in sample size influenced the data, we recalculated all results for a randomly selected sample of N = 25 Caucasian subjects and obtained the same results. Here we report data from the original sample of 32 subjects to ensure highest statistical power for within-group tests.



Fig. 1. Examples of Chinese (left) and Caucasian (right) faces used as stimuli in the experiment.

to raw "familiar" responses and *R* to raw "recollect" responses, Yonelinas, 2002) for hits and false alarms in the "familiar" condition.[4]

2.5. Event-related potential recording and measurement

The EEG was recorded in the study and test blocks with a 256-channel HydroCel Geodesic Sensor Net™ (HGSN 256 v. 1.0, Tucker, 1993; Fig. 2) connected to an AC-coupled high-input impedance amplifier (200 MΩ, Net Amps™, Electrical Geodesics Inc., Eugene, OR). Amplified analog voltages (0.1–100 Hz bandpass) were digitized at 250 Hz. The recording reference was the vertex channel (Cz). Individual sensors were adjusted until impedances were less than 50 kΩ.

Epochs of 1300 ms, starting 100 ms before target onset, were generated offline from the continuous record. Horizontal and vertical eye movements were corrected using the ocular correction ICA transformation in Brain Vision Analyzer 2.0.1 (Brain Products GmbH, Munich, Germany). Trials with non-ocular artifacts were discarded. ERPs were aligned to a 100-ms baseline before target onset, averaged separately for each channel and condition, digitally low-pass filtered at 40 Hz, and recalculated to average reference. A minimum of 15 trials per condition was ensured for each subject (mean trials per condition can be found in the Supplemental Materials, Table S1).

For memory-related ERPs, time segments and regions of interest (ROIs) were defined by visual inspection (Figs. 3–5) and according to previous research on both the Dm (Herzmann & Curran, 2011; Stahl et al., 2010) and old/new effects (Cruse & Wilding, 2009; Curran & Hancock, 2007; Hayama et al., 2008; Herzmann & Curran, 2011). Mean amplitudes for each time segment were computed by averaging the channels within each ROI for each condition and subject.

2.6. Data analysis

For both behavioral and ERP data, between-group as well as within-group results are reported. All analyses were conducted with stimulus race coded as own-race or other-race. This coding has the advantage of more intuitively testing not only for the presence of the other-race effect, but also for whether the other-race effect is larger in one group than in the other. A significant other-race effect across subjects would be indicated by a main effect of stimulus race. A group × stimulus race interaction would indicate differences in the other-race effect for Caucasian and Asian subjects.[5] Eta-squared – indicating the proportion (between 0 – none and 1 – all) of variance in the dependent variables accounted for by the variation in the independent variable – is provided for all analyses. All *p*-values associated with more than one degree of freedom were corrected according to the Greenhouse–Geisser procedure for sphericity violations (Winer, 1971). All epsilons for these analyses were below .75. We report corrected *p*-values but uncorrected degrees of freedom. We were primarily interested in main effects and interactions including the factors stimulus race and group and will thus only report these effects.

For behavioral measures, the highest-level analyses were mixed-model ANOVAs with the between-subject factor group (Asian, Caucasian) and the within-subject factor stimulus race (own-race, other-race). *t*-Tests were conducted within groups.

For memory-related ERP measures, the highest-level analyses were conducted across pairs of memory-judgment conditions to highlight Dm effects (subsequently "recollected" vs. subsequently "familiar"; subsequently "familiar" vs. subsequently forgotten) and old/new effects ("recollected" vs. "familiar" – measuring recollection processes; "familiar" vs. correctly rejected – measuring familiarity processes). Between-subject analyses were calculated as mixed-model ANOVAs with the between-subject factor group (Asian, Caucasian) and repeated measures on the following within-subject factors: stimulus race (own-race, other-race), memory judgment (2 levels, see conditions above), frontal–parietal (anterior to posterior gradient of ROIs) and left–right (laterality gradient of ROIs). For the Dm analysis, the additional within-subject factor time segment (300–600 ms, 600–1000 ms) was included. The frontal–parietal factor had three levels (frontal, central, parietal; Fig. 2) and the left–right factor five levels (left inferior, left superior, medial, right superior, right inferior; Fig. 2). For the parietal and late frontal old/new effect, the frontal–parietal factor had four levels (fronto-polar, frontal, central, parietal; Fig. 2) and the left–right factor three levels (left superior, medial, right superior; Fig. 2),

For perception-related ERPs, between-group analyses were conducted by mixed-model ANOVAs with the between-subject factor group (Asian, Caucasian) and repeated measures on the following within-subject factors: stimulus race (own-race, other-race), hemisphere (left, right), and memory judgment ("recollect," "familiar," and forgotten for the study phase or correctly rejected for the test phase).

Within-group analyses were conducted with the same within-subject factors also included in the between-group analyses.

3. Results

3.1. Memory performance

Table 1 summarizes behavioral and statistical indicators of memory performance.

3.1.1. Between-group effects

Significant main effects of stimulus race, which indicated significant other-race effects across subject groups, were found for the area below the ROC curve ($P(A)$), the percent of hits for "recollect" judgments, the percent of hits for IRK "familiar" judgments, and the percent of false alarms for IRK familiarity, $Fs(1,55) = 126.7, 28.9, 4.3,$ and 5.7, $ps < .05$, η^2s = 0.61, 0.28, 0.07, and 0.09, respectively. No significant other-race effects were seen in the response bias c_a, $p = .41$ or the percent of false alarms for "recollect" judgments, $p = .48$.

Significant group × stimulus race interactions indicated larger other-race effects for Caucasian than for Asian subjects for the area below the ROC curve ($P(A)$), the percent of hits for "recollect" judgments, and the percent of false alarms for IRK familiarity, $Fs(1,55) = 24.6$, 19.7, and 5.6, $ps < .01$, η^2s = 0.12, 0.19, and 0.09, respectively.

3.1.2. Within-group effects

Post-tests within subject-groups showed that other-race effects in the area below the ROC curve ($P(A)$) were present for both Asian, $t(24) = 5.0$, $p < .001$, $\eta^2 = 0.52$, and Caucasian subjects, $t(31) = 11.0$,

[4] Recent research has raised doubts about the extent to which remember/know judgments can be used to estimate separate recollection and familiarity processes. Some researchers argue that these judgments reflect merely confidence differences attributable to a single, continuously varying memory signal (Dunn, 2004; Rotello et al., 2005; Wixted and Stretch, 2004). Although we acknowledge this position, we nevertheless take remember/know judgments to be useful adjuncts to our ERP indices of familiarity and recollection because better behavioral, dual-process measures do not exist.

[5] Because in some previous studies stimulus race was coded in the same way as the subjects (in this case: Asian or Caucasian), it needs to be noted that in a 2 × 2 design the present and previous coding schemes are interchangeable and only differ in whether equivalent effects are reflected as statistical main effect or an interaction.

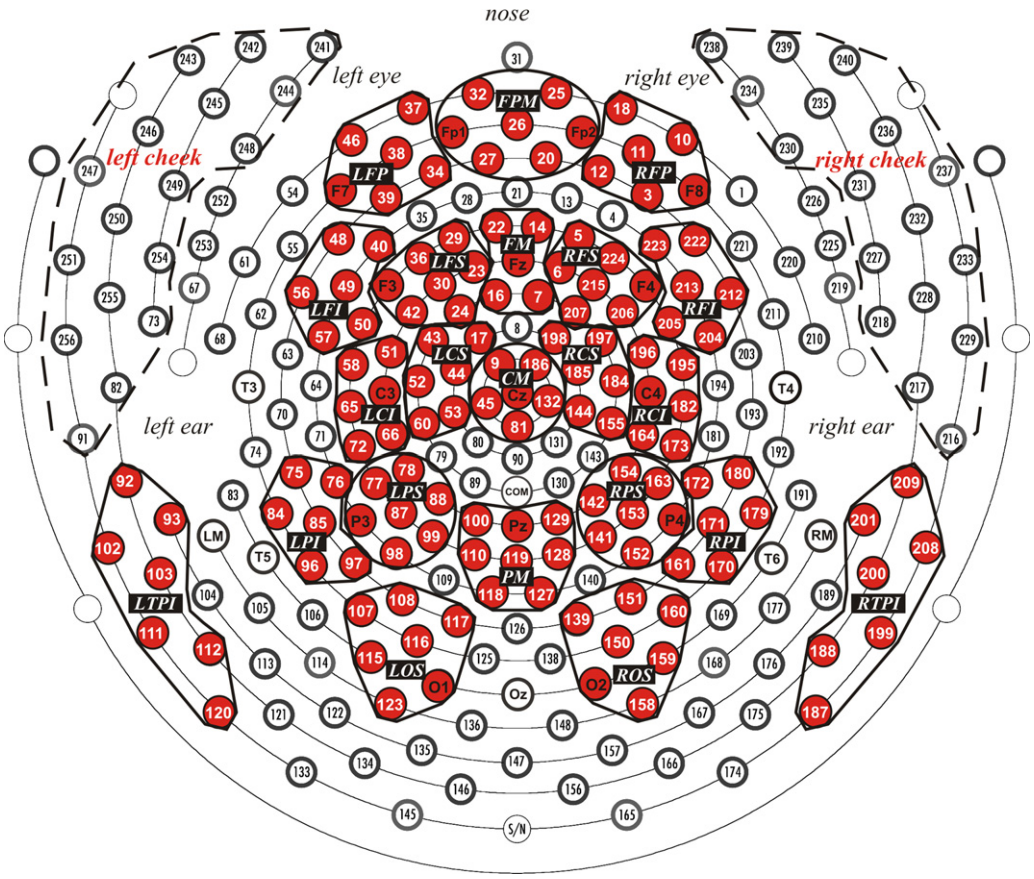


Fig. 2. Geodesic sensor net layout. Electrode sites are numbered. Red clusters are regions of interest included in analyses. LFP = left frontal-polar, FPM = frontal-polar medial, RFP = right frontal-polar, LFS = left frontal superior, FM = frontal medial, RFS = right frontal superior, LCI = left central inferior, LCS = left central superior, CM = central medial, RCS = right central superior, RCI = right central inferior, LPI = left parietal inferior, LPS = left parietal superior, PM = parietal medial, RPS = right parietal superior, RPI = right parietal inferior, LTPI = right temporal-parietal inferior, LOS = left occipital superior, ROS = right occipital superior, RTPI = right temporal-parietal inferior.

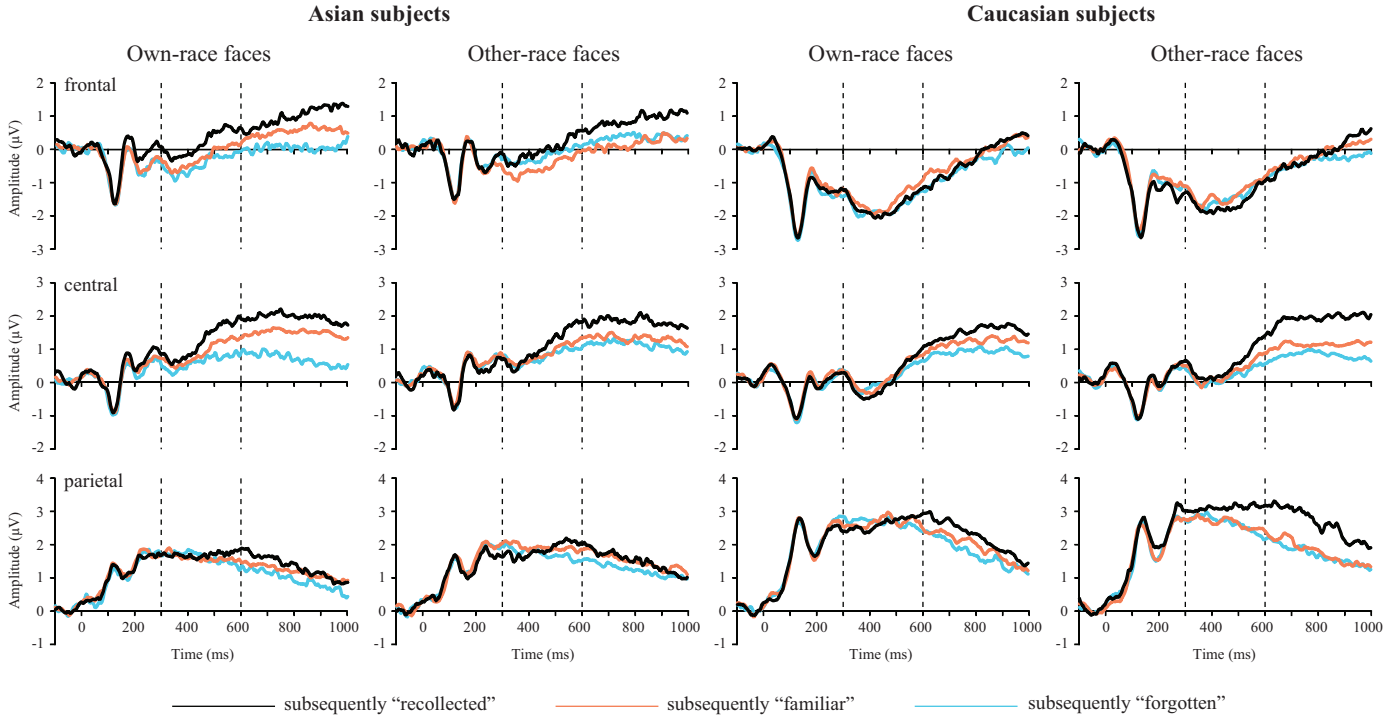


Fig. 3. Mean amplitudes from the study phase depicting encoding-related brain activation (Dms) for subsequently "recollected," "familiar," and forgotten own-race and other-race faces for Asian and Caucasian subjects. Vertical lines highlight time segments of 300–600 ms and 600–1000 ms used for statistical analyses. Amplitudes were averaged across five regions of interest for each spatial location (frontal: LFI, LFS, FM, RFS, RFI; central: LCI, LCS, CM, RCS, RCI; parietal: LPI, LPS, PM, RPS, RPI; Fig. 2 for abbreviations of regions of interest and their locations).

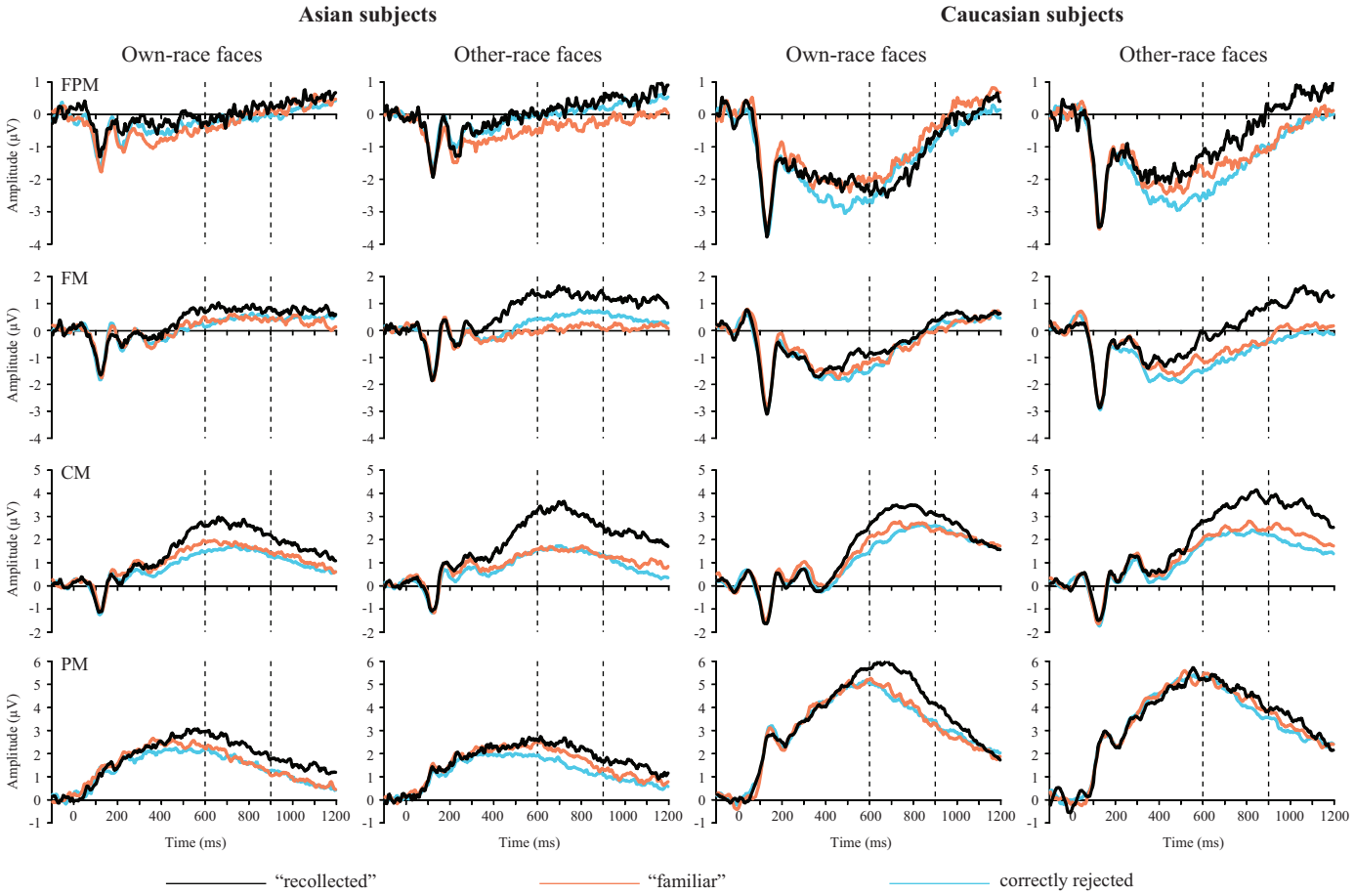


Fig. 4. Mean amplitudes from the test phase depicting recognition-related brain activation for "recollected" and "familiar" old faces and correctly rejected new faces for Asian and Caucasian subjects. Vertical lines highlight time segments of 600–900 ms and 900–1200 ms used for statistical analyses. See Fig. 2 for abbreviations of regions of interest and their locations.

$p < .001$, $\eta^2 = 0.79$. For the percent of hits for "recollect" judgments and the percent of false alarms for IRK familiarity, respectively, other-race effects were only found for Caucasian subjects, $ts(31) = 6.6$ and -3.9, $p < .001$, η^2s = 0.59 and 0.33. For the percent of hits for IRK "familiar" judgments, other-race effects were only present for Asian subjects, $t(24) = 2.1$, $p < .05$, $\eta^2 = 0.16$.

3.2. Dm during memory encoding

Mean amplitudes at selected electrode sites from the study phase are shown in Fig. 3. Topographies of ERP subsequent memory effects can be found in the Supplemental Materials (Fig. S1). The Dm was measured in two time segments: 300–600 ms and 600–1000 ms. ROIs were five channel groups each over frontal, central, and parietal regions (frontal: LFI, LFS, FM, FRS, FRI; central: LCI, LCS, CM, RCS, RCI; parietal: LPI, LPS, PM, RPS, RPI; Fig. 2). Please see Section 2.6 for setup of statistical analyses.

3.2.1. Between-group effects

Analyses of ERPs during the study phase did not yield any significant main effects of or interactions with stimulus race or group.

Table 1
Indicators of behavioral performance and statistical analyses for memory performance in Asian and Caucasian participants with own-race and other-race faces. Statistical indicators show *p*-values indicating other-race effects measured as main effect of stimulus race (own-race, other-race faces) in between-group analyses and as *t*-tests between own-race and other-race faces in within-group analyses. Standard deviations are given in parentheses.

	Performance indicators				Statistical indicators (*p*-values)		
	Asian subjects		Caucasian subjects		Other-race effects		
	Own-race	Other-race	Own-race	Other-race	Across subjects	Asian subjects	Caucasian subjects
P(*A*)	0.72 (0.07)	0.69 (0.08)	0.77 (0.09)	0.68 (0.08)	***	***	***
c_a	−0.06 (0.46)	0.01 (0.43)	−0.07 (0.33)	−0.07 (0.39)	ns	ns	ns
Hit "recollect"	0.25 (0.17)	0.24 (0.17)	0.35 (0.16)	0.24 (0.16)	***	ns	***
Hit IRK "familiar"	0.57 (0.21)	0.52 (0.19)	0.57 (0.16)	0.55 (0.15)	*	*	ns
False alarm "recollect"	0.06 (0.10)	0.06 (0.10)	0.04 (0.08)	0.05 (0.11)	ns	ns	ns
False alarm IRK "familiar"	0.31 (0.15)	0.31 (0.13)	0.30 (0.13)	0.37 (0.14)	*	ns	***

Note: *P*(*A*) – area below the receiver operating characteristic curve; c_a – response bias; ns – not significant.
* $p < .05$.
*** $p < .001$.

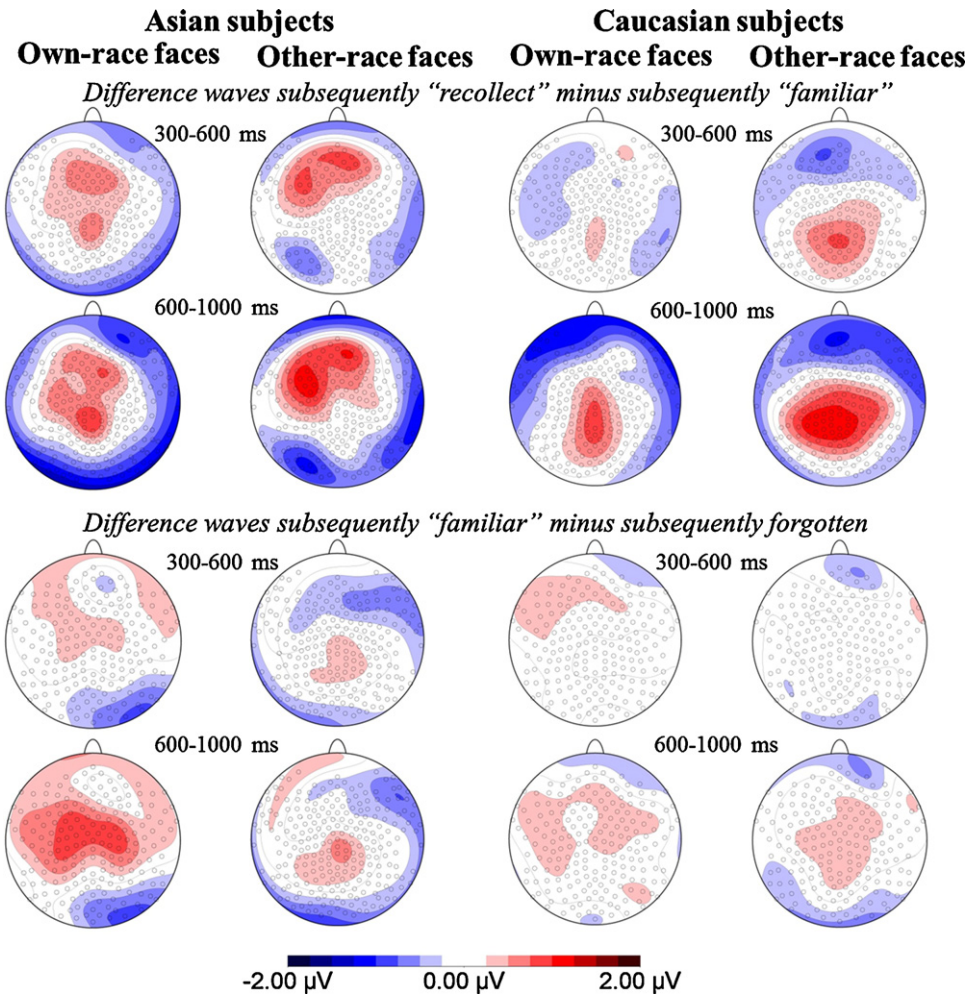


Fig. 5. Voltage maps of ERP difference waves between memory judgments showing old/new effects at 600–900 ms and 900–1200 ms for Asian and Caucasian subjects. Spherical spline interpolation was used.

3.2.2. Within-group effects

For *Asian subjects*, significant Dms over all stimulus sets and time segments, as indicated by main effects of memory judgment, were found for subsequently "recollect" vs. "familiar," $F(1,24) = 6.3$, $p < .05$, $\eta^2 = 0.21$, and subsequently "familiar" vs. forgotten faces, $F(1,24) = 6.9$, $p < .05$, $\eta^2 = 0.22$. No interactions with stimulus race were observed for any Dm, $ps > .13$.

For *Caucasian subjects*, significant Dms over all stimulus sets and time segments, as indicated by main effects of memory judgment, were observed for subsequently "recollected" vs. "familiar," $F(1,31) = 7.0$, $p < .05$, $\eta^2 = 0.19$. A time segment × memory judgment interaction, $F(1,31) = 12.4$, $p < .001$, $\eta^2 = 0.29$, was found for the Dm for subsequently "familiar" vs. forgotten faces, which shows that the memory difference reached significance in the second time segment, $F(1,31) = 6.9$, $p < .05$, $\eta^2 = 0.18$, but not in the first, $p = .34$.

The Dm between subsequently "recollected" and subsequently "familiar" faces yielded a significant stimulus race × memory judgment interaction, $F(1,31) = 5.0$, $p < .05$, $\eta^2 = 0.14$, which indicated that a significant Dm was found for other-race faces, $F(1,31) = 11.6$, $p < .01$, $\eta^2 = 0.27$, but not for own-race faces, $p = .71$.

A main effect of stimulus race was found for the Dm between subsequently "recollected" and subsequently "familiar" faces, $F(1,31) = 4.2$, $p < .05$, $\eta^2 = 0.12$. A post-test indicated significantly more positive mean amplitudes for subsequently "recollected" other-race than own-race faces, $F(1,31) = 8.5$, $p < .01$, $\eta^2 = 0.22$. No significant differences were found between subsequently forgotten own- and other-race faces.

In summary, Dm results for memory encoding show that other-race effects were only present in Caucasian subjects. For this subject group, the Dm for subsequent recollection and familiarity only differed significantly for other-race faces. This finding suggests that subsequent familiarity and recollection of own-race faces arose from similar memory encoding processes, whereas these processes differed for subsequent familiarity and recollection of other-race faces. In addition, the results might indicate that successful memory encoding required less neural activation for own-race faces, as seen in significantly less positive mean amplitudes for subsequently "recollected" own-race than other-race faces.

3.3. Old/new effects during recognition

Mean amplitudes from the test phase are shown in Fig. 4. Topographies of ERP old/new effects ("recollect" minus "familiar"; "recollect" minus correctly rejected) are depicted in Fig. 5. Old/new effects were measured between 600 and 900 ms, which corresponds to the parietal old/new effect, and between 900 and 1200 ms, which corresponds to late-frontal old/new effects. ROIs in both time segments were three channel groups each over fronto-polar, frontal, central, and parietal regions (fronto-polar: LFP, FPM,

RFP; frontal: LFS, FM, RFS, central: LCS, CM, RCS, parietal: LPS, PM, RPS; Fig. 2).[6] Please see Section 2.6 for setup of statistical analyses.

3.3.1. Parietal old/new effects between 600 and 900 ms

3.3.1.1. Between-group effects. Old/new effects between "recollected" and "familiar" faces yielded a significant stimulus race × memory judgment × frontal–parietal interaction, $F(3,165) = 3.6$, $p < .05$, $\eta^2 = 0.06$. Post-tests for the levels of the stimulus-race factor showed a significant memory judgment × frontal–parietal interaction for own-race faces, $F(3,165) = 4.4$, $p < .05$, $\eta^2 = 0.07$, but only a trend for other-race faces, $F(3,165) = 2.6$, $p = .08$, $\eta^2 = 0.04$. Old/new effects for own-race faces were significant only over central and parietal regions, $Fs(1,55) = 10.0$ and 7.6, $ps < .01$, $\eta^2 s = 0.15$ and 0.12.

The significance of topographical differences was tested by scaling the ERPs for the old/new effects (i.e., difference waves between "recollected" and "familiar" faces) for each participant to the same overall amplitude within each condition, with the average distance of the mean, derived from the individual mean ERPs, as divisor (Haig, Gordon, & Hook, 1997). Scaled ERPs confirmed distribution differences and showed a significant stimulus race × frontal–parietal interaction, $F(3,165) = 3.0$, $p < .05$, $\eta^2 = 0.05$. Post-tests for the levels of the stimulus-race factor yielded a significant main effect of frontal–parietal for own-race faces, $F(3,165) = 5.1$, $p < .01$, $\eta^2 = 0.08$, but only a trend for other-race faces, $F(3,165) = 2.4$, $p = .09$, 0.04. Thus, the topography of "recollect"-minus-"familiar" differences varied qualitatively between own-race and other-race faces, primarily due to regional variation observed for own-race faces.

No main effects or interactions with group or stimulus race were found for old/new effects between "familiar" and correctly rejected faces.

3.3.1.2. Within-group effects. Asian subjects showed significant old/new effects between "recollected" and "familiar" faces when measured across both own-race and other-race faces, $F(1,24) = 13.0$, $p < .001$, $\eta^2 = 0.35$. Old/new effects were significant for own-race, $F(1,24) = 7.6$, $p < .05$, $\eta^2 = 0.24$, and other-race faces, $F(1,24) = 11.8$, $p < .01$, $\eta^2 = 0.33$. No interactions with stimulus race or frontal–parietal were found. No old/new effects between "familiar" and correctly rejected new faces were observed.

Caucasian subjects had significant old/new effects between "recollected" and "familiar" faces when measured across both own-race and other-race faces, $F(1,31) = 13.8$, $p < .001$, $\eta^2 = 0.25$. They also showed a stimulus race × memory judgment × frontal–parietal interaction, $F(3,93) = 5.1$, $p < .05$, $\eta^2 = 0.14$, which indicated that old/new effects for own-race faces were significant only over central and parietal brain regions, $Fs(1,31) = 4.2$ and 4.7, $ps < .05$, $\eta^2 s = 0.16$ and 0.25, whereas those for other-race faces were significant over frontal-polar, frontal, and central regions, $Fs(1,31) = 7.1$, 10.6, and 10.7, $ps < .05$, $\eta^2 s = 0.19$, 0.29, and 0.38 (Fig. 5). Differences between topographies of own-race and other-race faces were analyzed by scaling the ERPs for the old/new effects. Distribution differences, indicated by a significant stimulus race × frontal–parietal interaction, remained significant for normalized old/new effects for "recollect" vs. "familiar," $F(3,93) = 6.3$, $p < .01$, $\eta^2 = 0.17$.

In summary, results for the parietal old/new effect between "recollected" and "familiar" stimuli showed other-race effects in the distribution of the brain activation associated with successful retrieval. Within-group analyses showed that these effects were only reliable for Caucasian subjects. Own-race faces elicited a typical parietal old/new effect, but other-race faces showed additional frontal activation. In the discussion section, we argue that the retrieval of other-race faces requires cognitive control processes such as post-retrieval monitoring (Cruse & Wilding, 2009; Friedman & Johnson, 2000; Hayama et al., 2008; Ranganath & Paller, 2000).

3.3.2. Late-frontal old/new effects between 900 and 1200 ms

3.3.2.1. Between-group effects. Old/new effects between "recollected" and "familiar" faces yielded a significant stimulus race × memory judgment interaction, $F(1,55) = 4.3$, $p < .05$, $\eta^2 = 0.07$. Post-tests for the levels of the stimulus-race factor showed a significant main effect of memory judgment for other-race faces, $F(1,55) = 16.1$, $p < .001$, $\eta^2 = 0.23$, but not for own-race faces, $p = .28$. There were no significant interactions with ROI. No old/new effects between "familiar" and correctly rejected new faces were found.

3.3.2.2. Within-group effects. Old/new effects between "recollected" and "familiar" faces were reliable only for other-race faces in Caucasian, $F(1,31) = 10.8$, $p < .01$, $\eta^2 = 0.26$, and Asian subjects, $F(1,24) = 6.1$, $p < .05$, $\eta^2 = 0.20$, but not for own-race faces, $ps > .15$.

In summary, results for the late-frontal old/new effect show other-race effects. Old/new effects over frontal, central, and parietal regions were found only for other-race faces. This could mean that for these faces, retrieval processes thought to be indicated by the parietal old/new effect were still ongoing. In addition, post-retrieval monitoring processes, thought to be reflected by the frontal old/new effect, were also only found for other-race faces, suggesting that the retrieval of these faces is more effortful and requires active monitoring.

3.4. Perceptual ERPs

Fig. 6 highlights the P100, N170, P200, and N250 in the study and test phases. ROIs were defined in both hemispheres as those regions where the ERPs were most pronounced across all conditions. ROIs for the P100 were occipital superior channel groups (LOS and ROS; Fig. 2). For the N170, P200, and N250, ROIs were temporal–parietal inferior channel groups (LTPI and RTPI; Fig. 2). Analyses for the P100 and N170 were conducted on the peak amplitude and peak latency in the selected ROIs – between 60 and 160 ms for the P100, and between 140 and 200 ms for the N170. P200 and N250 were calculated as mean amplitudes in the selected ROIs – between 188 and 216 ms for the P200, and between 228 and 288 ms for the N250.

3.4.1. Perceptual ERPs in the study phase

3.4.1.1. Between-group effects. No main effects of or interactions with group or stimulus race were found for the P100, P200, the amplitude of the N170, or the N250. Stimulus race influenced the N170 latency as seen in the significant stimulus race × hemisphere interaction, $F(1,55) = 5.2$, $p < .05$, $\eta^2 = 0.09$, which showed shorter N170 latencies for other-race than own-race faces over the left hemisphere, $F(1,55) = 4.0$, $p < .05$, $\eta^2 = 0.06$.

3.4.1.2. Within-group effects. Asian subjects did not show any main effects of or interactions with stimulus race. In Caucasian subjects, the significant stimulus race × hemisphere interaction, $F(1,31) = 6.4$, $p < .05$, $\eta^2 = 0.17$, showed longer N170 latencies for own-race than other-race faces over the left hemisphere, $F(1,31) = 11.0$, $p < .01$, $\eta^2 = 0.26$.

3.4.2. Perceptual ERPs in the test phase

3.4.2.1. Between-group effects. No main effects of or interactions with stimulus race were found for the P100 latency, the P200, or the

[6] The parietal old/new effect is typically measured over superior parietal regions (LPS, RPS). Here, we included additional regions over frontal and central regions to capture the widespread positivity seen for other-race faces in the contrasts "recollect" vs. "familiar" and "recollect" vs. correct rejection (Fig. 5).

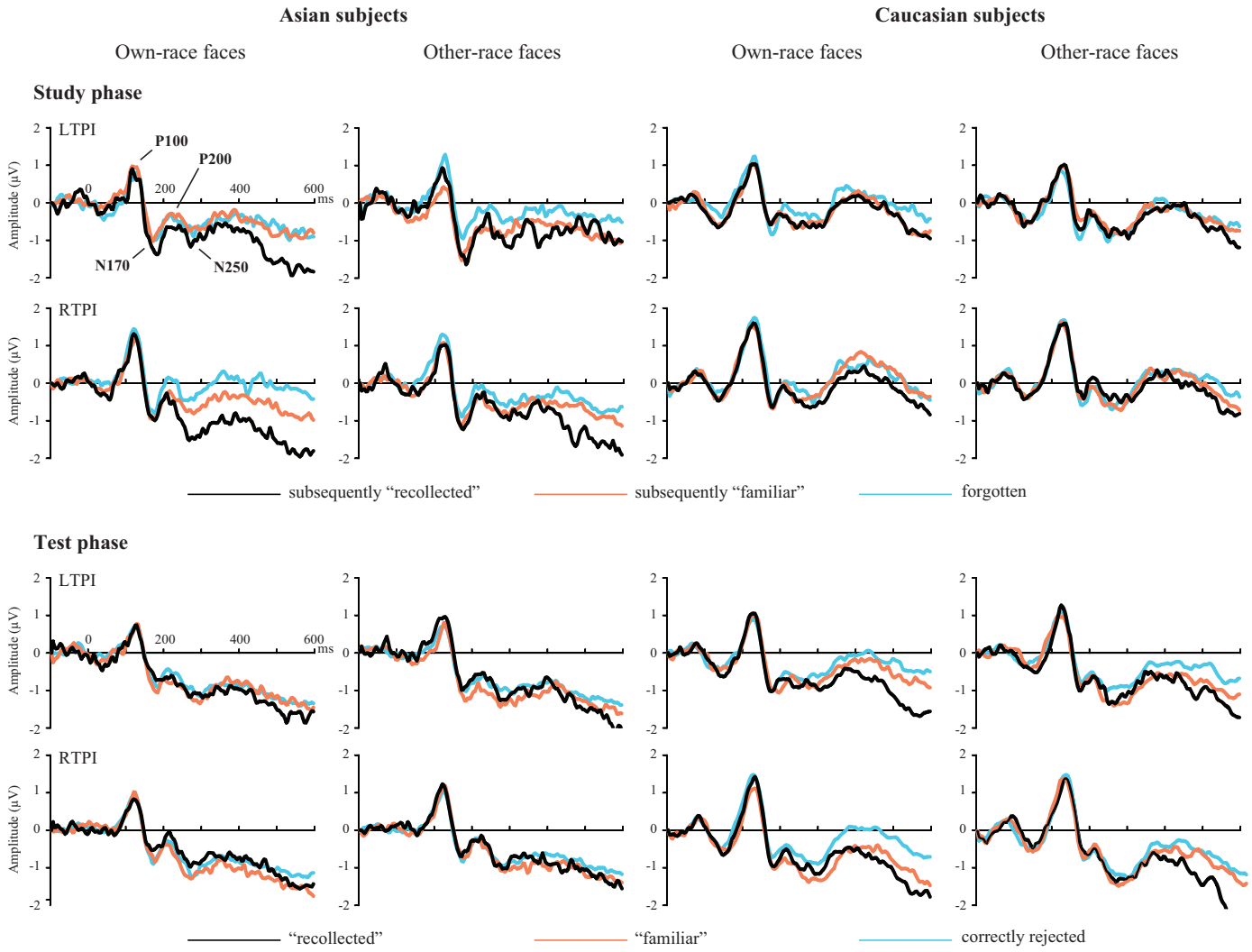


Fig. 6. Mean amplitudes from study and test phases over left and right hemispheres highlighting the P100, N170, P200, and N250 at the regions of interest used to determine the N170 and N250. See Fig. 2 for abbreviations of regions of interest and their locations.

N170 amplitude. Group × stimulus race interactions were found for the P100 amplitude, the N170 latency, and the N250 amplitude, $Fs(1,55) = 6.7$, 7.1, and 4.8, $ps < .05$, $\eta^2 s = 0.11$, 0.11, and 0.08.

3.4.2.2. Within-group effects. No significant effects were found for Asian subjects. In Caucasian subjects, the P100 amplitude was larger for own-race than for other-race faces, as indicated by a main effect of stimulus race, $F(1,31) = 6.3$, $p < .05$, $\eta^2 = 0.17$. The main effect of stimulus race for the N170 latency, $F(1,31) = 5.4$, $p < .05$, $\eta^2 = 0.15$, reached significance only over the left hemisphere, where other-race faces showed earlier N170 latencies than own-race faces, $F(1,31) = 4.5$, $p < .05$, $\eta^2 = 0.13$. Finally, the main effect of stimulus race for the N250, $F(1,31) = 5.8$, $p < .05$, $\eta^2 = 0.16$, showed that the N250 was more negative for other-race faces than for own-race faces.

4. Discussion

In this study, Asian and Caucasian participants studied and recognized Chinese and Caucasian faces. Behavioral performance and ERPs exhibited other-race effects, though in differing ways for Asian and Caucasian participants. These results are discussed in detail below.

4.1. Behavioral memory performance

Asian and Caucasian participants recognized faces from their own race more accurately than other-race faces. Other-race effects were seen in measures of recollection and familiarity. This indicates that experience with people from one's own race facilitates the recollection of old faces and familiarity-based discrimination of old and new own-race faces. These results replicate the other-race effect as documented in previous research (e.g., Horry et al., 2010; Marcon et al., 2009; Meissner & Brigham, 2001; Meissner et al., 2005; Valentine, 1991). The significant enhancement of familiarity processes for own-race faces, seen in increased hit rates in Asian subjects and reduced false alarm rates in Caucasian subjects, is a novel finding of the present study. For "familiar" judgments, both subject groups showed higher accuracy in familiarity for own-race than for other-race faces but differed with respect to the measure of familiarity (i.e., hit rates or false alarm rates) that showed other-race effects.

The other-race effect in memory performance was more pronounced in Caucasian subjects. This is in line with previous studies that showed greater other-race effects for white subjects than for black subjects (Horry et al., 2010; Meissner et al., 2005). Whereas the present Caucasian subjects had never lived in an Asian country, the Asian participants had lived in the United States for an average

of 2.3 years and were enrolled at a university with predominantly Caucasian students, faculty, and staff. It is thus very likely that the magnitude of the other-race effects reflects the different levels of experience with other-race faces. In addition, Asian subjects came from multiple Asian countries but only Chinese faces were used as stimuli. It is therefore possible that the smaller other-race effect for Asian subjects was also influenced using non-optimal own-race faces for this group.

4.2. ERP memory encoding effects

Like behavioral measures, memory encoding-related ERPs showed more pronounced other-race effects in Caucasian subjects. In fact, other-race effects in memory encoding were only found in within-group analyses of these subjects. These analyses resemble previous ERP studies on the other-race effect, which only considered Caucasian subjects (Lucas et al., 2011; Stahl et al., 2010). In the present study, no other-race effects were found in between-subject analyses. This could be a power problem because our Asian subjects, due to their diverse amounts of experience with other-race faces, were a more heterogeneous group than our Caucasian subjects, who had never lived in an East Asian country. Training studies have shown that memory performance for other-race faces can be modulated by requiring participants to individuate between other-race faces (Tanaka & Pierce, 2009). It is therefore possible that Asian subjects are more varied in their memory encoding-related brain activation because of their varying experience with other-race faces.

In Caucasian participants, lifelong experience with a race led to similar brain activation for subsequent recollection and familiarity, whereas limited experience resulted in significantly higher brain activation for recollection than familiarity. Dms in Remember–Know paradigms predominantly show significant differences between recollection and familiarity (e.g., Friedman & Johnson, 2000; Yovel & Paller, 2004). Only two studies have reported indistinguishable Dms for recollection and familiarity; these findings were interpreted as a reflection of either similarly deep (Smith, 1993) or shallow (Friedman & Trott, 2000) memory encoding processes for subsequently "recollected" and "familiar" items. Similarly deep or elaborate memory encoding of subsequently "recollected" and "familiar" own-race faces is a likely explanation for the Dm findings in the present study because Caucasian subjects recognized own-race faces more accurately than other-race faces. This finding might be interpreted as more elaborate memory encoding for own-race than other-race faces. Encoding of other-race faces appeared more effortful and only a small subset of other-race faces – those items that were subsequently "recollected" – could be encoded at a deeper level.

Caucasian subjects also showed less positive amplitudes for subsequently "recollected" own-race than other-race faces. A likely explanation is that higher levels of experience required less neural activation and thus led to more efficient memory encoding of later successfully remembered faces, as indicated by more accurate memory performance associated with less positive amplitudes. These results replicate findings from studies on neural efficiency, which reported lower absolute levels of brain activation in a variety of tasks for subjects with higher mental ability or superior task performance (e.g., Andreasen et al., 1995; Babiloni et al., 2010; Motes, Malach, & Kozhevnikov, 2008; Neubauer & Fing, 2009). The present Dm findings seem to suggest more efficient memory encoding for own-race faces.

Only one previous study investigated the Dm for own-race and other-race faces (Lucas et al., 2011). The results of this and the present study are difficult to compare because of several procedural and analytical differences. Lucas et al. averaged across familiarity and recollection yielding Dms between correctly recognized and forgotten items. Furthermore, African-American faces were used as stimuli and presented not intermixed with Caucasian faces but in separate blocks, possibly influencing memory encoding strategies.

Previous studies have suggested that the other-race effect is a memory encoding-related phenomenon (Hugenberg et al., 2010; Marcon et al., 2009; Meissner et al., 2005). The present study provides first neural results for this view by tracing the memory advantage of own-race faces in Caucasian subjects to particular patterns of brain activation in the study phase. These ERP patterns indicate more efficient and more elaborate memory encoding processes. However, as discussed next, ERPs recorded during retrieval indicate that it is unlikely that the other-race effect is exclusively caused by differences in memory-encoding processes.

4.3. ERP retrieval effects

Parietal old/new effects between "recollected" and "familiar" faces, thought to be associated with recollection processes, showed different distributions of brain activation for own-race and other-race faces. These effects were found across both subject groups, although within-group analyses suggested that these effects were stronger for Caucasian than Asian subjects. Old/new effects with the typical parietal distribution were found for own-race faces, replicating previous studies on the parietal old/new effect for face stimuli (Curran & Hancock, 2007; Stahl et al., 2010; Wiese et al., 2008). Old/new effects for other-race faces showed an additional strong frontal activation. Only one previous study measured old/new effects for own-race and other-race faces in Caucasian participants (Stahl et al., 2010). Although they do not report different distributions of old/new effects, Fig. 3 in Stahl et al. (2010) suggests that old/new effects for other-race faces were larger over frontal regions, whereas own-race faces showed the typical parietal distribution. Analyses of normalized amplitudes confirmed the topographical differences in the present results and suggest that the old/new effects for own-race and other-race faces may have non-identical neural sources. It appears that for other-race faces the parietal old/new effect overlaps with a frontal old/new effect. These results show that it is necessary to engage additional, frontal brain regions in order to remember other-race faces accurately. Despite the additional neural resources, memory performance for other-race faces remained less accurate than for own-race faces, indicating that other-race face recognition is difficult and effortful. These effortful processes most likely represent post-retrieval monitoring that has been associated in ERP, fMRI, and neuropsychological research with activation in prefrontal brain areas (Cruse & Wilding, 2009; Friedman & Johnson, 2000; Gallo, McDonough, & Scimeca, 2010; Hayama et al., 2008; Moscovitch, 1992; Ranganath & Paller, 2000; Schacter & Slotnick, 2004). Post-retrieval monitoring might be strategically engaged to accomplish the more difficult task of retrieving other-race faces. Poorer memory performance for other-race faces is a widely known phenomenon and could very well have been familiar to our participants. Hence they may have recruited additional resources to aid the discrimination between old and new other-race faces. Such strategies may have been used to a larger degree by the Caucasian subjects who had no experience with other-race faces. Taken together with the previously discussed Dm results, it appears that both encoding and retrieval processing is more effortful for other-race than own-race faces.

Other-race effects in the parietal old/new effects were more pronounced in Caucasian subjects than in Asian subjects, who showed no distribution differences between own-race and other-race faces in within-group post-tests. This finding is in line with the behavioral measures of recollection, for which only Caucasian participants showed significant other-race effects. Asian subjects had non-significantly higher accuracy in "recollect" judgments for own-race than other-race faces. This tendency might have contributed to

the significant difference between "recollect" and "familiar" own-race and other-race faces in the overall analysis of the parietal old/new effect.

Late-frontal old/new effects, thought to be associated with post-retrieval monitoring, were only present for other-race faces (Figs. 4 and 5). This provides further support for the notion that recollection of other-race faces is difficult and effortful. Other studies measuring old/new effects in such late time segments have often reported different patterns of old/new effects than those in previous time segments (e.g., Cruse & Wilding, 2009; Curran, Schacter, Johnson, & Spinks, 2001; Ranganath & Paller, 2000). In the present study, the same retrieval processes active between 600 and 900 ms appear to continue for other-race faces, whereas they are concluded for own-race faces.

From a single-process perspective, the behavioral recollection advantage associated with own-race faces could be interpreted as a confidence effect, such that experience with a race enhances confidence rather than recollection *per se*. Previous research, however, has suggested that parietal old/new effects vary between "recollect" and "familiar" responses without varying with the level of familiarity confidence (Woodruff et al., 2006). The different distributions of ERP old/new effects for own-race vs. other-race faces provide evidence that varying levels of experience with a race influence not merely confidence, but also recollection.

Taken together, significant differences between own-race and other-race faces for the old/new effects show that the other-race effect is not only related to memory encoding (Hugenberg et al., 2010; Marcon et al., 2009; Meissner et al., 2005). We provided evidence that recollecting other-race faces takes more time and requires post-retrieval monitoring. This effortful retrieval is not simply a result of weaker, less detailed memory representations created during memory encoding, because it is seen for "recollected" other-race faces, which can be assumed to be encoded to a similar degree as own-race faces.

4.4. Comparison with car expertise

Comparing the present study with the study on car expertise (Herzmann & Curran, 2011) provides insights into the nature of the neural correlates associated with own-race and other-race face recognition. In both studies, overall recognition, recollection, and discrimination between old and new items at the familiarity level (i.e., false alarms for "familiar" judgments) were facilitated by increased experience. For own-race faces and expertise-related stimuli, brain activations in the study phases were more efficient, shown by smaller Dms between "recollected" and forgotten items, and more elaborate, indicated by indistinguishable Dms for recollection and familiarity. These similarities suggest that the recognition advantage for own-race faces depends on similar neural mechanisms of memory encoding as expertise performance with cars. Indeed, deeper memory encoding of more diagnostic information, which aids within-category discrimination and subsequent recollection, has been proposed to underlie not only experts' memory performance (Brandt, Cooper, & Dewhurst, 2005; Gobet & Simon, 1996; Long & Prat, 2002; Rawson & Van Overschelde, 2008) but also the advantage in own-race face recognition (Marcon et al., 2009; Meissner et al., 2005).

The old/new effects recorded during retrieval for own-race faces resembled those of car experts. Old/new effects of other-race faces, however, did not resemble those of car novices. Whereas other-race faces elicited a frontally distributed old/new effect and required post-retrieval monitoring, cars in car novices did not lead to similar results but to an insignificant, parietal old/new effect (Herzmann & Curran, 2011). The between-study comparison of items with increased experience (i.e., own-race faces and cars in car experts) suggests that the correlation between experience and detail of recollection in both domains arises from similar neural mechanisms. The differences between studies for novice-like stimuli (i.e., other-race faces and cars in car novices) could originate from multiple sources. First, they could be due to procedural differences between the two studies. Most notably, expert and novice stimuli in the car-expertise study were learned and recognized in separate blocks; in the present study, they were intermixed, thereby introducing a task-switching component that could have led to stronger activation of frontal brain regions in the most difficult condition: successfully recollecting other-race faces. Aside from procedural differences, it might be that the involvement of frontal retrieval-monitoring processes in the present study is associated with awareness of the other-race effect (i.e., knowledge about the difficulty to individuate other-race faces). Car novices cannot be expected to have similar beliefs about cars and are thus less likely to engage monitoring processes. Also, cars are not as socially relevant as faces, and they might therefore be given a lower priority for accurate recognition. These speculations await evaluation in future research.

4.5. ERP correlates of perception

Other-race effects on ERP correlates of perception were found only in Caucasian subjects and were not particularly prominent. Previous studies have reported other-race effects on perceptual ERPs, but the particular nature of these effects varied. Some studies reported a larger and later N170 for other-race faces (Stahl et al., 2008, 2010); others reported a larger N170 the onset of which was not later (Wiese et al., 2008); and still others reported a larger and earlier N170 (Gajewski et al., 2008). These discrepancies are probably due to differences in experimental design, task, and/or stimuli. To this diverse pattern of other-race effects, we add yet another result. We found earlier N170 latencies for other-race faces over the left hemisphere in both the study and test phases. This can indicate that feature processing is quicker for other-race faces because previous research associated the N170 over the left hemisphere with processing of facial features (Scott & Nelson, 2006), and several studies have shown that other-race faces are processed predominantly in a feature-based manner (Michel, Caldara, et al., 2006; Michel, Rossion, et al., 2006; Tanaka et al., 2004). In the present study, no other-race effects were found for the N170 amplitude. This replicates the finding from the car expertise study, where expertise effects were also absent (Herzmann & Curran, 2011). It is possible that processes leading to changes in the N170 amplitude are not as readily observed in the context of a study/test recognition task as they have been in other perception/categorization tasks (Busey & Vanderkolk, 2005; Gauthier, Curran, Curby, & Collins, 2003; Tanaka & Curran, 2001).

Experience with a race also influenced the P100 amplitude and the N250 in the test phase. Higher P100 amplitudes have been related to greater motivation or attention (Hillyard & Anllo-Vento, 1998). The present other-race effects in Caucasian subjects, showing larger P100 amplitudes for own-race faces, could thus indicate higher levels of attention or motivation for own-race faces. Similar results were found neither in previous research (Gajewski et al., 2008; Herrmann et al., 2007; Stahl et al., 2008, 2010; Wiese et al., 2008, 2009) nor in the study phase of the present experiment. This suggests that differences in attention were present during memory testing but not memory encoding. These results contrast with previous findings that showed larger N100 amplitudes for other-race faces (Ito & Urland, 2005; Kubota & Ito, 2007). This disparity with the present results could be due to differences in task demands, since neither of these studies used a recognition task. It is also possible that the effects of stimulus race on the P100 and N170 could have been influenced by systematic differences

between Chinese and Caucasian faces, which were taken from two different databases.

Caucasian subjects showed a more negative N250 for other-race faces than for own-race faces. The few studies that have investigated the N250 in real-world experts are in line with this finding. Wiese et al. (2008) reported a larger N250 for other-age (i.e., old) faces in young participants. Other studies that did not analyze the N250 nonetheless contain figures that show more negative N250 amplitudes for other-race faces (Fig. 3 in Herrmann et al., 2007; Fig. 2 in Stahl et al., 2008; Figs. 1 and 3 in Stahl et al., 2010). These results in real-world experts conflict with expertise-training studies, which have shown more negative N250s for trained stimuli following subordinate-level training (Scott et al., 2006, 2008; Tanaka & Pierce, 2009). Also the previous car-expertise study is in contrast with findings of laboratory-trained experts in that no significant influence of expertise on the N250 amplitude was found (Herzmann & Curran, 2011). These discrepancies between laboratory-trained and real-world experts could indicate an artifact of training. In most training studies, participants receive an individuation training that emphasizes naming the perceived object (Scott et al., 2006, 2008) or face (Tanaka & Pierce, 2009). The N250 was shown to be larger for a face that is task relevant and associated with a name (Gordon & Tanaka, in press; Tanaka, Curran, Porterfield, & Collins, 2006). The importance placed upon naming the stimuli in individuation training could have caused increased N250 amplitudes in post-tests even though no naming was required at that point. All studies with real-world experts, in contrast, used recognition tasks. Although recognition requires individuation, recognition experiments do not provide labels or names for unfamiliar faces. Socio-cognitive accounts of the other-race effect (e.g., Sporer, 2001) would suggest that the name of the race is a prevalent label only for other-race faces, which could increase N250 amplitudes, so long as we accept the naming-dominance account of the N250. Despite these suggestions, the significance of the N250 amplitude as a marker of expertise or increased experience remains an open question for future research.

4.6. Conclusion

This study investigated the neural correlates of memory performance with own-race and other-race faces. It provided further support for the findings of behavioral studies, which suggest that the other-race effect is partially a memory encoding-based phenomenon (Hugenberg et al., 2010; Marcon et al., 2009; Meissner et al., 2005). The present study showed that the other-race effect is also a retrieval-based phenomenon. Recognizing other-race faces was found to be more effortful and to require additional post-retrieval monitoring, especially for Caucasian subjects, who had less experience with other-race faces when compared to Asian subjects. Comparisons with a previous investigation on car expertise (Herzmann & Curran, 2011) suggest that the recognition advantage of own-race faces might be based on similar neural mechanisms in memory encoding and recognition as expertise performance with cars.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.neuropsychologia.2011.07.019.

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