



# Neural evidence for the contribution of holistic processing but not attention allocation to the other-race effect on face memory

Grit Herzmann<sup>1</sup> · Greta Minor<sup>1</sup> · Tim Curran<sup>2</sup>

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## Abstract

Multiple mechanisms have been suggested to contribute to the other-race effect on face memory, the phenomenon of better memory performance for own-race than other-race faces. Here, two of these mechanisms, increased attention allocation and greater holistic processing during memory encoding for own-race than other-race faces, were tested in two separate experiments. In these experiments event-related potentials were measured during study (the difference due to memory, Dm) and test phase (old/new effects) to examine brain activation related to memory encoding and retrieval, allowing for selective investigations of these memory sub-processes. In Experiment 1, participants studied own-race (Caucasian) and other-race (Chinese) faces under focused or divided attention. In Experiment 2, participants studied own-race (Caucasian) and other-race (African American) faces presented upright or upside down (i.e., inverted). Both experiments showed decreases in memory performance when attention allocation or holistic processing was reduced, but these effects were similar for own-race and other-race faces. Manipulations of holistic processing, but not attention allocation, influenced the neural other-race effects during memory encoding. Inverted own-race faces showed similar neural patterns as upright other-race faces, indicating that when holistic processing of own-race faces was reduced, these faces were encoded similarly as upright other-race faces. No influences of the experimental manipulations on other-race effects during memory retrieval were found. The present study provides the first neural evidence that increased holistic processing during memory encoding contributes to the other-race effect on face memory.

**Keywords** Attention · Episodic memory · ERP · Holistic processing · Faces · Race

The other-race effect on face memory is a well-known phenomenon (e.g., Marcon, Susa, & Meissner, 2009; Meissner, Brigham, & Butz, 2005; Rossion & Michel, 2011). People are better at learning and recognizing faces of their own race than of a different race. Recently, we identified some of the neural correlates of the other-race effect on memory encoding and retrieval (Herzmann, Minor, & Adkins, 2017; Herzmann, Willenbockel, Tanaka, & Curran, 2011). In these studies, we used event-related brain potentials (ERPs) measured during the study phase and test phase of a recognition memory experiment, allowing for the

selective investigation of the influence of face race on memory encoding and memory retrieval processes. In these studies (Herzmann et al., 2017; Herzmann et al., 2011), memory encoding and retrieval processes were shown to preferentially facilitate memory for own-race faces (see Neural Correlates of the Other-Race Effect on Face Memory section). In the present two experiments, we tested if these enhancements for own-race faces were due to two suggested mechanisms contributing to the other-race effect: attention allocation (see Attention Allocation and the Other-Race Effect section) and holistic processing (see Holistic Processing and the Other-Race Effect section).

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✉ Grit Herzmann  
grit.herzmann@gmail.com

<sup>1</sup> Department of Psychology, The College of Wooster, Wooster, OH 44691-2363, USA

<sup>2</sup> Department of Psychology and Neuroscience, University of Colorado Boulder, Boulder, CO, USA

## Neural correlates of the other-race effect on face memory

We previously found that own-race faces were more efficiently and more elaborately encoded into memory during the study phase of a recognition memory task (Herzmann et al., 2011). Successfully encoded own-race as compared to other-race faces elicited lower mean amplitudes of electrical brain

activity over frontal, central, and parietal recording sites between 600 and 1,000 ms, which we interpreted as evidence for more efficient encoding of own-race faces. Less neural activity correlated with better memory performance for own-race faces than other-race faces. Recently, we replicated this finding of more efficient memory encoding for own-race faces (Herzmann et al., 2017).

Assessing the difference due to memory (Dm), we also found that own-race faces were accompanied by more elaborate (or deeper) memory encoding. The Dm is an ERP component typically observed between 400 and 1,000 ms as a central-parietal positivity during the study phase. It is defined as the amplitude difference between subsequently recognized and subsequently forgotten items and thought to reflect brain activation of successful memory encoding (Friedman & Johnson, 2000). Different patterns of Dms have been observed for recollection and familiarity, which are the two subprocesses of recognition memory as postulated by the dual-process theory (Yonelinas, 2002). Recollection is the retrieval of an item, for example, a face, together with context details, like where it was first seen. Familiarity reflects the recognition of an item without retrieval of additional details. A common method of measuring recollection and familiarity is the Remember-Know procedure (Tulving, 1985), in which participants are asked to identify studied items as either “remembered” (when the item plus additional information is retrieved) or “known” (when only the item is recognized without additional information). The Dm for recollection is measured between items judged as “remembered” and “known,” whereas the Dm for familiarity is the difference between items

judged as “known” and “forgotten” (Friedman & Johnson, 2000; Herzmann et al., 2011).

The majority of previous research using a variety of stimuli has found significant Dms for recollection but not familiarity. In research with words or pictures (Friedman & Johnson, 2000; Herzmann & Curran, 2011), the Dm for recollection showed a significant difference in brain activation, whereas the Dm for familiarity did not (i.e., mean amplitudes for “remembered” items were significantly more positive than for “known” items, which were not significantly different from “forgotten” items). Using an explicit-recollection task, Yovel and Paller (2004) assessed memory for faces together with the explicit retrieval of associated details, which approximates findings for recollection (when faces together with details were remembered) and familiarity (when faces without details were remembered). This study found that mean amplitudes for faces remembered with details were significantly more positive than for faces remembered without details, which were marginally more positive than those for forgotten faces (i.e., a significant Dm for recollection and a marginally significant Dm for familiarity). Note, the study does not specify the race of the participants or the face stimuli, but Fig. 1 suggests the use of predominantly Caucasian faces.

Using a modified Remember-Know task (Woodruff, Hayama, & Rugg, 2006), we previously found that own-race, but not other-race faces, were encoded into memory more elaborately (Herzmann et al., 2011). Whereas mean amplitudes for “remembered” other-race faces were significantly more positive than “known” other-race faces, which did not differ from forgotten other-race faces (i.e., a significant Dm



**Fig. 1** Sample stimuli for the divided-attention (left) and holistic-processing (right) experiment showing own-race (Caucasian) and other-race (Chinese and African American, respectively) faces

only for recollection but not familiarity), mean amplitudes for “remembered” own-race faces were not different from “known” faces, but both differed from forgotten own-race faces (i.e., no Dm for recollection but a significant Dm for familiarity). Previous studies (Friedman & Trott, 2000; Smith, 1993) that required participants to use deep (often semantic) encoding also showed the same pattern of results as we found for own-race faces. Our previous results therefore suggest that own-race faces might be encoded more deeply into memory. It should be noted that a previous study (Lucas, Chiao, & Paller, 2011) found different patterns of other-race effects in the Dm. The Dm between subsequently recognized and subsequently forgotten items was larger for own-race than other-race faces. The results of this and our previous study are difficult to compare because of several procedural and analytical differences, for example, Lucas et al. (2011) did not differentiate between recollection and familiarity.

During the test phase of our previous study, we found that memory retrieval of own-race faces included more details and required less retrieval monitoring (Herzmann et al., 2011). The FN400 and parietal old/new effect, ERP components recorded during the test phase, are considered indicators of retrieval-related brain activation (e.g., Rugg & Curran, 2007). The 300–500 ms FN400 is thought to measure familiarity processes while the 500–800 ms parietal old/new effect is taken to reflect recollection processes (Curran, 2000; Rugg & Curran, 2007). In our previous study (Herzmann et al., 2011), the parietal old/new effect for own-race as compared with other-race faces was larger over parietal areas, the region in which this effect is typically observed (Rugg & Curran, 2007). This result suggested more detailed recollection for own-race faces. Old/new effects for other-race faces were localized over frontal and central areas and extended in time up to 1,200 ms poststimulus, suggesting that cognitive control and postretrieval monitoring strategies were engaged when recognizing these faces (Cruse & Wilding, 2009; Ranganath & Paller, 2000). The difference in the spatial distribution of the old/new effects for own-race and other-race faces was replicated recently (Herzmann et al., 2017). In the present study, we manipulated encoding conditions to test two possible underlying mechanisms of the other-race effect: attention allocation and holistic processing.

### Attention allocation and the other-race effect

Differences in attention allocation have been suggested to contribute to the other-race effect. Recognition memory studies that manipulated attention and investigated the other-race effect, as well as other effects of social categorization (e.g., in-group advantages), have yielded mixed results. Some showed that dividing attention during memory encoding abolished the in-group advantage (own-gender bias in Palmer, Brewer, & Horry, 2013; other-race effect in Semplonius & Mondloch, 2015; other-race

effect in Zhou, Pu, Young, & Tse, 2014). Others showed no influence of divided attention during encoding on the in-group advantage (own-gender bias in Loven, Herlitz, & Rehnman, 2011; own-age bias in Neumann, End, Luttmann, & Schweinberger, 2015). Three of these studies used an auditory-monitoring task during encoding to divide attention (Loven et al., 2011; Palmer et al., 2013; Zhou et al., 2014), as did the present study. The other studies used visual distracter tasks (Neumann et al., 2015; Semplonius & Mondloch, 2015). It is important to note that the type of distracter task does not seem to correlate with the obtained result regarding attention and in-group bias. However, Palmer et al. (2013) suggested that the difficulty of the distracter task played a role in whether attention affected the in-group advantage or not. They argued that a more challenging distracter task, such as the one used in Loven et al. (2011), equally reduced memory performance for in-group and out-group faces. A moderately difficult distracter task, as used in their own study (Palmer et al., 2013), only diminished performance for own-race faces. Hence, out-group performance was unaffected and in-group performance reduced (Palmer et al., 2013).

Studies that found that dividing attention abolished the in-group advantage (Palmer et al., 2013; Semplonius & Mondloch, 2015; Zhou et al., 2014) showed a selective reduction in memory performance for in-group faces in the divided attention condition whereas out-group faces were not significantly affected by divided attention. These findings suggest that the in-group advantage arises because more attention is paid to in-group faces in the focused attention condition. When attention is divided during encoding, this facilitation is diminished, and in-group faces are processed superficially like out-group faces (Palmer et al., 2013; Semplonius & Mondloch, 2015; Zhou et al., 2014).

Studies that found that dividing attention did not influence the in-group advantage (Loven et al., 2011; Neumann et al., 2015) showed a general reduction in performance for both in-group and out-group faces under divided attention, but the size of the in-group advantage was preserved. One of these studies (Neumann et al., 2015) recorded ERPs but focused on early visual and memory-related processes that occur before the Dm and old/new effects are observed. These ERPs mirrored the behavioral results and did not show an influence of attention on the in-group advantage. Results of these studies therefore suggest that the in-group advantage is not a result of more effortful, attention-demanding processing of in-group faces. Rather the in-group advantage is postulated to result from a qualitatively different processing style that is independent of attention allocation, such as holistic processing, which is caused by superior experience with these faces (Loven et al., 2011; Neumann et al., 2015).

### Holistic processing and the other-race effect

Holistic processing, when “all features of the face are obligatorily processed together” (Hayward, Crookes, & Rhodes, 2013,

p. 1225), has been investigated with three different tasks: inversion, the part-whole task, and the composite task (Hayward et al., 2013). Across these different tasks, holistic processing has consistently been shown to be more engaged during the processing of own-race than other-race faces. Own-race, but not other-race, faces have been found to be affected more by manipulations of holistic processing in recognition memory tasks (see Hayward et al., 2013; Rossion & Michel, 2011, for review). Recent behavioral memory studies, however, provided evidence that other-race faces are also processed holistically but to a lesser degree, suggesting that the processing difference between own-race and other-race faces is quantitative and not qualitative (DeGutis, Mercado, Wilmer, & Rosenblatt, 2013; Harrison, Gauthier, Hayward, & Richler, 2014).

Holistic processing has been assumed to at least partially contribute to other-race effects on recognition memory (DeGutis et al., 2013; Hancock & Rhodes, 2008). Individual differences studies using own-race faces found a positive correlation between the degree of holistic processing and memory performance (DeGutis et al., 2013; Richler, Cheung, & Gauthier, 2011; Wang, Li, Fang, Tian, & Liu, 2012): The higher the degree of holistic processing, the better face memory. A similar relationship was observed for other-race effects (DeGutis et al., 2013; Hancock & Rhodes, 2008): Larger differences in holistic processing between own-race and other-race faces (i.e., larger other-race effects) were associated with larger other-race effects on recognition memory. It should be noted that some studies which were either different (Horry, Cheong, & Brewer, 2015) or similar (Zhao, Hayward, & Bühlhoff, 2014) in design than those mentioned above failed to show a relationship between holistic processing and recognition memory. It was suggested that other factors, such as attractiveness, distinctiveness, and/or emotions, influence the other-race effect (Zhao et al., 2014).

Previous ERP studies have found effects of inversion on perceptual ERP correlates, but limited results were seen for memory-related ERPs. Marzi and Viggiano (2011) investigated the influence of inversion on memory-related ERPs and did not find an influence of inversion on neural memory effects during the study and test phase. This study only used Caucasian faces and cannot draw any conclusions about the other-race effect. Stronger influences of inversion on own-race than other-race faces have been found for the N170, a neural correlate of perceptual processes (Vizioli, Foreman, Rousselet, & Caldara, 2010; Wiese, Kaufmann, & Schweinberger, 2014; Wiese, Stahl, & Schweinberger, 2009). In line with the behavioral evidence reviewed above, these results suggested that other-race faces were processed less holistically than own-race faces (Vizioli et al., 2010), that other-race faces might be categorized as out-group at an early processing stage (Wiese et al., 2014), and that other-race faces were processed holistically but less efficiently than own-race faces (Wiese et al., 2009). Given the established impact of holistic processing on perceptual processes, Experiment 2 of

the present study aimed to investigate its impact on memory encoding and retrieval.

## The present study

In the present experiments, we tested whether attention allocation and/or holistic processing contribute to the other-race effect on face memory as suggested by the behavioral and ERP studies reviewed above. We used ERPs to measure brain activation during memory encoding and retrieval separately to draw specific conclusions about the underlying neural mechanisms of the memory advantage for own-race faces. In addition, the two current experiments were also replications of our initial investigation (Herzmann et al., 2011). Results and discussions for the replication conditions are reported in the Supplemental Materials (Replication of Previous Findings section). The Supplemental Materials also provide information on the P100, N170, and N250 ERP components (see P100, N170, and N250 ERP Components section).

## Experiment 1: Effects of attention allocation on the other-race effect

Experiment 1 tested whether superior memory performance for own-race as compared with other-race faces is due to differences in attention allocation during encoding. Previous studies on the influence of attention on in-group and out-group faces have yielded mixed results (Loven et al., 2011; Neumann et al., 2015; Palmer et al., 2013; Semplonius & Mondloch, 2015; Zhou et al., 2014). Some researchers assume that more attention is paid to in-group than out-group faces under natural, undivided encoding conditions leading to out-group effects (Palmer et al., 2013; Semplonius & Mondloch, 2015; Zhou et al., 2014). If the other-race effect is due to differences in attention allocation, we predicted that dividing attention during memory encoding would diminish the attentional advantage for own-race faces and reduce memory performance more for own-race than other-race faces as seen in previous studies (Palmer et al., 2013; Semplonius & Mondloch, 2015; Zhou et al., 2014). Neural processes and memory performance for own-race and other-race faces was therefore assumed to also be comparable for the divided attention condition. If, instead, attention has little impact on the other-race effect on face memory as suggested by two studies of out-group effects (Loven et al., 2011; Neumann et al., 2015), neural processes and memory performance were assumed to show comparable other-race effects in the focused and divided attention conditions. We also expected to see lower memory performance and increased mean amplitudes in the divided attention condition for own-race and other-race faces due to the additional attentional demand (Neumann et al., 2015).

## Method

**Participants** Thirty-six healthy, right-handed Caucasian adults volunteered in this study. Three participants were excluded because of low performance on the distracter task, which suggested that the manipulation of divided attention was possibly compromised in these participants. Data of 33 (15 men; mean age  $21.0 \pm 2.5$  years) participants were included in the analysis. All participants had normal or corrected-to-normal vision. The study was approved by the Institutional Review Board and was conducted in accordance with the Declaration of Helsinki. All participants gave written informed consent and were paid for their participation.

**Materials** Stimulus material was the same as in Herzmann et al. (2011). Stimuli (see Fig. 1, left) consisted of 432 unfamiliar Caucasian (Color FERET database; Phillips, Moon, Rizvi, & Rauss, 2000) and 432 unfamiliar Chinese faces (CAS-PEAL database, Gao et al., 2004). Because the CAS-PEAL database consists of only grayscale photographs, all pictures were converted to grayscale and then fitted into a vertical ellipse of  $170 \times 255$  pixels ( $3.2^\circ \times 5^\circ$  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. Female and male faces were represented equally in all stimulus sets. All faces showed neutral or weakly smiling expressions. No faces had beards or glasses. Stimuli were shown on a uniform gray background at a viewing distance of one meter on a 17-inch flat-panel LCD monitor (Dell Professional P170S, refresh rate 60 Hz). Stimulus presentation and EEG recording were time-locked to the refresh point.

**Procedure** The experiment consisted of two sessions, which each lasted about 2 hours. Sessions were identical and each consisted of eight study blocks followed immediately by their corresponding recognition blocks. Each study block presented 36 faces. This was different from our previous study (Herzmann et al., 2011), where 40 faces were presented. A pilot experiment showed that 40 faces with the distracter condition yielded chance performance in over half of the participants. Each test block presented all 36 studied and 18 novel distracter faces for a total of 54 faces. Equal numbers of own-race and other-race faces were presented intermixed in all blocks. 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.

For the divided attention manipulation, participants completed a number tracking task during half of the study blocks (i.e., divided attention condition) and had to complete no additional task in the other study blocks (i.e., focused attention condition). Study blocks with divided attention and their

corresponding recognition blocks alternated with study blocks of focused attention and their corresponding recognition blocks. The starting condition, either divided or focused attention, was counterbalanced across participants.

The number tracking task required participants to attend to the numbers 1 to 9, which were presented by headphones, and to press the space bar each time the current number was odd and was also preceded by an odd number (adapted from Curran, 2004). Trials in the study blocks of the divided attention condition started with the presentation of a number for 1 second, followed by the presentation of the fixation cross for 200 ms, the presentation of a target face for 2 seconds, and an interstimulus interval of 300 ms. The participants were instructed to respond to the numbers, if appropriate, during the 1-second-long presentation of the number. Accuracy of the responses to the numbers was recorded. Trials in the study blocks of the focused attention condition started with the presentation of a fixation cross for 200 ms, followed by the presentation of a target face for 2 seconds, and an interstimulus interval of 800 ms. In all study blocks, participants were instructed to look carefully at the targets and try to memorize them for the recognition block; no overt response was required for the memory task. 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 seconds. Participants were asked to withhold their response until the five response options appeared on the screen 1.5 seconds after target onset. This was done to minimize movement-related artifacts. After 1.5 seconds had passed, a horizontal, 4-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, who provided evidence that this procedure identified separate neural correlates for recollection and familiarity). 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 unfamiliar”—left ring finger, and “definitely unfamiliar”—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 one second. One study phase lasted about 2 minutes, and one test phase about 10 minutes.

To ensure understanding of the number tracking task, participants first practiced making memory judgments without the distracter task for eight study and 12 test trials, then practiced the number tracking task by itself for eight trials, and finally practiced the number tracking task together with the memory task for eight study and 12 test trials. If, in the last practice, memory performance was not above 50% (i.e., at least 50% of the responses for old faces were “recollect,” “definitely familiar,” or “maybe familiar,” and 50% of the

response for new faces were “maybe unfamiliar” and “definitely unfamiliar”) and accuracy for the number tracking task was not above 75%, the practice was repeated with new faces and new numbers. During the practices, participants received instructions for “recollect” and “familiar” memory judgments. Recollection was explained as consciously remembering specific details of the appearance of a face or of the experience of learning the face: 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 of 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, but there were no time restraints for them to respond.

**Performance measurement** For recognition memory performance, we considered the area below the receiver operating characteristic (ROC) curve,  $P(A)$  (Green & Swets, 1966), response bias  $c_a$ , and percentage of hits as well as percentage of false alarms of “recollect” and “familiar” responses. ROC curves were computed from all five possible response options, with “recollect” responses treated as reflecting higher confidence than “definitely familiar” responses. We interpreted 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 familiarity because these responses are contingent upon nonrecollection. We thus calculated the independent remember/know (IRK) estimate of familiarity ( $IRK = F/(1 - R)$ ), where  $F$  refers to raw “familiar” responses and  $R$  to raw “recollect” responses (Yonelinas, 2002) for hits and false alarms in the “familiar” condition.

**Event-related recording and measurement** EEG data was recorded in the study and recognition test phase with a 128-channel Geodesic Sensor Net<sup>TM</sup> (HydroCel GSN 128 1.0; Tucker, 1993) connected to an AC-coupled, 128-channel, high-input impedance amplifier (200 M $\Omega$ , Net Amps<sup>TM</sup>, 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 k $\Omega$ .

Epochs of 1,100 ms for study-phase items and 1,300 ms for test-phase items, each starting 100 ms before stimulus onset, were generated off-line 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 nonocular 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 participant.

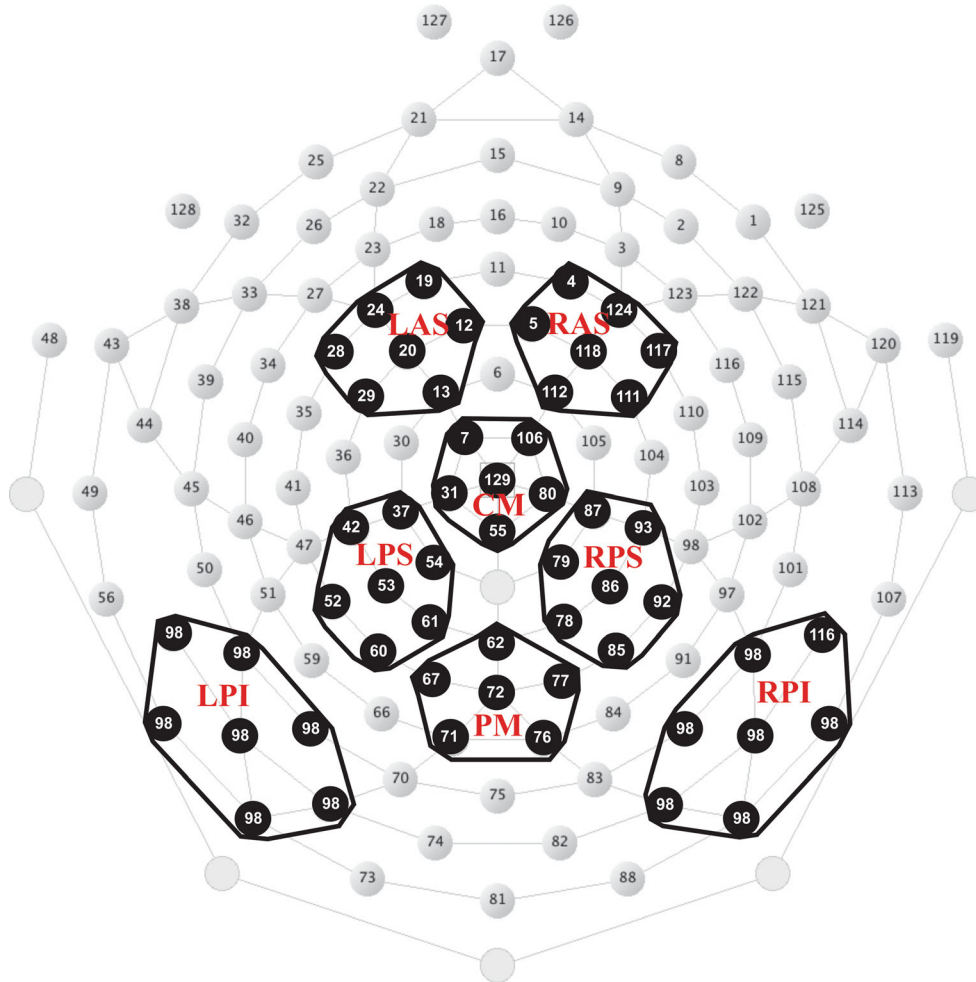
Time segments and regions of interest (ROIs; see Fig. 2) were defined according to visual inspection and previous research (Herzmann, Bird, Freeman, & Curran, 2013; Herzmann & Curran, 2011; Herzmann et al., 2011). Mean amplitudes were computed by averaging the channels within each ROI for each condition and participant. Time segments and regions of interest are given in the Results section.

## Results and discussion

In all statistical analyses, posttests that followed up on any significant main effect or interaction were Bonferroni-corrected for multiple comparisons. All  $p$  values associated with more than one degree of freedom were corrected according to the Huynh–Feldt (Huynh & Feldt, 1976) procedure for sphericity violations, but we report uncorrected degrees of freedom. Effect sizes are given as partial eta-squared ( $\eta_p^2$ ).

**Memory performance** Table 1 summarizes the indicators of memory performance for Experiment 1. Dividing attention during memory encoding lowered subsequent memory performance but did not influence the other-race effect. The magnitude of the decrease in performance was the same for own-race and other-race faces. Statistical analysis using repeated-measures ANOVAs with the within-subject factors race (Caucasian, Chinese) and attention (divided, focused) confirmed this observation by showing significant main effects of attention and race, but no Attention  $\times$  Race interactions (see Table 1). Memory performance was better when faces were studied in the focused attention condition, as indicated by the area below the ROC curve and hit recollect,  $F_s(1, 32) = 15.7$  and  $15.6$ ,  $p_s = .0001$ ,  $\eta_p^2_s = .33$ . Memory performance was better for own-race than other-race faces, as shown by the area below the ROC curve, hit recollect, and false alarms IRK familiar,  $F_s(1, 32) = 192.5$ ,  $167.0$ , and  $33.9$ ,  $p_s = .0001$ ,  $\eta_p^2_s = .86$ ,  $.84$ , and  $.52$ , respectively.

**ERP correlates of memory encoding** Figure 3 shows mean ERP amplitudes, and Fig. 4 depicts topographies of the Dms (difference waveforms). Dms were measured between 500 and 900 ms. This time segment is comparable to the 600–1,000 ms segment from our previous study (Herzmann et al., 2011). We chose an earlier window here because memory-encoding effects emerged and ended earlier in the current study. ROIs were LAS (left anterior superior), CM (central medial), RAS (right anterior superior), LPS (left parietal superior), PM (parietal media), and RPS (right parietal superior);



**Fig. 2** Geodesic sensor net layout. Electrode sites are numbered. Black clusters are regions of interest included in analyses. LAS = left anterior superior, RAS = right anterior superior, CM = central medial, LPS = left

parietal superior, PM = parietal medial, RPS = right parietal superior, LPI = left parietal inferior, RPI = right parietal inferior

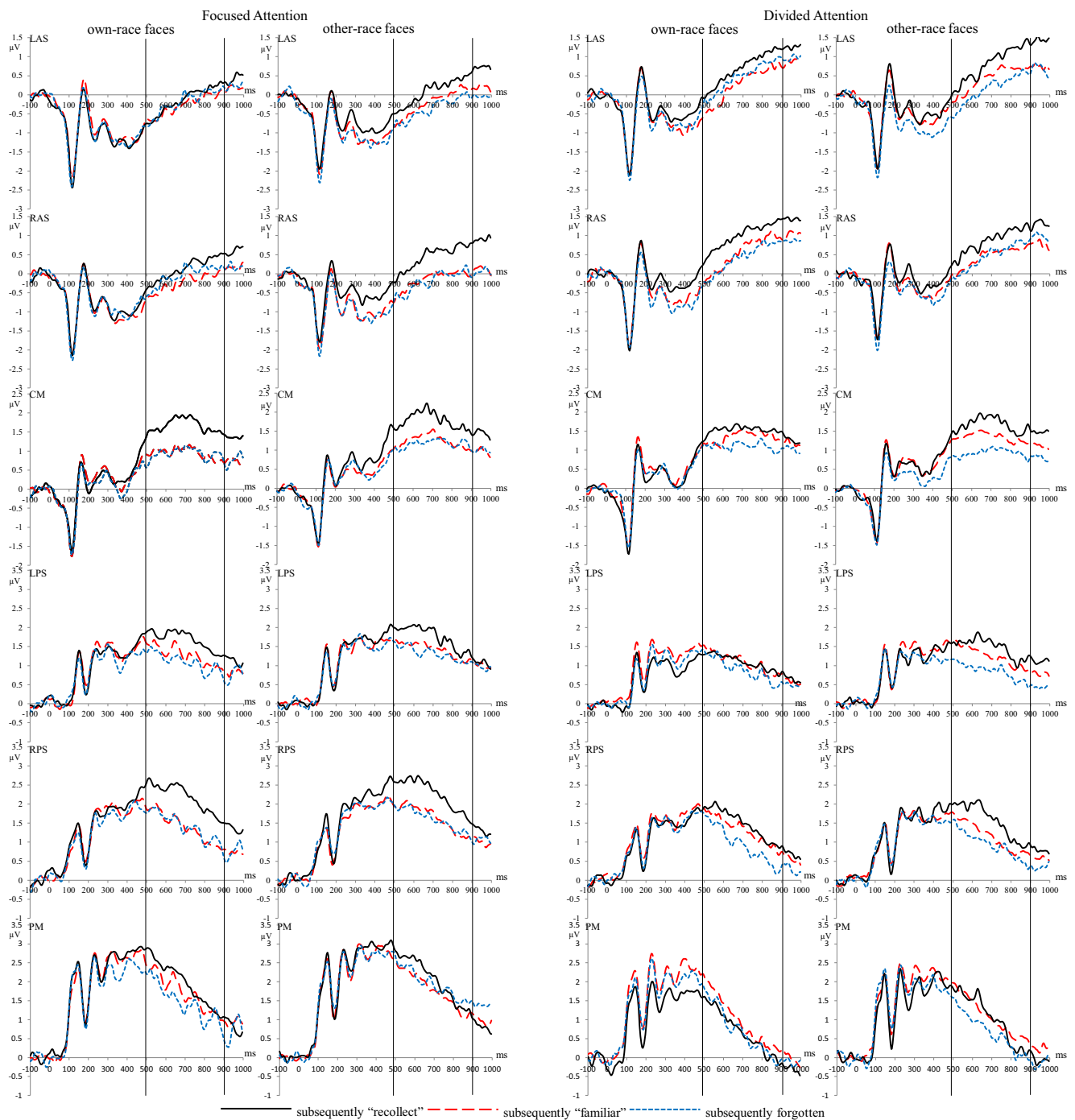
see Fig. 2). These ROIs correspond roughly to those used in Herzmann et al. (2011), taking into consideration that a different electrode montage was used. Repeated-measures ANOVAs were calculated with the within-subject factors

hemisphere (left, middle, right), anterior-posterior (anterior, posterior), race (Caucasian; Chinese in the divided attention or African American in Experiment 2), and Dm (“recollected” and “familiar” for recollection; “familiar” and forgotten for

**Table 1** Indicators of behavioral memory performance for own-race and other-race faces in Experiment 1

	Focused attention			Divided attention		
	Caucasian	Chinese	Cohen’s <i>d</i> ave	Caucasian	Chinese	Cohen’s <i>d</i> ave
P(A)	0.83 (0.08)	0.73 (0.10)	1.11***	0.80 (0.08)	0.70 (0.10)	1.11***
<i>c</i> <sub>a</sub>	−0.02 (0.35)	−0.13 (0.42)	0.29	−0.05 (0.37)	−0.13 (0.43)	0.20
Hit “recollect”	0.48 (0.19)	0.31 (0.20)	0.87***	0.44 (0.21)	0.27 (0.19)	0.85***
Hit IRK “familiar”	0.56 (0.16)	0.57 (0.19)	0.06	0.56 (0.16)	0.59 (0.17)	0.18
False alarm “recollect”	0.05 (0.06)	0.06 (0.07)	0.15	0.06 (0.07)	0.06 (0.07)	0.00
False alarm IRK “familiar”	0.21 (0.14)	0.34 (0.17)	0.83***	0.24 (0.14)	0.36 (0.18)	0.75***

*Note.* Cohen’s *d* average, a measure of effect size for highly correlated data that uses the average standard deviation as the denominator (Cumming, 2012), gives the effect size of the other-race effect for each condition. Standard deviations are given in parentheses. Left columns contain data for the conditions that represent replications of our previous results (see Supplemental Materials, Replication of Previous Findings section). \*\*\**p* < .001



**Fig. 3** Mean amplitudes from the study phase of Experiment 1 depicting encoding-related brain activation for subsequently “recalled,” subsequently “familiar,” and subsequently forgotten own-race and other-race faces for the focused (left) and divided (right) attention

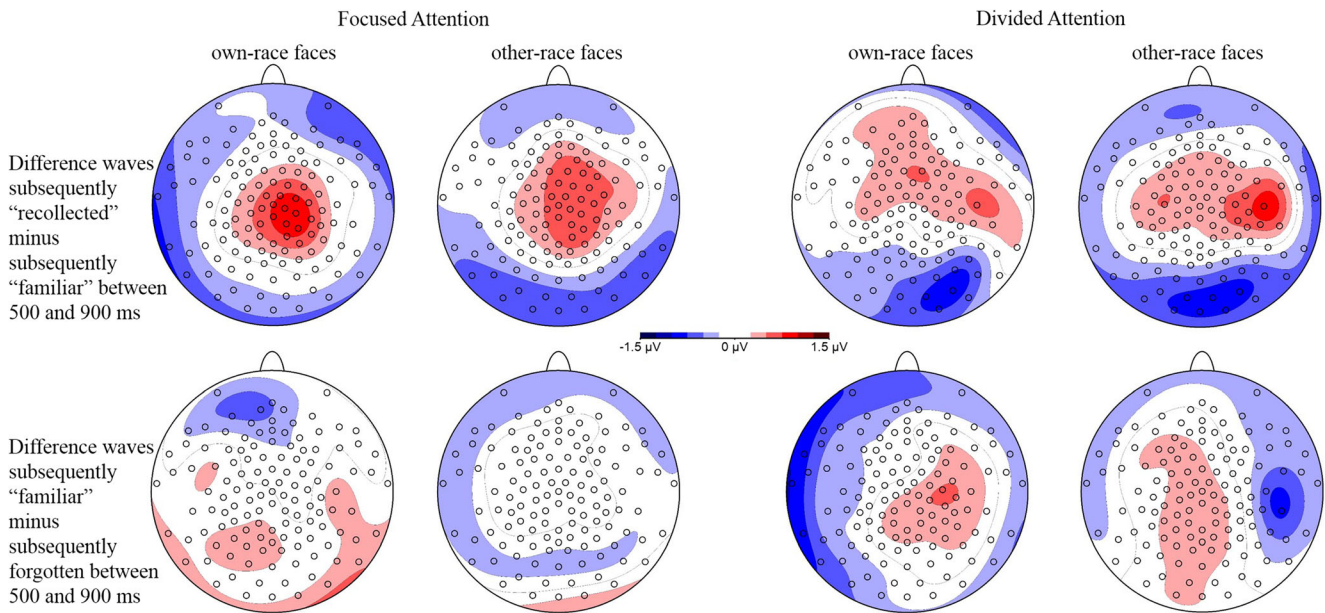
familiarity) as well as the factor attention (divided, focused). Table 2 shows statistical results for the overall ANOVAs. We report only main effects and interactions with the attention and race factor to focus on the main objective of the study.

Dms, which were significant for recollection but not familiarity (see Figs. 3–4 and Table 2), were not influenced by manipulations of attention or race (see Table 2). Significant main

condition. Vertical lines highlight the time segment of 500–900 ms for statistical analyses. Panels on the left show ERPs for the conditions that represent replications of our previous results (see Supplemental Materials, Replication of Previous Findings section)

effects of race and the Attention  $\times$  ROI interaction showed that the experimental manipulations were effective and that other-race faces elicited more positive mean amplitudes (see Fig. 3). Posttests for the Attention  $\times$  ROI interaction showed that mean amplitudes for subsequently “recalled,” subsequently “familiar,” and subsequently forgotten faces were each more positive for the divided attention than the focused attention





**Fig. 4** Voltage maps of ERP difference waves between subsequent memory judgments showing Dms at 500–900 ms for own-race and other-race faces in Experiment 1. Spherical spline interpolation was

used. Panels on the left show ERPs for the conditions that represent replications of our previous results (see [Supplemental Materials, Replication of Previous Findings](#) section)

condition but only over anterior brain regions,  $F_s(1, 32) = 19.0$  and  $20.6$ ,  $p_s = .0001$ ,  $\eta_p^2$ s =  $.37$  and  $.39$ , for the recollection and familiarity contrast, respectively (see Fig. 3).

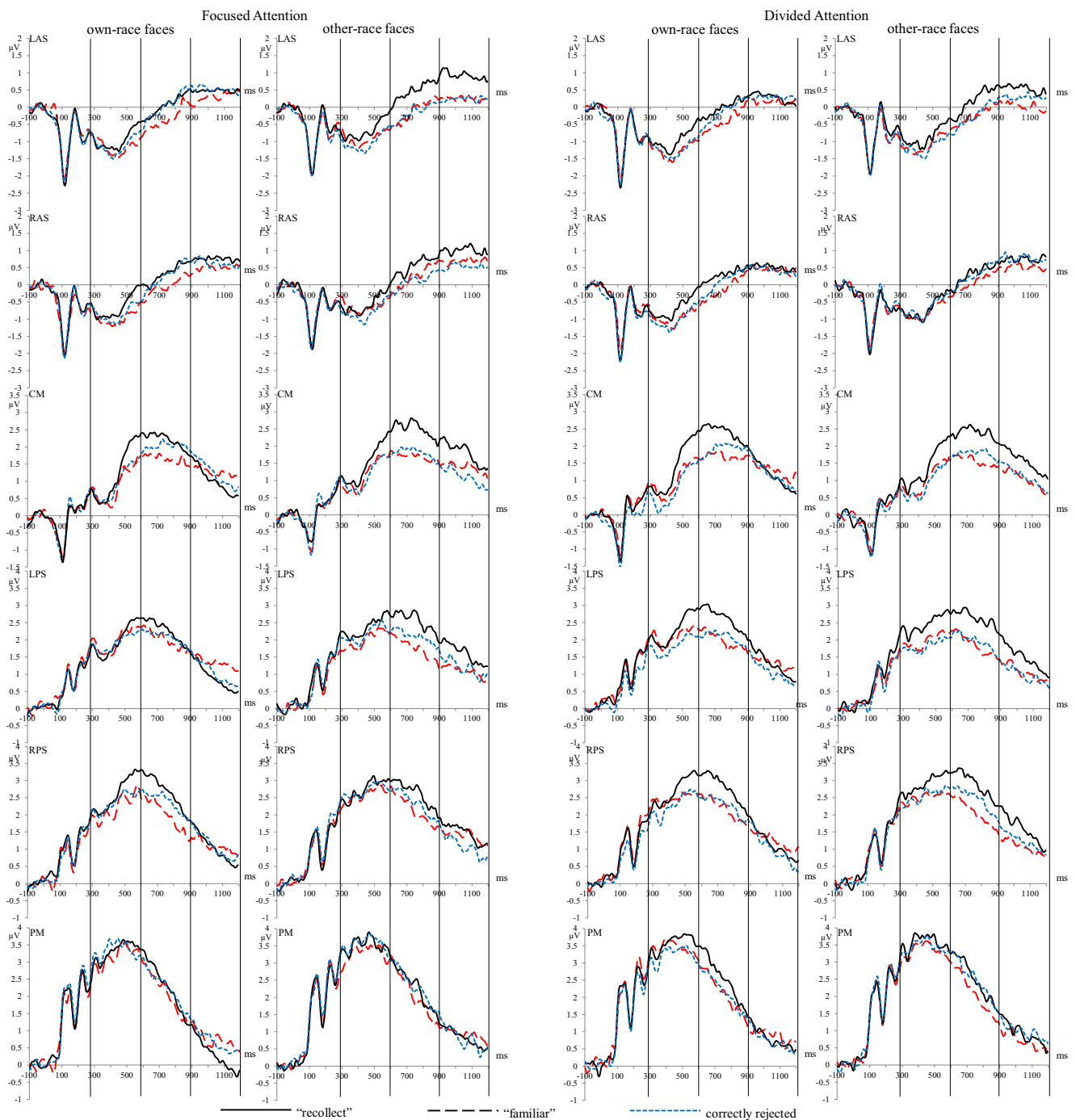
measured in three time segments: 300–600 ms, 600–900 ms, and 900–1,200 ms, corresponding to the same time segments as in our previous study (Herzmann et al., 2011). ROIs were LAS, CM, RAS, LPS, PM, and RPS, which were matched to our previous study (Herzmann et al., 2011), taking into account the difference in electrode montage. Statistical analysis and

**ERP correlates of memory retrieval** Figure 5 shows mean ERP amplitudes of the old/new effects. Old/new effects were

**Table 2** Complete statistical results of experimental manipulations showing main effects of and interactions with Dm, stimulus race, and attention/inversion (for the divided-attention and holistic-processing experiment, respectively) for the Dm related to recollection and familiarity

Main effects and interactions		Experiment 1: Divided attention <i>F</i> and <i>p</i> values	Experiment 2: Holistic processing <i>F</i> and <i>p</i> values
Difference due to memory (Dm) in the study phase 500–900 ms			
Rec	Dm	$F(1, 32) = 20.6, p = .0001, \eta_p^2 = .39$	$F(1, 33) = 8.1, p = .01, \eta_p^2 = .20$
	Race	$F(1, 32) = 6.1, p = .019, \eta_p^2 = .16$	$F(1, 33) = 1.4, p = .24, \eta_p^2 = .05$
	Attention/Inversion	$F(1, 32) = 0.3, p = .58, \eta_p^2 = .01$	$F(1, 33) = 0.2, p = .70, \eta_p^2 = .01$
	Dm × Race	$F(1, 32) = 0.03, p = .87, \eta_p^2 = .001$	$F(1, 33) = 2.0, p = .17, \eta_p^2 = .06$
	Dm × Attention/Inversion	$F(1, 32) = 2.7, p = .11, \eta_p^2 = .08$	$F(1, 33) = 0.6, p = .45, \eta_p^2 = .02$
	Dm × Race × Attention/Inversion	$F(1, 32) = 0.4, p = .55, \eta_p^2 = .01$	$F(1, 33) = 5.9, p = .02, \eta_p^2 = .15$
	Attention/Inversion × ROI	$F(1, 32) = 44.4, p = .0001, \eta_p^2 = .58$	$F(1, 33) = 12.8, p = .001, \eta_p^2 = .28$
Fam	Dm	$F(1, 32) = 3.5, p = .07, \eta_p^2 = .10$	$F(1, 33) = 6.6, p = .015, \eta_p^2 = .17$
	Race	$F(1, 32) = 2.3, p = .14, \eta_p^2 = .07$	$F(1, 33) = 2.0, p = .16, \eta_p^2 = .06$
	Attention/Inversion	$F(1, 32) = 0.1, p = .76, \eta_p^2 = .003$	$F(1, 33) = 3.4, p = .07, \eta_p^2 = .09$
	Dm × Race	$F(1, 32) = 1.1, p = .31, \eta_p^2 = .03$	$F(1, 33) = 2.0, p = .17, \eta_p^2 = .06$
	Dm × Attention/Inversion	$F(1, 32) = 2.0, p = .17, \eta_p^2 = .06$	$F(1, 33) = 1.0, p = .35, \eta_p^2 = .03$
	Dm × Race × Attention/Inversion	$F(1, 32) = 0.7, p = .79, \eta_p^2 = .002$	$F(1, 33) = 0.5, p = .49, \eta_p^2 = .02$
	Attention/Inversion × ROI	$F(1, 32) = 38.9, p = .0001, \eta_p^2 = .55$	$F(1, 33) = 20.2, p = .0001, \eta_p^2 = .38$

*Note.* Gray shading highlights significant results. Rec = recollection contrast; Fam = familiarity contrast; Dm = Dm contrasts for recollection (subsequently “recollected” vs. subsequently “familiar”) and familiarity (subsequently “familiar” and subsequently forgotten); Race = stimulus race; Attention = focused/divided attention; Inversion = holistic processing (upright/inverted); ROI = anterior-posterior ROIs; Hemisphere = left, middle, right



**Fig. 5** Mean amplitudes from the test phase of Experiment 1 depicting retrieval-related brain activation for “recollected” old, “familiar” old, and correctly rejected new own-race and other-race faces for the focused (left)

and divided (right) attention condition. Vertical lines highlight the time segments of 300–600, 600–900, and 900–1,200 ms used for statistical analyses

reporting follows those for the ERPs of memory encoding (see ERP Sorrelates of Memory Encoding section). Table 3 shows statistical results for the overall ANOVAs. The general pattern of results for the old/new effects across the three time segments was similar, hence, for brevities’ sake, we only report the 600–900 ms time interval. Please see the [Supplemental Material](#) for complete

ERP results of memory retrieval (Effects of Attention Allocation and Holistic Processing on Memory Retrieval section).

Significant old/new effects were observed only for recollection (see Fig. 5 and Table 3) and were not influenced by attention or race conditions (see Table 3). The Attention  $\times$  ROI interaction did not yield any significant posttests, and thus the

**Table 3** Statistical results of experimental manipulations showing main effects of and interactions with old/new effects, stimulus race, and attention/inversion (for the divided-attention and holistic-processing experiment, respectively) for the old/new effects related to recollection and familiarity

Main effects and interactions		Experiment 1: Divided attention <i>F</i> and <i>p</i> values	Experiment 2: Holistic processing <i>F</i> and <i>p</i> values
Old/new effects in the test phase 600–900 ms			
Rec	ONE	<i>F</i> (1, 32) = 40.1, <i>p</i> = .0001, $\eta_p^2 = .56$	<i>F</i> (1, 33) = 36.9, <i>p</i> = .0001, $\eta_p^2 = .53$
	Race	<i>F</i> (1, 32) = 1.1, <i>p</i> = .29, $\eta_p^2 = .04$	<i>F</i> (1, 33) = 0.14, <i>p</i> = .72, $\eta_p^2 = .004$
	Attention/Inversion	<i>F</i> (1, 32) = 0.01, <i>p</i> = .91, $\eta_p^2 = .00$	<i>F</i> (1, 33) = 6.4, <i>p</i> = .017, $\eta_p^2 = .16$
	ONE × Race	<i>F</i> (1, 32) = 0.2, <i>p</i> = .68, $\eta_p^2 = .01$	<i>F</i> (1, 33) = 6.9, <i>p</i> = .013, $\eta_p^2 = .17$
	ONE × Attention/Inversion	<i>F</i> (1, 32) = 0.7, <i>p</i> = .42, $\eta_p^2 = .02$	<i>F</i> (1, 33) = 2.5, <i>p</i> = .12, $\eta_p^2 = .07$
	ONE × Race × Attention/Inversion	<i>F</i> (1, 32) = 0.7, <i>p</i> = .42, $\eta_p^2 = .02$	<i>F</i> (1, 33) = 0.8, <i>p</i> = .37, $\eta_p^2 = .03$
	Attention/Inversion × ROI	<i>F</i> (1, 32) = 4.0, <i>p</i> = .05, $\eta_p^2 = .11$	<i>F</i> (1, 33) = 29.0, <i>p</i> = .0001, $\eta_p^2 = .47$
Fam	ONE	<i>F</i> (1, 32) = 3.6, <i>p</i> = .07, $\eta_p^2 = .10$	<i>F</i> (1, 33) = 0.4, <i>p</i> = .51, $\eta_p^2 = .01$
	Race	<i>F</i> (1, 32) = 0.01, <i>p</i> = .92, $\eta_p^2 = .00$	<i>F</i> (1, 33) = 6.5, <i>p</i> = .016, $\eta_p^2 = .16$
	Attention/Inversion	<i>F</i> (1, 32) = 0.3, <i>p</i> = .57, $\eta_p^2 = .01$	<i>F</i> (1, 33) = 7.5, <i>p</i> = .01, $\eta_p^2 = .19$
	ONE × Race	<i>F</i> (1, 32) = 0.4, <i>p</i> = .54, $\eta_p^2 = .01$	<i>F</i> (1, 33) = 0.2, <i>p</i> = .67, $\eta_p^2 = .01$
	ONE × Attention/Inversion	<i>F</i> (1, 32) = 0.01, <i>p</i> = .93, $\eta_p^2 = .00$	<i>F</i> (1, 33) = 2.1, <i>p</i> = .15, $\eta_p^2 = .06$
	ONE × Race × Attention/Inversion	<i>F</i> (1, 32) = 0.3, <i>p</i> = .56, $\eta_p^2 = .01$	<i>F</i> (1, 33) = 1.1, <i>p</i> = .30, $\eta_p^2 = .03$
	Attention/Inversion × ROI	<i>F</i> (1, 32) = 0.3, <i>p</i> = .57, $\eta_p^2 = .01$	<i>F</i> (1, 33) = 29.8, <i>p</i> = .0001, $\eta_p^2 = .47$

Note. Gray shading highlights significant results. Rec = recollection contrast; Fam = familiarity contrast; ONE = old/new effect contrast for recollection (“recollected” vs. “familiar”) and familiarity (“familiar” vs. correct rejection); Race = stimulus race; ROI = anterior-posterior ROIs; Attention = focused/divided attention; Inversion = holistic processing (upright/inverted)

attention effect was not significant in any individual ROI after Bonferroni correction.

**Discussion** Experiment 1 showed no effect of attention manipulations on behavioral or neural other-race effects during memory encoding and retrieval. Clear effects of divided attention in the form of reduced memory performance and increased brain activation during memory encoding and retrieval provided evidence that the experimental manipulation was successful. Face encoding elicited more positive amplitudes in the divided-attention than in the in the focused-attention condition, which is consistent with previous findings (Neumann et al., 2015). More positive amplitudes were observed, especially over anterior regions (see Figs. 3 and 5, especially LAS and RAS), suggesting that these conditions required additional neural resources that might originate from the prefrontal cortex. These additional resources are less likely to have been generated from the parietal cortex, where memory encoding effects have typically been observed (Herzmann et al., 2011; Lucas et al., 2011; Yovel & Paller, 2004). Cognitive control processes, which originate from the prefrontal cortex (e.g., Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004), appeared to be more involved in the divided attention condition.

The independence of the behavioral and neural other-race effects from attentional manipulations is in line with previous research showing that the own-gender (Loven et al., 2011) and other-age effects (Neumann et al., 2015) were independent from the allocation of attention during study. Validating and extending

these findings, we showed that variations in attention during memory encoding did also not influence the other-race effect. Our results are also consistent with a previous study that examined the influence of attention allocation on ERPs occurring before the Dm and old/new effects were measured (Neumann et al., 2015). Perceptual and memory-related brain processes of in-group effects are thus independent from manipulations of attention.

The present experiment, however, is in contrast to several previous studies that observed an influence of attention on in-group effects (Palmer et al., 2013; Semplonius & Mondloch, 2015; Zhou et al., 2014). Our auditory distracter task was similar to that of Loven et al. (2011). Palmer et al. (2013), who also used an auditory distracter task, suggested that Loven et al.’s number-monitoring task was more difficult than their own tone-monitoring task. They assumed that a harder task has similar effects on own-race and other-race faces whereas an easier task affects own-race faces more than other-race faces. Our experiment is consistent with these assumptions regarding easy and difficult distracter tasks. This suggests that future research should use an easier distracter task to investigate the impact of attention on own-race, but not other-race faces. However, the task dependence of the influence of attention allocation on memory performance for own-race and other-race faces might suggest that attention allocation plays an insignificant or at least less reliable role in the other-race effect on face memory.

Taken together, no influence of attention allocation on the other-race effect in memory performance and the neural

correlates of the other-race effect in memory encoding and retrieval were found despite evidence of successful experimental manipulations. These results do not suggest that attention is not necessary for memory processes, as seen in reduced memory performance and increased brain activation in the divided-attention condition. The results rather showed that the differences in processing of own-race and other-race faces are independent from attention manipulation which led to preserved other-race effects in the divided-attention condition. The second experiment investigated holistic processing as another candidate for causing the other-race effect.

## Experiment 2: Effects of holistic processing on the other-race effect

Experiment 2 tested whether superior memory performance for own-race as compared with other-race faces is due to a greater level of holistic encoding. Greater degrees of holistic processing have been consistently found for own-race as compared with other-race faces (see Hayward et al., 2013; Rossion & Michel, 2011, for review). Other-race faces have been found to be processed holistically, but to a lesser degree (DeGutis et al., 2013; Harrison et al., 2014; Wiese et al., 2009). The other-race effect on holistic processing is positively correlated with the other-race effect on recognition memory (DeGutis et al., 2013; Hancock & Rhodes, 2008). Thus, the other-race effect can be assumed to be at least partially due to differences in holistic processing. This hypothesis was tested in our second experiment. Faces were studied and recognized under natural (upright presentation) conditions or when holistic processing was limited (inverted presentation). Inversion has been shown to affect memory performance for own-race faces more than other-race faces (Hayward et al., 2013; Rossion & Michel, 2011). We therefore expected a greater effect of inversion on neural correlates of own-race faces. Inversion has also been shown to reduce holistic processing for own-race faces but not abolish it (Richler et al., 2011), which is very similar to the finding of reduced but not absent holistic processing for other-race faces (DeGutis et al., 2013; Harrison et al., 2014; Wiese et al., 2009). We therefore assumed that we would find a similar reduction in holistic processing for own-race faces in the inverted condition as compared with other-race faces in the upright condition because face processing in both situations, inverted own-race faces and upright other-race faces, has been found to be holistic but reduced (DeGutis et al., 2013; Harrison et al., 2014; Richler et al., 2011; Wiese et al., 2009).

## Method

The method of Experiment 2 with respect to the general procedure, performance measurement, ERP recording, and ERP

measurement was identical to Experiment 1. Differences between the experiments with regard to participants, materials, and procedural details are noted below.

**Participants** Thirty-four (11 men; mean age  $22.6 \pm 2.7$  years) healthy, right-handed, Caucasian adults volunteered in this experiment.

**Materials** In contrast to Experiment 1, stimuli (see Fig. 1, right) consisted of 480 unfamiliar African American and 480 unfamiliar Caucasian faces from the MORPH database (Ricanek & Tesafaye, 2006). In addition, luminance and spatial frequency were not equated, colored pictures were used, and face stimuli included hair. These changes in stimulus material were done to extend the findings of the other-race effect to more natural face pictures. Stimuli were cropped ( $170 \times 255$  pixels,  $3.2^\circ \times 5^\circ$  of visual angle) to show the face and hair but no necks or clothing.

**Procedure** A total of 20 study and test blocks were divided equally across the two sessions. Each study block presented 32 faces. The number of studied faces per block was lower than our previous 40 faces (Herzmann et al., 2011). Task difficulty in the inverted condition led to chance performance when more than 32 faces were used as determined in a pilot experiment. Each test block presented 48 faces, all 32 studied faces and 16 novel distracter faces. For the experimental manipulation, half of all faces were presented upright and the other half was rotated  $180^\circ$  and presented upside down (inverted) during study and test blocks. For any given stimulus, the orientation in the study and test block was the same. Equal numbers of upright and inverted stimuli were presented intermixed in the study and test blocks.

## Results and discussion

Statistical analyses and ERP measurement (time segments and ROIs) followed those in Experiment 1, with the exception that the attention factor was replaced with the within-subject inversion (inverted, upright) factor.

**Memory performance** Table 4 summarizes the indicators of memory performance for Experiment 2. Turning faces upside down lowered subsequent memory performance. Apart from hit IRK familiar, inhibiting holistic processing did not influence the other-race effect on memory performance. Statistical analysis using repeated measures ANOVAs with the within-subject factors race (Caucasian, African American) and inversion (upright, inverted) confirmed this observation by showing significant main effects of inversion for all performance measures,  $F_s(1, 33) > 9.0$ ,  $p_s < .005$ ,  $\eta_p^2_s > .21$ . A main effect of race indicating better memory performance for own-race than other-race faces was found for the area below the ROC

**Table 4** Indicators of behavioral memory performance for own-race and other-race faces in Experiment 2

	Upright presentation			Inverted presentation		
	Caucasian	African American	Cohen's $d_{ave}$	Caucasian	African American	Cohen's $d_{ave}$
P(A)	0.88 (0.08)	0.82 (0.08)	0.75***	0.79 (0.08)	0.73 (0.08)	0.75***
$c_a$	0.00 (0.30)	0.00 (0.39)	0.00	−0.35 (0.38)	−0.45 (0.48)	0.23
Hit “recollect”	0.47 (0.20)	0.36 (0.20)	0.55***	0.40 (0.20)	0.29 (0.19)	0.56***
Hit IRK “familiar”	0.64 (0.15)	0.61 (0.14)	0.21	0.67 (0.15)	0.70 (0.17)	0.19
False alarm “recollect”	0.02 (0.03)	0.03 (0.04)	0.29	0.04 (0.05)	0.05 (0.09)	0.15
False alarm IRK “familiar”	0.17 (0.10)	0.24 (0.15)	0.56***	0.38 (0.18)	0.47 (0.19)	0.49***

*Note.* Cohen's  $d_{ave}$  average, a measure of effect size for highly correlated data which uses the average standard deviation as the denominator (Cumming, 2012), gives the effect size of the other-race effect for each condition. Gray shading highlights the two measures where the other-race effect was influenced by inversion (i.e., a Race  $\times$  Inversion interaction). Standard deviations are given in parentheses. Left columns contain data for the conditions that represent replications of our previous results (see Supplemental Materials, Replication of Previous Findings section). \*\*\*  $p < .001$

curve, hit recollect, and false alarms IRK familiar,  $F_s(1, 33) = 116.9, 77.0, \text{ and } 28.2, p_s = .0001, \eta_p^2_s = .78, .70, \text{ and } .46$ , respectively. Hit IRK familiar and the response bias  $c_a$ , were the only measures to show a Race  $\times$  Inversion interaction,  $F_s(1, 33) = 7.1 \text{ and } 4.8, p_s = .012 \text{ and } .035, \eta_p^2_s = .13 \text{ and } .18$ , respectively. Whereas more “familiar” hits were made for old own-race faces in the upright condition, other-race faces received more “familiar” hits in the inverted condition, but none of the posttests were significant. The response bias did not differ in the upright condition but tended to be more liberal for other-race than own-race faces in the inverted condition,  $t(33) = 2.0, p = .104$  (uncorrected .052).

**ERP correlates of memory encoding** Figure 6 shows mean ERP amplitudes and Fig. 7 depicts topographies of the Dms (difference waveforms). Table 5 summarizes statistical results for the overall ANOVA.

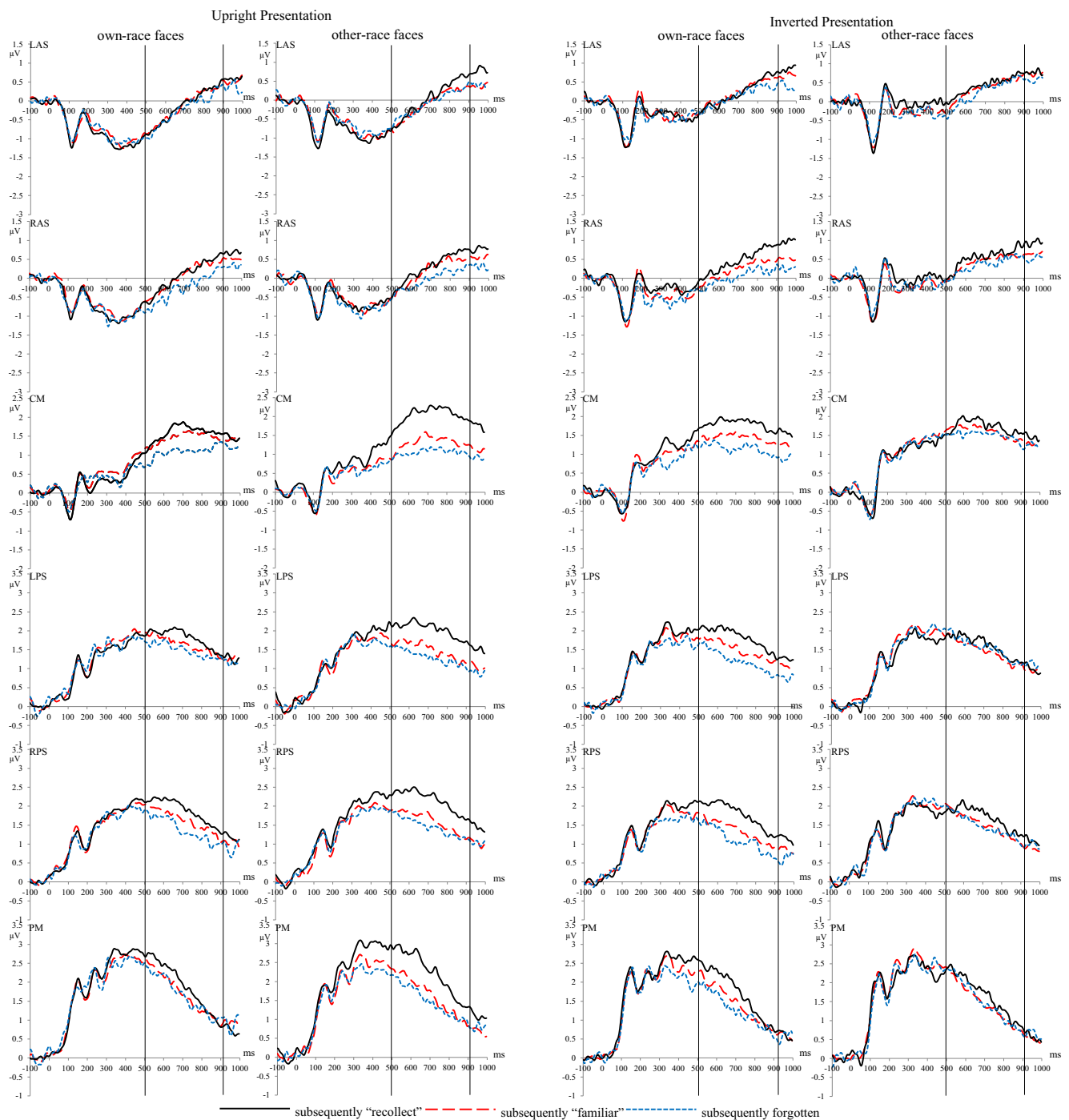
The significant Dm for recollection yielded a significant three-way interaction of Memory  $\times$  Race  $\times$  Inversion. Dms for own-race and other-race faces differed in the upright,  $F(1, 33) = 7.0, p = .026, \eta_p^2 = .17$ , but not the inverted condition,  $p = .66$ . In the upright condition, the Dm for recollection was significant for other-race faces,  $F(1, 33) = 15.4, p = .0001$ , but not for own-race faces,  $p = .20$ . When tested for each race and inversion condition individually, Dms for recollection were only significant for upright other-race,  $F(1, 33) = 19.1, p = .0001, \eta_p^2 = .32$ , and inverted own-race faces,  $F(1, 33) = 6.9, p = .039, \eta_p^2 = .17$  (see Fig. 6); these Dms did not differ significantly from each other,  $F(1, 33) = 2.4, p = .13, \eta_p^2 = .07$  (uncorrected for multiple comparisons). Significant effects involving inversion and race showed that the experimental manipulations were effective. Posttests for the interactions involving inversion and ROI showed that for the Dm for recollection and familiarity inverted faces elicited significantly more positive amplitudes than upright faces over anterior regions,  $F_s(1, 33) = 10.7 \text{ and } 21.4, p_s = .004 \text{ and } .0001, \eta_p^2_s = .25 \text{ and } .39$ , respectively (see Fig. 6).

**ERP correlates of memory retrieval** Figure 8 shows mean ERP amplitudes of the old/new effects. Table 6 summarizes statistical results for the overall ANOVA. We only report the results for the 600–900 ms time interval. Please see the Supplemental Material for complete ERP results of memory retrieval (Effects of Attention Allocation and Holistic Processing on Memory Retrieval section).

Significant memory (old/new) effects were only observed for recollection (see Fig. 8 and Table 6) and were not influenced by inversion (see Table. 3). A significant Memory Judgment  $\times$  Race interaction for recollection indicated that old/new effects were larger for own-race than other-race faces, although all old/new effects were significant,  $F_s(1, 33) = 61.0 \text{ and } 11.3, p_s = .0001 \text{ and } .004, \eta_p^2_s = .65 \text{ and } .26$ , respectively. Significant main effects of inversion and race showed that the experimental manipulations were effective and yielded more positive amplitudes for the inverted than upright and other-race than own-race condition. Inversion  $\times$  ROI interactions indicated that mean amplitudes for inverted faces were more positive than for upright faces especially over anterior regions,  $F_s(1, 33) = 45.2 \text{ and } 45.8, p_s < .0001 \text{ and } .0001, \eta_p^2_s = .58 \text{ and } .58$ , for recollection and familiarity, respectively.

**Discussion** Experiment 2 showed small effects of manipulations of holistic processing on the other-race effect in memory performance. Significant effects of disruptions in holistic processing were found on the neural correlates of memory encoding but not memory retrieval. These results suggest that other-race effects on face memory are partly due to more automatic holistic processing of own-race faces during memory encoding but not retrieval.

Memory performance was significantly lower when holistic processing was reduced but only a small effect of restrictions on holistic processing were seen on the other-race effect in familiarity judgments to previously studied faces. The predominant lack of changes in the other-race effect after limitations in holistic processing is contrary to most previous findings (Hancock



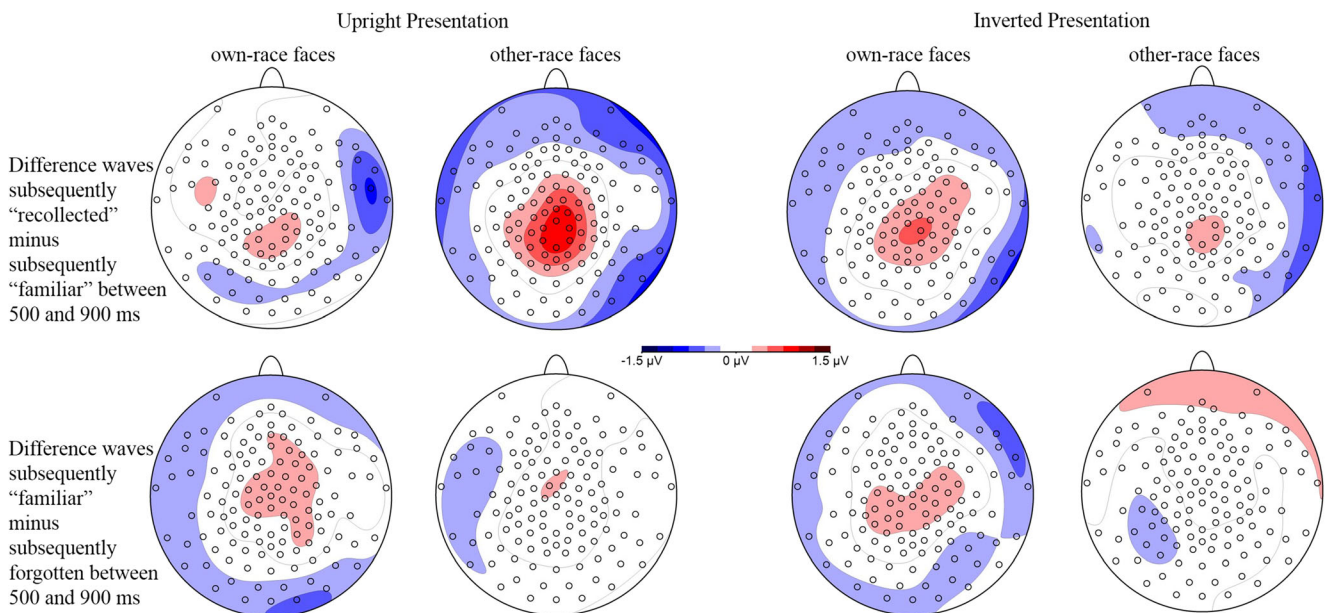
**Fig. 6** Mean amplitudes from the study phase of Experiment 2 depicting encoding-related brain activation for subsequently “recollected,” subsequently “familiar,” and subsequently forgotten own-race and other-race faces for the upright (left) and inverted (right) presentation

condition. Vertical lines highlight the time segment of 500–900 ms used for statistical analyses. Panels on the left show ERPs for the conditions that represent replications of our previous results (see Supplemental Materials, Replication of Previous Findings section)

& Rhodes, 2008; Vizioli et al., 2010; see Hayward et al., 2013, for review). One other study that used African American and Caucasian faces, as did the present experiment, also found no influence of inversion on the other-race effect (Buckhout & Regan, 1988). It is possible that the stimulus material or other differences between the present and previous studies like the

number of items in the study list or the experimental design gave rise to the observed differences.

Considering solely the behavioral data, holistic processing appeared to contribute to the other-race effect only to a small extent. The ERP results for the Dm during memory encoding, however, suggested that reductions of holistic processing



**Fig. 7** Voltage maps of ERP difference waves between subsequent memory judgments showing Dms at 500–900 ms for own-race and other-race faces in Experiment 2. Spherical spline interpolation was used.

Panels on the left show ERPs for the conditions that represent replications of our previous results (see Supplemental Materials, Replication of Previous Findings section)

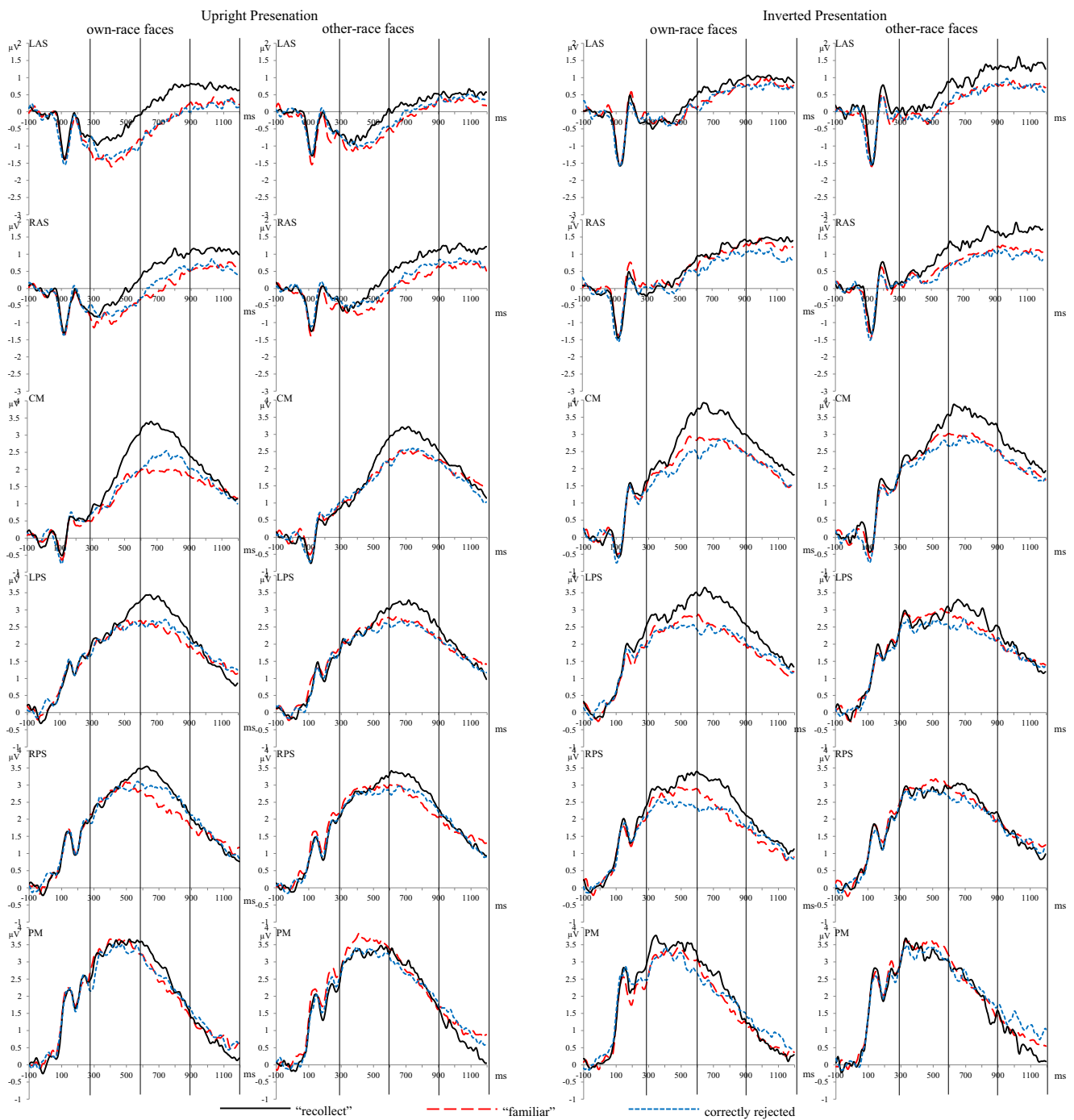
altered the neural processes that underlie the observed memory judgments. A possible explanation of these findings is that the Dm activation reflects only a partial contribution to the memory performance that is influenced by many more underlying brain processes like consolidation and decision processes which were not measured in the present experiment. These other neural processes could have offset the effects seen in the Dm (Speer & Curran, 2008; Yick, Buratto, & Schaefer, 2015). In general, it is not uncommon to find disparity between behavioral data and neural correlates of memory encoding or retrieval (Collier, Wolf, Valdez, Gur, & Gur, 2014; Kamp, Bader, & Mecklinger, 2017; Speer & Curran, 2008; Wolff, Kemter, Schweinberger, & Wiese, 2014).

Manipulations of holistic processing influenced the other-race effect during memory encoding. When face stimuli were turned upside-down, a significant Dm for recollection was found for own-race faces. This Dm was indistinguishable from the Dm for recollection for upright other-race faces (see Fig. 7). These results suggest that reducing holistic processing for own-race faces reduced the own-race advantage on memory encoding and led to similar Dm patterns for inverted own-race faces as for upright other-race faces. These results provide support for the assumption made by previous behavioral studies that increased holistic processing contributes to the memory advantage for own-race faces (DeGutis et al., 2013; Hancock & Rhodes, 2008). It further qualifies this assumption by showing that the advantage in holistic processing is present during memory encoding but not memory retrieval.

The stronger influence of inversion on memory encoding for own-race than other-race faces is similar to the previously observed influence of inversion on memory performance for

own-race and other-race faces (Hancock & Rhodes, 2008; Vizioli et al., 2010; see Hayward et al., 2013 for review). The present finding of a significant influence of inversion on study-phase ERPs is in contrast to the only previous study that also investigated the effect of inversion on general face recognition during the study phase (Marzi & Viggiano, 2011). These studies, however, differed in their measurement of study-phase ERPs which makes them difficult to compare. Whereas Marzi and Viggiano (2011) measured brain activation between 300 and 500 ms, the present study used a later time segment between 500 and 900 ms, where the Dm is typically observed (Herzmann et al., 2011; Lucas et al., 2011; Yovel & Paller, 2004). In fact, the present Dms did not emerge until about 450 ms (see Fig. 6, especially CM). Thus, no significant main effect of Dm was found between 300 and 500 ms,  $p > .35$ .

It should be noted that both upright own-race faces and inverted other-race faces did not show a significant Dm for recollection (see Fig. 7). Instead of assuming that similar mechanisms underlie the encoding of inverted other-race and upright own-race faces, a different interpretation that considers all three memory judgment conditions (subsequently “recollect,” subsequently “familiar,” and subsequently forgotten) is more appropriate. The difference between subsequently “recollect” and subsequently forgotten faces was significant for own-race faces,  $F(1, 33) = 9.8, p = .004, \eta_p^2 = .23$  (see Fig. 6, especially CM), but not other-race faces,  $p = .31$ . There are two possible mechanisms for the absent Dm for inverted other-race faces. First, brain activation for subsequently remembered items could be lowered to the level of subsequently forgotten items, suggesting that neural activation was not sufficient to establish a reliable memory



**Fig. 8** Mean amplitudes from the test phase of Experiment 2 depicting retrieval-related brain activation for “recollected” old, “familiar” old, and correctly rejected new own-race and other-race faces for the upright (left)

and inverted (right) presentation condition. Vertical lines highlight the time segments of 300–600, 600–900, and 900–1,200 ms used for statistical analyses

representation. Second, brain activation for subsequently forgotten items could be raised to the level of subsequently remembered items, suggesting a general increase in brain activation to compensate for a difficult task. The latter explanation fits the pattern of the inverted other-race faces, as seen in Fig. 6. In fact mean amplitudes for forgotten, inverted, other-race faces were significantly more positive than for forgotten, upright, other-race

faces,  $F(1, 33) = 5.3, p = .028, \eta_p^2 = .14$ . The absence of a Dm for inverted other-race faces could thus be due to the difficulty of the task which engaged neural resources but failed to lead to successful creation of memory representations as seen in the low memory performance.

Mean amplitudes during memory encoding and retrieval were more positive for inverted than upright faces which is



consistent with previous findings (Marzi & Viggiano, 2011). Greater brain activation was especially observed over anterior regions (see Figs. 6 and 8, LAS and RAS), suggesting a greater involvement of the prefrontal cortex and cognitive control processes (Ridderinkhof et al., 2004). Together with lower memory performance for the inverted presentation, these results provide evidence that the experimental manipulations had the intended effects.

## General discussions

This study tested the contributions of two possible mechanisms underlying the other-race effect on face memory. In two separate experiments, we reduced attentional resources during memory encoding (Experiment 1) or holistic processing (Experiment 2) to test the hypothesis that enhancements in face memory for own-race faces might be caused by superior attention allocation or a higher degree of holistic processing. We proposed that these reductions would alter own-race face processing and make it more similar to that of other-race faces. The results indicated that this assumption was true for holistic processing, but that manipulations of attention did not influence the other-race effect on face memory. We also showed that inversion affected memory encoding but not memory retrieval.

Inverting faces during the study phase reduced the previously found advantage on memory encoding related to subsequent recollection for own-race as compared to other-race faces (see Fig. 7, top row). Whereas subsequently “recollected” and “familiar” own-race faces elicited similar brain activation in the upright condition, neural activation for subsequently “recollected” and “familiar” own-race faces in the inverted condition was significantly different from each other. This pattern of results suggests that in the upright condition, subsequently “recollected” and “familiar” own-race faces were processed similarly, whereas in the inverted condition, only subsequently “recollected” own-race faces were associated with increased neural activation. These results might suggest that holistic processing, which has been shown to be more pronounced for own-race faces (Harrison et al., 2014; Hayward et al., 2013; Wiese et al., 2009), facilitated memory for upright own-race faces by enhancing memory encoding for all subsequently recognized faces (i.e., recollected and familiar faces). No similar effects were found for ERP correlates of memory retrieval even though faces were shown inverted during both study and test. This might point to a stronger influence of holistic processing on memory encoding than retrieval.

Inverted own-race faces elicited similar patterns of brain activation during encoding as upright other-race faces (see Fig. 7). This might point to similar underlying neural mechanisms that are engaged for inverted own-race and upright other-race faces. These mechanisms likely draw on reduced

levels of holistic processing as suggested by previous research (DeGutis et al., 2013; Harrison et al., 2014; Richler et al., 2011). Additional evidence for this assumption comes from results of the present condition of inverted other-race faces. Turning other-race faces upside down impaired face memory tremendously as shown by the lowest behavioral performance (see Table 4, inverted other-race faces) and the absent Dm effects (see Figs. 6 and 7, inverted other-race faces). These results add to previous research (DeGutis et al., 2013; Harrison et al., 2014), which showed that memory for upright other-race faces involves reduced levels of holistic processing that are further diminished when other-race faces are turned upside down.

We would like to note that our present ERP results for memory encoding and retrieval do not directly reflect magnitudes of holistic processing. It can, however, be assumed that differences between the inverted and upright condition reflect differences in holistic processing because memory performance and perceptual processes showed similar effects as in previous research (Hayward et al., 2013; Wiese et al., 2009). It could also be assumed that alternative explanations, like differences in attention allocation or shifts in encoding strategy, either triggered in a bottom-up or intentional manner could have contributed to the data. Given that the race and orientation factor of Experiment 2 were manipulated in a random, intermixed design, the latter explanation, however, appear less likely.

Manipulations of attention did not influence the other-race effect on face memory, but it did reduce memory performance and increased brain activation showing that attention is necessary for memory processes but not for the other-race effect on face memory. In fact, various aspects of the other-race effect were unaffected by our experimental manipulations, which thus demonstrates its stability across different testing conditions. Overall memory performance was better for own-race faces, whereas false alarms for “familiar” faces were higher for other-race faces. Both experiments also showed overall more positive amplitudes for other-race faces, indicating that more neural activation was required to process these faces. The absence of selective influences of attention and holistic processing on these aspects of the other-race effect on face memory suggest that other factors such as perceptual learning mechanisms (Goldstone, 1998), strategies in memory encoding ( Craik & Lockhart, 1972), or memory consolidation may have an influence.

The most impressive result when considering the multitude of analyses conducted is the stability of the other-race effect. This observation is in contrast to accounts that assume the other-race effect to be more susceptible to outside influences. For example, sociocognitive accounts (Shriver, Young, Hugenberg, Bernstein, & Lanter, 2008; Wilson & Hugenberg, 2010) propose that by shifting motivational goals, the processing of other-race faces can become similar to that of own-race faces, which would abolish the other-race effect.

Although this was not the focus of the present study, the stability of the other-race effect observed here suggests little influence of motivational factors on the other-race effect. Instead, the present findings support the perceptual expertise account, which postulates that own-race faces profit from greater visual experience which leads to more effective holistic processing (Meissner & Brigham, 2001; Rossion & Michel, 2011; Wiese et al., 2009). When holistic processing for own-race faces is diminished, these faces would be processed more similar to other-race faces, as seen in the present study.

## Conclusions

Measuring brain processes of memory encoding and retrieval separately, the present study provided the first evidence that increased holistic processing during memory encoding contributes to the own-race advantage in face memory (Hancock & Rhodes, 2008; Hayward et al., 2013; Vizioli et al., 2010). Reducing holistic processing for own-race faces led to similar neural patterns of memory encoding as seen for upright other-race faces. Manipulations of holistic processing had a lesser effect on the other-race effect for ERP correlates of memory retrieval. These findings suggest a stronger importance of memory encoding for the other-race effect on face memory, a conclusion that could not have been drawn from behavioral data alone. Manipulations of attention did not influence the other-race effects on face memory, which is in line with previous findings for the own-age (Neumann et al., 2005) and own-gender bias (Loven et al., 2011), but might also be due to the use of a difficult distracter task (Palmer et al., 2013). The present study additionally provided evidence for the reliability of other-race effects on memory encoding and retrieval. Many of the signatures of other-race effects in face memory (Herzmann et al., 2017; Herzmann et al., 2011) were replicated in two experiments that varied several aspects of the experimental design like stimulus material, procedure, and task demands.

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