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Learning own- and other-race facial identities: Testing implicit recognition with event-related brain potentials

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Abstract

Exposure to varying images of the same person can encourage the formation of a representation that is sufficiently robust to allow recognition of previously unseen images of this person. While behavioural work suggests that face identity learning is harder for other-race faces, the present experiment investigated the neural correlates underlying own- and other-race face learning. Participants sorted own- and other-race identities into separate identity clusters and were further familiarised with these identities in a matching task. Subsequently, we compared event-related brain potentials (ERPs) in an implicit recognition (butterfly detection) task for learnt and previously unseen identities. We observed better sorting and matching for own- than other-race identities, and behavioural learning effects were restricted to own-race identities. Similarly, the N170 ERP component showed clear learning effects for own-race faces only. The N250, a component more closely associated with face learning was more negative for learnt than novel identities. ERP findings thus suggests a processing advantage for own-race identities at an early perceptual level whereas later correlates of identity learning were unaffected by ethnicity. These results suggest learning advantages for own-race identities, which underscores the importance of perceptual expertise in the own-race bias.

Keywords: face recognition, event-related potentials, own-race bias, identity learning, N170, N250

1.1. Introduction

People are better at remembering faces from their own compared to a different ethnic group, a well-established phenomenon called the own-race bias (ORB, or other-race effect; Malpass & Kravitz, 1969; Meissner & Brigham, 2001). The ORB is commonly studied using pre-experimentally unfamiliar faces that are learnt from a single picture, and these pictures subsequently have to be recognised among newly presented distractors. However, experiments using this basic paradigm can only give limited insight into how own- and other-race faces are learnt and recognised in real life. These limitations stem from fundamental differences in unfamiliar and familiar face recognition, and from recent findings demonstrating how faces become familiar. While we can easily recognise the people we know from a wide range of different images, seeing that different pictures show the same unfamiliar person can be very difficult (Bruce et al., 1999; Jenkins, White, Van Montfort, & Burton, 2011). Face learning therefore reflects the establishment of representations that allow for recognition independent of a specific image (Jenkins & Burton, 2011). Nonetheless, studies on the ORB have typically ignored image-independent face recognition, which is arguably critical for identification in applied contexts, such as eyewitness testimony. Similarly, studies on the neural correlates of the ORB have largely focused on pictorial rather than face learning (e.g., Golby, Gabrieli, Chiao, & Eberhardt, 2001; Herzmann, Willenbockel, Tanaka, & Curran, 2011; Wiese, Kaufmann, & Schweinberger, 2014). The present study thus aimed to fill this gap by examining the neural processes accompanying own- and other-race face identity learning.

Many studies highlight how difficult it can be to recognise unfamiliar faces from different pictures, even when these are presented simultaneously (e.g., Bruce et al., 1999; Jenkins et al., 2011; Megreya & Burton, 2006). By contrast, we are able to easily recognise a familiar face from almost any image (Burton, Wilson, Cowan, & Bruce, 1999). These profound differences in performance between unfamiliar and familiar face recognition most likely reflect differences in how they are represented. Familiar face recognition is thought to rely on stored memory representations that gradually develop over time. These structural codes, termed face recognition units (Bruce & Young, 1986), become increasingly abstract, i.e., independent of particular viewing conditions, the more we become familiar with a face and therefore allow for recognition across a substantial range of variation (Burton et al., 1999; Burton, Jenkins, Hancock, & White, 2005; Jenkins et al., 2011; Kramer, Jenkins, Young, & Burton, 2017). For any unfamiliar face, however, such representations are not available. Instead, unfamiliar face recognition is largely based on pictorial codes that are closely tied to the original encounter with a given face (Hancock, Bruce, & Burton, 2000). As a consequence, small variations between images of an unfamiliar person, e.g. with respect to pose and lighting conditions, typically impair performance (e.g., Longmore, Liu, & Young, 2008).

The few available studies on image-independent processing of other-race faces suggest that difficulties in unfamiliar face recognition are even more pronounced for faces from different ethnic groups. First, face matching tasks in which participants have to indicate whether two simultaneously presented pictures show the same person or not (see e.g., Megreya & Burton, 2006) are often surprisingly difficult, even for own-race faces. However, a further decrease in performance has been observed for other-race faces (Kokje, Bindemann, & Megreya, 2018; Megreya, White, & Burton, 2011). Second, when participants are presented with printed cards showing multiple images of two different identities and are asked to sort these cards into as many piles as they perceive identities in the set, they often drastically overestimate the true number of identities (Jenkins et al., 2011). Yet participants create even more identity clusters when the faces are from a different ethnic group (Laurence, Zhou, & Mondloch, 2016; Yan, Andrews, Jenkins, & Young, 2016; Zhou & Mondloch, 2016).

These findings clearly demonstrate difficulties with unfamiliar other-race facial identities at a perceptual level, but they also suggest that learning new facial identities from a different ethnic group might be more difficult. Getting to know how different a face can look in different pictures appears to be key to acquiring image-independent familiarity with that face (Bruce, 1994; Burton, 2013; Burton, Kramer, Ritchie, & Jenkins, 2016; Burton, Schweinberger, Jenkins, & Kaufmann, 2015). Studies examining face learning therefore often use so-called ambient images (see Figure 1), which capture a high degree of "naturalistic" variability in appearance, e.g., with respect to lighting, viewing angle, or emotional expressions. Of particular relevance for the present study, Andrews, Jenkins, Cursiter & Burton (2015) presented participants with multiple cards showing ambient images of two different identities and, in contrast to the study by Jenkins and colleagues (2011) discussed above, informed the participants about the true number of identities in the set and specifically instructed them to sort the images into two clusters, one for each identity. In a subsequent matching task, novel exemplars of the identities seen during sorting were matched more accurately than images of unfamiliar faces (Andrews, Burton, Schweinberger, & Wiese, 2017; Andrews et al., 2015). These findings indicate that exposure to within-identity variability during sorting results in the formation of image-independent representations. At the same time, given that sorting images according to identity is more difficult for other-race faces (e.g., Yan et al., 2016), it might also be harder to learn other-race faces through exposure to within-identity variability.

Figure 1. Exemplary ambient images. All images show the same person. Images are reprinted with full permission of the depicted person.

Support for the suggestion that other-race identities are harder to learn from highly variable images comes from two recent studies which directly compared own- and other-race face identity learning. First, Hayward and colleagues found that participants learned other-race identities less efficiently than own-race identities, and that training generalised more poorly to novel exemplars of the learnt other- relative to own-race identities (Hayward, Favelle, Oxner, Chu, & Lam, 2017). Second, better learning of own- relative to other-race identities has also been observed by Zhou, Matthews, Baker, & Mondloch (2018). These authors found that a higher degree of variability during learning was needed for later image-independent recognition of other- as compared to own-race identities. These learning difficulties associated with other-race faces have been interpreted to reflect reduced perceptual expertise with the other-race category (e.g., Proietti, Laurence, Matthews, Zhou, & Mondloch, 2018; Zhou et al., 2018). At the same time, Cavazos, Noyes, & O'Toole (2018) found that own- and other-race faces equally benefitted from multi-image training. Although an ORB was observed, the presentation of multiple images during learning led to face representations that facilitated subsequent recognition of novel exemplars of both own- and other-race faces.

The aim of the present study was to investigate the neural correlates of face identity learning for own- and other-race faces. While face processing is thought to consist of a number of successive stages (see e.g., Bruce & Young, 1986; Schweinberger & Neumann, 2016), behavioural measures can only inform about the outcome of these various processing steps. Here, we analysed event-related brain potentials (ERPs) to more directly determine at what processing stage differences between own- and other-race face learning would occur. ERPs reflect transient voltage changes in the electroencephalogram (EEG) that are time-locked to a specific event, e.g., the presentation of a visual stimulus. They consist of positive and negative deflections, so-called components, which are associated with distinct stages of stimulus processing, in this case, the processing of faces. ERPs therefore provide an excellent tool for the purpose of the present study.

The first face-sensitive ERP component is the N170, a negative deflection peaking approximately 170 ms after stimulus onset at occipito-temporal electrodes. N170 is more negative for faces than for other classes of objects (Bentin, Allison, Puce, Perez, & McCarthy, 1996), but usually considered to be insensitive to familiarity (Bentin & Deouell, 2000; Eimer, 2000a; Schweinberger, Pfütze, & Sommer, 1995; Zimmermann & Eimer, 2013, 2014). Hence, it is typically interpreted to reflect processes prior to the identification of an individual face (but see Schweinberger & Neumann, 2016, for a detailed discussion of identity adaptation effects), such as structural encoding or the detection of a face-like pattern (Eimer, 2000b; Eimer, 2011). N170 has been observed to be more negative for other- relative to own-race faces (e.g., Cassidy, Boutsen, Humphreys, & Quinn, 2014; Herrmann et al., 2007; Stahl, Wiese, & Schweinberger, 2010; Wiese & Schweinberger, 2018), which presumably indicates more effortful structural processing of other-race faces. However, other studies did not observe ethnicity effects in N170 (e.g., Gajewski, Schlegel, & Stoerig, 2008; Herzmann et al., 2011; Wiese, Stahl, & Schweinberger, 2009), which may, at least partly, reflect differential task demands (Senholzi & Ito, 2013; Wiese, 2013).

N170 is immediately followed by a positive deflection, the occipito-temporal P2, peaking roughly 200 ms after stimulus onset. Generally, P2 amplitude is more positive for “typical” compared to “atypical” faces. For example, more positive P2 amplitudes have been observed for veridical relative to spatially caricatured faces (Schulz, Kaufmann, Kurt, & Schweinberger, 2012; Wuttke & Schweinberger, 2019). In addition, P2 is usually more positive for own- when compared to other-race faces (Stahl et al., 2010; Wiese & Schweinberger, 2018), although this effect was observed to be attenuated in participants with substantial other-race contact (Stahl, Wiese, & Schweinberger, 2008). Moreover, shifting participants’ attention to individual rather than ethnic category information eliminated this P2 effect (Stahl et al., 2010). These findings suggest that ethnicity effects in the P2 time range are shaped by both long-term experience and current task demands.

The subsequent N250 is the earliest component consistently associated with the processing of facial identity. More negative N250 amplitudes have been observed for famous (Andrews et al., 2017; Gosling & Eimer, 2011) and personally familiar (Wiese, Tüttenberg, et al., 2019) relative to unfamiliar faces. Similarly, N250 is more negative for immediate repetitions of faces relative to conditions in which two different faces are presented in succession. This so-called N250r (r for repetition; Begleiter, Porjesz, & Wang, 1995; Bindemann, Burton, Leuthold, & Schweinberger, 2008; Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Schweinberger et al., 1995) has been interpreted to reflect access to perceptual face representations. More negative amplitudes in the N250 time range have also been observed for other- relative to own-race faces (Herzmann et al., 2011; Stahl et al., 2010; Wiese et al., 2014; Wiese & Schweinberger, 2018), which may reflect more effortful processing of individual other-race faces (Herzmann, 2016). We note that these interpretations might at first sight appear somewhat difficult to integrate. While a larger N250 for familiar versus unfamiliar faces or repeated versus non-repeated faces may reflect the (pre-)activation of a face representation, overall more negative amplitudes for other-race faces in the N250 time range, independent of familiarity or repetition, seem to suggest more effort when participants are trying to access such representations.

The N250 has also been linked to face learning, with increased amplitudes for newly learnt relative to novel faces (Kaufmann, Schweinberger, & Burton, 2009; Tanaka, Curran, Porterfield, & Collins, 2006), and these N250 learning effects were evident across different images of the respective faces (Kaufmann et al., 2009). Interestingly, learning effects within the N250 time range have also been observed following individuation training with a specific category of other-race faces (Tanaka & Pierce, 2009). To date, only one previous study investigated ERP correlates of identity learning using ambient images (Andrews et al., 2017). After sorting ambient images of two identities into respective identity clusters, images seen during the sorting task elicited more negative N250 amplitudes compared to images of novel identities. More importantly, these learning effects were highly similar for images presented during sorting and a new set of images of the learnt identities, suggesting the establishment of new image-independent representations.

The present study used a paradigm similar to Andrews et al. (2017) to study the neural correlates of own- and other-race face identity learning in an implicit learning study. Specifically, we sought to investigate whether learning is more challenging for faces of a different ethnic group and, if so, at what neural processing stage such ethnicity-related difficulties would manifest. Participants first sorted ambient images of two identities into two separate identity clusters. Subsequently, to promote further familiarisation with these identities, particularly in light of the above-described difficulties with other-race faces, participants completed four blocks of a matching task during which the sorting task images were repeatedly presented. Feedback was provided after each trial. Finally, to assess recognition at the neural level, participants watched a sequence of faces while their EEG was recorded. Participants were asked to respond to infrequently occurring target stimuli (i.e., butterflies) and therefore the task did not require explicit recognition of recently learnt faces. Stimuli in this task consisted of the images seen during sorting/matching (learnt ID/same images), a new set of images of the identities presented during sorting/matching (learnt ID/different images), and images of two unfamiliar faces (novel ID). This sequence of tasks was completed with both own-race and other-race identities.

In line with previous findings (e.g., Laurence et al., 2016), we expected better sorting of own- than other-race identities. Based on recent findings that other-race faces are harder to learn than own-race faces (e.g., Zhou et al., 2018), we also expected overall better matching accuracy with own-race faces and a stronger performance increase over blocks for this face category. With respect to ERPs, we expected to replicate the findings of Andrews et al. (2017) for own-race faces. Specifically, if the sorting and matching tasks triggered the formation of face representations, more negative N250 amplitudes would be expected for learnt ID/same images compared to novel ID images. In addition, if these representations were sufficiently robust to allow for the recognition of novel own-race exemplars (e.g., Andrews et al., 2015; 2017), we would expect N250 amplitudes of learnt ID/different images to be highly similar to those of learnt ID/same images. However, as other-race face learning has been found to not readily generalise to novel instances (e.g., Hayward et al., 2017), we anticipated N250 learning effects to be largely restricted to those other-race images presented during sorting and matching.

2. Method

2.1. Participants

20 undergraduate and postgraduate students as well as staff members (10 female, 18 – 37 years, $M_{\text{age}} = 23.6$, $SD_{\text{age}} = 5.8$) at Durham University gave written informed consent to take part in the experiment. All had a Caucasian ethnic background. Participants reported normal or corrected-to-normal vision, and no neurological or psychiatric conditions. All were right-handed as assessed by the Edinburgh Handedness questionnaire (Oldfield, 1971). Participants received course credit or a monetary compensation of £14 for taking part. The study was approved by the local Ethics Committee at Durham University's Department of Psychology.

2.2. Stimuli and Design

We compiled 40 images of each of four Caucasian and four East Asian male photo models via a Google image search (see also Tüttenberg & Wiese, in press). For each identity, the first 40 images of each identity were chosen where the face covered an area of at least 190 x 285 pixels and facial features were not covered by e.g., sunglasses. All images were converted to grey scale and framed within an area of 190 x 285 pixels. In addition, for the sorting task (see below), 20 images for each identity were re-sized to 3 x 4 cm, printed, laminated and cut out to create a single picture card for each image. There were also 12 images of butterflies (previously used in Andrews et al., 2017). After completion of the main experiment, participants were asked to rate the quality of contact with Caucasian and East Asian people on a scale from 1 to 4 (1 – very superficial, 2 – rather superficial, 3 – rather intense, 4 – very intense; Wiese, 2012).

For each identity, images were randomly divided into two sets (A, B) of 20 images each. The identities within each ethnic group were joined to pairs (Caucasian ID1/2, Caucasian ID3/4, East Asian ID1/2, and East Asian ID3/4). In total, there were four different image sets for each ethnic group (sets A and B for ID1/2 and ID3/4, respectively).

A sequence of three different tasks was employed, a sorting task, a matching task and a final butterfly detection task (Figure 2). This sequence was completed twice, once with Caucasian and once with East Asian identities in separate blocks. The order (Caucasian first, East Asian first) was counterbalanced across participants.

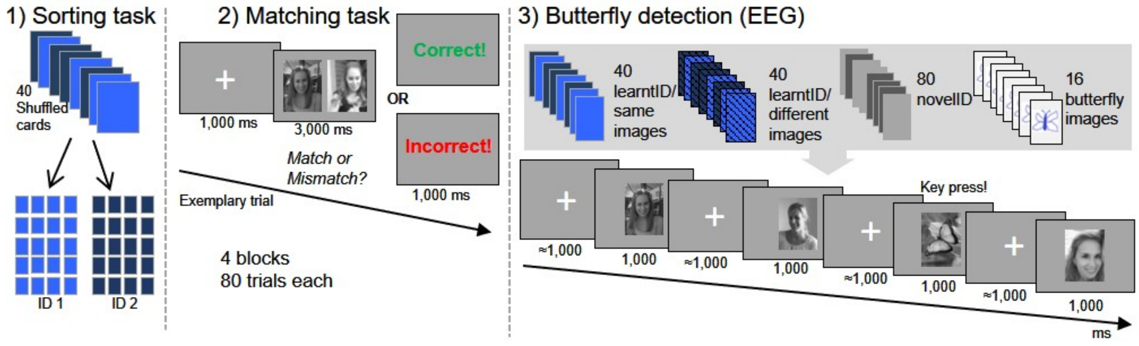


Figure 2. Overview of the procedure. For more detailed information, refer to main text. Note that images shown in the figure are not those used in the experiment. Images are reprinted with full permission of the depicted persons.

For the sorting task, Set A of one identity pair (ID1/2A, or ID3/4A) for the respective ethnic group was selected. The identity set used in the sorting task was counterbalanced across participants.

The subsequent matching task comprised four blocks with 80 trials each. These were 40 match trials (20 for each of the two identities encountered in the sorting task) and 40 mismatch trials in which one image of each of the two identities was shown. Selected images were those presented during sorting to encourage continued familiarisation with the identities. Each image was presented four times per block, twice in match and mismatch trials, respectively. Although specific images were repeated both within and across blocks, two individual images were never shown together more than once. Images were presented side-by-side on dark grey background on a computer monitor. Both images were displayed at 5.6 x 8.4 cm with a 3.5 cm gap between images. Each image had equal probability to appear as left or right image.

The final picture viewing task consisted of 176 trials, i.e., 40 trials comprising the images of the two identities seen during sorting and matching (learnt ID/same images; e.g., ID1/2A), 40 trials showing new images of the identities seen during sorting and matching (learnt ID/different images; e.g., ID1/2B), and 80 trials comprising images of two previously unseen identities (novel ID, e.g., ID3/4A and B). The remaining 16 trials showed images of butterflies (with four randomly selected images presented twice) which were not analysed and only included to create task demands (see below). Images were presented on dark grey background in the centre of a computer monitor within an area of 195 x 280 pixels (5.6 x 8.4 cm), corresponding to a viewing angle of 3.21° x 4.81° at a viewing distance of 100 cm, which was maintained with a chin rest.

2.3. Procedure

After providing written informed consent, participants were prepared for EEG recording. They then completed the first sorting task. Participants received a pile of 40 shuffled cards of two identities and were told that the images were of two different people with 20 images per identity. They were asked to sort these images into two separate identity clusters.

Following the sorting task, participants were seated in front of a computer monitor to engage in the matching task. Participants saw pairs of faces and had to judge as accurately as possible via key presses whether the two faces showed the same or different persons. Key assignment to match and mismatch responses was counterbalanced across participants. Images were presented for 3,000 ms, preceded by a fixation cross shown for 1,000 ms. After each trial, participants received feedback (‘Correct!’ or ‘Incorrect!’ in green or red letters, respectively; or ‘No response detected’ (also in red) if participants failed to submit their answer within 3,000 ms) which was presented for 1,000 ms.

Finally, in the butterfly detection task, participants saw a sequence of single face images and were instructed to press a key as fast and as accurately as possible whenever an image of a butterfly was presented. Images were shown for 1,000 ms and preceded by a fixation cross which was presented for an average duration of 1,000 ms (randomly jittered between 800 and 1,200 ms). Images were presented in random order. Afterwards, participants completed the second block with stimuli from the respective other ethnic group.

2.4. EEG recording and data analysis

EEG was recorded from 64 sintered Ag/Ag-Cl electrodes with an ANT Neuro system (Enschede, Netherlands). An electrode on the forehead served as ground and Cz as recording reference. EEG was sampled at a rate of 512 Hz (DC to 120 Hz). Recording sites corresponded to an extended 10 – 20 system. Blink correction was performed using the algorithm implemented in BESA 6.3 (Gräfelfing, Germany). EEG was segmented from -200 until 1,000 ms relative to stimulus onset whereby the first 200 ms served as baseline. Artefact rejection was carried out using an amplitude threshold of 100 µV and a gradient criterion of 75 µV. All remaining trials were recalculated to average reference, digitally low-pass filtered at 40 Hz (12 dB/oct, zero phase shift) and then averaged according to experimental conditions. The average number of trials was 35.1 (*SD* = 6.0) for learnt ID/same images, 34.5 (*SD* = 6.3) for learnt ID/different images, and 69.7 (*SD* = 11.4) for novel ID in the own-race identity condition, and 34.9 (*SD* = 5.4) for learnt ID/same images, 34.9 (*SD* = 5.1) for learnt ID/different images, and 70.1 (*SD* = 10.4) for novel ID in the other-race identity condition.

In the averaged waveforms, mean amplitudes for N170 (130 – 180 ms), P2 (180 – 220 ms) as well as early (220 – 300 ms) and late (300 – 400 ms) N250 components at P9/10 and TP9/10 were calculated. Time windows for the respective components were selected based on visual inspection of the grand averages. Note that the analysis of an early and late N250 time window as well as the selection of the respective time ranges corresponds to approaches in previous ERP studies on face identity learning (Andrews et al., 2017; Kaufmann et al., 2009).

Statistical analyses were performed using repeated measures analyses of variance (ANOVA). Matching task accuracy was analysed using the within-subjects factors ethnicity (own-race, other-race), trial type (match, mismatch) and block (1, 2, 3, 4). Post-hoc comparisons as well as analysis of quality of contact, sorting task errors and accuracy of butterfly detection were performed using paired samples t-tests. EEG data were analysed using repeated measures ANOVAs with the within-subjects factors hemisphere (left, right), site (TP, P), ethnicity (own-race, other-race) and ID type (learnt ID/same images, learnt ID/different images, novel ID). Degrees of freedom were adjusted using the Greenhouse-Geisser procedure whenever appropriate.

Following an estimation approach in data analysis (see e.g., Cumming, 2012; Cumming & Calin-Jageman, 2017), we report effect sizes and appropriately sized confidence intervals (CI) throughout. As suggested by these authors, 95% CIs for Cohen's *d* for paired samples t-tests were corrected for bias and computed by using the mean SD rather than the SD of the difference as the denominator (Cohen's d_{unb}), which were computed using ESCI (Cumming & Calin-Jageman, 2017). 90% CIs for partial eta squared (η_p^2) were calculated using scripts by M.J. Smithson (http://www.michaelsmithson.online/stats/CIstuff/CI.html).

3. Results

3.1. Behavioural results

3.1.1. Quality of contact

Participants reported higher quality of contact with own-race ($M = 3.300$, 95% CI [2.93, 3.68]) than with other-race people ($M = 1.900$, 95% CI [1.45, 2.35]), $t(19) = 3.99$, $p < .001$, $M_{diff} = 1.400$, 95% CI [0.67, 2.14], Cohen's $d_{unb} = 1.512$, 95% CI [0.64, 2.48].

3.1.2. Sorting errors

Participants made fewer errors when sorting own- compared to other-race identities, $t(19) = 4.62$, $p < .001$, $M_{diff} = 2.900$, 95% CI [1.59, 4.21], Cohen's $d_{unb} = 1.165$, 95% CI [0.56, 1.85] (see Figure 3a).

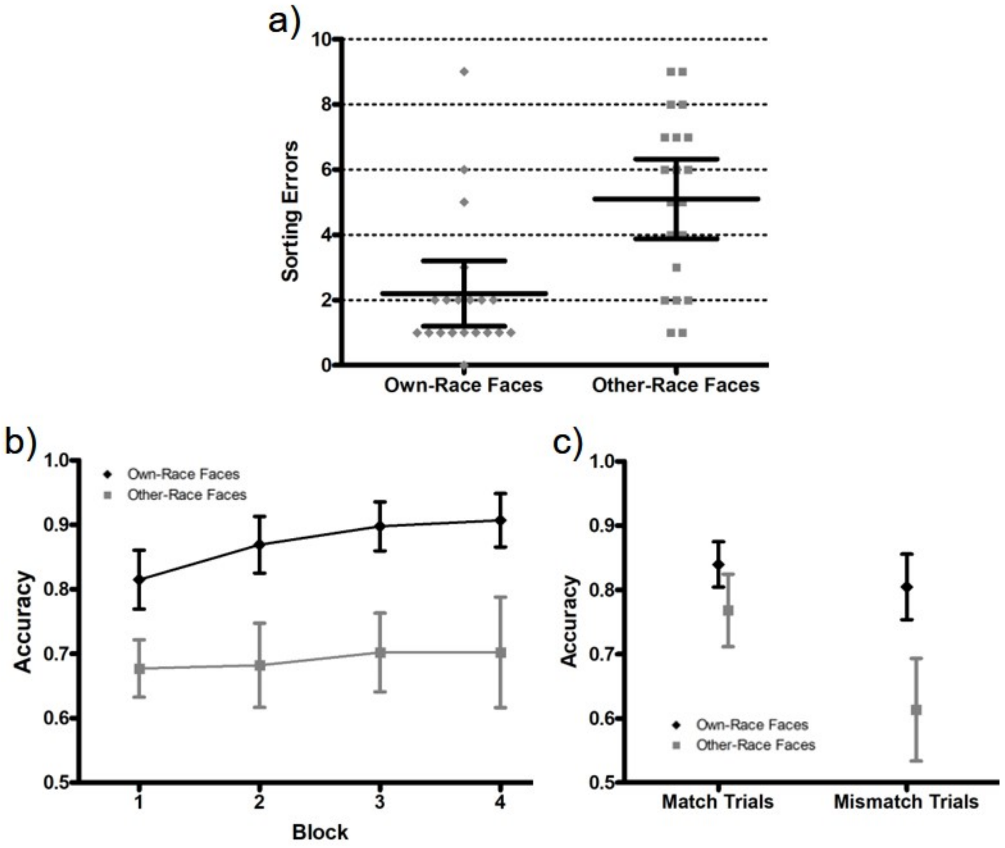


Figure 3. Behavioural results. (a) Sorting and (b, c) Matching task results. Error bars denote 95% confidence intervals (CIs), grey squares in (a) depict individual subjects' data.

3.1.3. Matching task

A repeated measures ANOVA with the within-subjects factors ethnicity (own-race, other-race), trial type (match, mismatch) and block (1, 2, 3, 4) on matching task performance yielded significant main effects of ethnicity, trial type and block, reflecting better performance for own- relative to other-race identities, $F(1,19) = 41.60$, $p < .001$, $\eta_p^2 = .686$, 90% CI [0.43, 0.79], for match compared to mismatch trials, $F(1,19) = 15.77$, $p = .001$, $\eta_p^2 = .454$, 90% CI [0.16, 0.62], and an increase in performance across blocks, $F(3,57) = 8.21$, $p = .001$, $\eta_p^2 = .302$, 90% CI [0.12, 0.42]. In addition, the ethnicity x block interaction approached significance, $F(3,57) = 2.39$, $p = .078$, $\eta_p^2 = .112$, 90% CI [0.00, 0.21] (see Figure 3b). We further calculated pairwise comparisons to test our a priori prediction of larger performance increases across blocks for own- than other-race faces. For own-race identities, performance increased from block 1 to block 2, $t(19) = 3.79$, $p = .001$, $M_{diff} = 0.054$, 95% CI [0.02, 0.08], Cohen's $d_{unb} = 0.483$, 95% CI [0.19, 0.80], from block 2 to block 3, $t(19) = 2.25$, $p = .036$, $M_{diff} = 0.029$, 95% CI [0.01, 0.06], Cohen's $d_{unb} = 0.301$, 95% CI [0.02, 0.60], but not from block 3 to block 4, $t(19) = 0.84$, $p = .413$, $M_{diff} = 0.010$, 95% CI [-0.01, 0.03], Cohen's $d_{unb} =$ 0.106, 95% CI [-0.15, 0.37]. For other-race identities, no improvement in performance was detected across blocks (block 1 to block 2, $t(19) = 0.27$, $p = .794$, $M_{diff} = 0.005$, 95% CI [-0.04, 0.05], Cohen's $d_{unb} = 0.039$, 95% CI [-0.26, 0.34]; block 2 to block 3, $t(19) = 1.11$, $p = .282$, $M_{diff} = 0.020$, 95% CI [-0.02, 0.06], Cohen's $d_{unb} = 0.135$, 95% CI [-0.11, 0.39]; block 3 to block 4, $t(19) = 0.01$, $p = .999$, $M_{diff} = 0.001$, 95% CI [-0.04, 0.04], Cohen's $d_{unb} = 0.001$, 95% CI [-0.22, 0.22]).

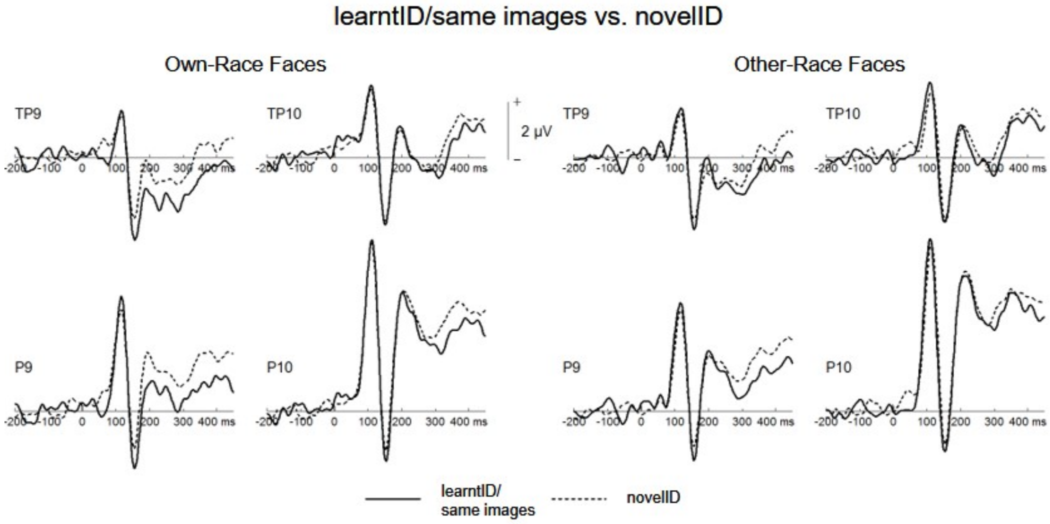
Furthermore, two significant two-way interactions were observed. First, there was a significant ethnicity x trial type interaction, $F(1,19) = 9.95$, $p = .005$, $\eta_p^2 = .344$, 90% CI [0.07, 0.54]. Follow-up tests revealed significant effects of ethnicity for both match, $t(19) = 4.35$, $p < .001$, $M_{diff} = 0.121$, 95% CI [0.06, 0.18], Cohen's $d_{unb} = 1.128$ [0.52, 1.81], and mismatch trials, $t(19) = 6.18$, $p < .001$, $M_{diff} = 0.241$, 95% CI [0.16, 0.32], Cohen's $d_{unb} =$ 1.506, 95% CI [0.86, 2.26], with larger ethnicity effects for the latter (see Figure 3c). Second, a significant block x trial type interaction was observed, $F(3,57) = 8.83$, $p < .001$, $\eta_p^2 = .317$, 90% CI [0.13, 0.43]. Follow-up tests revealed higher accuracy for match compared to mismatch trials, which was significant from blocks 1 to 3 (1: $t(19) = 6.05$, $p < .001$, $M_{diff} =$ 0.158, 95% CI [0.10, 0.21], Cohen's $d_{unb} = 1.532$ [0.86, 2.31], 2: $t(19) = 3.15$, $p = .005$, $M_{diff} =$ 0.089, 95% CI [0.03, 0.15], Cohen's $d_{unb} = 0.715$, 95% CI [0.22, 1.26], 3: $t(19) = 7.64$, $p =$ .012, $M_{diff} = 0.077$, 95% CI [0.02, 0.14], Cohen's $d_{unb} = 0.679$, 95% CI [0.15, 1.25], but only approached significance in block 4, $t(19) = 2.09$, $p = .051$, $M_{diff} = 0.055$, 95% CI [-0.01, 0.11], Cohen's $d_{unb} = 0.390$, 95% CI [-0.01, 0.81], reflecting an increase in accuracy on mismatch trials while accuracy on match trials remained relatively stable.

3.1.4. Butterfly detection

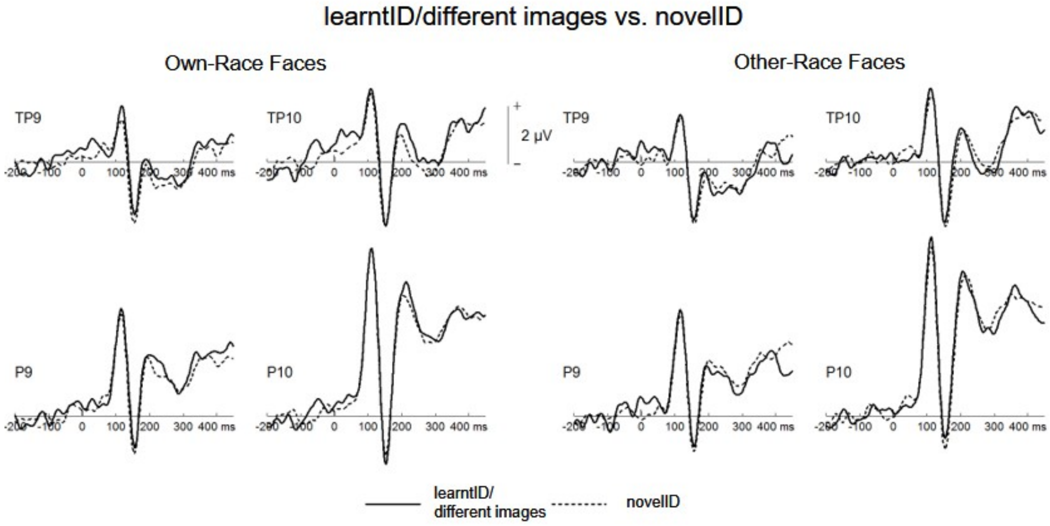
Accuracy in the butterfly detection task approached ceiling and was highly similar for own- ($M = 0.991$, 95% CI [0.98, 1.00]) and other-race blocks ($M = 0.988$, 95% CI [0.97, 1.00]), $t(19) = 0.30$, $p = .772$, $M_{diff} = 0.003$, 95% CI [-0.02, 0.02], Cohen's $d_{unb} = 0.095$, 95% CI [-0.56, 0.76].

3.2. ERP results

For the sake of conciseness, only significant main effects of, and interactions involving, the experimental factors ethnicity and ID type are reported in the main text. All other significant results, and results for the main effects of the experimental factors that did not reach significance, are reported in Table 1. ERP results are depicted in Figures 4 and 5.



learntID/same images vs. novelID



learntID/different images vs. novelID

Figure 4. Grand average ERPs. Upper half shows grand average ERPs for learnt ID/same images and novel ID, lower half shows grand average ERPs for learnt ID/different images and novel ID for own- and other-race faces, at electrodes P9/10 and TP9/10

Table 1. Additional ERP results not reported in the main text.

ERP	Effect	Follow-up	*df*	*F*	*p*	η^2_p	90% CI	Mean (μV)	90% CI
N170	Site		1,19	14.08	.001	.426	0.13, 0.60	TP: -0.78	-1.61, 0.06
								P: 0.66	-0.79, 2.11
	Ethnicity		1,19	0.15	.703	.008	0.00, 0.15	Own-race: -0.10	-1.23, 1.03
								Other-race: -0.02	-1.16, 1.12
	Ethnicity x Site x ID type		2,38	2.69	.080	.124	0.00, 0.27		
		Own-race / TP9/10	2,38	2.61	.087	.121	0.00, 0.26	Learnt ID/same: -1.08	-2.02, -0.14
								Learnt ID/diff.: -0.50	-1.42, 0.41
								Novel ID: -0.80	-1.70, 0.11
		Own-race / P9/10	2,38	2.91	.067	.133	0.00, 0.28	Learnt ID/same: 0.32	-1.12, 1.76
								Learnt ID/diff.: 0.78	-0.63, 2.20
								Novel ID:0.68	-0.84, 2.19
		Other-race / TP9/10	2,38	0.48	.577	.025	0.00, 0.11	Learnt ID/same: -0.87	-1.87, 0.13
								Learnt ID/diff.: -0.64	-1.52, 0.24
								Novel ID: -0.68	-1.66, 0.10
		Other-race / P9/10	2,38	2.34	.110	.110	0.00, 0.25	Learnt ID/same: 0.47	-1.05, 1.98
								Learnt ID/diff.: 0.98	-0.57, 2.52
								Novel ID: 0.74	0.76, 2.25
P2	Hemisphere		1,19	8.28	.010	.303	0.05, 0.51	Left: 0.50	-0.60, 1.59
								Right: 2.42	0.75, 4.09
	Site		1,19	63.76	<.001	.770	0.57, 0.84	TP: 0.12	-0.87, 1.11
								P: 2.80	1.29, 4.31
	Ethnicity		1,19	0.27	.609	.014	0.00, 0.18	Own-race: 1.41	0.21, 2.60
								Other-race: 1.51	0.22, 2.80
	ID type		2,38	1.76	.187	.085	0.00, 0.21	Learnt ID/same: 1.30	0.03, 2.56
								Learnt ID/diff.: 1.64	0.39, 2.90
								Novel ID: 1.44	0.22, 2.66
	Ethnicity x Site		1,19	3.52	.076	.156	0.00, 0.38		
		TP9/10	1,19	0.01	.942	.001	0.00, 0.01	Own-race: 0.13	-0.85, 1.10
								Other-race: 0.11	-0.94, 1.16
		P9/10	1,19	1.13	.301	.056	0.00, 0.26	Own-race: 2.68	1.23, 4.15
								Other-race: 2.92	1.33, 4.51
early N250	Hemisphere		1,19	6.33	.021	.250	0.02, 0.46	Left: 0.04	-1.04, 1.11
								Right: 1.58	0.59, 2.57
	Site		1,19	81.39	<.001	.811	0.64, 0.87	TP: -0.54	-1.33, 0.25
								P: 2.15	1.21, 3.10
	Ethnicity		1,19	1.24	.280	.061	0.00, 0.27	Own-race: 0.71	-0.15, 1.56
								Other-race: 0.91	0.10, 1.72
	ID type		1,19	2.35	.109	.110	0.00, 0.25	Learnt ID/same: 0.57	-0.29, 1.42
								Learnt ID/diff.: 0.94	0.04, 1.84
								Novel ID: 0.92	0.15, 1.69
late N250	Hemisphere		1,19	8.54	.009	.310	0.05, 0.51	Left: 0.67	-0.35, 1.70
								Right: 2.14	1.00. 3.28

Site		1,19	67.01	<.001	.779	0.58, 0.85	TP: 0.34	-0.55, 1.22
							P: 2.48	1.40, 3.55
Ethnicity		1,19	1.79	.197	.086	0.00, 0.30	Own-race: 1.28	0.36, 2.20
							Other-race: 1.54	0.52, 2.55
Ethnicity x Site		1,19	4.01	.060	.174	0.00, 0.40		
	TP9/10	1,19	0.22	.642	.012	0.00, 0.17	Own-race: 0.28	-0.61, 1.17
							Other-race: 0.39	-0.56, 1.34
	P9/10	1,19	4.91	.039	.205	0.01, 0.42	Own-race: 2.27	1.26, 3.29
							Other-race: 2.68	1.52, 3.85

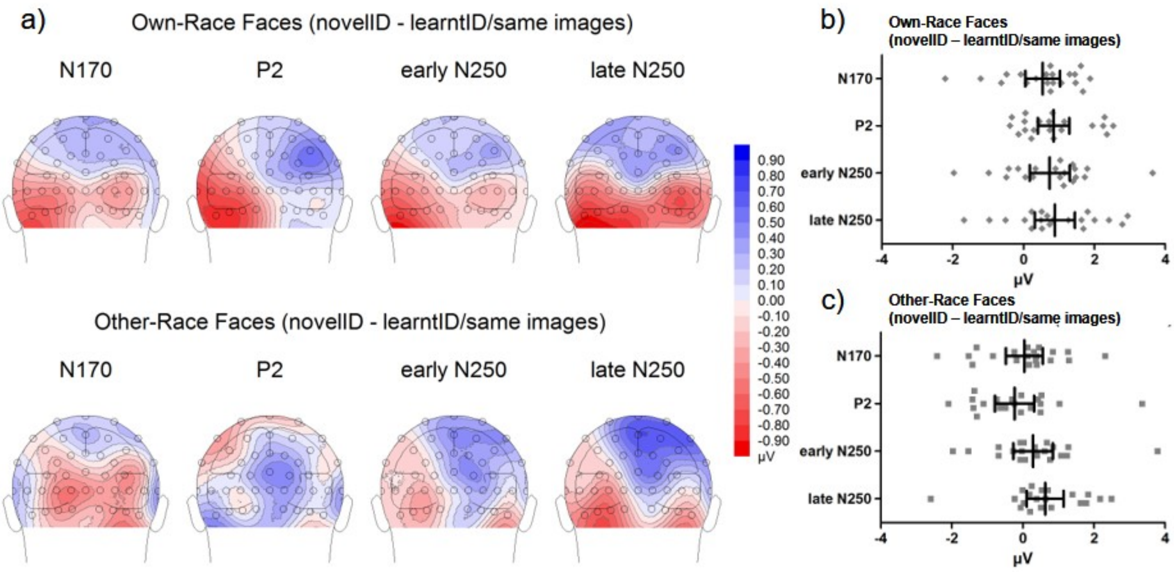


Figure 5. Voltage maps and ERP learning effects. a) Voltage maps showing the scalp distribution of learning effects (novel ID – learnt ID/same images) for own- and other-race faces in N170, P2, early and late N250. b and c) Mean learning effects for own- and other-race faces. Error bars denote 95% confidence intervals, grey squares indicate individual subjects' data.

3.2.1. N170

A repeated measures ANOVA with the within-subjects factors hemisphere (left, right), site (TP, P), ethnicity (own-race, other-race) and ID type (learnt ID/same images, learnt ID/different images, novel ID) on N170 mean amplitude revealed a significant main effect of ID type, $F(2,38) = 4.13$, $p = .036$, $\eta_p^2 = .179$, 90% CI [0.01, 0.33], which was further qualified by a significant ethnicity x hemisphere x ID type interaction, $F(2,38) = 5.51$, $p = .008$, $\eta_p^2 = .225$, 90% CI [0.04, 0.37]. Follow-up analyses yielded a significant effect of ID type for own-race identities in the left hemisphere, $F(2,38) = 8.48$, $p = .001$, $\eta_p^2 = .309$, 90% CI [0.10, 0.45], indicating significantly more negative amplitudes for learnt ID/same images relative to novel ID, $F(1,19) = 5.39$, $p = .032$, $\eta_p^2 = .221$, 90% CI [0.01, 0.44]. A trend towards more negative amplitudes for learnt ID/different images as compared to novel ID was observed, $F(1,19) = 3.99$, $p = .060$, $\eta_p^2 = .174$, 90% CI [0.00, 0.40]. The effect of ID type for own-race identities at right-hemispheric electrodes and for other-race identities in both hemispheres failed to reach significance, all *F*s $\leq$ 2.24, *p*s $\geq$ .121, η_p^2s $\leq$ .105. Additional follow-up analyses of the above three-way interaction were conducted to test for potential differences between own- and other-race faces. Post-hoc analyses did not yield any significant effects of ethnicity, all *F*s(1,19) $\leq$ 1.76, *p*s $\geq$ .201, η_p^2s $\leq$ .085.

3.2.2. P2

A corresponding ANOVA on P2 mean amplitude showed a significant ethnicity x ID type interaction, *F*(2,38) = 4.62, *p* = .016, η_p^2 = .196, 90% CI [0.02, 0.34], which further interacted with hemisphere, *F*(2,38) = 5.41, *p* = .009, η_p^2 = .222, 90% CI [0.04, 0.37]. Follow-up tests showed a significant effect of ID type for own-race identities at left-hemispheric electrodes, *F*(2,38) = 11.11, *p* = .001, η_p^2 = .369, 90% CI [0.15, 0.51], indicative of significantly more positive amplitudes for novel ID compared to learnt ID/same images, *F*(1,19) = 15.95, *p* = .001, η_p^2 = .456, 90% CI [0.16, 0.62], but comparable amplitudes for learnt ID/different images and novel ID, *F*(1,19) = 1.79, *p* = .196, η_p^2 = .086, 90% CI [0.00, 0.30]. A comparable effect of ID type was not observed for own-race identities at right-hemispheric electrodes, and was absent for other-race identities over both hemispheres, all *F*s(1,19) $\leq$ 1.28, *p*s $\geq$ .285, η_p^2s $\leq$ .063. Post-hoc analyses of the above three-way interaction to test for potential effects of ethnicity revealed a significant effect of ethnicity for the learnt ID/same image condition in the left hemisphere, *F*(1,19) = 9.79, *p* = .006, η_p^2 = .340, 90% CI [0.07, 0.54], indicating more positive amplitudes for other- compared to own-race identities. No further significant effects of ethnicity were observed, all *F*s(1,19) $\leq$ 3.19, *p*s $\geq$ .090, η_p^2s $\leq$ .144.

3.2.3. Early N250

Analysis of the early N250 time window yielded a significant ethnicity x site interaction, $F(1,19) = 4.88$, $p = .040$, $\eta_p^2 = .204$, 90% CI [0.01, 0.42], which further interacted with hemisphere, $F(1,19) = 4.91$, $p = .039$, $\eta_p^2 = .205$, 90% CI [0.01, 0.42]. Post-hoc analyses indicated more negative amplitudes for own- relative to other-race identities at P10, $F(1,19) = 5.45$, $p = .031$, $\eta_p^2 = .223$, 90% CI [0.01, 0.44]. No comparable differences were observed at P9 and TP9/10, all $F\text{s}(1,19) \leq 1.02$, $p\text{s} \geq .324$, $\eta_p^2\text{s} \leq .051$.

3.2.4. Late N250

In the late N250 time window, a significant ethnicity x hemisphere interaction was obtained, $F(1,19) = 5.00$, $p = .038$, $\eta_p^2 = .208$, 90% CI [0.01, 0.43], indicating a trend towards more negative amplitudes for own- relative to other-race identities in the right hemisphere, $F(1,19) = 4.28$, $p = .053$, $\eta_p^2 = .184$, 90% CI [0.00, 0.40], but comparable amplitudes in the left hemisphere, $F(1,19) = 0.01$, $p = .993$, $\eta_p^2 \leq .001$, 90% CI [0.00, 0.01].

In addition, a significant main effect of ID type was observed, $F(2,38) = 7.44$, $p = .002$, $\eta_p^2 = .281$, 90% CI [0.08, 0.43]. Post-hoc contrasts showed significantly more negative amplitudes for learnt ID/same images relative to novel ID, $F(1,19) = 16.88$, $p = .001$, $\eta_p^2 = .470$, 90% CI [0.17, 0.63], but no significant difference between learnt ID/different images and novel ID, $F(1,19) = 0.01$, $p = .909$, $\eta_p^2 = .001$, 90% CI [0.00, 0.02]. The ethnicity x ID type interaction did not reach significance, $F(2,38) = 0.49$, $p = .616$, $\eta_p^2 = .025$, 90% CI [0.00, 0.11].

4. Discussion

The aim of the present study was to investigate the neural correlates of own- and other-race face identity learning. Caucasian participants first sorted ambient images of two own- and other-race faces into separate clusters for each identity and were further familiarised with these identities during a matching task. In line with our hypotheses, we observed better sorting of own- compared to other-race faces. Moreover, as predicted, participants were more accurate at matching own- relative to other-race identities, and an improvement in matching accuracy across blocks was evident for own-race identities only. In addition, we compared ERPs for previously seen and unseen images of the learnt identities with those for images of novel identities. Starting in the N170 time range, more negative amplitudes were observed for learnt ID/same images compared to novel ID images. However, this ERP learning effect was only obtained for own-race identities. Within the late N250 time range, increased amplitudes for learnt ID/same images relative to novel ID images were observed, and this effect was not further modulated by ethnicity. These findings are discussed in more detail below.

In line with previous work, we observed better sorting and matching for own- than for other-race faces (e.g., Laurence et al., 2016; Yan et al., 2016), suggesting that recognising an unfamiliar face from different images is even more challenging for faces from a different ethnic group. The present results extend previous findings to the variant of the sorting task in which participants are informed about the correct number of identities in the set. Given that participants are instructed to only make two piles, it appears difficult to interpret sorting errors in this version of the task to reflect poor generalisation across different images of the same identities. Instead, sorting errors should be taken to reflect intrusion errors, i.e., mixing up images of two different identities, and such errors seem to be more likely for other- relative to own-race faces. In addition, during matching, participants further became increasingly familiar with own-race identities, which was evident from a gradual gain in accuracy across blocks 1 to 3, while no improvement was detected for other-race identities.

These findings suggest an own-race advantage in identity learning from multiple, highly variable images (see also Hayward et al., 2017; Zhou et al., 2018).

Regarding our ERP results, we observed clearly more pronounced learning effects for own- compared to other-race identities in two relatively early time windows. Within the N170 time range, more negative amplitudes for learnt ID/same images relative to the novel ID condition were obtained for own-race but not for other-race identities. Similarly, P2 was more positive in the novel ID condition compared to learnt ID/same images of own-race identities, while a comparable effect was absent for other-race identities. While N170 has often been reported to be insensitive to familiarity (e.g., Bentin & Deouell, 2000; Schweinberger & Burton, 2003; Zimmermann & Eimer, 2013; 2014), others have observed familiarity effects within the N170 time range, e.g. for personally familiar faces (Caharel, Jacques, d'Arripe, Ramon, & Rossion, 2011; Caharel et al., 2002; but see Keyes, Brady, Reilly, & Foxe, 2010; Wiese, Tüttenberg, et al., 2019). However, previous studies investigating face learning usually did not find familiarity effects in N170 (Andrews et al., 2017; Kaufmann et al., 2009; but see Scott, Tanaka, Sheinberg, & Curran, 2006 for increased N170 following training with multiple exemplars of non-face objects). Importantly, N170 familiarity effects observed in previous studies typically reflect the repeated presentation of a specific image (Caharel, Courtay, Bernard, Lalonde, & Rebai, 2005), or generalise across relatively small changes in viewpoint (Caharel et al., 2011). Similarly, ERP learning effects in the present study likely represent image repetition to some extent. Our results are therefore in line with the suggestion that familiarity or learning effects prior to N250 do not reflect image-independent face recognition.

At the same time, we suggest that the modulations of components prior to N250 in the present study to some extent reflect the facilitated processing of recently learnt own-race identities. On the one hand, the finding of more negative N170 and less positive P2 amplitudes for learnt ID/same images compared to novel ID images indeed more closely resembles image learning rather than image-independent face learning. Our ERP effects were observed after repeated presentation of a specific image set during learning (each image was presented 8 times during matching alone) and learning effects did not generalise to novel instances. Moreover, as noted above, it is known that N170 is affected by image repetition (Caharel et al., 2005). On the other hand, however, image repetition alone cannot fully account for the present N170/P2 learning effects. Specifically, if these ERP effects only reflected image repetition, a similar effect should have also been obtained for other-race faces. Yet, N170 learning effects were clearly absent for other-race identities. In addition, results from the matching task indicate that participants were indeed able to recognise individual identity for own-race faces presented during learning, at least within the set presented during matching[1].

However, it is not entirely clear why none of the ERP learning effects, including those observed in the late N250 time range, generalised to a new set of images. This result is clearly at variance with previous studies (Andrews et al., 2017). The discrepancy to previous work might be related to the extensive training with a specific subset of images in the present study. More specifically, the repeated presentation of images from the sorting task during matching may have resulted in the integration of these images into novel representations. It appears plausible that direct links between the specific images of a given identity were formed during matching, while more abstract representations, e.g., containing information about possible within-person variability, were not established. In other words, our procedure might have

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[1] Some additional support comes from correlational analyses. For own-race identities, higher overall matching accuracy was associated with more negative amplitudes for the learnt ID / same image condition at electrodes P9/TP9 in the N170, $r(18) = -.430$ [-.73, .02], $p_{\text{one-tailed}} = .029$, but not in the P2, $r(18) = -.215$ [-.60, .25], $p_{\text{one-tailed}} = .182$. No corresponding correlations were observed for other-race identities, neither in the N170, $r(18) = -.026$ [-.46, .42], $p_{\text{one-tailed}} = .457$, nor in the P2, $r(18) = -.303$ [-.66, .16], $p_{\text{one-tailed}} = .097$.

strongly tied newly-learnt representations to the particular image set, which made the later integration of novel pictures more difficult. Therefore, the lack of image-independent ERP learning effects in the present study seems to suggest that the perceptual representations formed for the recently learnt identities only include those specific images that were repeatedly presented during sorting and matching. However, as they allow recognition of identity over a range of different images, such representations may reflect a first step towards complete image-independent face recognition. Crucially, such representations also appear to be much harder to establish for other-race faces.

Of note, a further important difference between the present study and Andrews et al. (2017) lies in the number of to-be-learnt identities. In Andrews et al. (2017), participants were required to learn two identities, whereas in the present study, participants had to learn two own- as well as two other-race identities. Learning twice as many identities may have increased memory load in the present study, and future research may investigate whether increasing memory load indeed impairs identity learning. We further note that participants learned own- and other-race identities in separate blocks. Given that block designs are more susceptible to strategic and motivational effects than intermixed designs, one might argue that this experimental approach may have hampered learning effects in the present study, particularly for other-race identities. However, the use of an intermixed design in which all identities would be presented in the same block would have arguably further increased memory load during learning. We therefore believe that our decision against this option was adequate.

It could also be argued that the absence of image-independent learning effects may have resulted from characteristics of the task at test, given that the butterfly detection task did not explicitly ask for the processing of facial identity. However, as noted above, Andrews et al. (2017) successfully demonstrated learning effects within the N250 time range in a butterfly detection task. In addition, a number of studies suggest that face recognition, as reflected in the N250/N250r, is largely automatic (e.g., Neumann & Schweinberger, 2008; Wiese, Ingram, et al., 2019; but see Zimmermann & Eimer, 2014). Accordingly, if a robust representation had been established during learning, familiarity effects should have been observed even though the task did not explicitly require the processing of facial identity.

Interestingly, although learning effects within N170 and P2 were limited to own-race identities, we did not find main effects of ethnicity within these time windows (see Table 1). As detailed in the introduction, N170 is often found to be more negative for other- relative to own-race faces (e.g., Cassidy et al., 2014; Wiese et al., 2014), although others did not find respective effects (e.g., Herzmann et al., 2011; Wiese et al., 2009). Previous attempts to reconcile such findings have focused on differential task demands, with ethnicity effects unlikely to emerge when identity is not task-relevant (Wiese, 2013). The present results further support this suggestion as in the present study N170 ethnicity effects were absent in a task that required participants to respond to infrequently occurring butterflies. Ethnicity effects in the present study first emerged in the N250 time range. At variance with previous work which typically reports more negative N250 amplitudes for other- relative to own-race faces (Herzmann et al., 2011; Stahl et al., 2010, Wiese & Schweinberger, 2018), we observed relatively more negative N250 amplitudes for the own-race face category. While we cannot say with certainty what may account for this finding, it could be related to the fact that we used multiple images of a very limited number of identities. Given the known sensitivity of the N250 for learning (Kaufmann et al., 2009; Tanaka et al., 2006), it appears possible that this finding reflects face learning during the test phase, even in the case of novel identities, which might have been easier for own-race identities.

In the present study, we analysed two consecutive N250 time windows (for similar approaches, see Andrews et al., 2017; Kaufmann et al., 2009) that capture typical N250 time ranges (220 – 300 ms) as well as a later segment (300 – 400 ms). Learning effects in the present experiment were only observed in the later N250 time range, which may suggest that newly established representations of recently learnt faces may take somewhat longer to be accessed relative to longer known face identities (see Andrews et al., 2017). At the same time, inspection of Figure 4 might suggest that the learning effect which first emerges in the N170 carries over to later time segments. This may indicate overlapping cognitive processes that are captured by more than one of the respective ERP components. Whereas N170 and P2 components do indeed reveal highly similar patterns, a clearly different pattern was observed in both N250 time windows (see above). This suggests that while the early N170 learning effect may carry over to the ensuing P2, subsequent components reflect, at least in part, different underlying cognitive processes.

As discussed in the introduction, the ORB is usually taken to result from either differences in perceptual expertise (e.g., Michel, Rossion, Han, Chung, & Caldara, 2006; Rhodes et al., 2009; Valentine & Endo, 1992; Valentine, Lewis, & Hills, 2016) or socio-cognitive factors, such as early categorisation of faces into social in- and out-groups (e.g., Hugenberg, Young, Bernstein, & Sacco, 2010; Levin, 1996, 2000; Sporer, 2001). Difficulties in learning other-race facial identities have typically been interpreted to reflect reduced perceptual expertise with the other-race face category (e.g., Proietti et al., 2018; Zhou et al., 2018), as identity learning tasks strongly emphasise processing of individuating information for both own- and other-race faces. The results of the present study confirm previous findings from behavioural studies, which observed advantages for own-race face identity learning. Moreover, our ERP results suggest that such learning advantages manifest at an early perceptual level, which is in line with expertise accounts.

A potential limitation of the present study is that only Caucasian participants were tested. It is therefore in principle possible that the East Asian face identities were simply more difficult to learn, independent of their ethnic in- or out-group status. If this were the case, East Asian participants should show similar difficulties of learning the specific East Asian face identities used in the present study. However, in a recently conducted behavioural study (Tüttenberg & Wiese, in press), we tested both Caucasian and East Asian participants living in the UK with the same stimulus set. We observed clearly different learning patterns in the two participant groups. While Caucasian participants showed a clear advantage for own-race facial identities, East Asian participants learned both own- and other-race identities similarly well. This was interpreted to reflect East Asian participants' increased experience with other-race Caucasian faces. However, we acknowledge that this interpretation would be substantially strengthened had we been able to test a group of East Asian participants living in an East Asian country. Therefore, while an interpretation of our results in terms of differential expertise appears parsimonious, we cannot fully rule out the possibility that some differences with respect to difficulty exist between the sets.

Moreover, the present study used only male faces. Interestingly, previous work on face identity learning almost exclusively used female identities (e.g., Andrews et al., 2015, 2017; Matthews & Mondloch, 2018; Proietti et al., 2018; Zhou et al., 2018) and only very few studies used both female and male identities (Cavazos et al., 2018; Hayward et al., 2017). However, these latter two studies used more identities with fewer images per identity compared to the present study. Accordingly, the observed learning effects for male identities in the present experiment may be considered a strength as they contribute to establishing learning effects for different categories of faces and thus face learning as a general phenomenon. Moreover, and similar to previous studies that used so-called ambient images (e.g., Andrews et al., 2015, 2017; Laurence et al., 2016; Short & Wagler, 2017; Yan et al., 2016; Zhou & Mondloch, 2016), we opted for grey scale images rather than presenting them in colour. Previous work has shown that unfamiliar face recognition is unaffected by colour versus grey scale format (Bruce et al., 1999). In addition, it could be argued that learning facial identities from colour images may be even *more* difficult than learning faces from grey scale images as colour adds further variability to the images participants have to integrate into the new identity representations. We acknowledge, however, that this is an empirical question that may be explored in future experiments.

To the best of our knowledge, this is the first study to investigate the neural correlates underlying own- and other-race face identity learning. We observed a clear advantage for own-race face identity learning, which presumably reflects reduced perceptual expertise with other-race faces. Moreover, we found face learning effects in two ERP components, N170 and P2. These effects were limited to own-race identities, and suggest an advantage for processing own-race identities at an early perceptual level. Later neural correlates of identity learning in the late N250 time range were not statistically different for own- and other-race identities. Overall, given the clear emphasis in the present study to represent all face identities at an individual level, our finding of clear learning advantages for own-race faces is well in line with perceptual expertise accounts of the own-race bias.

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