

Facial misidentifications arise from the erroneous activation of visual face memory



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ABSTRACT

Misidentifications are a common phenomenon in unfamiliar face processing, but little is known about the underlying cognitive and neural mechanisms. We used the face identity-sensitive N250r component of the event-related brain potential as a measure of identity-sensitive face matching process in visual working memory. Two face images were presented in rapid succession, and participants had to judge whether they showed the same or two different individuals. Identity match and mismatch trials were presented in random sequence. On similar mismatch trials, perceptually similar faces of two different individuals were shown, while two physically distinct faces were presented on dissimilar mismatch trials. Misidentification errors occurred on 40% of all similar mismatch trials. N250r components were elicited not only in response to an identity match, but also on trials with misidentification errors. This misidentification N250r was smaller and emerged later than the N250r to correctly detected identity repetitions. Importantly, N250r components were entirely eliminated on similar mismatch trials where participants correctly reported two different facial identities. Results show that misidentification errors are not primarily a post-perceptual decision-related phenomenon, but are generated during early visual stages of identity-related face processing. Misidentification errors occur when stored representations of a particular individual face in visual working memory are incorrectly activated by a perceptual match with a different face.

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1. Introduction

The recognition of facial identity is highly relevant in everyday life, where many different faces are encountered, and have to be identified quickly and reliably. To perform this difficult task, the human cognitive system has developed highly specialized face processing structures and mechanisms (Diamond and Carey, 1986; Gauthier et al., 2000, 1999; Schwaninger et al., 2003; Tanaka and Curran, 2001). Humans are "face experts", and face recognition is believed to be an easy and effortless task. While this may be true for familiar faces, the recognition of unfamiliar faces is surprisingly poor and error-prone (e.g., Bruce, 1982; Burton et al., 1999; Ellis et al., 1979; Patterson and Baddeley, 1977; Terry, 1993, 1994), even in matching tasks with little demands on face memory (e.g., Bindemann et al., 2010; Bruce et al., 1999; Henderson et al., 2001;

Megreya et al., 2011; Megreya and Burton, 2006, 2007).

These performance impairments for unfamiliar faces compared to familiar faces suggest qualitative differences in their perceptual processing or memory storage. The fact that the repeated presentation of familiar faces facilitates familiarity judgments, while no such repetition priming effects are observed for unfamiliar faces (Ellis et al., 1990, 1987) points towards differences in the way that these two types of faces are represented in memory. In addition, familiar and unfamiliar face processing may already differ during earlier perceptual encoding stages. Visual representations of familiar faces are assumed to be based on robust and flexible structural codes, while unfamiliar face representations may primarily involve superficial pictorial codes (e.g., Hancock et al., 2000; Johnston and Edmonds, 2009). While pictorial codes contain only image-specific information about a face, structural codes contain those view-invariant visual representations that are crucial for the detection of face identity (e.g., Bruce and Young, 1986). Such differences between image-dependent and image-invariant representational codes may explain why familiar face recognition remains effective under conditions such as low image quality, changes in lighting, different viewpoints, different facial

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expressions, or changed paraphernalia like beards, eye glasses, or hats, whereas unfamiliar face recognition is strongly affected by such interfering changes (e.g., Bruce, 1982; Bruce et al., 1999, 2001; Burton et al., 1999; Diamond and Carey, 1977; Patterson and Baddeley, 1977; Terry, 1994). If unfamiliar face recognition is mainly based on image-dependent perceptual representations, it is not surprising that misidentifications (or “false positives” in terms of signal detection theory) are a common phenomenon in situations where unfamiliar faces have to be identified. These false positives can have serious consequences in legal and security issues like eyewitness testimonies and passport checks, such as the false identification of suspects, the sentencing of innocent defendants, or unauthorized persons passing border controls (Bindemann and Sandford, 2011; Bruce et al., 1999; Burton et al., 1999; Henderson et al., 2001; Kemp et al., 1997).

Because research has mainly focused on the mechanisms of successful face recognition and their neural correlates, little is known about the mechanisms that underlie the misidentification of unfamiliar faces. In the present study, we employed event-related brain potential (ERP) measures of face recognition to identify the cognitive and neural processes that determine whether a particular face is misidentified or not. Most previous ERP studies on face processing have focused on the face-sensitive N170 component that is triggered at lateral posterior electrodes between 140 ms and 190 ms after stimulus onset. Since the N170 is typically not affected by familiarity (Eimer, 2000a; Gosling and Eimer, 2011), facial identity repetitions (Schweinberger et al., 2002; Zimmermann and Eimer, 2014), or emotional expression (Eimer and Holmes, 2002; Eimer et al., 2003), it has been linked to early structural encoding of faces that occurs independently from the analysis of expression and precedes the processing of facial identity (Eimer, 2000b). The earliest ERP marker of identity-related face processing is the N250r component. The N250r is an increased negativity at lateral posterior electrodes elicited in response to the sequential presentation of faces with matching identities, as compared to the sequential presentation of faces with different identities. It usually peaks between 230–280 ms, is often found to be larger over the right hemisphere, and is accompanied by a fronto-central positivity (Schweinberger et al., 2004, 2002). This component is considered to reflect the transient activation of short-term visual memory representations of a face that has recently been encountered by the subsequent presentation of a face of the same individual (Schweinberger and Burton, 2003; Schweinberger et al., 2002). While the N250r is observed in face repetition experiments, a similar N250 component has been found in response to famous as compared to unfamiliar faces (Gosling and Eimer, 2011), demonstrating that N250/N250r components reflect the activation of both long-term and short-term face memory representations. The observation that the N250r is typically larger for repetitions of familiar as compared to unfamiliar faces (Herzmann et al., 2004; Herzmann and Sommer, 2007; Pfützte et al., 2002) suggests that face-specific memory traces may be activated more strongly for long-term representations of familiar faces than for transient representations of previously unfamiliar faces (but see Zimmermann and Eimer, 2014, for an experiment finding no differences in N250r amplitudes between familiar and unfamiliar faces).

Inverse dipole localization techniques have suggested that the N250r component is generated in the fusiform gyrus (Schweinberger et al., 2002). A region within the fusiform gyrus (the fusiform face area, FFA) shows increased activation during the perception of faces compared to the perception of other objects (e.g., Kanwisher et al., 1997). Although it has been argued that the FFA might not be specialized for faces per se, but for individuation within any object class of high expertise (Gauthier et al., 2000, 1999), there is evidence that the FFA is genuinely face-sensitive

(Rhodes et al., 2004; see also McKone, Kanwisher, and Duchaine, 2007, for a review arguing that the FFA is specialized for faces and not for any object class of expertise). Individual faces are assumed to be represented in a holistic manner in the FFA (e.g., Schiltz and Rossion, 2006; Yovel and Kanwisher, 2005). According to the neurocognitive model proposed by Haxby et al. (2000), face perception and recognition are based on a distributed neural network. The core system for the visual analysis of faces includes the occipital face area (OFA) which is involved in the early perception of facial features, the FFA that processes invariant aspects of faces, most notably identity, and parts of the superior temporal sulcus (STS) that are involved in the processing of changeable aspects of faces (e.g., emotional expressions or lip movements). Consistent with their model, Hoffman and Haxby (2000) found a stronger activation in the FFA than in the STS during an identity matching task, and the reverse pattern (stronger activation in the STS) when participants performed a gaze matching task. Within this core visual face processing system, the FFA appears to be the primary area where visual information about individual facial identity is processed and maintained, in line with its proposed role as the neural generator of the N250r component (Schweinberger et al., 2002).

As the N250r reflects the activation of visual memory representations of individual faces that are triggered by an identity match with a currently seen face image, this component can provide important new insights into the mechanisms that are responsible for the misidentification of unfamiliar faces. Such misidentifications might arise whenever a particular face incorrectly activates a stored visual representation of a different individual face. In this case, N250r components should be observed for repetitions of two different faces on trials where observers incorrectly report a face identity match. Alternatively, misidentifications may be generated primarily during later post-perceptual stages of cognitive processing. If this is the case, an incorrect activation of visual face memory by a non-matching face would not be sufficient to produce an incorrect report of a face identity match, because this perceptual evidence can be overridden by subsequent decision-related mechanisms. Therefore N250r components will sometimes be observed also on trials where two different faces are presented successively, and no identity match is reported.

To test these alternative hypotheses, we conducted an experiment where observers performed a sequential face matching task. Two face images were presented in rapid succession (with stimulus onset asynchronies of 600–700 ms), and participants had to report on each trial whether these images showed the same or two different individuals. Previous studies that employed similar rapid sequential face matching procedures have found reliable N250r components for face identity repetitions (Zimmermann and Eimer, 2013, 2014). Because unfamiliar face matching is easy when physically identical images are repeated on identity match trials (Young et al., 1985), two different pictures of the same person were shown on these trials. To increase the probability of misidentifications (i.e., incorrect reports of a face identity match on trials where faces of two different individuals were shown), we manipulated the similarity of the face pairs on identity mismatch trials. On some of these trials, these two faces were obviously different (dissimilar mismatch trials). On other trials, faces of two different but similar individuals were shown (similar mismatch trials). Similar mismatch trials were twice as frequent as dissimilar mismatch trials and identity match trials, in order to be able to compute separate ERPs for trials with misidentification errors and trials where two similar faces were correctly reported as showing two different individuals.

On dissimilar mismatch trials, two randomly chosen faces from a set of dissimilar faces were presented in succession. The choice

of face pairs on similar mismatch trials was based on similarity ratings between individual faces obtained in a separate pilot study that was conducted prior to the EEG experiment with a different participant sample. The face pairs shown on these trials were those that were rated as being physically similar in this pre-study. In other words, similarity between face pairs was defined a priori, and was not based on explicit similarity judgments during the EEG study. This approach was chosen because we wanted to measure ERP correlates of misidentification errors under conditions where participants performed an explicit identity matching task. Hence, the present study focused on the electrophysiological correlates of erroneous subjective perception of identity and not on the subjective assessment of similarity.

In line with previous studies, clear N250r components were expected to be observed for identity match trials as compared to dissimilar mismatch trials. The critical question was whether N250r components would also be elicited on similar mismatch trials, and whether their presence versus absence on these trials would be determined by participants incorrectly reporting an identity match (misidentification error) or not. One possibility is that misidentifications of unfamiliar faces are the direct and inevitable result of an incorrect activation of a visual face memory representation by a non-matching face image, and occur only when such a representation is activated. In this case, N250r components should be elicited on similar mismatch trials with misidentification errors, but should be entirely absent on similar mismatch trials where participants correctly judged the two faces to show different individuals. Alternatively, misidentification errors might be primarily or exclusively generated at post-perceptual decision-related stages. If this is the case, N250r components should not differ systematically between similar mismatch trials with correct and incorrect responses. Instead of being sensitive to the subjectively perceived and reported presence versus absence of an identity match, the N250r might simply reflect the degree of physical similarity between face pairs (see Cooper et al., 2007; Schweinberger et al., 2002; for evidence that the N250r shows some image-dependence). Because this similarity is larger on trials where images of two identical individuals are shown than on similar mismatch trials, N250r components should be larger and/or emerge earlier on identity match trials. However, if perceptual similarity determines the N250r, this component should also be elicited on similar mismatch trials as compared to dissimilar mismatch trials, irrespective of participants' perceptual reports. To investigate whether the relationships between the activation of visual face memory (as reflected by the N250r component), the presence of misidentification errors, and the physical similarity of face pairs might be mediated by individual differences in face recognition abilities, we correlated the pattern of N250r components observed for individual participants with their performance in the Cambridge Face Memory Test (CFMT; Duchaine and Nakayama, 2006).

In summary, if the activation of visual face memory representations in a sequential identity matching task, as reflected by the N250r component, is directly responsible for correct or incorrect judgments of facial identity, the N250r should be primarily or exclusively sensitive to participants' perceptual reports, and be much less affected by the degree of physical similarity between a face pair. If correct or incorrect identity judgments in response to unfamiliar faces are primarily generated at later decision-related stages, the N250r should mainly reflect physical similarity rather than categorical perceptual identity judgments.

If an incorrect activation of visual face memory, as reflected by N250r components on similar mismatch trials, produces misidentification errors, this should have knock-on effects on subsequent post-perceptual processing stages that are involved in conscious face recognition. The explicit recognition of individual

faces is associated with a sustained broadly distributed positivity that emerges around 350–400 ms after stimulus onset. This late positive component (P600f; Gosling and Eimer, 2011) is similar in its time-course and centroparietal scalp distribution to the P3b component that is observed in many target detection tasks, and is assumed to reflect the allocation of attention towards target objects (e.g., Folstein and van Petten, 2011). In previous ERP studies of face recognition, P600f components were observed in response to correctly identified famous faces (Eimer et al., 2012; Gosling and Eimer, 2011), as well as to pre-experimentally unfamiliar faces that served as targets in target/nontarget discrimination tasks (Parkeby et al., 2015; Tanaka et al., 2006). To assess how misidentification errors affect post-perceptual stages where identity matches between face pairs are explicitly recognized, we measured P600f components for identity match trials, dissimilar mismatch trials, and similar mismatch trials with correct responses or misidentification errors. Clear P600f components should be present on identity match trials as compared to dissimilar mismatch trials, reflecting the explicit recognition of an identity repetition. Critically, if misidentification errors are due to an explicit classification of similar mismatching faces as being identical, larger P600f components should also be observed on similar mismatch trials where such errors occur relative to similar mismatch trials with correct responses.

2. Method

2.1. Participants

Twelve paid volunteers (seven female) participated in the present study. Their ages ranged from 25 to 40 ($M=30.4$ years, $SD=5.1$). All participants reported normal or corrected-to-normal vision and gave their informed consents prior to testing. All participants were tested on the Cambridge Face Memory Test (CFMT; Duchaine and Nakayama, 2006) prior to EEG recording in order to assess their face recognition abilities. Scores ranged from 40 to 70 ($M=57.9$, $SD=9.8$), representing the broad range of face processing abilities found in the general population (Bindemann et al., 2012; Russell et al., 2009).

2.2. Stimuli and procedure

Photographs of faces in a frontal view with neutral expression were taken from the Color FERET Database (Phillips et al., 2000, 1998). Images were converted to greyscale and cropped by a standardized procedure using Adobe Photoshop 6.0 (Adobe Systems Inc., San Jose, CA). Hair and ears were cropped using a curved line positioned at the lower part of the forehead and the remaining parts of the facial outline were preserved (e.g., jawline, cheekbones; see Fig. 1 for examples). The stimulus set included 16 target faces and 16 distractor faces. For each target face (eight male, eight female), two different images of the same person were employed, which differed in lighting and head orientation (see Fig. 1). To generate trials where successively presented faces of two different individuals are perceptually similar, each individual target face was paired with one similarity-matched distractor face. The selection of these target-distractor pairs was based on the results of a previous rating study, where eight participants rated the similarity of 113 pairs of potential target and distractor faces on a 7-point Likert-scale ranging from 1 (not similar at all) to 7 (very similar). From the 12 female and 12 male face pairs that were rated as most similar, we chose eight female pairs and eight male pairs to be the stimuli of the present experiment by excluding those faces with facial hair or hardly removable hairstyles. The selected target-distractor pairs received similarity ratings ranging

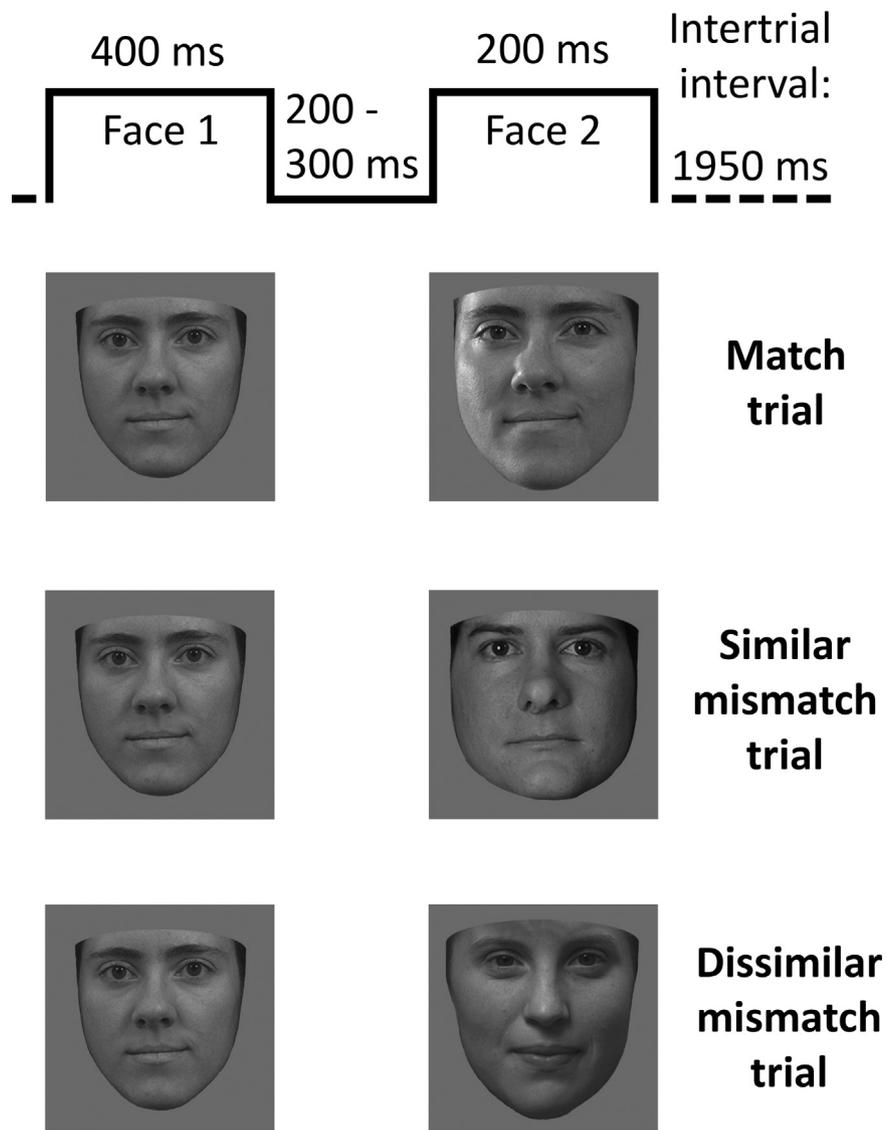


Fig. 1. Top panel: temporal parameters of stimulus presentation on each trial. Bottom panels: examples of different trial types. On each trial, either two pictures of the same person (match trials), or two pictures of different but similar persons (similar mismatch trials), or two pictures of obviously different persons (dissimilar mismatch trials) could be presented.

from 3.63 to 5.13 ($M=4.21$, $SD=.44$). One of the faces in each pair was assigned the role of target face, and the other was employed as a distractor face.

On each trial, two faces were presented centrally and in rapid succession on a CRT monitor against a dark gray background at a viewing distance of 100 cm, using the Cogent 2000 toolbox for Matlab 2008b (MathWorks, Natick, MA). The first face was presented for 400 ms, and the second face for 200 ms. Both were separated by a jittered interstimulus interval ranging from 200 ms to 300 ms. The intertrial interval between the offset of the second face on the preceding trial and the onset of the first face on the next trial was 1950 ms. To avoid that particular facial features in the two face images stimulated the same retinal regions, the first and second face differed in size ($5.2^\circ \times 5.7^\circ$ visual angle for the first face, and $5.7^\circ \times 6.2^\circ$ for the second face). The experiment included three trial types (160 match trials, 320 similar mismatch trials, and 160 dissimilar mismatch trials). In match trials, two different images of the same target face were presented. In similar mismatch trials, one of the target faces and its associated similarity-matched distractor face were presented. In dissimilar mismatch trials, images of two randomly chosen target faces of the

same gender were presented (see Fig. 1 for illustrations of these three trial types). The order in which the two face images were presented on each trial was randomized. All 640 trials were presented in randomized order in 10 blocks of 64 trials. Each block lasted approximately three minutes, with self-paced breaks between blocks.

Participants were instructed to judge on each trial whether the two face images showed the same or two different individuals, and to press the left button on a response pad to signal an identity match and the right button for an identity mismatch. They responded with the index and middle fingers of their preferred hand. After each block, participants received feedback about their reaction times but not about their response accuracy. They were not informed that the goal of the experiment was to investigate misidentification errors, and that there were twice as many mismatch trials with physically similar faces than dissimilar mismatch trials. The experiment was preceded by a training block of 32 trials that was identical to the subsequent blocks, except that face images of four different individuals were shown that were not used in the main experiment.

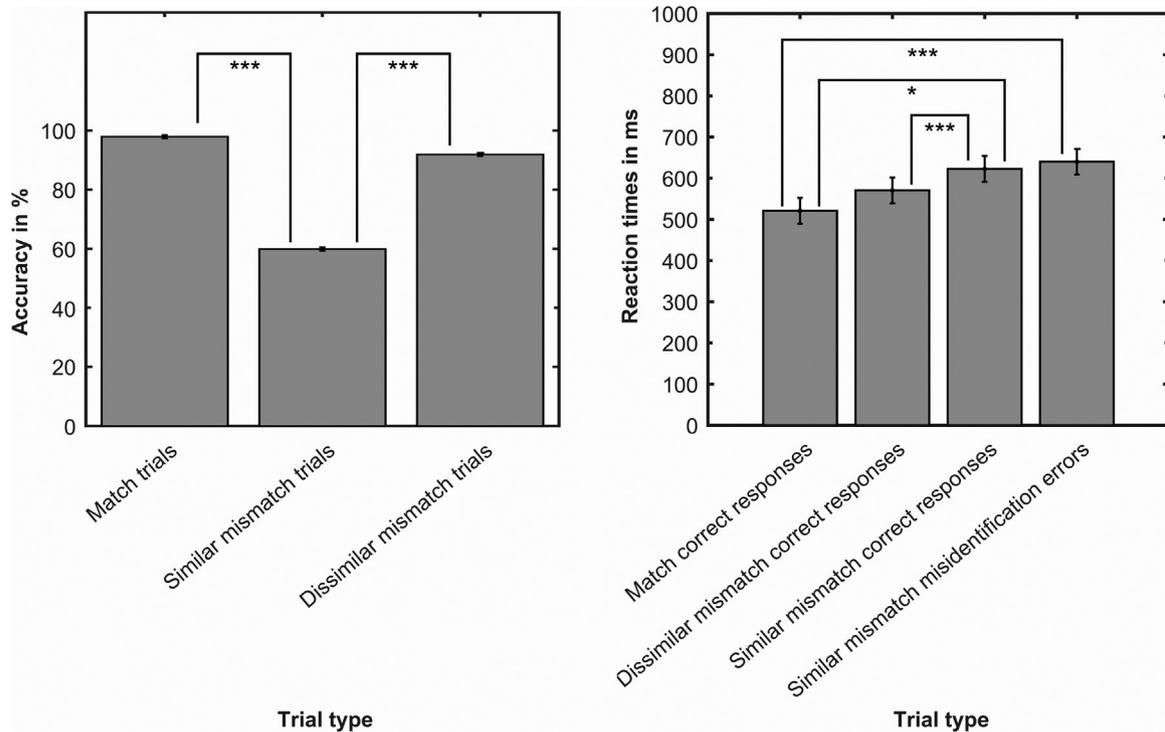


Fig. 2. Left panel: percentage accuracy as a function of different trial types. Right panel: reaction times in ms as a function of different trial types. Error bars depict the 95% confidence interval of the main effect (Jarmasz and Hollands, 2009). Asterisks indicate significance levels according to Bonferroni-corrected post hoc comparisons (* = $p < .05$, *** = $p < .001$).

2.3. EEG recording and data analysis

EEG was DC-recorded with a BrainAmps DC amplifier (upper cut-off frequency 40 Hz, 500 Hz sampling rate) and Ag-AgCl electrodes mounted on an elastic cap from 27 scalp sites Fpz, F7, F3, Fz, F4, F8, FC5, FC6, T7, C3, Cz, C4, T8, CP5, CP6, P7, P3, Pz, P4, P8, PO7, PO8, Oz, P9, PO9, PO10, and P10 according to the extended international 10–20 system. Horizontal electrooculogram (HEOG) was recorded bipolarly from the outer canthi of both eyes. An electrode placed on the left earlobe served as reference for online recording and EEG was re-referenced offline to a common average. All electrode impedances were kept below 5 k Ω . No additional offline filters were applied. EEG was epoched offline from 100 ms before to 600 ms after the onset of the second face of each pair. For each EEG epoch, amplitude values were computed relative to a 100 ms baseline (ranging from 50 ms before to 50 ms after the onset of the second face stimulus). Three steps of artifact rejection were conducted. First, EEG epochs with activity exceeding $\pm 60 \mu\text{V}$ at FPz (indicating eye blinks or vertical eye-movements) were rejected. Second, all epochs with activity exceeding $\pm 30 \mu\text{V}$ in the bipolar HEOG channel (reflecting horizontal eye-movements) were removed. Third, EEG epochs with activity exceeding $\pm 80 \mu\text{V}$, voltage steps of more than 50 $\mu\text{V}/\text{ms}$, or an activity of less than 0.5 μV for more than 500 ms at any other electrode were excluded from further analyses. Overall, 5.7% of all trials were excluded. After artifact rejection, EEG waveforms were averaged separately for four types of trials (identity match trials and dissimilar mismatch trials with correct responses, similar mismatch trials with misidentification errors, and similar mismatch trials with correct responses). The average number of trials available for EEG averaging for individual participants was 142 ($SD=18$), 136 ($SD=13$), 119 ($SD=50$), and 175 ($SD=46$), for these four trial types, respectively.

Mean amplitude values were computed at lateral posterior electrodes P7, P8, PO7, PO8, P9, PO9, PO10, and P10 and for two

successive N250r time intervals defined relative to the onset of the second face (early N250r: 220–250 ms post-stimulus; late N250r: 250–350 ms post-stimulus; see Neumann and Schweinberger, 2008, for a study that also employed two successive N250r measurement windows). In addition, mean amplitudes were also computed and analyzed for the N170 component (measured from 160–190 ms post-stimulus). Furthermore, mean amplitudes of the P600f component were computed and analyzed at parietal midline electrode Pz within a 400–550 ms post-stimulus time window. Behavioral and ERP data were analyzed with repeated measures ANOVAs. In cases of violations of the assumption of sphericity as indicated by Mauchly's tests, the Huynh-Feldt correction was applied. In order to preserve the transparency of the statistical design, we report uncorrected degrees of freedom together with corrected p -values. For multiple comparisons across trial types using paired t -tests, Bonferroni corrections were applied. The onset latencies of N250r components on match trials and similar mismatch trials with misidentification errors were compared with a jackknife-based procedure (Miller et al., 1998). The jackknifing procedure estimates onset latencies from grand averages that are computed from subsamples of participants where one participant is successively excluded from the original sample. N250r onset latencies were computed within a 200–300 ms post-stimulus time window, separately for match trials and dissimilar mismatch trials with misidentification errors. Onset latencies were defined relative to an absolute onset criterion of $-0.4 \mu\text{V}$, and were compared with paired t -tests, with t -values corrected according to the formula described by Miller et al. (1998).

3. Results

3.1. Behavior

Fig. 2 shows response accuracy (left panel) and reaction times

(RTs) for different trial types. Participants failed to respond on 1.5% of all trials, which were excluded from all further analyses. For accuracy, a one-way repeated measures ANOVA revealed a significant main effect of *trial type* (match trials vs. dissimilar mismatch trials vs. similar mismatch trials; $F(2,22)=53.6$; $p < .001$). Accuracy was high and not significantly different on match trials and dissimilar mismatch trials (97.9% and 91.9%; $t(11)=2.3$; $p > .05$). As intended, accuracy was much lower for similar mismatch trials (59.9%), and differed significantly both from match trials ($t(11)=7.0$; $p < .001$) and dissimilar mismatch trials ($t(11)=10.0$; $p < .001$). The high percentage of incorrect responses on similar mismatch trials allowed us to analyze these trials separately for correct rejections and misidentification errors. Thus, all further analyses were conducted separately for four different levels of the factor *trial type*, as described in the Methods section.

For RTs, a one-way repeated measures ANOVA showed a significant main effect of *trial type* on reaction times ($F(3,33)=14.0$; $p < .001$). Bonferroni-corrected post hoc comparisons showed that RTs on match trials were faster than for correct responses ($t(11)=-4.0$; $p < .05$) and misidentification errors ($t(11)=-7.6$; $p < .001$) on similar mismatch trials. RTs for correct responses on dissimilar mismatch trials were significantly faster than for correct responses on similar mismatch trials ($t(11)=-7.6$; $p < .001$). The RT difference between correct responses on dissimilar mismatch trials and misidentification errors on similar mismatch trials approached significance ($t(11)=-3.1$; $p=.06$). There were no reliable RT differences between correct responses on match trials and correct responses on dissimilar mismatch trials ($t(11)=-2.2$; $p > .05$) or between correct responses and misidentification errors on similar mismatch trials ($t(11)=-0.8$; $p > .05$).

3.2. Item analyses

To test whether some of the distractor faces consistently yielded misidentification errors when paired with their associated target face on similar mismatch trials, and whether other distractor faces were consistently associated with correct rejections on these trials (reflecting systematic differences in overall physical similarity between face pairs across different similar mismatch trials), we conducted descriptive item analyses for each of the 16 different face images presented on similar mismatch trials.

Table 1 shows mean accuracy rates and corrected item-scale correlations for these items. It is notable that items 6, 7, 8, and 9 yielded accuracy rates above 80% or below 20%, while accuracy

Table 1
Mean item accuracy rates and corrected item scale correlations for all 16 similar mismatch trials presented throughout the experiment.

Item no.	Mean accuracy (SD)	Corrected item scale correlation	Number of participants with 0% accuracy	Number of participants with 100% accuracy
1	.36 (.29)	.35	0	0
2	.66 (.31)	.57	0	2
3	.46 (.31)	.56	0	1
4	.79 (.27)	.68	0	5
5	.29 (.31)	.64	2	0
6	.94 (.14)	.48	0	8
7	.83 (.19)	.71	0	3
8	.91 (.12)	.55	0	6
9	.17 (.27)	.64	4	0
10	.38 (.29)	.78	1	0
11	.73 (.26)	.75	0	2
12	.77 (.20)	.61	0	1
13	.59 (.37)	.47	1	0
14	.48 (.27)	.47	0	1
15	.34 (.28)	.46	1	1
16	.76 (.26)	.40	0	3

for the remaining 12 items ranged between 79% and 34% ($M=52.7\%$), suggesting that the similarity between these items and their associated face on dissimilar mismatch trials was particularly high or low. For this reason, we analyzed the ERP data both with those four items included and excluded (see Section 3.3.2). Corrected item-scale correlations ranged from .35 to .78, indicating that performance for individual items was affected by a general underlying factor (most likely participants' general face matching ability), but that the rank order of participants across these items varied considerably. To further illustrate the fact that participants' identity judgments in response to identical face pairs differed considerably across different similar mismatch trials, Table 1 also reports the number of participants that consistently made misidentification errors in response to a particular face pair (0% accuracy); and of those participants who always judged this pair to show two different individuals (100% accuracy). With the possible exception of items 6 and 8, participants' responses to specific face pairs were not uniform.

3.3. ERPs

3.3.1. N250r components – main analyses

Fig. 3 shows ERPs triggered at Fz (top left panel), at Pz (top right panel), and at lateral posterior electrodes over the left and right hemispheres (bottom panels) in the 600 ms interval after the onset of the second face, separately for all four *trial types*. As predicted, a clear N250r component was elicited for match trials as compared to dissimilar mismatch trials. Critically, an N250r also seems to be present on similar mismatch trials with misidentification errors, although this component appears to be attenuated and emerges later relative to the N250r on match trials. The other notable observation is that there appear to be no ERP differences between similar and dissimilar mismatch trials with correct responses in the N250r time window, indicating that no N250r component was present on similar mismatch trials where face pairs were correctly judged to show two different individuals.

These informal observations were confirmed by statistical analyses that were conducted separately for the early and late N250r time windows. For the early N250r (220–250 ms post-stimulus), a repeated measures ANOVA with the factors *trial type* (match trials/correct responses vs. dissimilar mismatch trials/correct responses vs. similar mismatch trials/correct responses vs. similar mismatch trials/misidentification errors), *hemisphere* (left vs. right), and *electrode site* (P7/8 vs. PO7/8 vs. P9/10 vs. PO9/10) revealed a significant main effect of *trial type* ($F(3,33)=7.6$; $p < .001$). Bonferroni-corrected post hoc comparisons showed a reliable N250r component for match trials as compared to dissimilar mismatch trials ($t(11)=-3.4$; $p < .05$), and to similar mismatch trials with correct responses ($t(11)=-5.1$; $p < .01$). The remaining four pairwise comparisons did not reach significance (all $|t(11)| < 2.8$; all $p > .05$), demonstrating that no reliable N250r component was present during the early N250r time interval for similar mismatch trials with misidentification errors. Fig. 4 (left panel) shows the scalp distribution of the N250r component (computed by subtracting ERP mean amplitudes on dissimilar mismatch trials from ERP mean amplitudes on match trials in the 220–250 ms post-stimulus interval). In the ANOVA, a significant *trial type* \times *electrode site* interaction ($F(9,99)=2.8$; $p < .01$), was accompanied by a three-way interaction between *response condition*, *hemisphere*, and *electrode site* ($F(9,99)=2.1$; $p < .05$), reflecting the fact that the early N250r on match trials was most pronounced at more superior electrodes over the left hemisphere (P7, PO7), but not over the right hemisphere.

A corresponding repeated measures ANOVA for the late N250r time interval (250–350 ms post-stimulus) again revealed a significant main effect of *trial type* ($F(3,33)=38.9$; $p < .001$).

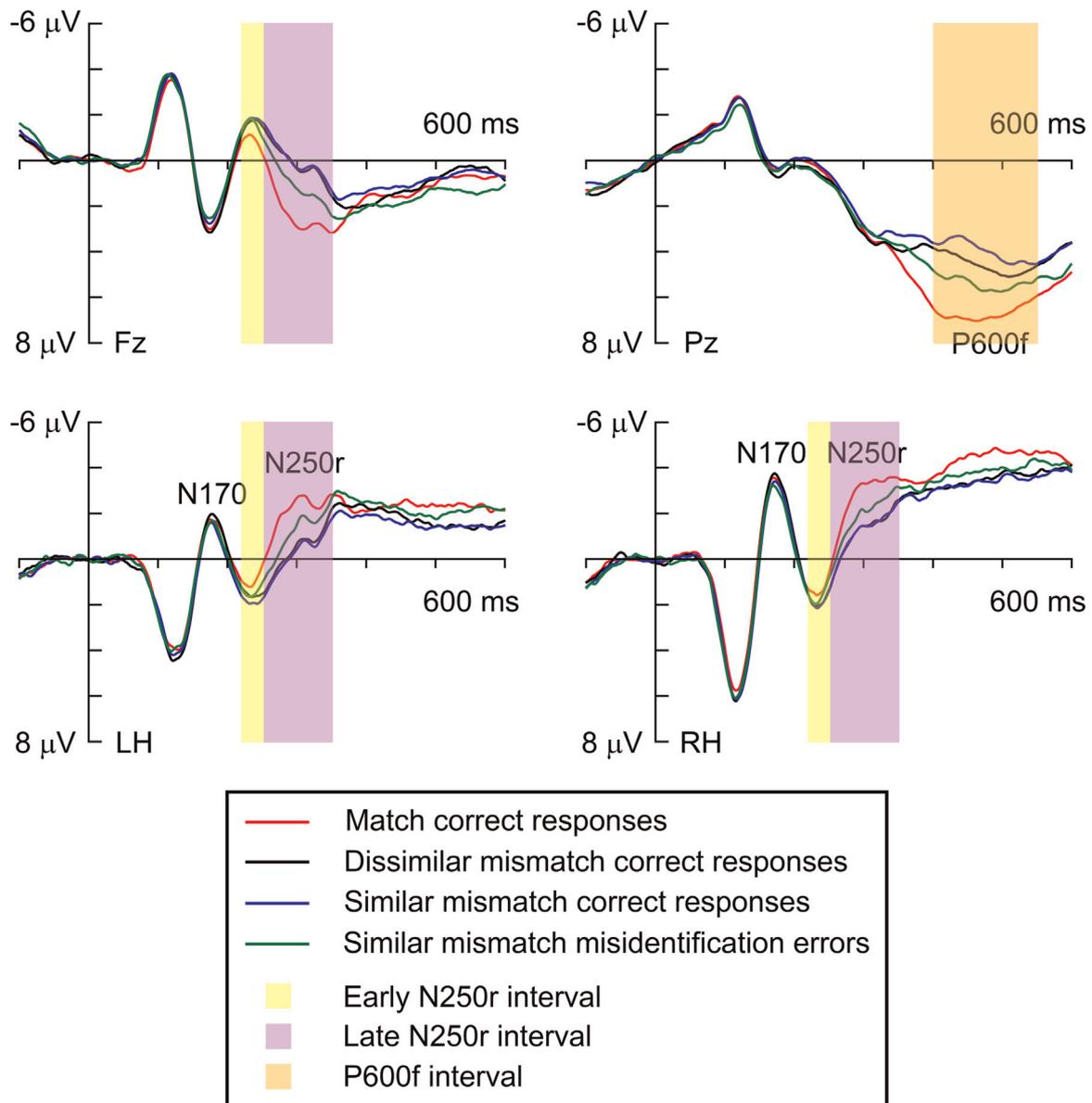


Fig. 3. Grand-averaged ERPs for different response conditions at midline electrodes Fz and Pz (top panel) and at lateral posterior electrodes (bottom panels) in the 600 ms interval after the onset of the second face. ERPs were averaged across lateral posterior electrodes of the left hemisphere (P7, PO7, P9, and PO9) and the right hemisphere (P8, PO8, P10, PO10). The fronto-central positivity measured at Fz showed an exactly reversed pattern to the negativity measured at the lateral posterior electrodes. The P600f component at parietal midline electrode Pz is largest for identity match trials, and is also present for similar mismatch trials with misidentification errors.

Bonferroni-corrected post hoc comparisons showed a reliable N250r component on match trials as compared to dissimilar mismatch trials ($t(11) = -7.0$; $p < .001$), and similar mismatch trials ($t(11) = -8.3$; $p < .001$) with correct responses. In addition, and critically, there was now also a significant N250r on similar mismatch trials with misidentification errors, both when compared to dissimilar mismatch trials ($t(11) = -3.8$; $p < .05$) and similar mismatch trials ($t(11) = -4.9$; $p < .01$) with correct responses. However, a direct comparison of ERPs on match trials and similar mismatch trials with misidentification errors showed that N250r amplitudes were reliably larger on match trials ($t(11) = -6.8$; $p < .001$). There was no significant ERP difference between similar and dissimilar mismatch trials with correct responses during the late N250r interval, ($t(11) = -0.4$; $p > .05$), confirming that no N250r component was elicited on those similar mismatch trials where participants correctly reported two different facial identities. Fig. 4 (right panel) shows the scalp topographies of the late N250r component on match trials (as compared to dissimilar

mismatch trials) and on similar mismatch trials with misidentification errors (as compared to dissimilar and similar mismatch trials with correct responses, respectively). N250r components on match trials and similar mismatch trials with misidentification errors were larger at inferior electrodes (P9, PO9, PO10, and P10) than at more superior electrodes (P7, P8, PO7, and PO8), as reflected by a significant *trial type* \times *electrode site* interaction ($F(9,99) = 4.5$; $p < .01$) in the ANOVA of ERP mean amplitudes in the late N250r interval. While N250r components were smaller in size on similar mismatch trials with misidentification errors relative to match trials, they showed a similar scalp distribution on both types of trials. This was confirmed by an additional ANOVA that compared late N250r mean amplitudes on match trials and on similar mismatch trials with misidentification errors. There were no reliable *trial type* \times *hemisphere*, *trial type* \times *electrode site*, or *trial type* \times *hemisphere* \times *electrode site* interactions (all $F < 1$).

While the N250r component on match trials was reliably

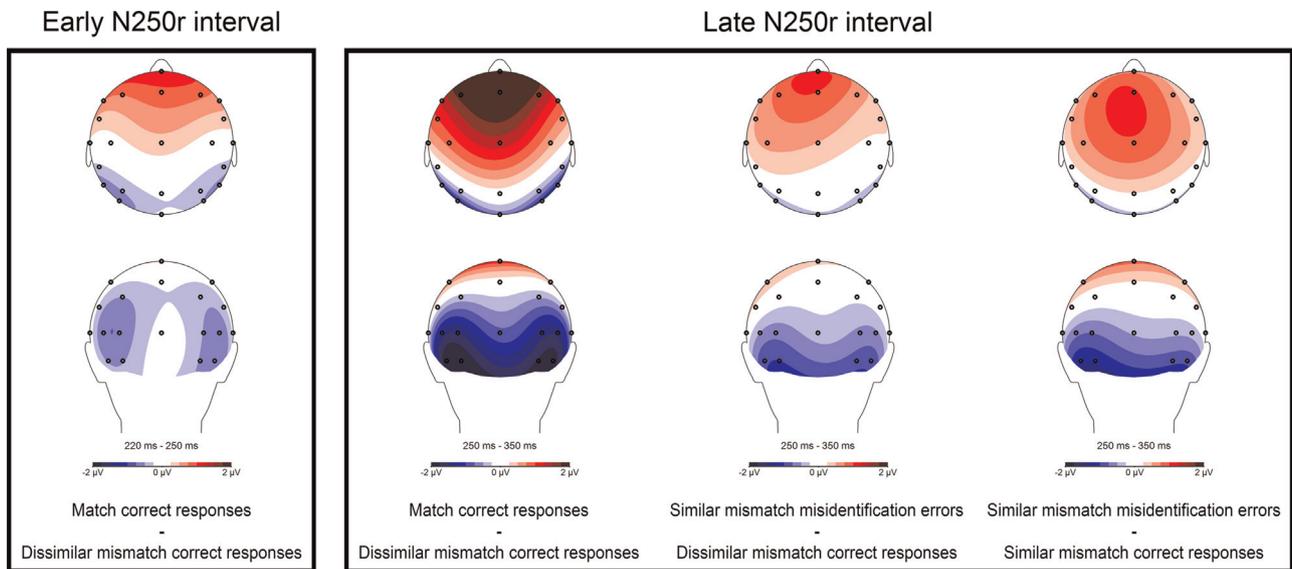


Fig. 4. Left panel: scalp distribution of the difference in negativity between correct responses on match trials and on dissimilar mismatch trials in the early N250r interval (220–250 ms). Right panel: scalp distributions of differences in negativity between correct responses on match trials and on dissimilar mismatch trials, between misidentification errors on similar mismatch trials and correct responses on dissimilar mismatch trials, and between misidentification errors and correct responses on similar mismatch trials (from left to right) in the late N250r interval (250–350 ms).

present both in the early and late N250r time window, the N250r elicited on similar mismatch trials with misidentification errors was only found during the late N250r interval, suggesting that N250r components emerged earlier on match trials. To provide additional evidence for such an onset latency difference, we conducted a four-way repeated measures ANOVA with the additional factor *time interval* (220–250 ms vs. 250–350 ms). There was a significant main effect of *trial type* ($F(3,33)=25.0$; $p < .001$), and, importantly, a significant *time interval* \times *trial type* interaction ($F(3,33)=24.3$; $p < .001$), reflecting the later onset of N250r components on similar mismatch trials with misidentification errors relative to match trials. To test this latency difference more directly, we computed N250r difference waveforms for match trials (by subtracting ERPs measured at lateral posterior electrodes on dissimilar match trials from ERPs on match trials) and for similar mismatch trials with misidentification errors (by subtracting ERPs for dissimilar match trials from ERPs for these misidentification trials), and averaged the resulting difference waves across both hemispheres. We then compared the onset latencies of the N250r component on these trials with a jackknife-based procedure, using an absolute onset criterion of $-0.4 \mu\text{V}$ (as described in the Section 2). This analysis revealed that the N250r component on match trials emerged 221 ms post-stimulus, while the onset latency of the N250r on similar mismatch trials with misidentification errors was 243 ms. This onset latency difference of 22 ms was statistically reliable ($t_c(11)=2.38$; $p < .05$).

As shown in Figs. 3 and 4, the lateral posterior N250r component was accompanied by a positive deflection at more anterior electrodes that also emerged earlier for match trials as compared to similar mismatch trials with misidentification errors, and was absent for similar and dissimilar mismatch trials with correct responses. Analyses of ERP mean amplitudes at Fz in the early and late N250r time windows confirmed that this positive counterpart of the N250r showed a very similar pattern as the posterior N250r component. During the early N250r time window, ERPs on match trials were reliably more positive than ERPs for the other three trial types (all $t(11) > 3.5$; all $p < .05$), which did not differ significantly from each other (all $|t(11)| < 0.4$; all $p > .05$). During the late N250r interval, there was a significantly enhanced positivity for match trials and for similar mismatch trials with

misidentification errors relative to similar and dissimilar mismatch trials with correct responses (all $t(11) > 3.8$; all $p < .05$), which did not differ from each other ($t(11)=0.1$; $p > .05$). In addition, this positive anterior counterpart of the N250r was larger for match trials as compared to similar mismatch trials with correct responses ($t(11)=6.0$; $p < .001$).

3.3.2. N250r components – additional analyses with reduced item set

Because a subset of the face pairs shown on similar mismatch trials was associated with either very low or very high probabilities of misidentification errors (see Section 3.2.), these particular pairs may have been relatively low or high in terms of their perceptual similarity. To rule out the possibility that the N250r differences observed between similar mismatch trials with misidentification errors or correct responses (i.e., a clear N250r for the former trials, no N250r for the latter trials) primarily reflect systematic differences in the perceptual similarity between individual face pairs, we reanalyzed the N250r data after excluding the four most extreme items (items 6, 7, 8, and 9; see Table 1). The results of these additional analyses perfectly replicated the results found in our main analyses. For the early N250r time window, the main effect of *trial type* was significant ($F(3,33)=6.8$; $p = .001$). Bonferroni-corrected post hoc comparisons confirmed that an N250r component was present for match trials as compared to dissimilar mismatch trials ($t(11) = -3.4$; $p < .05$). In contrast, there was no early N250r component for similar mismatch trials with misidentification errors ($t(11)=0.5$; $p > .05$). For the late N250r interval, a main effect of *trial type* was again present ($F(3,33)=30.4$; $p < .001$). Bonferroni-corrected post hoc comparisons revealed that N250r components were elicited not only on match trials ($t(11) = -7.0$; $p < .001$), but also on similar mismatch trials with misidentification errors as compared to dissimilar mismatch trials ($t(11) = -3.3$; $p < .05$). As before, the N250r was larger on match trials than on similar mismatch trials with misidentification errors ($t(11) = -6.5$; $p < .001$), and there were no ERP amplitude differences between similar and dissimilar mismatch trials with correct responses ($t(11)=0.5$; $p > .05$), demonstrating that no N250r was elicited on similar mismatch trials where the presence of two different face identities was correctly detected. Finally, the

additional four-way ANOVA with the additional factor *time interval* again revealed a significant *time interval* \times *trial type* interaction ($F(3,33)=18.3$; $p < .001$), reflecting the fact that the N250r was delayed for similar mismatch trials with misidentification errors relative to match trials.

3.3.3. Impact of face learning on the N250r component

Since each individual face was presented multiple times, the increased familiarity of particular faces in the course of the experiment may have affected N250r components. To assess possible effects of face learning on the N250r, we split the EEG-data in two halves (blocks 1–5 and blocks 6–10) and conducted further ANOVAs comprising the additional factor *experimental half*. For the early N250r time window, we found a significant *experimental half* \times *trial type* interaction ($F(3,33)=4.8$; $p < .01$). Post-hoc tests revealed that this interaction was caused by differences in the size of the early phase of the generic N250r between the first and second experimental half. Whereas the negativity difference between match trials and dissimilar mismatch trials with correct

responses was smaller ($0.5 \mu\text{V}$) and only approached significance after Bonferroni correction ($t(11)=-2.4$; $p=.07$) during the first half of the experiment, it was larger ($0.9 \mu\text{V}$) and significant ($t(11)=-3.6$; $p < .05$) during the second experimental half. For the late N250r time window, there were no significant interactions comprising the factors *experimental half* and *trial type* (all $F < 2.0$; all $p > .05$).

3.3.4. Correlations between N250r components and behavioral measures of face recognition ability

An analysis of the relationship between participants' CFMT scores and their behavioral accuracy on similar mismatch trials revealed a trend towards a positive correlation, which did not reach statistical significance ($\rho=.32$; $p > .05$). In order to investigate the relationship between the N250r component and individual face recognition ability, we correlated participants' individual CFMT scores with their individual N250r amplitudes in the late N250r time interval (250–350 ms post-stimulus) for both match trials and similar mismatch trials with misidentification

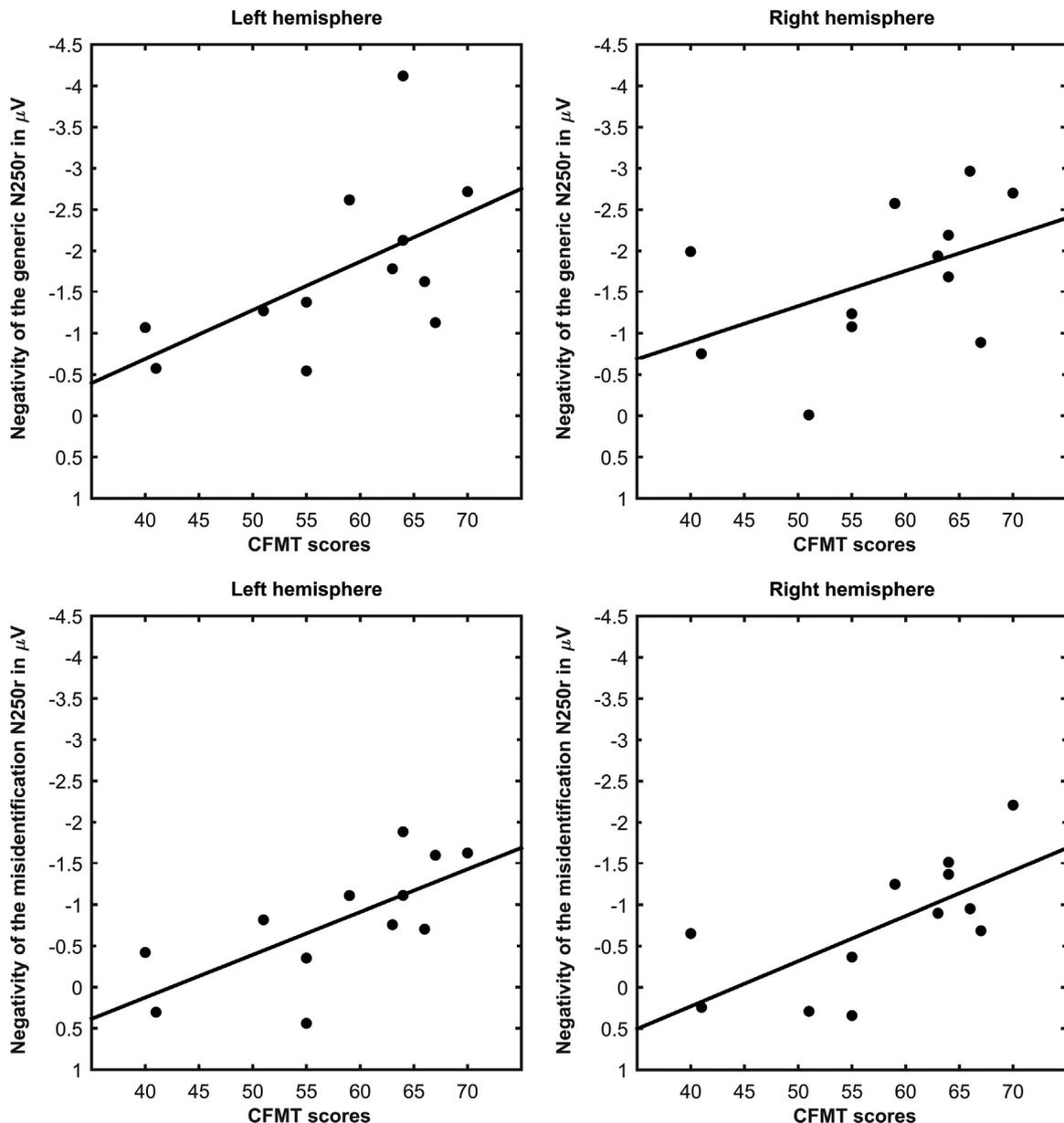


Fig. 5. Scatterplots of the correlations between participants' CFMT scores and individual mean amplitude size of the generic N250r (top panels) and the misidentification N250r (bottom panels) in the late N250r interval. The solid line depicts the slope of the regression.

errors relative to dissimilar mismatch trials. Since amplitudes at adjacent electrodes are strongly intercorrelated, we averaged amplitude values across the lateral posterior electrodes of the left hemisphere (P7, PO7, P9, and PO9) and the right hemisphere (P8, PO8, P10, PO10). Due to our small sample size, we used Spearman's rank correlation coefficient. Because the N250r is a component with a negative polarity, negative correlations between CFMT scores and N250r amplitudes reflect positive relationships between high CFMT scores (i.e., good face recognition abilities) and N250r amplitudes. Fig. 5 shows scatterplots illustrating the relationship between participants' CFMT scores and individual N250r amplitudes over the left and right hemispheres for the N250r on match trials (top panels) and the N250r on similar mismatch trials with misidentification errors (bottom panels). There was a significant correlation between N250r amplitudes on match trials over the left hemisphere and CFMT scores ($\rho = -.61$; $p < .05$). A trend in the same direction was also present for N250r amplitudes over the right hemisphere, but was not significant ($\rho = -.49$; $p > .05$). Interestingly, N250r amplitudes on similar mismatch trials with misidentification errors were closely and significantly correlated with CFMT scores, both over the left hemisphere ($\rho = -.71$; $p < .05$) and the right hemisphere ($\rho = -.73$; $p < .01$). These correlations remained highly significant when N250r amplitudes on trials with misidentification errors were computed after excluding the four face pairs with extremely good or poor accuracy rates ($\rho = -.83$; $p < .001$, and $\rho = -.79$; $p < .01$, for the left and right hemisphere, respectively).

3.3.5. N170 components

As can be seen in Fig. 3 (bottom panels), there were no obvious differences between trial types for the face-sensitive N170 component that preceded the N250r. An ANOVA of N170 mean amplitudes measured during the 160–190 ms post-stimulus time window obtained a significant main effect of *trial type* ($F(3,33) = 3.7$; $p < .05$), but Bonferroni-corrected post hoc tests found no reliable differences for any pairwise comparison between trial types (all $|t(11)| < 3.2$; all $p > .05$).

3.3.6. P600f components

As expected, a late enhanced positivity (P600f component) was elicited at Pz on identity match trials (Fig. 3, top right panel), reflecting the explicit recognition of a face identity repetition. Importantly, P600f amplitudes on similar mismatch trials with misidentification errors were larger than on similar mismatch trials with correct responses, but smaller than on identity match trials. In an analysis of P600f mean amplitudes obtained during a 400–550 ms post-stimulus time window, a significant main effect of *trial type* was obtained ($F(3,33) = 15.2$; $p < .001$). Bonferroni-corrected post hoc comparisons showed that P600f amplitudes were significantly larger on match trials as compared to dissimilar mismatch trials ($t(11) = 4.1$; $p < .05$) and similar mismatch trials ($t(11) = 6.9$; $p < .001$) with correct responses. Importantly, P600f amplitudes on similar mismatch trials with misidentification errors were reliably larger than on similar mismatch trials with correct responses ($t(11) = 3.8$; $p < .05$). However, this misidentification P600f component was smaller than the P600f measured on trials where an identity match was correctly reported ($t(11) = 3.4$; $p < .05$).

4. Discussion

Misidentifications are a common phenomenon in unfamiliar face recognition and matching (e.g., Bruce, 1982; Bruce et al., 1999; Burton et al., 1999; Henderson et al., 2001). The aim of the present study was to investigate the mechanisms underlying

misidentification errors, using an ERP marker of early visual-perceptual stages of face recognition. A face identity matching procedure was employed where two different face images of the same or different persons were presented in rapid succession, and participants had to judge whether each face pair showed the same person (match trials) or two different individuals (mismatch trials). On some mismatch trials, the two face images were clearly different, while on others, they were perceptually similar to each other. Accuracy was high on match trials, where the two face images were nearly always correctly classified as showing the same person. Similarly, an identity difference between face pairs was correctly reported on more than 90% of all dissimilar mismatch trials. In contrast, and as intended, participants' accuracy was much lower on similar mismatch trials, where 40% of all face pairs were incorrectly judged to show the same individual (misidentification errors). To determine whether such errors are primarily generated at a stage where representations in short-term visual face memory are activated and compared to perceptual representations of a currently seen face, or at later post-perceptual stages where decisions about identity judgments are made, we measured N250r components on match trials and on similar mismatch trials with correct and incorrect responses.

As expected, clear N250r components were found on match trials where two faces of the same person were shown in succession as compared to dissimilar mismatch trials. This confirms previous reports that the N250r is triggered by repetitions of unfamiliar faces (e.g., Pfützte et al., 2002; Schweinberger et al., 2004), even when face pairs are presented in rapid succession (Zimmermann and Eimer, 2013, 2014). The N250r component on match trials showed the typical scalp topography, with a negativity at lateral posterior electrodes accompanied by a fronto-central positivity (see Fig. 4), was already reliable during a 220–250 ms post-stimulus time window, and remained present during the subsequent 250–350 ms time interval. Separate analyses for the first and second half of the experiment showed that the amplitude of this generic N250r in the early 220–250 ms interval increased during the experiment. The N250r is usually larger for familiar compared to unfamiliar faces (Herzmann et al., 2004; Herzmann and Sommer, 2007; Pfützte et al., 2002). Therefore, the increase of the early N250r in the second experimental half might represent a gradual familiarization of the stimulus faces.

The central aim of this study was to investigate whether an N250r component would also be elicited on similar mismatch trials, and whether the presence of an N250r on these trials was determined by whether participants made a misidentification error or correctly reported the presence of two different individual faces. On trials with misidentification errors, an N250r component was clearly present. In contrast, no N250r was triggered on similar mismatch trials with correct responses. This pattern of N250r results demonstrates that misidentification errors for unfamiliar faces are closely linked to an incorrect activation of a visual face memory representation of a specific individual face by a seen face that is perceptually similar, but does in fact belong to a different person. When such representations are activated (as reflected by the presence of an N250r component on some similar mismatch trials), misidentification errors are made. In contrast, no misidentification errors occur when the presentation of a particular face does not activate a memory representation of a similar face of a different individual (as shown by the absence of the N250r on other similar mismatch trials). If misidentification errors were primarily or exclusively generated at stages that follow the activation of visual face memory where response decisions related to the presence versus absence of an identity match are made, there should have been no systematic differences between N250r components on similar mismatch trials with correct or incorrect responses.

Even though N250r components were reliably present both on match trials and on similar mismatch trials with misidentification errors, the misidentification-related N250r was attenuated and delayed relative to the N250r that was elicited in response to an actual identity match. The N250r on match trials was already reliably present between 220 ms and 250 ms post-stimulus (at least during the second half of the experiment), while the N250r on similar mismatch trials with misidentification errors only emerged during the late N250r measurement window (250–350 ms post-stimulus). The delay of the N250r on trials with misidentification errors was also confirmed with an additional jackknife-based onset latency analysis, which showed that it emerged 22 ms later relative to match trials (243 ms versus 211 ms post-stimulus). The attenuation and delay of the N250r component on misidentification trials as compared to the N250r triggered by a successful identity match is likely to reflect differences in the physical similarity between the two successively presented faces between these trials. Even though the face pairs shown on similar mismatch trials were selected on the basis of their visual resemblance, and in spite of the fact that two different face images were shown on all trials, the degree of physical overlap between two images of the same person was generally larger than the overlap between similar faces of two different individuals. Some earlier studies have observed larger N250r components for repetitions of the same face image relative to repetitions of two different images of the same individual (Cooper et al., 2007; Schweinberger et al., 2002), suggesting that the visual face memory activation processes reflected by the N250r show some degree of image-dependence. However, other recent studies from our lab (Zimmermann and Eimer, 2013, 2014) found that N250r components to identity repetitions were not reliably different when faces were presented in the same view or in two different views, indicating that the N250r is much more sensitive to identity-related information than to repetitions of low-level visual features.

These observations suggest that image-dependent pictorial cues and more abstract representations of facial identity may both contribute to the N250r component. This is consistent with the idea that the N250r reflects the activation of picture-independent face recognition units (FRUs; see Herzmann et al., 2004; Herzmann and Sommer, 2007; Pfütze et al., 2002; Pickering and Schweinberger, 2003; Schweinberger and Burton, 2003; Schweinberger et al., 2002), and that the activation strength of a specific FRU is determined by the overlap with input provided by structural encoding processes, which both includes view-centered pictorial descriptions as well as view-independent representations of a face (Bruce and Young, 1986). If this is correct, the delay and attenuation of N250r components measured on similar mismatch trials with misidentification errors relative to the N250r elicited on match trials is associated with image-dependent pictorial cues (i.e., the higher physical similarity between two images of the same person). In contrast, the presence of an N250r on trials with misidentification errors and the absence of this component on other similar mismatch trials with correct responses reflect the contribution of higher-level representations of facial identity. The fact that N250r components emerged earlier and were larger on match trials as compared to similar mismatch trials with misidentification errors suggests that visual face memory representations were activated more rapidly and more strongly on match trials. In line with this hypothesis, RTs were about 120 ms faster on these trials relative to trials with misidentification errors, indicating that participants were more confident in reporting an identity match on trials where two images of the same person were shown.

It may still be argued that the presence versus absence of N250r components on similar mismatch trials with correct versus incorrect responses is also primarily due to differences in the low-

level visual similarities between the specific face pairs that were shown on these trials. N250r components are elicited for those face pairs that are highly similar to each other, and these pairs are also likely to produce misidentification errors. In contrast, other less similar pairs of faces do not elicit an N250r and are correctly judged to show two different individuals. To test this possibility, we conducted additional N250r analyses for similar mismatch trials after excluding faces that were consistently associated with very high or low accuracy rates. These analyses perfectly confirmed the pattern of N250r results obtained in the main analyses across all face images, demonstrating that the sensitivity of the N250r to perceptual judgments about facial identity on similar mismatch trials does not simply reflect differences in the physical similarity between the face pairs shown on these trials, but instead the presence versus absence of face matching processes that result in the activation of identity-sensitive representations in visual face memory.

The observation that there were no differential ERP differences in the N250r latency range between similar and dissimilar mismatch trials where participants correctly reported the absence of an identity match demonstrates that no N250r component was elicited when two perceptually similar face images are judged to show two different individuals. Interestingly, RTs were reliably slower on similar as compared to dissimilar mismatch trials with correct responses (see Fig. 2), indicating that participants were more confident in reporting the presence of two different individuals when the two face images were clearly different. As N250r components were entirely absent on both types of trials, this observation suggests that decision-related processing stages beyond visual face memory can affect performance in identity judgment tasks. Deciding that two face images belong to different individuals takes longer on trials where these two images are perceptually similar, and this is the case even when no identity-matching visual face memory representations are incorrectly activated on these trials.

Further evidence for the involvement of post-perceptual explicit face recognition processes in the present face matching task was provided by the P600f component (Fig. 3, top right panel). In previous face recognition experiments, an enhanced positivity to recognized target faces emerged around 400 ms after stimulus onset at centroparietal midline electrodes (e.g., Gosling and Eimer, 2011; Parketny et al., 2015; Tanaka et al., 2006). In the present study, a clear P600f component was triggered on trials where a face identity match was correctly reported. Importantly, larger P600f amplitudes were elicited on similar mismatch trials with misidentification errors relative to similar mismatch trials with correct responses. This shows that the incorrect activation of visual face memory by non-matching faces (as reflected by the N250r components) on trials with misidentification errors had a knock-on effect on subsequent stages of face processing, and activated neural processes associated with explicit face recognition. However, the P600f component observed on similar mismatch trials where misidentification errors occurred was smaller than the P600f that was triggered on trials where an identity repetition was successfully detected. This reduced size of the P600f component on misidentification trials relative to trials with correctly reported identity repetitions is likely to reflect differences in participants' confidence in their perceptual judgments between these two types of trials. The amplitudes of late positive components in target detection tasks are strongly affected by observers' confidence with respect to the presence versus absence of a target event, with larger positive components when confidence is high (e.g., Eimer and Mazza, 2005). In the present study, confidence may have been higher on trials where an identity match was successfully detected than on trials with misidentification errors because matching visual face memory representations were more

strongly activated on the former type of trials (as reflected by earlier and larger N250r components). The fact that RTs were much faster on identity match trials than on trials with misidentification errors also suggests that participants were more confident in their perceptual judgments where two images of the same face were shown.

Individual face recognition abilities, as assessed by the CFMT (Duchaine and Nakayama, 2006), were found to be correlated with the size of individual N250r components on match trials and on similar mismatch trials with misidentification errors. High CFMT scores were associated with larger N250r amplitudes to identity repetitions, although this effect was reliable only over the left hemisphere (Fig. 5, top panels). Since the N250r is an electrophysiological marker of successful face identity matching processes, it is plausible to assume that such processes are activated more efficiently in individuals that are better at face recognition. However, the same link between CFMT performance and N250r amplitudes was also observed for the N250r on trials with misidentification errors, and this effect was reliable over both hemispheres (Fig. 5, bottom panels). This is surprising, as it is not immediately obvious why good performance in a behavioral test of memory-based face recognition should be linked to a stronger erroneous activation of visual face memory on trials with misidentification errors. The observation that there was a non-significant tendency for participants with high CFMT scores to commit fewer misidentification errors shows that this link is not simply due to a better signal-to-noise ratio of the misidentification N250r for these participants. It is possible that the positive correlation between CFMT scores and the size of the misidentification N250r is due to the specific demands of this behavioral test. Because face images in the CFMT are presented from different viewpoints and with different levels of superimposed noise, perceptual matching processes in visual working memory that lead to high performance in this test need to be sufficiently flexible in order to not be disrupted by such task-irrelevant pictorial changes. For participants with high CFMT scores, visual face memory matching processes are highly flexible across image changes, and this flexibility may have resulted in larger N250r amplitudes on similar mismatch trials with misidentification errors. This suggestion needs to remain speculative at present, since the correlation between good CFMT performance and misidentification N250r amplitudes was unexpected and will need to be explored in future research.

Concluding, the present study has provided new insights on the processes that are responsible for the misidentifications of unfamiliar faces by investigating their electrophysiological correlates. Our results suggest that misidentification errors are generated at early stages of identity-sensitive face processing where a perceptual representation of a currently seen face is matched to a visual representation of a particular individual face that is stored in face memory. When the identity of two perceptually similar face images showing two different individuals has to be judged, misidentification errors occur if and only if an identity-matching stored visual face representation is incorrectly activated.

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References

- Bindemann, M., Avetisyan, M., Blackwell, K.-A., 2010. Finding needles in haystacks: identity mismatch frequency and facial identity verification. *J. Exp. Psychol.: Appl.* 16, 378–386. <http://dx.doi.org/10.1037/a0021893>.
- Bindemann, M., Avetisyan, M., Rakow, T., 2012. Who can recognize unfamiliar faces? Individual differences and observer consistency in person identification. *J. Exp. Psychol.: Appl.* 18, 277–291. <http://dx.doi.org/10.1037/a0029635>.
- Bindemann, M., Sandford, A., 2011. Me, myself, and I: different recognition rates for three photo-IDs of the same person. *Perception* 40, 625–627. <http://dx.doi.org/10.1068/p7008>.
- Bruce, V., 1982. Changing faces: visual and nonvisual coding processes in face recognition. *Br. J. Psychol.* 73, 105–116. <http://dx.doi.org/10.1111/j.2044-8295.1982.tb01795.x>.
- Bruce, V., Henderson, Z., Greenwood, K., Hancock, P.J.B., Burton, A.M., Miller, P., 1999. Verification of face identities from images captured on video. *J. Exp. Psychol.: Appl.* 5, 339–360. <http://dx.doi.org/10.1037/1076-898X.5.4.339>.
- Bruce, V., Henderson, Z., Newman, C., Burton, A.M., 2001. Matching identities of familiar and unfamiliar faces caught on CCTV images. *J. Exp. Psychol.: Appl.* 7, 207–218. <http://dx.doi.org/10.1037/1076-898X.7.3.207>.
- Bruce, V., Young, A., 1986. Understanding face recognition. *Br. J. Psychol.* 77, 305–327. <http://dx.doi.org/10.1111/j.2044-8295.1986.tb02199.x>.
- Burton, A.M., Wilson, S., Cowan, M., Bruce, V., 1999. Face recognition in poor-quality video: evidence from security surveillance. *Psychol. Sci.* 10, 243–248. <http://dx.doi.org/10.1111/1467-9280.00144>.
- Cooper, T.J., Harvey, M., Lavidor, M., Schweinberger, S.R., 2007. Hemispheric asymmetries in image-specific and abstractive priming of famous faces: evidence from reaction times and event-related brain potentials. *Neuropsychologia* 45, 2910–2921. <http://dx.doi.org/10.1016/j.neuropsychologia.2007.06.005>.
- Diamond, R., Carey, S., 1977. Developmental changes in the representation of face. *J. Exp. Child Psychol.* 23, 1–22. [http://dx.doi.org/10.1016/0022-0965\(77\)90069-8](http://dx.doi.org/10.1016/0022-0965(77)90069-8).
- Diamond, R., Carey, S., 1986. Why faces are and are not special: an effect of expertise. *J. Exp. Psychol.: Gen.* 115, 107–117. <http://dx.doi.org/10.1037/0096-3445.115.2.107>.
- Duchaine, B., Nakayama, K., 2006. The Cambridge face memory test: results for neurologically intact individuals and an investigation of its validity using inverted face stimuli and prosopagnosic participants. *Neuropsychologia* 44, 576–585. <http://dx.doi.org/10.1016/j.neuropsychologia.2005.07.001>.
- Eimer, M., 2000a. Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clin. Neurophysiol.* 111, 694–705. [http://dx.doi.org/10.1016/S1388-2457\(99\)00285-0](http://dx.doi.org/10.1016/S1388-2457(99)00285-0).
- Eimer, M., 2000b. The face-specific N170 component reflects late stages in the structural encoding of faces. *NeuroReport* 11, 2319–2324. <http://dx.doi.org/10.1097/00001756-200007140-00050>.
- Eimer, M., Gosling, A., Duchaine, B., 2012. Electrophysiological markers of covert face recognition in developmental prosopagnosia. *Brain* 135, 542–554. <http://dx.doi.org/10.1093/brain/awr347>.
- Eimer, M., Holmes, A., 2002. An ERP study on the time course of emotional face processing. *NeuroReport* 13, 427–431. <http://dx.doi.org/10.1097/00001756-200203250-00013>.
- Eimer, M., Holmes, A., McGlone, F.P., 2003. The role of spatial attention in the processing of facial expression: An ERP study of rapid brain responses to six basic emotions. *Cogn. Affect. Behav. Neurosci.* 3, 97–110. <http://dx.doi.org/10.3758/CABN.3.2.97>.
- Eimer, M., Mazza, V., 2005. Electrophysiological correlates of change detection. *Psychophysiology* 42, 328–342. <http://dx.doi.org/10.1111/j.1469-8986.2005.00285.x>.
- Ellis, A.W., Young, A.W., Flude, B.M., 1990. Repetition priming and face processing: Priming occurs within the system that responds to the identity of a face. *Q. J. Exp. Psychol. Sect. A* 42, 495–512. <http://dx.doi.org/10.1080/14640749008401234>.
- Ellis, A.W., Young, A.W., Flude, B.M., Hay, D.C., 1987. Repetition priming of face recognition. *Q. J. Exp. Psychol. Sect. A* 39, 193–210. <http://dx.doi.org/10.1080/14640748708401784>.
- Ellis, H.D., Shepherd, J.W., Davies, G.M., 1979. Identification of familiar and unfamiliar faces from internal and external features: Some implications for theories of face recognition. *Perception* 8, 431–439. <http://dx.doi.org/10.1068/p080431>.
- Folstein, J.R., van Petten, C., 2011. After the P3: late executive processes in stimulus categorization. *Psychophysiology* 48, 825–841. <http://dx.doi.org/10.1111/j.1469-8986.2010.01146.x>.
- Gauthier, I., Skudlarski, P., Gore, J.C., Anderson, A.W., 2000. Expertise for cars and birds recruits brain areas involved in face recognition. *Nat. Neurosci.* 3, 191–197. <http://dx.doi.org/10.1038/72140>.
- Gauthier, I., Tarr, M.J., Anderson, A.W., Skudlarski, P., Gore, J.C., 1999. Activation of the middle fusiform "face area" increases with expertise in recognizing novel objects. *Nat. Neurosci.* 2, 568–573. <http://dx.doi.org/10.1038/9224>.
- Gosling, A., Eimer, M., 2011. An event-related brain potential study of explicit face recognition. *Neuropsychologia* 49, 2736–2745. <http://dx.doi.org/10.1016/j.neuropsychologia.2011.05.025>.

- Hancock, P.J.B., Bruce, V., Burton, A.M., 2000. Recognition of unfamiliar faces. *Trends Cogn. Sci.* 4, 330–337. [http://dx.doi.org/10.1016/S1364-6613\(00\)01519-9](http://dx.doi.org/10.1016/S1364-6613(00)01519-9).
- Haxby, J.V., Hoffman, E.A., Gobbini, M., 2000. The distributed human neural system for face perception. *Trends Cogn. Sci.* 4, 223–233. [http://dx.doi.org/10.1016/S1364-6613\(00\)01482-0](http://dx.doi.org/10.1016/S1364-6613(00)01482-0).
- Henderson, Z., Bruce, V., Burton, A.M., 2001. Matching the faces of robbers captured on video. *Appl. Cogn. Psychol.* 15, 445–464. <http://dx.doi.org/10.1002/acp.718>.
- Herzmann, G., Schweinberger, S.R., Sommer, W., Jentsch, I., 2004. What's special about personally familiar faces? A multimodal approach. *Psychophysiology* 41, 688–701. <http://dx.doi.org/10.1111/j.1469-8986.2004.00196.x>.
- Herzmann, G., Sommer, W., 2007. Memory-related ERP components for experimentally learned faces and names: Characteristics and parallel-test reliabilities. *Psychophysiology* 44, 262–276. <http://dx.doi.org/10.1111/j.1469-8986.2007.00505.x>.
- Hoffman, E.A., Haxby, J.V., 2000. Distinct representations of eye gaze and identity in the distributed human neural system for face perception. *Nature neuroscience* 3, 80–84. <http://dx.doi.org/10.1038/71152>.
- Jarmas, J., Hollands, J.G., 2009. Confidence intervals in repeated-measures designs: the number of observations principle. *Can. J. Exp. Psychol.* 63, 124–138. <http://dx.doi.org/10.1037/a0014164>.
- Johnston, R.A., Edmonds, A.J., 2009. Familiar and unfamiliar face recognition: a review. *Memory* 17, 577–596. <http://dx.doi.org/10.1080/09658210902976969>.
- Kanwisher, N., McDermott, J., Chun, M.M., 1997. The fusiform face area: a module in human extrastriate cortex specialized for face perception. *J. Neurosci.* 17, 4302–4311.
- Kemp, R., Towell, N., Pike, G., 1997. When seeing should not be believing: photographs, credit cards and fraud. *Appl. Cogn. Psychol.* 11, 211–222. [http://dx.doi.org/10.1002/\(SICI\)1099-0720\(199706\)11:3<211::AID-ACP430>3.0.CO;2-O](http://dx.doi.org/10.1002/(SICI)1099-0720(199706)11:3<211::AID-ACP430>3.0.CO;2-O).
- McKone, E., Kanwisher, N., Duchaine, B.C., 2007. Can generic expertise explain special processing for faces? *Trends Cogn. Sci.* 11, 8–15. <http://dx.doi.org/10.1016/j.tics.2006.11.002>.
- Megreya, A.M., Bindemann, M., Havad, C., 2011. Sex differences in unfamiliar face identification: evidence from matching tasks. *Acta Psychol.* 137, 83–89. <http://dx.doi.org/10.1016/j.actpsy.2011.03.003>.
- Megreya, A.M., Burton, A.M., 2006. Unfamiliar faces are not faces: evidence from a matching task. *Mem. Cogn.* 34, 865–876. <http://dx.doi.org/10.3758/BF03193433>.
- Megreya, A.M., Burton, A.M., 2007. Hits and false positives in face matching: a familiarity-based dissociation. *Percept. Psychophys.* 69, 1175–1184. <http://dx.doi.org/10.3758/BF03193954>.
- Miller, J., Patterson, T., Ulrich, R., 1998. Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology* 35, 99–115. <http://dx.doi.org/10.1111/1469-8986.3510099>.
- Neumann, M.F., Schweinberger, S.R., 2008. N250r and N400 ERP correlates of immediate famous face repetition are independent of perceptual load. *Brain Res.* 1239, 181–190. <http://dx.doi.org/10.1016/j.brainres.2008.08.039>.
- Parketny, J., Towler, J., Eimer, M., 2015. The activation of visual face memory and explicit face recognition are delayed in developmental prosopagnosia. *Neuropsychologia* 75, 538–547. <http://dx.doi.org/10.1016/j.neuropsychologia.2015.07.009>.
- Patterson, K.E., Baddeley, A.D., 1977. When face recognition fails. *J. Exp. Psychol.: Hum. Learn. Mem.* 3, 406–417. <http://dx.doi.org/10.1037/0278-7393.3.4.406>.
- Pfütze, E.-M., Sommer, W., Schweinberger, S.R., 2002. Age-related slowing in face and name recognition: evidence from event-related brain potentials. *Psychol. Aging* 17, 140–160. <http://dx.doi.org/10.1037/0882-7974.17.1.140>.
- Phillips, P.J., Moon, H., Rizvi, S.A., Rauss, P.J., 2000. The FERET evaluation methodology for face recognition algorithms. *IEEE Trans. Pattern Anal. Mach. Intell.* 22, 1090–1104. <http://dx.doi.org/10.1109/34.879790>.
- Phillips, P.J., Wechsler, H., Huang, J., Rauss, P., 1998. The FERET database and evaluation procedure for face recognition algorithms. *Image Vis. Comput.* 16, 295–306. [http://dx.doi.org/10.1016/S0262-8856\(97\)00070-X](http://dx.doi.org/10.1016/S0262-8856(97)00070-X).
- Pickering, E.C., Schweinberger, S.R., 2003. N200, N250r, and N400 event-related brain potentials reveal three loci of repetition priming for familiar names. *J. Exp. Psychol.: Learn. Mem. Cogn.* 29, 1298–1311. <http://dx.doi.org/10.1037/0278-7393.29.6.1298>.
- Rhodes, G., Byatt, G., Michie, P.T., Puce, A., 2004. Is the fusiform face area specialized for faces, individuation, or expert individuation? *J. Cogn. Neurosci.* 16, 189–203. <http://dx.doi.org/10.1162/0899892904322984508>.
- Russell, R., Duchaine, B., Nakayama, K., 2009. Super-recognizers: People with extraordinary face recognition ability. *Psychon. Bull. Rev.* 16, 252–257. <http://dx.doi.org/10.3758/PBR.16.2.252>.
- Schiltz, C., Rossion, B., 2006. Faces are represented holistically in the human occipito-temporal cortex. *NeuroImage* 32, 1385–1394. <http://dx.doi.org/10.1016/j.neuroimage.2006.05.037>.
- Schwaninger, A., Carbon, C.C., Leder, H., 2003. Expert face processing: specialization and constraints. In: Schwarzer, G., Leder, H. (Eds.), *Development of Face Processing*. Hogrefe, Göttingen, pp. 81–97.
- Schweinberger, S.R., Burton, A.M., 2003. Covert recognition and the neural system for face processing. *Cortex* 39, 9–30. [http://dx.doi.org/10.1016/S0010-9452\(08\)70071-6](http://dx.doi.org/10.1016/S0010-9452(08)70071-6).
- Schweinberger, S.R., Huddy, V., Burton, A.M., 2004. N250r: a face-selective brain response to stimulus repetitions. *NeuroReport* 15, 1501–1505. <http://dx.doi.org/10.1097/01.wnr.0000131675.00319.42>.
- Schweinberger, S.R., Pickering, E.C., Jentsch, I., Burton, A., Kaufmann, J.M., 2002. Event-related brain potential evidence for a response of inferior temporal cortex to familiar face repetitions. *Cogn. Brain Res.* 14, 398–409. [http://dx.doi.org/10.1016/S0926-6410\(02\)00142-8](http://dx.doi.org/10.1016/S0926-6410(02)00142-8).
- Tanaka, J.W., Curran, T., 2001. A neural basis for expert object recognition. *Psychol. Sci.* 12, 43–47. <http://dx.doi.org/10.1111/1467-9280.00308>.
- Tanaka, J.W., Curran, T., Porterfield, A.L., Collins, D., 2006. Activation of preexisting and acquired face representations: The N250 event-related potential as an index of face familiarity. *J. Cogn. Neurosci.* 18, 1488–1497. <http://dx.doi.org/10.1162/jocn.2006.18.9.1488>.
- Terry, R.L., 1993. How wearing eyeglasses affects facial recognition. *Curr. Psychol.* 12, 151–162. <http://dx.doi.org/10.1007/BF02686820>.
- Terry, R.L., 1994. Effects of facial transformations on accuracy of recognition. *J. Soc. Psychol.* 134, 483–492. <http://dx.doi.org/10.1080/00224545.1994.9712199>.
- Young, A.W., Hay, D.C., McWeeny, K.H., Flude, B.M., Ellis, A.W., 1985. Matching familiar and unfamiliar faces on internal and external features. *Perception* 14, 737–746. <http://dx.doi.org/10.1068/p140737>.
- Yovel, G., Kanwisher, N., 2005. The neural basis of the behavioral face-inversion effect. *Curr. Biol.* 15, 2256–2262. <http://dx.doi.org/10.1016/j.cub.2005.10.072>.
- Zimmermann, F.G.S., Eimer, M., 2013. Face learning and the emergence of view-independent face recognition: an event-related brain potential study. *Neuropsychologia* 51, 1320–1329. <http://dx.doi.org/10.1016/j.neuropsychologia.2013.03.028>.
- Zimmermann, F.G.S., Eimer, M., 2014. The activation of visual memory for facial identity is task-dependent: evidence from human electrophysiology. *Cortex* 54, 124–134. <http://dx.doi.org/10.1016/j.cortex.2014.02.008>.