Human brain potential correlates of repetition priming in face and name recognition

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Abstract
We investigated repetition priming in the recognition of famous people by recording event-related brain potentials (ERPs) and reaction times (RTs). Participants performed speeded two-choice responses depending on whether or not a stimulus showed a famous person. In Experiment 1, a facilitation was found in RTs to famous (but not to unfamiliar) faces when primed by the same face shown in an earlier priming phase of the experiment. In ERPs, an influence of repetition priming was observed neither for the N170 nor for a temporal N250 component which in previous studies had been shown to be sensitive to immediate face repetitions. ERPs to primed unfamiliar faces were more negative over right occipitotemporal areas than those to unprimed faces, but this effect was specific for repetitions of the same image, consistent with recent findings. In contrast, ERPs to primed familiar faces were more positive than those to unprimed faces at parietal sites from 500–600 ms after face onset, and these priming effects were comparable regardless of whether the same or a different image of the celebrity had served as prime. In Experiment 2, similar results were found for name recognition—a facilitation in RTs to primed familiar but not unfamiliar names, and a parietal positivity to primed names around 500–600 ms. ERP repetition effects showed comparable topographies for faces and names, consistent with the idea of a common underlying source. With reference to current models of face recognition, we suggest that these ERP repetition effects for familiar stimuli reflect a change in post-perceptual representations for people, rather than a neural correlate of recognition at a perceptual level.

Keywords: Priming; ERPs; Face recognition; Name recognition

1. Introduction

Human faces are very rich in social information, in providing cues not only to a person’s identity, but also to emotional state, age, gender and so forth. It is, therefore, not surprising that face perception has attracted a lot of interest in current research. Indeed, it is widely believed that face recognition is subserved by specific processes that are qualitatively different from processes underlying the recognition of other types of objects [1,20,30,31,40,41].

The present paper investigates repetition priming in the recognition of famous faces and names by recording event-related brain potentials (ERPs) and reaction times (RTs). Research on priming has contributed to our understanding of the visual recognition of words [49,50], pictures of objects [70], or faces [12,25,27,65]. Repetition priming refers to the observation that the processing of stimuli can be altered, and often enhanced, when the same stimuli have been previously encountered. Priming is often observed in terms of decreased RTs or error rates in responding to repeated, as compared with novel, stimuli and priming can be present in the absence of explicit memory for the study items [32]. Moreover, the effects of repetition often exhibit a degree of perceptual specificity, in that they are reduced when the perceptual format of the stimuli is changed between a study and a test phase [27,39,76].

Although priming effects have usually been investigated with behavioural measures, ERP studies have contributed significantly to our understanding of processes related to memory and priming [51]. ERPs have been widely used to study face perception, with many of the older studies focussing on various ERP components related to identity matching [3] or semantic matching [2], memory encoding [75], or hemispheric asymmetries for faces [68,69,73]. In contrast, many of the very recent ERP studies on neural correlates of face perception have focussed on one particular component, the N170, an electrically negative wave over occipito-temporal areas, approximately 170 ms after the onset of a face. The N170 is prominent for...
faces but absent, or strongly attenuated, for visual stimuli other than faces [6]. However, although the N170 may signal face specificity (for controversial issues, see [21]), subsequent research has shown that this component is not influenced by the familiarity of faces [7,22,60]. Similarly, the N170 is insensitive to repetition priming [5,17,66]. The available evidence, therefore, suggests that the N170 is related to early structural encoding of faces, rather than to the individual recognition of familiar faces [7,23,61].

Rather than focussing on whether or not faces are special, the present study aims at identifying processes that are involved in priming and in the recognition of individual faces. Given the insensitivity of the N170 to face familiarity, it seems likely that other ERP components would be better qualified as candidates for a neural correlate of face recognition and priming. The evidence on this issue is limited, however. In one recent study by Paller et al. [53] some faces were experimentally familiarized and the ERP differences between learned and new faces were assessed. Some faces, ‘unnamed faces’ were learned purely visually whereas others ‘named faces’ were supplemented with biographical and name information during learning. Compared with new faces, named faces elicited more electrical positivity at anterior and posterior scalp locations between 300 and 600 ms in the recognition test. For unnamed faces, however, this effect was confined to posterior sites. In another recent study by Eimer [22] famous faces were found to elicit an increased negativity between 300 and 500 ms and an increased positivity between 500 and 700 ms when compared with unfamiliar faces. Furthermore, these differences were attenuated for repeated stimuli. Although the reasons for the discrepancy between the results by Paller et al. [53] and Eimer [22] are unclear at present, these studies were designed to investigate differing issues within face recognition. The Paller et al. study used experimentally familiarized rather than famous faces, and Eimer’s study required participants to identify non-face stimuli, or immediate stimulus repetitions, rather than make familiarity decisions. Thus, task or stimulus differences may account for the different findings.

The time range of 300–700 ms in which ERP modulations due to face familiarity were identified by both Eimer [22] and Paller et al. [53] is comparable to the time range in which ERP modulations of associative priming (e.g. Gorbachev’s face as a prime for Yeltsin’s face) are observed in face recognition [63,66]. Cognitive models of face recognition assume that associative priming affects post-perceptual processing, and in particular interactions between stimulus-independent representations for personal identity (so-called “person identity nodes” or PINs) and semantic representations [15]. ERP correlates of these processes should therefore, be independent of the stimulus type (e.g. faces, personal names, voices) in which a famous person is presented. While it is unclear to what extent the familiarity effects found by Eimer [22] and Paller et al. [53] would be face-specific, there is good evidence that ERP effects of associative priming are independent of the stimulus type [63], and are thus confined to post-perceptual processing.

Two classes of ERP phenomena for faces have been discussed so far. The N170 exhibits a degree of specificity for faces, but at the same time it is insensitive to face familiarity. A class of later ERP modulations within the 300–700 ms time range appear sensitive to face familiarity, but it is unclear whether these modulations are specifically related to face processing, or whether they are governed more by semantic processing of a person’s identity.

Various groups have reported ERP modulations elicited by the repetition of faces. The most consistent finding is that ERPs elicited by repeated faces evoke more positivity (or less negativity) around 300–600 ms at parietal-central locations than ERPs elicited by new faces [3,33,35,52,56,57,72]. This effect is referred to by different groups as either the ‘ERP repetition effect’ [35,54,56,62,66], ‘old/new effect’ or as a modulation of the N400 [3,8,56]. However, it is important to note that different ERP effects of face repetitions may be elicited, depending on factors such as the familiarity of faces [66], the lag between repetitions [54], or the way in which memory for the prime face is accessed (direct or indirect [33]). While the ERP repetition effects between 300 and 600 ms at parietal-central locations may well be functionally similar to the N400, the standard N400 is typically elicited in rather different experimental settings. In the present study, we will therefore use the term ‘ERP repetition effect’ as a theoretically neutral and convenient shorthand label.

Of particular interest for the present study, recent research has identified a distinct ERP modulation as a result of the immediate repetition of faces. This effect is seen in the time range in between the N170 and the above-mentioned later modulations beyond 300 ms. Schweinberger et al. [66] found that immediate repetition of faces caused an increased negativity between 180 and 290 ms at inferior temporal sites. This relatively early ERP repetition effect peaked around 250 ms ‘N250r’ and was strongly lateralized to the right hemisphere (for similar results, see also [5]). This effect could only partially be related to representations for familiar faces, because the effect was observed for unfamiliar faces as well, though with reduced amplitude. However,
subsequent research showed that when between two and four other faces intervened between repetitions, repetition priming still caused increased negativity at right inferior temporal sites, but only for repeated familiar faces [54].

Relative to immediate repetitions, this effect was smaller in amplitude and had a slightly longer peak latency (around 280 ms). Repetition of written personal names also caused increased negativity at inferior temporal electrodes for familiar but not unfamiliar names. However, the effect for names was observed predominantly over left temporal areas (for further evidence that ERPs can differentiate brain systems subserving memory for faces and names, see [74]). These two features of this ERP effect—specificity for familiar stimuli and different topography for faces and names—suggest that it does not reflect a general facilitation of perceptual encoding, nor does it reflect a stimulus-independent facilitation of semantic processing. In terms of cognitive models of face recognition [13–15,81], this ERP effect may therefore reflect the transient activation of perceptual recognition units for faces and names (FRUs and NRUs, respectively).

The aim of this study is to investigate ERP correlates of repetition priming over longer time intervals (i.e. more than 15 min) and in a situation in which many more (i.e. several hundreds) stimuli intervene between any repetitions. A large body of experimental studies has demonstrated behavioural repetition priming under those conditions (e.g. [11,12,25,27,28]). For some time, researchers tended to explain repetition priming in terms of increased activation levels, or decreased thresholds, at the level of recognition units [12,50]. However, more recent models of face recognition argue that changes at the level of recognition units are rather than a change in activation levels of the representation of a person’s identity. The idea that long-term priming still caused increased negativity at right inferior temporal electrodes for familiar but not unfamiliar names. However, the effect for names was observed predominantly over left temporal areas (for further evidence that ERPs can differentiate brain systems subserving memory for faces and names, see [74]). These two features of this ERP effect—specificity for familiar stimuli and different topography for faces and names—suggest that it does not reflect a general facilitation of perceptual encoding, nor does it reflect a stimulus-independent facilitation of semantic processing. In terms of cognitive models of face recognition [13–15,81], this ERP effect may therefore reflect the transient activation of perceptual recognition units for faces and names (FRUs and NRUs, respectively).
stimulus-specific perceptual levels of processing, i.e. in FRU or NRU activation. Divergent ERP repetition effects for faces and names should also be seen to the extent that these effects directly reflect a strengthening of stimulus-specific (either FRU–PIN or NRU–PIN) links. It is also noteworthy that research into the N400 ERP component has suggested topographical differences between responses to pictures of objects and words [29,48]. These findings suggest that the neural generators for the effects with different domains of stimuli are non-identical, implying that semantic knowledge might not be stored in a domain-independent manner (for a recent review, see [44]). For present purposes, findings of an N400-like ERP repetition effect which differs topographically between faces and names might, therefore, give rise to the possibility that semantic knowledge for people may be stored in a domain-specific manner. This type of finding would be in some contrast to current models of face perception [13–15] which suggest that knowledge for people is accessed via PINs in a domain-independent manner. Thus, if ERP correlates of priming reflected changes only at the level of domain-independent PINs (even if these were ultimately a result of a strengthening of either FRU–PIN or NRU–PIN links, respectively), they should be comparable for faces and names.

2. Experiment 1

2.1. Method

2.1.1. Participants

Eighteen participants (10 women and 8 men) aged between 17 and 50 years (M = 22.7 years, S.D. = 7.9 years) were paid to contribute data to this study. All participants reported normal or corrected-to-normal visual acuity. Three further participants were excluded and replaced because of technical problems in data acquisition.

2.2. Stimuli and apparatus

Photographs of faces of 90 famous people from various areas (e.g. politics, entertainment, sports, TV) were used in the present experiment. Photographs of faces were also obtained from 90 unfamiliar people. Famous faces were either obtained via the internet from various celebrity websites, or were scanned from magazines. Unfamiliar faces were also obtained from various sources including model agency websites, magazines, and photographs made available for research purposes by colleagues in various universities. Famous faces were matched to unfamiliar counterparts with respect to gender and approximate age. Both famous and unfamiliar faces consisted of approximately equal numbers of men and women (47 men and 43 women). Two different photographs were used for each person, resulting in a set of 360 faces in total (90 famous and 90 unfamiliar faces with two portraits of each). The celebrities were selected on the basis of high ratings for ease of face recognition.

Faces were obtained from different sources but were all software-edited using Adobe Photoshop®. All faces were converted to greyscale, all background was removed, and each face was framed within an area 170 pixels (wide) × 216 pixels high, corresponding to 6.0 cm × 7.6 cm. An attempt was also made to homogenise the stimuli with respect to average luminance and contrast. Mean luminance values for familiar and unfamiliar stimuli (M = 50.9 and 50.8 cd/m², respectively) were equivalent.

Both the 90 familiar and the 90 unfamiliar faces were further subdivided into three sets (with 30 faces each). The assignment of face set to experimental condition (unprimed, primed same, primed different; see later) was completely counterbalanced across participants.

2.3. Procedure

The experiment consisted of a priming and a test phase. After the electroencephalogram (EEG) electrodes were applied and prior to the experiment, participants received written task instructions. During the priming phase, participants viewed a series of 120 faces (60 famous and 60 unfamiliar) in randomised order. Twelve faces preceded these critical faces for practice reasons; the faces shown in these practice trials were not shown subsequently.

The interval between the onsets of successive face stimuli was 4000 ms. At the beginning of each trial, a fixation cross appeared for 1000 ms and was then replaced by a face stimulus, presented for 2000 ms and followed by a blank screen for another 1000 ms. For every face, participants decided by speeded two-choice key presses whether it represented a famous or an unfamiliar person. Participants were asked to respond as quickly and accurately as possible. They used simultaneous key presses of the two middle fingers to indicate a famous person, and simultaneous key presses of the two index fingers to indicate an unfamiliar person. Incorrect or missing responses were indicated by a brief feedback tone (500 Hz, 250 ms).

During one block of the test phase, participants viewed a series of 180 critical faces (90 famous and 90 unfamiliar), again with an additional 12 unrelated practice faces preceding these critical faces at the beginning of the block. Participants completed a familiarity judgement for each stimulus as before. Face stimuli from three conditions were presented in random order. One-third of stimuli were presented for the first time (unprimed condition). One-third of stimuli were repeated from the priming phase (primed same condition). One-third of stimuli showed a face that had been viewed in the priming phase, but this time a different photograph was used (primed different condition). In both the priming phase...
and the test phase, short breaks were allowed after every 60 critical trials.

The priming and test phases of Experiment 1 were intertwined with the priming and test phases of Experiment 2 that investigated name recognition (see later). Therefore, the priming and test phases of Experiment 1 were separated by a block in which participants recognized names. Any famous names used in this block were from different people to those used in the face recognition experiment, so that any potential contribution from cross-domain repetition priming [16] was avoided. There was an additional block of trials in which participants performed blinks (20 trials), as well as deliberate horizontal and vertical eye movements of predefined visual angle (10 trials each). These trials served as an individual calibration used for the correction of ocular contributions to the EEG (see later).

The order of Experiments 1 and 2, with intertwined priming and test phases, was counterbalanced across participants. In short, the order of blocks for one-half of the participants was priming phase E1, priming phase E2, electrooculogram (EOG) calibration block, test phase E1, test phase E2 (E1 and E2 refer to Experiments 1 and 2, respectively). For the other half of the participants, the order was priming phase E2, priming phase E1, EOG calibration block, test phase E2, test phase E1. The minimum time between repetitions, calculated simply as the interval between the end of the priming phase and the beginning of the respective test phase, was approximately 15 min (M = 15.3 min, range 14–17 min), with the small variability across participants being a result of slightly different times that these participants had used for breaks. The absolute minimum number of stimuli between any repetitions, including stimuli used as triggers in the EOG calibration trials but not including instructions that were displayed on the screen in order to announce different phases of the experiment, was 184. The average time between a prime and a target face was, approximately 30 min, the average number of stimuli intervening between any repetitions was 340.

2.4. Performance

Responses were scored as correct if the correct combination of keys was pressed within a time window lasting from 100 to 2000 ms after stimulus onset. Errors of omission (no key press), of commission (wrong key combination), and inconsistent responses (e.g. a simultaneous key press of one index finger and the other middle finger) were recorded separately. Mean RTs were calculated for correct responses only.

2.5. Event-related potentials

The EEG was recorded with sintered Ag/AgCl electrodes mounted in an electrode cap (Easy-Cap™) at the scalp positions Fp1, Fp2, C3, C4, T3, T4, P3, P4, O1, O2, F3, F7, F8, T7, T8, P7, P8, F7, F8, TP9, TP10, FT9, FT10, P7, P8, P9, P10, PO7, PO8, PO9, PO10, C3, C4, Fp1, Fp2, TP9 and TP10. Note that the T7, T8, P7, and P8 locations are equivalent to T3, T4, T5, and T6 in the old nomenclature [55]. The C3 electrode was positioned 0.75 cm anterior to the midpoint of a straight line between C4 and C2, and the C4 electrode was positioned 0.75 cm anterior to the midpoint of a straight line between C3 and C2. The Fp1 electrode was positioned 2 cm anterior to F7 at the outer canthus of the left eye, and the Fp2 electrode was positioned 2 cm anterior to F8 at the outer canthus of the right eye. The positions TP9 and TP10 refer to inferior temporal locations over the left and right mastoids, respectively. The TP9 (right upper mastoid) electrode served as initial common reference, and a forehead electrode (AFz) served as ground. Electrode impedances were kept below 10 kΩ and were typically below 5 kΩ. The horizontal EOG was recorded from Fp1 and Fp2, at the outer canthi of both eyes, and the vertical EOG was monitored from an electrode above the right eye against an electrode below the right eye. All signals were recorded in DC mode, with low-pass filters set to 40 Hz (−6 dB attenuation at a slope of approximately 12 dB per octave), and sampled at a rate of 250 Hz.

Offline, epochs were generated that lasted from 200 ms before stimulus onset until 2000 ms after stimulus onset. Automatic artifact detection software was run for an initial sorting of trials, and all trials were then visually inspected for artifacts of ocular (e.g. blinks, saccades) and non-ocular origin (e.g. channel blockings or drifts). Trials with non-ocular artifacts, trials with saccades, and trials with incorrect behavioural responses were discarded. For all remaining trials, ocular blink contributions to the EEG were corrected [24]. ERPs were averaged separately for each channel and for each experimental condition. Each averaged ERP was low-pass filtered at 10 Hz with a zero phase shift digital filter, and re-calculated to average reference, excluding the vertical EOG channel.

3. Results

3.1. Behaviour

Mean error rates and RTs to faces in the test phase are shown in Table 1. No omissions were observed. Average

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<th>RT Mean (ms)</th>
<th>PE Mean</th>
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<tr>
<td>Famous target face</td>
<td>Unprimed 847 7.4</td>
<td>Primed same 751 3.7</td>
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<td>Primed different 775 4.5</td>
<td>Mean 791 5.2</td>
</tr>
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| Unfamiliar target face | Unprimed 822 4.1 | Primed same 819 3.3 |
|                       | Primed different 811 2.4 | Mean 817 3.3 |
percentages of errors (PE) of commission and inconsistent responses were 4.2 and 0.4%, respectively. An inspection of Table 1 shows that error rates varied with priming conditions in a similar way as RTs did. As there was, therefore, no evidence of a speed-accuracy trade-off and because error rates were so low, they were not analysed further.

Mean correct RTs were submitted to an analysis of variance (ANOVA) with repeated measures on familiarity (famous versus unfamiliar) and priming (unprimed versus primed same versus primed different). Where appropriate, we performed epsilon corrections for heterogeneity of covariances with the Huynh–Feldt method [37] throughout.

The ANOVA on RTs revealed a significant effect of priming, $F(2, 34) = 17.9, P < 0.001$, and a trend for a main effect of familiarity, $F(1, 17) = 3.6, P = 0.07$. Most importantly, these main effects were moderated by a significant interaction between priming and familiarity, $F(2, 34) = 12.2, P < 0.001$. The interaction was further evaluated by performing separate ANOVAs for famous and unfamiliar faces. Priming was highly significant for famous faces, $F(2, 34) = 24.2, P < 0.001$. Bonferroni-corrected paired contrasts revealed that, relative to the unprimed condition, priming was significant both by the same, $F(1, 17) = 56.6, P < 0.001$, and by different pictures of the target celebrity, $F(1, 17) = 18.0, P < 0.01$. The RTs in the primed same and primed different conditions did not differ significantly, $F(1, 17) = 3.4, P > 0.10$. Priming did not affect RTs for unfamiliar faces, $F(2, 34) < 1$.

3.2. Event-related potentials

The mean number of error- and artifact-free trials (out of a possible maximum of 30) that contributed to an individual averaged ERP for famous faces in the primed same, primed different, and unprimed conditions were 26.1, 25.9, and 24.2, respectively. For unfamiliar faces, the respective numbers were 25.8, 25.8, and 25.8. ERPs to target faces were quantified by mean amplitude measures in the time segments 100–140 ms (occipital P120), 160–200 ms (occipito-temporal N170), 200–300, 300–400, 400–500, 500–600, 600–700, 700–800 and 800–1200 ms. The first two segments were chosen to correspond to distinct peaks in the waveforms; the following 100 ms segments and the final 400 ms segment were arbitrarily chosen.
For every time segment, ANOVAs were then performed, with repeated measures on the variables familiarity (famous versus unfamiliar), priming (primed same versus primed different versus unprimed), and electrode (32 levels). Note that because the average reference sets the mean activity across all electrodes to zero, any condition effects in these ANOVAs are only meaningful in interaction with electrode site. Therefore, any condition effect reported below is in interaction with electrode site. If significant effects of priming showed up in these overall ANOVAs, additional analyses were performed on specific regions of interest (ROIs) in order further to locate these effects. These ROIs were (a) prefrontal/lateral frontal (Fp1, Fp2, F7, F8, FT9, FT10, F9, F10), (b) frontal-central (F3, F4, Fz, C3, C4), (c) central-parietal (Cz, Pz, C3, C4, P3, P4), (d) temporal (T3, T4, T5, T6, TP9, TP10, P5, P10), and (e) occipital (O1, O2, PO9, PO10).

For both the 100–140 ms segment and the 160–200 ms segment which encompasses the N170, no significant effects of priming or familiarity were observed, and there was also no interaction between these variables, all F values < 1.3.

Fig. 1 shows the priming effects for famous faces. Effects of priming were most clear in the 500–600 ms segment, F(62, 1064) = 2.7, P < 0.01. Most importantly, there was a clear interaction between priming and familiarity in the 500–600 ms segment, F(62, 1064) = 4.6, P < 0.001. This interaction was also observed in the 600–700 ms segment, F(62, 1064) = 2.7, P < 0.01. In the 700–800 ms segment, both the effects of priming and the interaction of priming and familiarity reduced to trends, F(62, 1064) = 1.7, P = 0.09, and F(62, 1064) = 1.7, P = 0.08, respectively, and the effects had vanished in the 800–1200 ms segment, F(62, 1064) < 1.55, P > 0.10.

In order to evaluate further the interactions between priming and familiarity observed in the 500–600 ms and 600–700 ms segments, separate ANOVAs were performed for famous and unfamiliar faces. In the 500–600 ms segment, priming was significant for famous faces, F(62, 1064) = 5.3, P < 0.001, but not for unfamiliar faces, F(62, 1064) = 1.9, P = 0.07 (see also Figs. 2–4). Bonferroni-corrected paired contrasts revealed that relative to the unprimed condition, priming for famous faces was significant both by the same, F(31, 527) = 8.6, P < 0.001, and by different pictures of the target celebrity, F(31, 527) = 5.8, P < 0.001, whereas ERPs did not differ between the primed same and the primed different conditions, F(31, 527) = 1.4, P > 0.10. The ROI analysis revealed significant priming effects at prefrontal/lateral frontal sites, F(2, 34) = 11.3,
Fig. 3. ERP difference waves calculated by subtracting ERPs to unprimed faces from either ERPs to faces primed by either the same image or by a different image of the same person. Traces for familiar faces, recordings shown were (from top to bottom) from prefrontal, frontal, parietal, temporal, and temporo-occipital sites, over the left and right hemisphere, respectively. Arrows indicate the ERP repetition effect around 500–600 ms at parietal electrodes.

In the 600–700 ms segment, priming just failed to reach significance for famous faces, $F(2, 34) = 2.0, P < 0.0503$, whereas a significant effect occurred for unfamiliar faces, $F(2, 1064) = 2.2, P < 0.05$. Bonferroni-corrected paired contrasts for this latter effect revealed only a difference between the unprimed condition and the primed same condition, $F(31, 527) = 3.5, P < 0.05$, (cf. Fig. 4) but not for the other two comparisons, $P_s > 0.10$. The ROI analysis revealed that this effect was only significant at central-parietal sites, $F(1, 17) = 5.1, P < 0.05$.

Finally, there were highly significant effects of face familiarity for all time segments from 300 to 1200 ms, $F_s (31, 527) > 4.8, P_s < 0.001$, and there was an almost significant trend for familiarity already in the 200–300 ms segment, $F(31, 527) = 2.3, P = 0.06$. Relative to unfamiliar faces, familiar faces elicited more positivity at frontal, central, and parietal electrodes, and a strong posterior temporal negativity (not shown), in line with recent findings [53].

The performance data in this experiment suggest that long-term repetition facilitates the recognition of familiar but not unfamiliar faces, a finding which is in line with previous research [9, 12, 25–27]. These effects were similar regardless of whether a famous face was primed by the identical picture, or whether it was primed by a different picture of the celebrity. This suggests that the present priming effects were dependent on the repetition of a familiar face, rather than on the repetition of the same image.

Clear priming effects for familiar but not unfamiliar faces were also observed in the ERP data. As expected, the N170 was unaffected by priming. Notably, a negativity in the time range between 200 and 300 ms (N250) at inferior temporal sites that was previously demonstrated to be sensitive to immediate face repetitions [5, 66] or repetitions across a very small number of intervening items [54] was absent in the present data, suggesting that this ERP component is insensitive to repetition priming across longer intervals. Instead, priming effects for familiar faces were most clear during the time segment 500–600 ms. The latency and topography of this ERP modulation, with primed faces showing more
positivity at parietal-central sites and more negativity at prefrontal and lateral frontal sites, is similar to ERP modulations previously reported for faces. Specifically, similar modulations between around 300 and 600 ms have been reported as a result of associative priming [63] and repetition priming [8, 54, 56, 66]. Both its relatively long latency and its similarity (in terms of topography) to “semantic” ERP modulations such as the well-known N400 component argue for a post-perceptual locus of this ERP priming effect. Similar N400-like ERP modulations have been observed in the absence of P300 effects [56], and thus it is unlikely that the present ERP repetition effect can be attributed to a correlation between RTs and the P300 component. If this ERP correlate of long-term repetition priming for famous faces indeed reflects an effect at the level of PINs and semantic information (rather than an effect on perceptual representations of faces), then one straightforward prediction is that a similar ERP repetition effect should be observed for famous names. If, on the other hand, this ERP repetition effect reflected the transient activation of stimulus-specific representations of familiar faces, then a different ERP repetition effect should be seen for familiar names. To investigate this issue further, Experiment 2 studied repetition effects for personal names of celebrities.

5. Experiment 2

5.1. Method

5.1.1. Participants

The same 18 participants that contributed data to Experiment 1 also took part in Experiment 2. The order of the experiments was counterbalanced as described in the procedure section.

5.2. Stimuli and apparatus

The names of 90 famous people from various areas (e.g. politics, entertainment, sports, TV) were used and 90 unfamiliar names were also prepared. Note that none of the 90 celebrities whose names were used had appeared as faces in Experiment 1, so that any potential contribution from cross-domain repetition priming [16] was eliminated. The celebrities were selected on the basis of high ratings for ease of name recognition in a preliminary study, scoring an average of 1.99 out of 2 (range: 1.64–2, means across the same 11 raters and on the same rating scale that had been used for the celebrities in Experiment 1). Each unfamiliar name was matched to a famous name with respect to gender, number of syllables, and cultural background (most names were Anglo-American but to give an example, for famous names Monica Lewinsky and Diego Maradona, respective unfamiliar names Dorothy Rularsky and Franco Donatelli were chosen). Two different versions of each name were prepared that differed only with respect to the font in which the name was printed. The two fonts used were IBM-8bit (60 pt), and Courier New (also 60 pt). Names were presented in block capitals, forename above surname, in the centre of the screen. Characters were 6 mm in height. During the priming phase, half of the names were presented in IBM-8bit, and half were presented in Courier New. During the test phase, IBM-8bit font was always used. Assignment of stimuli to font for the priming phase was counterbalanced across participants.

During the test phase, names from three conditions were presented in random order. One-third of names were presented for the first time (unprimed condition). One-third of names were repeated from the priming phase, in which they had been presented in the same font (primed same condition). One-third of stimuli showed a name that had been presented in the priming phase, but using a different font type (primed different condition). As in Experiment 1, short breaks were allowed after every 60 critical trials.

5.3. Procedure and data acquisition

Except for the use of names as stimuli, all aspects of the procedure were completely analogous to those in Experiment 1. Performance and ERP data were collected in exactly the same way as in Experiment 1.

6. Results

6.1. Behaviour

The average percentage of errors of commission and inconsistent responses were 3.4 and 0.3%, respectively. No omissions were observed. An inspection of Table 2 shows that error rates varied with priming conditions in a similar way as RTs did. As there was, therefore, no evidence of a speed-accuracy trade-off and because error rates were so low, they were not analysed further. Mean correct RTs were submitted to an ANOVA with repeated measures on

<table>
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<th>Condition</th>
<th>RT (ms)</th>
<th>PE</th>
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<td>Famous target name</td>
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<td></td>
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<tr>
<td>Unprimed</td>
<td>826</td>
<td>7.0</td>
</tr>
<tr>
<td>Primed same</td>
<td>742</td>
<td>2.2</td>
</tr>
<tr>
<td>Primed different</td>
<td>745</td>
<td>3.4</td>
</tr>
<tr>
<td>Mean</td>
<td>771</td>
<td>4.2</td>
</tr>
<tr>
<td>Unfamiliar target name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unprimed</td>
<td>855</td>
<td>1.1</td>
</tr>
<tr>
<td>Primed same</td>
<td>866</td>
<td>3.3</td>
</tr>
<tr>
<td>Primed different</td>
<td>880</td>
<td>3.5</td>
</tr>
<tr>
<td>Mean</td>
<td>867</td>
<td>2.7</td>
</tr>
</tbody>
</table>
familiarity (famous versus unfamiliar) and priming (unprimed versus primed same versus primed different).

Mean error rates and RTs to names in the test phase can be seen in Table 2. The ANOVA on RTs revealed a significant effect of priming, \( F(2, 34) = 12.3, P < 0.001 \), and a significant effect of familiarity, \( F(1, 17) = 54.2, P < 0.001 \). These main effects were moderated by an interaction between priming and familiarity, \( F(2, 34) = 26.5, P < 0.001 \). The interaction was further evaluated by performing separate ANOVAs for famous and unfamiliar names. Priming was highly significant for famous names, \( F(2, 34) = 34.2, P < 0.001 \). Bonferroni-corrected paired contrasts revealed that, relative to the unprimed condition, priming was significant both by prime names printed in the same font, \( F(1, 17) = 51.0, P < 0.001 \), and by prime names printed in a different font from the target name, \( F(1, 17) = 39.8, P < 0.001 \). The RTs in the primed same and primed different conditions did not differ significantly, \( F(1, 17) < 1 \). For unfamiliar names, priming did not significantly affect RTs, although there appeared to be some trend for slower RTs to names that were primed by the same name in a different font, \( F(2, 34) = 2.8, P = 0.08 \).

6.2. Event-related potentials

The mean number of error- and artifact-free trials (out of a possible maximum of 30) that contributed to an individual averaged ERP for famous names in the primed same, primed different, and unprimed conditions were 24.5, 24.3, and 24.2, respectively. For unfamiliar names, the respective numbers were 25.6, 25.2, and 25.8. ERPs to target names were quantified by mean amplitude measures in the time segments 100–140 ms (occipital P120), 160–200 ms (occipito-temporal N170), 200–300, 300–400, 400–500, 500–600, 600–700, 700–800 and 800–1200 ms. The first two segments were chosen to correspond to distinct peaks in the waveforms; the following 100 ms segments and the final 400 ms segment were arbitrarily chosen.

For every time segment, ANOVAs were then performed analogous to those reported in Experiment 1. For the 100–140 ms segment, the 160–200 ms segment, and the 200–300 ms segment, no significant effects of priming or familiarity were observed, and there was also no interaction between these variables, all \( F \) values < 1.93. Effects of priming were observed in the 300–400 ms segment, \( F(62, 1064) = 2.2, P < 0.05 \), and in the 500–600 ms segment, \( F(62, 1064) = 2.2, P < 0.05 \), and in the 500–600 ms segment, \( F(62, 1064) = 2.2, P < 0.05 \), and in the 500–600 ms

![Fig. 5. ERPs in Experiment 2 recorded during the test phase for familiar names that were unprimed (solid lines) or that had been primed by the same name in the same (dashed lines) or a different (dotted lines) font in the priming phase. Recordings are shown for all 32 channels used. Arrows indicate the ERP repetition effect around 500–600 ms at parietal electrodes.](image-url)
segment, $F(62, 1064) = 2.0, P < 0.05$. There was a trend for a priming effect in the 600–700 ms segment, $F(62, 1064) = 1.7, P = 0.08$. Although interactions between priming and familiarity did not reach significance, $F_s(62, 1064) = 1.1, 1.6, and 1.4$, for 300–400 ms, 500–600 ms, and 600–700 ms segments, respectively, separate ANOVAs were performed for famous and unfamiliar names.

In the 300–400 ms segment, priming was not significant for famous names, $F(62, 1064) = 1.6, P > 0.10$, but priming approached significance for unfamiliar names, $F(62, 1064) = 1.7, P = 0.09$. Paired contrasts for this effect for unfamiliar names only revealed that, whereas the other two comparisons were far from significant, there was a marginal difference between the unprimed condition and the primed same condition (although this vanished after Bonferroni correction), $F(31, 527) = 2.1$, uncorrected $P = 0.06$, corrected $P = 0.18$. Thus, there was only a marginal priming effect for unfamiliar names when primed by the identical stimulus (also cf. Fig. 8).

In contrast, priming for famous names was significant in the 500–600 ms and the 600–700 ms segments, $F(62, 1064) = 2.7, P < 0.01$, and $F(62, 1064) = 2.3, P < 0.05$, respectively (see Figs. 5–7). Bonferroni-corrected paired contrasts suggested that, relative to the unprimed condition, there was significant priming for famous names by prime names in same font as the target name for the 500–600 ms segment, and a strong trend was present in the 600–700 ms segment, $F_s(31, 527) = 3.4$ and $2.8, P < 0.05$ and $P = 0.067$, respectively. There was also priming by prime names in different font from the target name, $F(31, 527) = 3.4$ and $3.5, P < 0.05$ and $P < 0.01$, for the 500–600 ms and 600–700 ms segments, respectively. ERPs did not differ between the primed same and the primed different conditions, $F_s(31, 527) < 1$. For both the 500–600 ms and 600–700 ms segments, the ROI analysis revealed significant priming effects at prefrontal/lateral frontal sites, $F(2, 34) = 7.0, P < 0.01$, and $F(2, 34) = 4.9, P < 0.05$, respectively, and at central-parietal sites, $F(2, 34) = 5.2, P = 0.01$, and $F(2, 34) = 4.3, P < 0.05$, respectively, but not at the other regions. For unfamiliar names, no significant priming effects between 500 and 700 ms were observed, $F_s(62, 1064) < 1$, see Fig. 8.

Finally, there were highly significant effects of name familiarity for all time segments from 300 to 800 ms, $F_s(31, 527) > 5.7, P_s < 0.001$, and also from 800–1200 ms, $F_s(31, 527) = 2.9, P < 0.05$. Relative to unfamiliar names, familiar names elicited more positivity at parietal sites, and more negativity at both temporal and lateral frontal electrodes (not shown).
7. Discussion

The performance data in this experiment on name recognition were remarkably similar to those observed for faces. Long-term repetition facilitated the recognition of familiar but not unfamiliar names, and similar effects were seen regardless of whether the prime for a famous target name was printed in the same font or in a different font. This suggests that the present priming effects were dependent on the repetition of a famous name, but that the precise repetition of the visual stimulus was not critical for this effect to occur. The only small difference relative to Experiment 1 was that there was a trend for slower responses to primed unfamiliar names. This observation might be related to previously reported "false fame" effects that can be caused by priming. Accordingly, an unfamiliar name that has been previously seen elicits some feeling of familiarity that may be misattributed as fame (see [38]).

Similar to what was seen in Experiment 1 for familiar faces, ERP repetition effects for names were again largely confined to familiar names. The absence of a repetition effect for unfamiliar names is interesting when considering the longevity of ERP repetition effects for regular words. Other research [18,78] suggests that proper names and words are differently represented in the cognitive system. With respect to the absence of an ERP repetition effect, it is interesting that unfamiliar names appear to behave like pseudowords. This suggests that the ERP repetition effect depends on a pre-existing memory representation, rather than on the meaningfulness of material.

The time segments 500–700 ms during which these priming effects were significant were also comparable to what was seen in Experiment 1. Similarly, the topography of the ERP repetition effect for names was similar to that seen for faces (also compare Figs. 1, 3, 5 and 7). Again, no effects of priming were seen on ERP components before 300 ms. These results argue for a post-perceptual locus of this ERP priming effect, suggesting that the ERP repetition effects seen in this study for both familiar faces and familiar names reflect a facilitated access at a common level of PI Ns and semantic information for people. In contrast, there is no evidence for a facilitation at the level of different stimulus-specific perceptual processes for faces and names.

However, this preliminary comparison between experiments is based on a visual comparison of effects only. In order to evaluate more formally whether or not the topography
of the ERP repetition effects observed for famous faces and famous names were qualitatively different, we calculated the difference waves between primed same and unprimed ERPs, and between primed different and unprimed ERPs, for each stimulus type. We then scaled mean amplitudes of these differences in the 500–600 ms segment for each participant across all electrodes, with the average distance from the mean, calculated from the grand mean ERP, as divisor. This procedure preserves the profile of the scalp topography while eliminating any remaining overall amplitude differences. The rationale for this procedure is based on the fact that qualitative differences in scalp topography of different effects demonstrate that these effects must have been generated by at least partially different brain sources, suggesting different cognitive processes [47].

The scaled amplitudes were submitted to a $2 \times 2 \times 32$ ANOVA with the variables Prime-Target similarity (primed same minus unprimed versus primed different minus unprimed), stimulus type (familiar faces versus familiar names), and site (32 levels). This ANOVA revealed a significant main effect of electrode site, $F(31, 527) = 8.00, P < 0.001$, indicating a topography of the priming effect that was systematically different from zero. However, there were no interactions of site with stimulus type, $F(31, 527) = 1.02, P > 0.10$, nor were there any interactions with prime-target similarity, $F(31, 527) = 1.20, P > 0.10$, or a three-way interaction, $F(31, 527) < 1$. To summarize, this formal analysis gives no evidence that the ERP repetition effects for familiar faces and familiar names were generated by different brain sources. Therefore, these results are in line with the view that the present ERP repetition effects reflect a modulation of cognitive processes common to faces and names.

8. General discussion

For both familiar faces and familiar names, the present experiments have revealed clear behavioural and electrophysiological effects of repetition priming across relatively long intervals in excess of 15 min and 100 intervening stimuli. A major finding of the present study is the very specific effect of priming on some ERP components but not on others. Firstly, the N170 component was found to be completely independent of face repetition priming. This confirms and extends earlier research in which repetitions across very short lags were demonstrated not to modulate the N170 [5,54,66]. In addition—even though this was not the main aim of the present study—we also found that face familiarity had no effect on the N170, consistent with recent research [7,22,60]. Secondly, it has been shown previously that face repetitions across very short lags modulate a right temporal ‘N250r’ component around 250 ms [5,66,67], an effect that has been related to the facilitated access to stored facial representations or FRUs [54]. However, no modulation of this component was seen in the present study with face repetitions across longer intervals. This is in line with the idea that the present ERP repetition effects do not reflect changes in face processing at the FRU level. Presumably, these changes are too transient to survive the considerable lag between prime and target used in the present study [14,15].

In that respect, it is interesting to note that the amplitude of the ‘N250r’ modulation decreased, to approximately one-third when between two and four faces intervened between repetitions [54], relative to its amplitude for immediate repetitions in otherwise similar conditions [66]. This would seem to suggest that the effect does not last for more than a few seconds and intervening stimuli—although it is not yet completely clear whether the critical variable is time or number of intervening stimuli. Notably, recent behavioural research has demonstrated systematic aftereffects of an adaptation to an individual face for the subsequent perception of face identity, with a roughly similar time course [45]. Although the time course of ERP repetition effects for faces needs more systematic study, these results in combination support the idea that an activation of face representations dissipates quickly within a few seconds. Therefore, more long-lasting repetition effects probably require an explanation in terms of different mechanisms.

Repetition priming effects have been modelled using a structural model of person recognition with an interactive activation architecture [14,15,25]. Specifically, the repeated presentation of a familiar face is thought to strengthen the activation architecture of person identity, which then facilitates the recognition of subsequently presented faces [35,38]. However, repetition priming effects have also been conceptualised as a bias [58,59,64]. In the context of the present study, a bias pattern of priming would be characterized by an increased tendency to respond “familiar” to both famous and unfamiliar stimuli when repeated, resulting in performance benefits for familiar stimuli, but costs for unfamiliar stimuli. This is clearly not the pattern of priming observed in the present experiments, in which performance benefits for famous stimuli were seen without costs for unfamiliar stimuli. Accordingly, a structural account provides a more straightforward explanation for the present priming effects than bias. However, a significant observation may be that a bias pattern of results is typically reported under conditions of relatively high stimulus uncertainty, for instance, when stimuli were personal names of only moderately famous celebrities [38], or celebrities’ voices which are very hard to recognize [64]. In contrast, we note that recognition rates for the faces and names of celebrities used in the present experiments were extremely high (>95%). High recognition rates are also typical for other studies in face repetition priming that put forward a structural account for the effects [25–27], and thus face recognition performance in these studies presumably relied on the access to very well-established memory representations for the celebrities. In sum, bias accounts of priming might be appropriate to
faces, but also that the same site of activation is seen for increased activity in retrosplenial cortex relative to unfamiliar research to suggest that not only do familiar faces elicit evidence from functional magnetic resonance imaging (fMRI) as faces, personal names, or famous landmarks). In that objects versus semantic memory for unique items (such dissociation of semantic memory for common words and because evidence exists (e.g. [42]) for a neuropsychological ent patterns of results are not necessarily in contradiction, in a domain-specific manner [29, 44]. However, these differences suggested that semantic knowledge might be stored in some contrast to the effects seen with common words and names, it does not necessarily imply that the same mechanisms mediate this effect. Rather, we think that a strengthening of stimulus-specific links (from FRUs to PINs in the case of faces, from NRUs to PINs in the case of names) is the stimulus-specific mechanism that mediates priming, whereas a faster and more efficient access to PINs and semantic information is the common effect caused by these mechanisms. Of particular interest, this explanation generates testable predictions for future evaluation. Specifically, on the basis of our interpretation we predict that the present ERP repetition effect should disappear for cross-domain repetition priming across long intervals (e.g. using a name as a prime for a familiar face in the test phase, and vice versa), in a similar way as behavioural repetition effects disappear under these conditions [27]. It is important to note that this prediction holds for a familiarity task in which one can argue that no common links are strengthened for faces and names. In contrast, cross-domain repetition priming can be demonstrated for tasks that involve common routes for faces and names, such as semantic judgment or name production [16, 25].

On a more general level, the present data also support the idea that semantic information about people is stored in an abstract way and independent of the precise perceptual input [15, 63], at least to the extent that the results imply that the same brain systems and cognitive processes mediate “semantic” levels of person recognition. This finding is in some contrast to the effects seen with common words and pictures of objects, for which topographical ERP differences suggested that semantic knowledge might be stored in a domain-specific manner [29, 44]. However, these different patterns of results are not necessarily in contradiction, because evidence exists (e.g. [42]) for a neuropsychological dissociation of semantic memory for common words and objects versus semantic memory for unique items (such as faces, personal names, or famous landmarks). In that respect, it is interesting that there is now preliminary evidence from functional magnetic resonance imaging (fMRI) research to suggest that not only do familiar faces elicit increased activity in retrosplenial cortex relative to unfamiliar faces, but also that the same site of activation is seen for familiar relative to unfamiliar voices [71]. Together with the present findings, such data support the idea that following stimulus and modality-specific perceptual analysis, information then converges into common and stimulus-independent processes of person recognition.

It is worth noting that ERP repetition effects for unfamiliar stimuli, although weak, were not completely absent. Instead, a significant effect was observed in Experiment 1 in the 600–700 ms time segment. However, unlike the effect for familiar faces, this repetition effect for unfamiliar faces was stimulus-specific. That is, it was seen for repetitions of the same image but not for repetitions of the same face across different images. Of particular interest, Fig. 4 suggests that stimulus-specific repetition effects for unfamiliar faces were more prominent over right than left occipitotemporal areas. A right hemisphere superiority for form-specific visual priming has previously been suggested by divided visual field studies of word recognition [46]. Convergent evidence has been obtained in recent fMRI studies [43], which suggested that right occipitotemporal areas are mainly sensitive to stimulus-specific priming (see also [19]). To reveal whether the hemispheric difference in the present stimulus-specific priming effect was reliable, we performed an ANOVA on ERP amplitude to unfamiliar faces in the 600–700 ms time segment from occipitotemporal recording sites (P7, P8, P9, PO7, PO8, PO9) with the factors priming, hemisphere, and site. This analysis revealed a significant interaction between priming and hemisphere [F(2, 34) = 5.02, P < 0.05, and two Bonferroni-corrected comparisons with the unprimed conditions revealed that this hemispheric difference in priming was significant for the primed same condition, F(1, 17) = 7.10, P < 0.05, but not for the primed different conditions, F(1, 17) = 2.12, P > 0.16. Interestingly, in Experiment 2, a marginally significant repetition effect for unfamiliar names was seen in the 300–400 ms segment, which also tended to be stimulus-specific (i.e. present for repetitions of names in the same but not in different fonts). An inspection of Fig. 8 suggests that this stimulus-specific repetition effects for unfamiliar names also tended to be more prominent over right than left occipitotemporal areas. Although these effects seem for names were just statistical trends, they are similar to those seen for faces (cf. Fig. 4). Therefore, these data corroborate recent findings of a role of right occipitotemporal areas in stimulus-specific repetition priming [43], and suggest that this issue warrants further exploration [19].

In conclusion, the present study has demonstrated that repetition across relatively long lags of more than 15 min and many intervening stimuli causes reliable behavioural and ERP repetition effects. Behavioural repetition effects, as well as ERP repetition effects for familiar stimuli, were independent of whether the same or a different image of a face, or a name in same or different font had been viewed as a prime. ERP repetition effects were maximal at parietal sites between 500 and 600 ms after stimulus onset, resembling an N400 effect, which was only seen for familiar
faces and names but not for unfamiliar stimuli. ERP repetition effects for unfamiliar faces and names were topographically indistinguishable, suggesting that they reflect a post-perceptual change in the activation of semantic representations of people (PINs and semantic information units), rather than a neural correlate of recognition at a perceptual level.

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