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Abstract

In everyday life we usually recognise personally familiar faces efficiently and without apparent effort. This study examined to which extent the neural processes involved in recognising personally familiar faces depend on attentional resources by analysing event-related brain potentials. In two experiments, participants were presented with multiple ambient images of highly personally familiar and unfamiliar faces and pictures of butterflies, with a letter string superimposed on each image. Their task was either to indicate when a butterfly occurred (effectively ignoring the letter strings) or to indicate whether each letter string contained the letter X or N. Attentional resource load was manipulated in the letter task by presenting the target among different distractor letters (high load; Experiment 1) or by using only a single repeated letter in each string (low load; Experiment 2). ERPs revealed more negative amplitudes for familiar relative to unfamiliar faces under both high and low load conditions, both in the N250, reflecting the activation of perceptual face representations, and in the subsequent Sustained Familiarity Effect (SFE). Nonetheless, while the magnitude of the N250 effect was not substantially affected by attentional load, the SFE was still present but reduced in the high relative to the low load experiment. These findings suggest that perceptual face representations are activated independent of the demands of a competing task. However, the subsequent SFE, presumably reflecting more sustained activation needed to access identity-specific knowledge that can guide potential interactions, strongly relies on the availability of attentional resources.

1. Introduction

Human observers are highly efficient at recognising familiar faces, even in severely degraded pictures (Burton, Wilson, Cowan, & Bruce, 1999). At first sight, this efficiency might not appear particularly surprising: Many of our daily-life interactions critically depend on the quick and accurate identification of others, and faces are arguably the most important stimulus for this task. In fact, we recognise faces dozens of times every day and typically without any apparent effort. However, face recognition can be more difficult than one might think. This has been demonstrated by asking participants whether different pictures of faces show the same person or not – a task which can often be surprisingly challenging for unfamiliar faces (Bruce et al., 1999), but is usually easy for familiar faces (Jenkins, White, Van Montfort, & Burton, 2011).

The present study used event-related brain potentials (ERPs) to examine the neural processes that allow us to recognise personally familiar faces with such high efficiency. Specifically, we asked how the availability of attentional resources influences subprocesses related to perceptual face recognition or to the subsequent integration of additional person-related (e.g., semantic or affective) information (see e.g., Bruce & Young, 1986, 2012). These subprocesses are associated with different ERP components (Schweinberger & Burton, 2003; Schweinberger & Neumann, 2016). The earliest face-sensitive ERP component, the N170 (Bentin, Allison, Puce, Perez, & McCarthy, 1996), differentiates between face and object stimuli (Eimer, 2011; Rossion & Jacques, 2008). The subsequent N250, a negative deflection at occipito-temporal electrodes between approximately 200 and 300ms, is consistently more negative for familiar relative to unfamiliar faces (Andrews, Burton, Schweinberger, & Wiese, 2017; Gosling & Eimer, 2011). The N250 also becomes increasingly more negative during the learning of new

facial identities (Kaufmann, Schweinberger, & Burton, 2009; Tanaka, Curran, Porterfield, & Collins, 2006) and is related to the activation of perceptual face representations.

We recently observed a further familiarity effect between 400 and 600ms at occipito-temporal electrodes (Wiese, Tüttenberg, et al., 2019). This Sustained Familiarity Effect (SFE) was found when testing participants with multiple so-called ambient images which contain "naturalistic" within-person variability (see Figure 1). Using such ambient images takes advantage of the fact that participants recognise familiar faces from a wide range of different images (Burton, Jenkins, & Schweinberger, 2011; Kramer, Young, & Burton, 2018) and poses more realistic demands on the face recognition system than using less variable stimuli. Interestingly, the SFE was detected for highly personally familiar versus unfamiliar faces, but it was absent for famous faces. Given its scalp distribution and timing, we suggested that the SFE might reflect the integration of visual with additional person-related, e.g., affective information. Moreover, its selectivity for personal familiarity might suggest that the effect is related to the salience of the presented identity and the preparation of a potential interaction.

Although we offered this account of the SFE in general (Wiese, Tüttenberg, et al., 2019), an alternative possibiulity for the lack of an SFE to celebrity faces is that participants might not have recognized all of the highly variable ambient images of the celebrities, which did elicit somewhat more negative responses than unfamiliar faces. Therefore, the non-significant result for celebrity faces might conceivably have been caused by a subgroup of participants not being sufficiently familiar with the used celebrities, and whether it is possible to show an SFE for celebrity faces remains an open question.

In the present study, however, our principal interest was in the origin of the SFE itself. We therefore looked more closely at ERPs to highly personally familiar faces to examine to what

extent the two ERP familiarity effects, i.e., the N250 and the SFE, depend on attentional resources.

A number of behavioural studies seem to suggest that the processing of familiarity does not require extensive resources (Bindemann, Burton, & Jenkins, 2005; Lavie, Ro, & Russell, 2003; Yan, Young, & Andrews, 2017). Moreover, implicit forms of recognition have been demonstrated even when participants were not able to explicitly recognize the faces. For example, prosopagnosic patients can show increased skin conductance responses for familiar relative to unfamiliar faces (Bauer, 1984; Tranel, Damasio, & Damasio, 1995; Daniel Tranel & Damasio, 1985), and demonstrate semantic priming effects for faces that were not explicitly recognized (Young, Hellawell, & De Haan, 1988). Such covert forms of recognition have been suggested to be mediated by affective and other automatic responses towards the familiar identities (Ellis & Lewis, 2001) and may therefore not require substantial cognitive resources.

Building on Perceptual Load Theory (Lavie, 1995, 2005), and of particular relevance for the present study, Jenkins and colleagues (Jenkins, Burton, & Ellis, 2002) presented famous faces with superimposed letter strings. Participants were asked to either indicate the color of the strings (blue or red; considered a low perceptual load task) or whether they contained the letter X or N (high perceptual load). The authors found that participants were substantially impaired in a subsequent explicit recognition test in the high relative to the low load condition but showed similar repetition priming effects, suggesting that perceptual load did not affect the implicit task. We note that what Jenkins et al. (2002) called *perceptual* load in this context refers to the idea that a perceptual task can create high or low resource demands and does not necessarily point to a perceptual locus of the effect. Here, we extended Jenkins et al.'s (2002) approach by using it to investigate the effect of resource load on the N250 and SFE to faces with high personal familiarity.

Previous studies have also examined to what extent the N250 depends on attentional resources. Interestingly, it has been shown that the N250 familiarity effect can be observed in cases of developmental prosopagnosia in the absence of explicit recognition (Eimer, Gosling, & Duchaine, 2012). Moreover, N250 is more negative when a familiar (target) face is preceded by a picture of the same relative to a different (prime) face (Schweinberger, Pfütze, & Sommer, 1995; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002; Wiese, Chan, & Tüttenberg, in press). This N250r effect (r for repetition) is typically interpreted as reflecting facilitated access to perceptual face representations. Some previous studies have found that the repetition effect is independent of perceptual load (Neumann, Mohamed, & Schweinberger, 2011; Neumann & Schweinberger, 2008). Others however reported the N250r can be affected by task demands (Zimmermann & Eimer, 2014). Together, these findings seem to suggest that whilst N250 effects are not completely automatic, the explicit recognition of familiarity may not be a necessary prerequisite.

As yet, relatively little is known about the SFE. The effect can be measured without an explicit familiarity response by the participants, but its magnitude decreases with image repetition, which suggests that it is not bound to a particular stimulus presentation (Wiese, Tüttenberg, et al., 2019). Importantly, the SFE is substantially larger than previous ERP markers of familiarity. It can be reliably elicited by an individual face in an individual participant, which might be relevant for applied situations such as criminal investigations. However, knowledge about the extent to which the SFE depends on attentional resources appears critical for any potential application.

While the SFE has only been observed for personally familiar faces, many experimental studies on face recognition use celebrities as familiar stimuli. However, processing the identity of faces we know from everyday life differs in potentially important respects from famous face recognition (see e.g., Ramon & Gobbini, 2018). Personally familiar faces presumably not only

exhibit more stable perceptual representations, they should also elicit the retrieval of more detailed semantic information and trigger stronger affective responses. The relevance of such affective responses for face recognition has been demonstrated in cases of Capgras syndrome, a psychiatric condition that results in the belief that close others have been replaced by impostors. This delusion seems to be related to an impaired affective response to personally highly familiar faces, while visual recognition itself is relatively intact (Ellis & Lewis, 2001; Ellis, Young, Quayle, & DePauw, 1997). Given this affective response to personally familiar faces, they might also attract attention in a particularly efficient way (Gobbini et al., 2013), which in turn might suggest that the SFE does not strongly depend on the availability of attentional resources. Moreover, while familiarity is often operationalized dichotomously, it is probably more realistic to understand it as a continuum between those individuals we know very well and for a long time and those we have just met and know only superficially (Kramer et al., 2018). Such differences in familiarity may well affect how much attentional resource is allocated to process a face, and highly familiar faces might be processed more automatically. We therefore used images of highly personally familiar faces for the present study.

In the two experiments reported here, we examined (i) to which extent the N250 familiarity effect and the SFE depend on attentional resources, and (ii) whether the two effects can be separated on the basis of this dependence. We presented multiple ambient images of highly personally familiar faces, of unfamiliar faces, and of butterflies while the participants' EEG was recorded. Letter strings were superimposed on all stimuli, which were presented twice in two consecutive blocks. While the task in the first block was to indicate whether the letter strings contained an X or N, participants were asked to detect butterfly stimuli in the second block. We analysed N170, N250, and the SFE to test whether potential familiarity effects would be affected by allocating attention to a task involving the superimposed letters (in high or low

load task variants) compared to responding to the pictures themselves (a butterfly detection task). While we reasoned that a clear N250 familiarity effect might well be observed even when participants are distracted from the faces (as it has e.g. been observed in the absence of explicit recognition, see above), the extent to which the SFE would be influenced by the task was unknown. We intentionally kept task order constant for all participants, with the letter task occurring first, for the following reason: If distraction in the letter task prevented the processing of facial familiarity at the level of the SFE, we would assume no corresponding difference between familiar and unfamiliar faces in the first block. At the same time, a clear SFE would be expected in the second block in which the letters were no longer task relevant. If, however, facial identity at the SFE level was processed even in the letter task, we would assume a corresponding familiarity effect in the first (and second) block. Moreover, as we have found that the SFE is reduced with image repetition (Wiese, Tüttenberg, et al., 2019), we always presented the letter task first to prevent a reduction of the effect by a previous presentation of the pictures.

To test these predictions, we compared ERPs in the letter and butterfly tasks within each of the two experiments. Importantly, Experiments 1 and 2 differed with respect to load in the letter task. Whereas strings of four different letters were used in Experiment 1 (e.g., WHXZ; high load), the same letter was presented four times in Experiment 2 (XXXX or NNNN; low load; see Figure 1). Based on previous findings from the N250r (Neumann & Schweinberger, 2008), we predicted no difference in the N250 familiarity effect in the high versus low load conditions. If, however, load affected the SFE, we would expect it to be larger in Experiment 2 than Experiment 1. To test potentially different effects of load, we directly compared the N250 effect and the SFE in the first blocks of Experiment 1 versus 2. Finally, we additionally analysed the N170 for any potential effects of personal familiarity and/or modulation by attention.
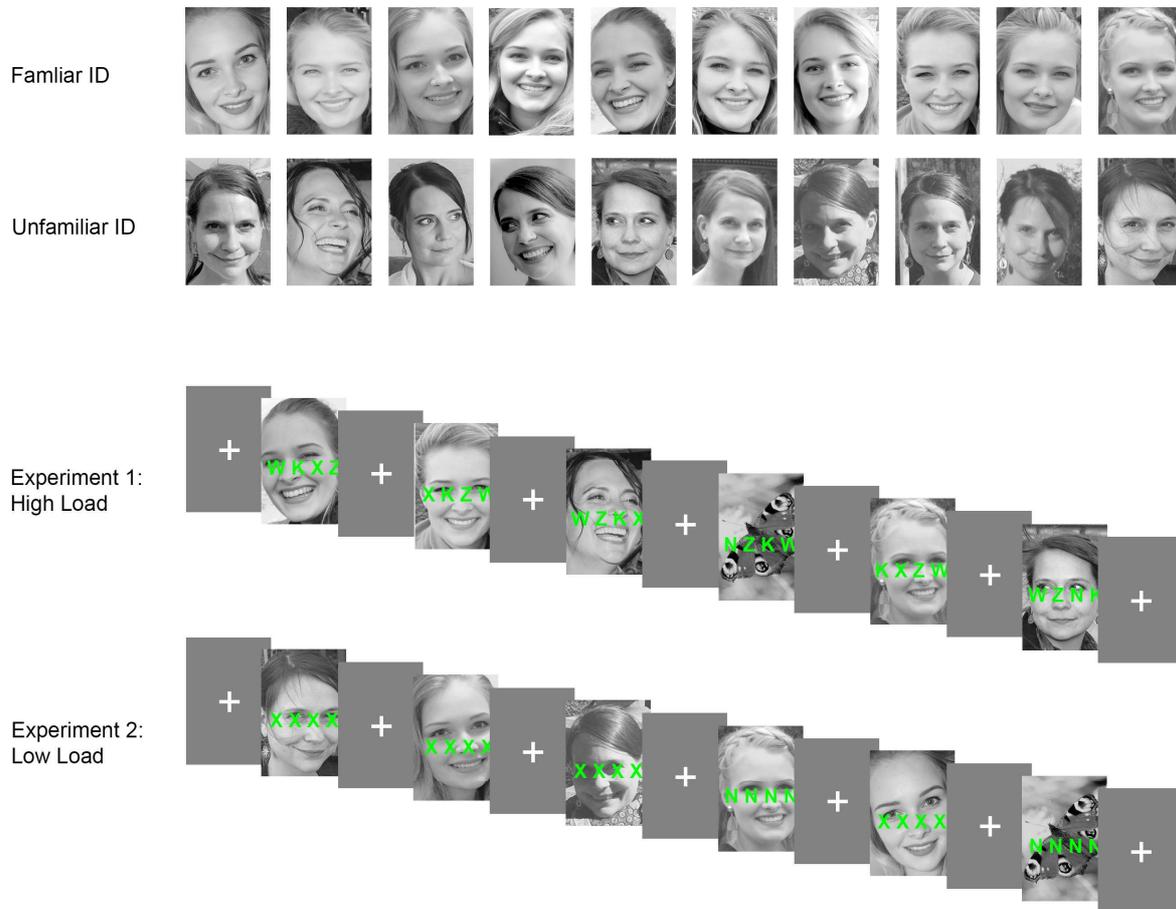
Figure 1. Sample "ambient" images from the experiment and illustration of the perceptual load manipulation in Experiment 1 and Experiment 2. All images are used with permission of the depicted persons.

2. Experiment 1: High Resource Demands

2.1 Methods

2.1.1. Participants

We tested 19 under- and postgraduate students at Durham University, one of whom was excluded for not fulfilling the criterion of at least 16 artefact-free trials in all conditions (see below). This sample size was determined on the basis of our previous study (Wiese et al., 2019) which revealed large ERP familiarity effects with N=18 (Experiment 3). The final sample of 18

participants consisted of 14 females and 4 males with a mean age 21.7 years (+/- 3.9 SD). Sixteen participants were right- and two were left-handed according to a modified version of the Edinburgh Handedness Inventory (Oldfield, 1971). None suffered from neurological or psychiatric disorders or took central-acting medication. Participants either received £7.50/h or course credit as a compensation. All gave written informed consent, and the study was approved by the ethics committee of Durham University's Psychology Department.

2.1.2. Stimuli

Stimuli consisted of 50 different ambient images of each of ten identities (see Figure 1 for examples). Six of these identities were highly personally familiar (i.e., close friends known from university) for at least one of the participants, whereas the other four were always unfamiliar. Images were provided by the depicted persons or were taken from photo archives of the authors. All depicted individuals gave written informed consent to the use of their pictures for the purposes of the experiment. In addition, eight different pictures of butterflies were used.

Rectangles around the faces and butterflies were cropped from the pictures, re-sized to 190 x 285 pixels, and converted to grey-scale. Letter strings containing four different capital letters (W, K, Z , and either X or N) were superimposed on the images slightly below the vertical midline (so that the eyes were typically not covered) in green Arial font (size 24). The position of specific letters within the string varied randomly across trials, and half of the stimuli in each familiarity condition contained an X while the other half contained an N. Stimuli were presented in the centre of the screen with grey background.

2.1.3. Experimental design and procedure

Participants were seated in an electrically shielded and sound-attenuated cabin (Industrial Acoustics, Niederkrüchten, Germany) with their heads in a chin-rest at a distance of 100 cm from a computer screen. In each of two blocks, participants saw 50 different images of one highly personally familiar identity and 50 images of one unfamiliar identity, as well as 20 butterfly images, presented in random order. We chose to present multiple ambient images per identity to test the influence of attentional resources on a crucial aspect of human face recognition – the ability to recognize highly familiar faces from a remarkably wide range of different images. Whether one or more identities are used per condition does not seem to be critical for this purpose, as long as a large number of different images is presented (see Experiment 1 versus Experiment 3 in Wiese et al., 2019). For the present study, however, using only one highly familiar identity was considered preferable, as we additionally aimed to test whether familiarity with a single facial identity can be robustly detected in individual participants, even when participants were distracted (see Introduction and bootstrapping analyses below). Each trial started with a fixation cross which varied in duration from 2,750ms to 3,250ms, followed by a face or butterfly stimulus, which was presented for 1,000ms.

In the first block, participants were instructed to indicate via left and right index finger button presses whether the letter string contained an X or N. Additional practice trials using different pictures were presented prior to the experiment. In the second block, participants were instructed to press a key with their right index finger whenever a butterfly was presented, but to withhold responses when a face stimulus was presented. Accordingly, while face identity was not task relevant in either of the two blocks, the task demand of responding to the letters actively distracted participants from the faces during the first block, whereas neither the letters nor the face identities were task-relevant in the second block. Task order was intentionally not counterbalanced, and all participants were presented with the X or N task first, to allow the

measurement of familiarity effects during the X or N task without any confound by image repetition.

2.1.4. EEG recording and data analysis

64-channel EEG was recorded (ANT Neuro, Enschede, the Netherlands) from DC-120 Hz with a sample frequency of 512 Hz using sintered Ag/AgCl electrodes mounted in a textile cap. An electrode on the forehead served as ground, and Cz was used as the recording reference. Recording sites corresponded to an extended 10-20 system, including ventral electrode positions such as TP9/TP10, P9/P10, and PO9/PO10.

Blink artifacts were corrected using BESA 6.0 (BESA GmbH, Graefelfing, Germany). EEG was then segmented from -200 to 1,000ms relative to stimulus onset, with the first 200ms as a baseline. Trials with non-ocular artifacts and saccades were rejected using the BESA 6.0 toolbox with an amplitude threshold of 100 µV and a gradient criterion of 75 µV. Remaining trials were re-calculated to the common average reference, digitally low-pass filtered at 40 Hz (12 dB/oct, zero-phase shift), and averaged according to experimental conditions (personally familiar and unfamiliar faces in the X or N and butterfly tasks, respectively). Only trials with correct responses were analysed. An inclusion criterion of at least 16 artifact-free trials per condition was applied (established prior to data analysis), which led to the exclusion of one participant. In the remaining participants, average number of trials was 41.8 (+/- 5.3 SD, min = 31) for familiar and 40.8 (+/- 5.2 SD, min = 30) for unfamiliar faces in the X or N task, and 47.9 (+/- 3.2 SD, min = 38) for familiar and 47.7 (+/- 3.4 SD, min = 39) for unfamiliar faces in the butterfly detection task.

In the resulting waveforms, mean amplitudes for N170 (140-170ms), N250 (200-300ms), and the SFE (400-600ms) were calculated at electrodes TP9/TP10 and P9/P10. We chose

occipito-temporal channels for analysis on the basis of our previous study (Wiese et al., 2019), and this decision is highly consistent with the scalp distribution of familiarity effects observed in the present data (see Figure 2 b and e; for additional analyses at fronto-parietal electrode sites, see supplementary material). Statistical analyses of ERP data were performed using repeated-measures analyses of variance (ANOVA), with the within-subjects factors hemisphere (left, right), electrode site (TP, P), task (X or N, butterfly detection), and familiarity (personally familiar, unfamiliar). Following an estimation approach in data analysis (e.g., Cumming, 2012), we report measures of effect size with appropriately sized confidence intervals (CIs) throughout. Cohen's d for repeated-measures t-tests was bias-corrected and calculated using the mean standard deviation rather than the standard deviation of the difference as the denominator (d_{unb}). CIs for d_{unb} were calculated using ESCI (Cumming & Calin-Jagemann, 2017); CIs for partial eta squared were calculated using scripts provided by M.J. Smithson (http://www.michaelsmithson.online/stats/CIstuff/CI.html).

No part of the study procedures and analyses was pre-registered prior to the research being conducted. We report all data exclusions, all inclusion/exclusion criteria, which were all established prior to data analysis, all manipulations, and all measures in the study. All study data, analysis code, and digital study materials (except for stimuli, as we do not have consent to publish facial photographs) has been archived in a publicly accessible repository, see https://osf.io/tfwum/?view_only=0cc13036c196453d940a4dafc35b715c.

2.2. Results

2.2.1. Performance

In the X or N task, proportion of correct responses was .76 (+/- .15 SD) for letter strings on butterflies, .83 (+/- .11 SD) for personally familiar, and .81 (+/- .13 SD) for unfamiliar faces.

Accuracies to letter strings on personally familiar and unfamiliar faces did not differ, M_{diff} = .027, 95% CI [-.015, .070], $t(17)$ = 1.346, p = .196, d_{unb} = 0.216, 95% CI [-0.115, 0.561]. Mean response times (RT) for correct responses was 699 ms (+/- 67 SD) in the butterfly, 688 ms (+/- 66 SD) in the personally familiar, and 704 ms (+/- 60 SD) in the unfamiliar face conditions. RT in the personally familiar condition was significantly faster relative to the unfamiliar condition, M_{diff} = 15.9 ms, 95% CI [2.8, 29.1], $t(17)$ = 2.558, p = .020, d_{unb} = 0.241, 95% CI [0.038, 0.460].

Performance in the butterfly detection task was very close to ceiling, with one participant missing one of the butterfly stimuli, one participant producing one false alarm to a personally familiar face, and two participants producing one and two false alarms to unfamiliar faces, respectively. Mean RT for correct butterfly detection was 477 ms (+/- 64 SD).

2.2.2. Event-related potentials

ERP results for Experiment 1 are depicted in Figure 2 a-c and in Figure 3a. Personally familiar faces elicited more negative amplitudes in both the X or N task and the butterfly task (Figure 2a), and these familiarity effects showed clearly occipito-temporal scalp distributions (Figure 2b). Moreover, difference curves suggested an onset of the familiarity effect in the N170 range, a clear peak between 200 and 300ms (N250), and a reduced effect in the subsequent SFE time window (400-600ms; Figure 3a).

These observations were supported by statistical analyses. A repeated-measures ANOVA on N170 mean amplitude with within-subjects factors hemisphere (left, right), electrode site (TP, P), task (X or N, butterfly detection), and familiarity (personally familiar, unfamiliar) revealed a significant main effect of familiarity, $F(1, 17)$ = 6.491, p = .021, η^2_p = .276, 90% CI [.026, .494], with more negative amplitudes for personally familiar relative to unfamiliar faces. The interaction of familiarity by task was not significant, $F(1, 17)$ = 3.659, p = .073, η^2_p = .177, 90% CI [0, .408].
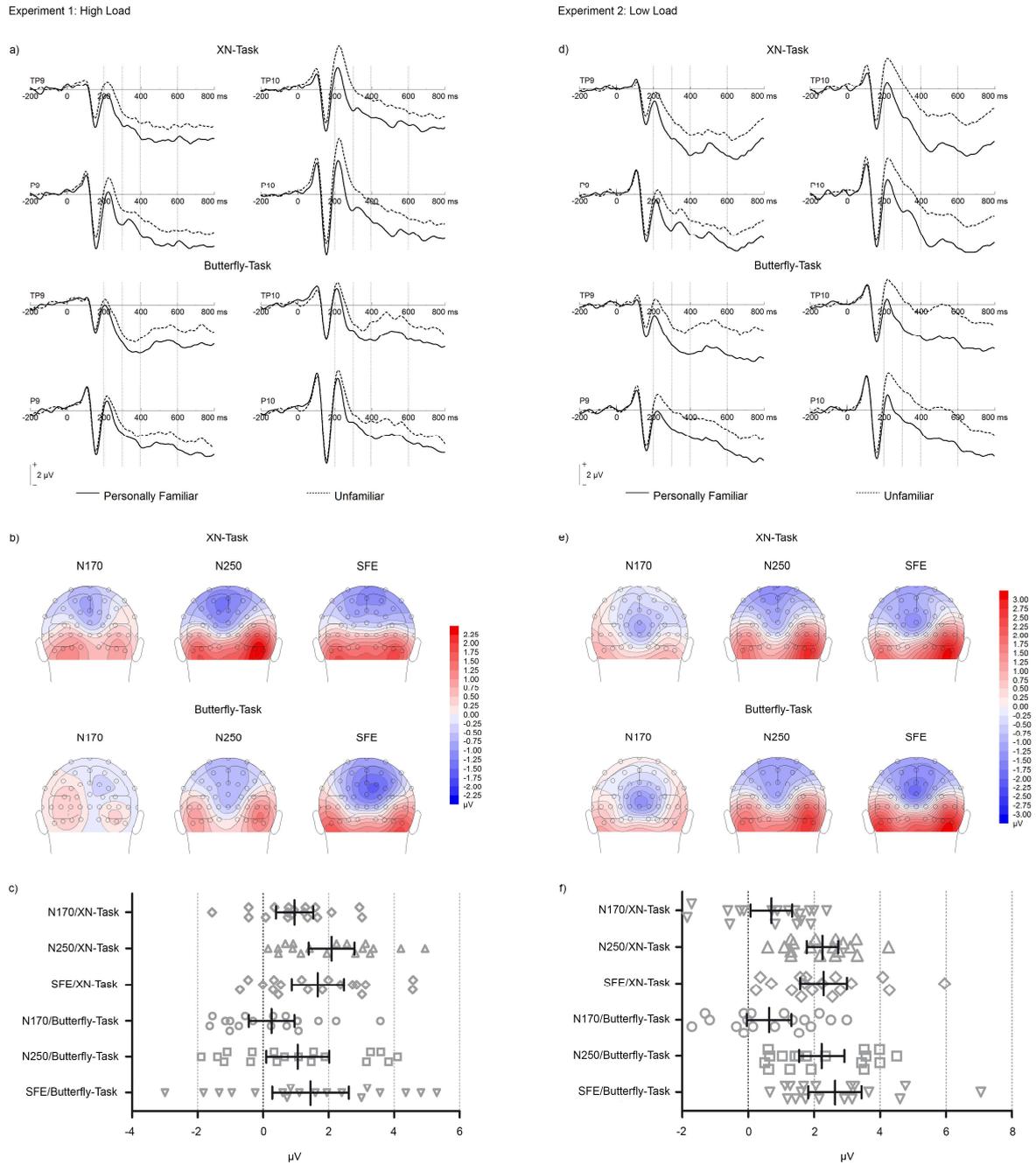
Figure 2. Event-related potential (ERP) results of Experiment 1 (a-c) and 2 (d-f). a) & d) Grand average ERPs for personally familiar and unfamiliar faces at occipito-temporal electrodes P9/P10 and TP9/TP10 in the X or N and butterfly tasks. b) & e) Scalp-topographical voltage maps of familiarity effects (unfamiliar minus personally familiar faces) in the N170, N250, and SFE time windows in the X or N and butterfly tasks. Spherical spline interpolation, 110° equidistant projections. c) & f) Mean (+/- 95% confidence intervals) and individual familiarity effects (unfamiliar minus personally familiar faces) in the N170, N250, and SFE time range for the X or N and butterfly task.
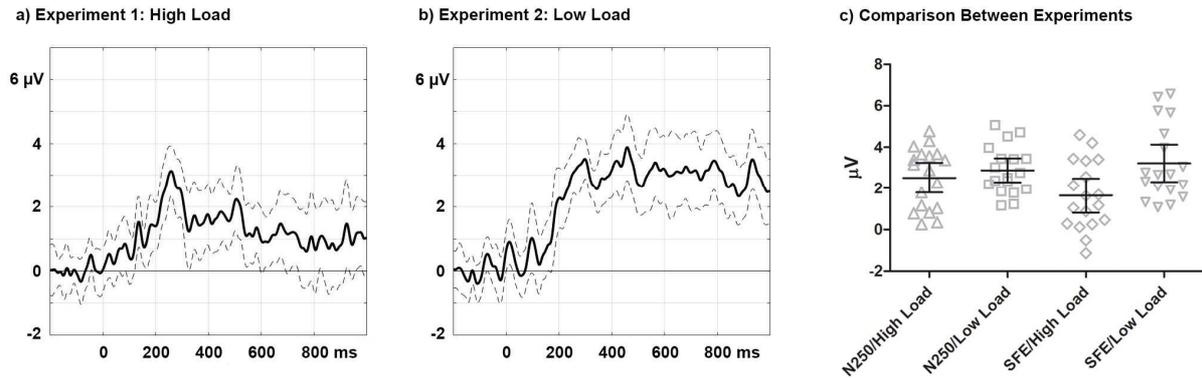
Figure 3. a) and b) Grand average difference curves (+/- 95% confidence intervals) of familiarity effects (unfamiliar minus personally familiar faces) at occipito-temporal electrode TP10 in the X or N task of Experiments 1 and 2, respectively. c) Mean (+/- 95% confidence interval) and individual familiarity effects (unfamiliar minus personally familiar) at electrode TP10 in the N250 and SFE time ranges.

An ANOVA with the factors hemisphere, electrode site, task, and familiarity in the N250 time window (200-300 ms) revealed a main effect of task, $F(1, 17) = 20.163$, $p < .001$, $\eta^2_p = .543$, 90% CI [.228, .690], as well as interactions of hemisphere by task, $F(1, 17) = 6.906$, $p < .018$, $\eta^2_p = .289$, 90% CI [.031, .504], and site by task, $F(1, 17) = 15.061$, $p = .001$, $\eta^2_p = .470$, 90% CI [.155, .640]. Importantly, the task by familiarity interaction was significant, $F(1, 17) = 7.621$, $p = .013$, $\eta^2_p = .310$, 90% CI [.041, .521]. Decomposing this interaction by testing familiarity effects in the two tasks separately revealed significantly more negative amplitudes for personally familiar relative to unfamiliar faces in both the X or N, $M_{diff} = 2.093$ µV, 95% [1.393, 2.793], $t(17) = 6.309$, $p < .001$, $d_{unb} = 0.626$, 95% CI [0.352, 0.950], and the butterfly detection task, $M_{diff} = 1.06$ µV, 95% [0.100, 2.020], $t(17) = 2.329$, $p = .032$, $d_{unb} = 0.384$, 95% CI [0.033, 0.760], with a larger effect size in the X or N task. Accordingly, differences due to the familiarity of the faces were detected in the N250 time range, even when participants were distracted in the X or N task.

An ANOVA with the factors hemisphere, electrode site, task, and familiarity in the SFE time window (400-600 ms) similarly yielded a significant main effect of familiarity, $F(1, 17) = 17.168$, $p < .001$, $\eta^2_p = .502$, 90% CI [.186, .663], as well as an interaction of hemisphere by site

x task, $F(1, 17) = 5.113$, $p = .037$, $\eta^2_p = .231$, 90% CI [.008, .456]. The task by familiarity

interaction was not significant, $F(1, 17) = 0.144$, $p = .709$, $\eta^2_p = .008$, 90% CI [0, .163]. However,

to test for potentially different familiarity effects in the X or N versus butterfly task, we analysed

the two tasks separately. This analysis revealed significantly more negative-going amplitudes for

personally familiar relative to unfamiliar faces, both in the X or N task, $M_{diff} = 1.670\,\mu V$, 95%

[0.873, 2.467], $t(17) = 4.419$, $p < .001$, $d_{unb} = 0.530$, 95% CI [0.242, 0.858], and in the butterfly

detection task, $M_{diff} = 1.449\,\mu V$, 95% [0.277, 2.620], $t(17) = 2.610$, $p = .018$, $d_{unb} = 0.576$, 95%

CI [0.100, 1.090], with similar effect sizes. Accordingly, statistically significant differences

between familiar and unfamiliar faces were observed, even when participants were distracted in

the X or N task.

3. Experiment 2: Low Resource Demands

3.1 Methods

3.1.1. Participants

We tested 18 right-handed Durham University under- and postgraduate students (13

female, mean age = 20.6 years +/- 1.9 SD). Selection criteria and compensation were identical to

Experiment 1, and the study was approved by the ethics committee of Durham University's

Psychology Department.

3.1.2. Stimuli

Stimulus selection and editing was identical to Experiment 1, except that to achieve a

personally familiar identity for each participant we had to use images of nine different familiar

identities as well as the four different unfamiliar identities across participants. Superimposed letter strings consisted either of four Xs or four Ns (see Figure 1).

3.1.3. Procedure and EEG recording

Experimental procedures, EEG recording and data analysis were analogous to Experiment 1. Following artifact rejection the average number of trials was 44.9 (+/- 5.1 SD, min = 28) for familiar and 44.8 (+/- 4.7 SD, min = 33) for unfamiliar faces in the X or N task, and 46.8 (+/- 3.8 SD, min = 34) for familiar and 46.6 (+/- 4.3 SD, min = 36) for unfamiliar faces in the butterfly detection task.

To complement the group analyses of Experiment 1 and 2 we additionally used a bootstrapping approach (Di Nocera & Ferlazzo, 2000) to test for reliable familiarity effects during the X or N task in individual participants in the N250 and SFE time windows. For this purpose, we calculated 10,000 random re-assignments of individual participants' EEG epochs to familiarity conditions. Although familiarity effects were right-lateralized in the present study, we decided to keep these analyses comparable to our previous experiments (Wiese, Tüttenberg, et al., 2019), and therefore assumed reliable effects if the true individual familiarity effect at TP9/TP10 was larger than 95% of random re-samplings.

3.2. Results

3.2.1. Performance

Mean proportions of correct responses in the X or N task were .96 (+/- .05 SD) in the condition involving letter strings superimposed on butterflies, .95 (+/- .04 SD) to the personally familiar faces, and .96 (+/- .03 SD) in the unfamiliar face condition. Personally familiar and unfamiliar conditions did not differ, $M_{diff} = 0.011$, 95% [-0.009, 0.032], $t(17) = 1.142$, $p = .269$,

$d_{unb} = 0.297$, 95% CI [-0.238, 0.852]. Mean RTs were 558 ms (+/- 65 SD) in the butterfly condition, 556 ms (+/- 77 SD) in the personally familiar and 550 ms (+/- 61 SD) in the unfamiliar faces condition. RTs for personally familiar and unfamiliar faces did not differ, $M_{diff} = 5.680$ ms, 95% [-8.430, 19.790], $t(17) = 0.849$, $p = .408$, $d_{unb} = 0.078$, 95% CI [-0.110, 0.271].

In the butterfly task, three participant missed one and one missed two of the butterfly stimuli, and four participants produced false alarms in response to faces (two with one false alarm for personally familiar faces, and two with one false alarm to unfamiliar faces). Mean correct RT for butterfly detection was 504 ms (+/- 61 SD).

We also directly compared performance in the X or N task between experiments to check whether the load manipulation was successful. A t-test on the proportion of correct responses averaged across familiarity conditions indicated significantly less accurate performance in the high load condition of Experiment 1 ($M = .81$, +/- .12 SD) relative to the the low load condition of Experiment 2 ($M = .96$, +/- .03 SD), $M_{diff} = .15$, 95% [.09, .20], $t(34) = 5.184$, $p < .001$, $d_{unb} = 1.690$, 95% CI [0.948, 2.490]. Similarly, a t-test on correct RTs revealed significantly slower responses in the high load (Experiment 1: $M = 698$ ms, +/- 62 SD) relative to the low load conditions (Experiment 2: $M = 554$ ms, +/- 66 SD), $M_{diff} = 143$ ms, 95% [100, 186], $t(34) = 6.732$, $p < .001$, $d_{unb} = 2.194$, 95% CI [1.392, 3.076]. These findings confirm that participants were more severely distracted in the high relative to the low load conditions.

3.2.2. Event-related potentials

ERP results for Experiment 2 are depicted in Figure 2 d-f and in Figure 3b. Personally familiar faces elicited more negative amplitudes than unfamiliar faces in both the X or N task and the butterfly task (Figure 2d). Again, familiarity effects had occipito-temporal scalp distributions (Figure 2e). Similar to Experiment 1, difference curves showed an onset of the familiarity effect

in the N170 range and a clear peak between 200 and 300ms (N250). However, in contrast to Experiment 1, the SFE was similar in magnitude to the N250 familiarity effect (Figure 3b).

These observations were confirmed through statistical analyses. A repeated-measures ANOVA in the N170 time window with the factors hemisphere, electrode site, task, and familiarity revealed significant main effects of familiarity, $F(1, 17) = 6.446$, $p = .021$, $\eta^2_p = .275$, 90% CI [.025, .493], with familiar faces eliciting more negative amplitudes than unfamiliar faces, and task, $F(1, 17) = 7.997$, $p = .012$, $\eta^2_p = .320$, 90% CI [.047, .529], as well as a site by task interaction, $F(1, 17) = 5.553$, $p = .031$, $\eta^2_p = .246$, 90% CI [.013, .469].

An ANOVA in the N250 time range with the factors hemisphere, electrode site, task, and familiarity revealed a significant main effect of familiarity, $F(1, 17) = 75.425$, $p < .001$, $\eta^2_p = .816$, 90% CI [.629, .875]. Moreover, significant interactions of hemisphere by task, $F(1, 17) = 7.358$, $p = .015$, $\eta^2_p = .302$, 90% CI [.037, .515], and of site by task, $F(1, 17) = 5.172$, $p = .015$, $\eta^2_p = .302$, 90% CI [.009, .458], were detected. A significant interaction of hemisphere x familiarity, $F(1, 17) = 7.445$, $p = .014$, $\eta^2_p = .305$, 90% CI [.039, .517], was further qualified by a significant four-way interaction of hemisphere by site by task by familiarity, $F(1, 17) = 4.559$, $p = .048$, $\eta^2_p = .211$, 90% CI [.001, .439]. Of particular interest, testing familiarity effects in the two tasks separately revealed significantly more negative amplitudes for familiar faces, both in the X or N task, $M_{diff} = 2.187$ µV, 95% [1.799, 2.574], $t(17) = 11.919$, $p < .001$, $d_{unb} = 0.685$, 95% CI [0.449, 0.981], and in the butterfly detection task, $M_{diff} = 2.242$ µV, 95% [1.616, 2.867], $t(17) = 7.554$, $p < .001$, $d_{unb} = 0.636$, 95% CI [0.381, 0.943], with similar effect sizes. Accordingly, and similar to Experiment 1, significant familiarity effects were detected in the N250 time range, even when participants were distracted by the X or N task.

An ANOVA in the SFE time window with the factors hemisphere, electrode site, task, and familiarity revealed significant main effects of task, $F(1, 17) = 14.133$, $p = .002$, $\eta^2_p = .454$,

90% CI [.140, .628], and familiarity, $F(1, 17) = 55.405$, $p < .001$, $\eta^2_p = .765$, 90% CI [.540, .841],

as well as interactions of hemisphere by familiarity, $F(1, 17) = 14.628$, $p = .001$, $\eta^2_p = .462$, 90%

CI [.148, .634], site by familiarity, $F(1, 17) = 7.042$, $p = .017$, $\eta^2_p = .293$, 90% CI [.033, .507],

and hemisphere by task by familiarity, $F(1, 17) = 4.923$, $p = .040$, $\eta^2_p = .225$, 90% CI [.006, .451].

Testing familiarity effects in the two tasks separately yielded significant familiarity effects in the

X or N task, $M_{diff} = 2.248$ µV, 95% [1.770, 2.729], $t(17) = 9.907$, $p < .001$, $d_{unb} = 0.834$, 95% CI

[0.531, 1.208], and the butterfly detection task, $M_{diff} = 2.233$ µV, 95% [1.547, 2.920], $t(17) =$

6.864, $p < .001$, $d_{unb} = 0.752$, 95% CI [0.437, 1.128], with similar effect sizes. Accordingly,

significant differences between familiar and unfamiliar faces were detected in the SFE time range,

even when participants were distracted in the X or N task.

To directly test our prediction of a similar familiarity effect in high versus low perceptual

load during visual face recognition (N250), but potentially not in the subsequent SFE time range,

we directly compared the corresponding familiarity effects in the X or N task between the two

experiments. Given the right-lateralized occipito-temporal scalp distribution of the familiarity

effects found in the analyses described above (see Figures 2b and e), we decided to perform these

analyses at electrode TP10 where the effects were maximal. For the N250, a two-sample t-test

comparing familiarity effects (see Figure 3c) yielded no significant difference between the high

versus low load conditions, $M_{diff} = 0.361$ µv, $t(34) = 0.818$, $p = .419$, $d_{unb} = 0.266$, 95% CI [-

0.386, 0.927]. Critically, a corresponding t-test in the SFE time range revealed a significantly

reduced familiarity effect under high relative to low perceptual load, $M_{diff} = 1.575$ µV, $t(34) =$

2.701, $p = .011$, $d_{unb} = 0.880$, 95% CI [0.207, 1.582]. We also compared both the N250

familiarity effect and the SFE in the butterfly task between experiments. These analyses revealed

a significant difference for the N250, with a larger effect in Experiment 2 ($M_{diff} = 1.373$ µV, $t(34)$

$= 2.192$, $p = .035$, $d_{unb} = 0.714$, 95% CI [0.050, 1.401]). At the same time, the SFE in the

butterfly task did not differ significantly between experiments (M_{diff} = 1.292 µV, $t(34)$ = 1.774, p = .085, d_{unb} = 0.578, 95% CI [-0.081, 1.255]).

Bootstrapping analysis for the high load condition (Experiment 1) revealed reliable differences between familiar and unfamiliar faces in 8/18 participants in the N250 time window, Proportion (P) = .44, 95% CI [.25, .66], and in 7/18 participants in the SFE time range, P = .39, 95% CI [.20, .61]. In the low load condition (Experiment 2), reliable familiarity effects were observed in 15/18 participants in the N250 time window, P = .83, 95% CI [.61, .94], and in 14/18 participants in the SFE, P = .78, 95% CI [.55, .91]. As the analyses of mean amplitudes for N250 reported above revealed no significant difference between the high versus low load conditions, this bootstrapping result of a substantially smaller proportion of individual participants with reliable effects in the high load condition is presumably related to larger variability, both between and within participants (see below for a more detailed discussion).

4. Discussion

In the two experiments reported here, we tested the extent to which neural responses to highly personally familiar faces depend on the availability of processing resources. We observed clearly more negative amplitudes for personally familiar relative to unfamiliar faces in both the N250 and the SFE time ranges, even when participants were severely distracted from the face stimuli. These findings suggest that familiarity was processed both at the level of perceptual face recognition (as indexed by the N250) and at subsequent processing stages (the SFE). Moreover, in neither of the two experiments were familiarity effects any larger in the butterfly detection task which did not distract participants from the face stimuli. This pattern of findings is indicative of face recognition taking place even in severely distracting conditions. However, while the N250

familiarity effect was similar in the high- and low-load experiments, and thus appears to be relatively insensitive to load manipulations, the SFE at right occipito-temporal electrode TP10 was present but substantially reduced in the high- relative to the low-load task. Moreover, reliability at the individual participant level was clearly reduced in the high-load experiment. These findings are discussed in more detail below.

Overall, our findings for the N250 effect and SFE suggest that familiarity was processed in both tasks and in both load conditions, which is generally in line with previous behavioural (Bindemann et al., 2005; Jenkins et al., 2002; Lavie et al., 2003) and ERP findings (Neumann et al., 2011; Neumann & Schweinberger, 2008). At the same time, the direct comparison of high- and low-load conditions in Experiments 1 and 2 revealed some interesting constraints to the idea that the familiarity of personally highly familiar faces is processed fully automatically. More specifically, while the N250 mean amplitude did not show a modulation by high versus low load, the right occipito-temporal SFE was substantially reduced in the high-load condition. The finding of a similar familiarity effect in the N250, even though the behavioural results indicate that participants were substantially more distracted in the high-load condition, is in line with previous findings in repetition priming experiments (Neumann et al., 2011; Neumann & Schweinberger, 2008). Moreover, a previous study on developmental prosopagnosia found N250 familiarity effects even in the absence of explicit recognition (Eimer et al., 2012). The N250 time range is assumed to reflect access to visual representations of familiar faces (Schweinberger & Burton, 2003; Schweinberger & Neumann, 2016). The findings relating to N250 therefore suggest that neither conscious awareness nor extensive attentional resources are necessary for activating such representations.

At the same time, it appears inadequate to conclude that the N250 familiarity effect is not affected by load at all, as the effect size was slightly smaller and the confidence interval wider

under high relative to low load. More importantly, our bootstrapping results indicate that about half as many individual participants demonstrated reliable effects in the high load condition. The selection of electrodes for the two analyses cannot explain this apparent difference, as bootstrapping results for TP10 alone are highly similar to the combination of TP9/TP10 in the N250 time range (with $P = .56$ and $P = .83$ in the high- and low-load experiments, respectively). Instead, these findings of statistically similar mean effects but different proportions of individual participants with reliable effects can be explained by the larger variability of familiarity effects in the high-load experiment. In other words, while the confidence intervals of the two N250 familiarity effects overlapped substantially and accordingly no significant difference was observed, more participants in the high-load experiment demonstrated relatively small (e.g., < $2\mu V$) individual effects. In addition, within-participant inter-trial variability was presumably larger in the high- relative to the low-load condition. This in turn would indicate that perceptual face representations were not as consistently activated, with some trials eliciting rather weak and others strong activations. Larger between-participants and inter-trial variability in the high-load experiment thus suggest more effective suppression of the neural familiarity response in at least some participants and/or some of the trials. Similarly, the finding of a smaller N250 effect in the butterfly task following the high relative to the low load task suggests that the similar mean effects during the first block came at the cost of reduced effects in the subsequent second block of Experiment 1, which followed the more demanding version of the task.

Importantly, however, processing stages subsequent to the perceptual recognition of face familiarity appear to more strongly depend on attentional resources. Although, as described above, a clear SFE was observed in both experiments even when attentional resources were directed away from the faces in the letter task, this ERP effect was substantially reduced in the high- relative to the low-load experiment. In contrast to N250, this reduction was evident both

when comparing mean amplitudes and in the bootstrapping analysis. Moreover, even the SFE observed in the low-load condition of Experiment 2 (with a peak amplitude close to 4 µV at TP10, see Figure 3b) was smaller than the corresponding effect found in our previous study (with a peak amplitude of approximately 5.5 µV; Wiese, Tüttenberg, et al., 2019). Together, these findings suggest that the SFE more heavily depends on attentional resources than the N250 effect, and that even a relatively easy distractor task reduces the effect. At the same time, bootstrapping results in the low-load condition of Experiment 2 indicated that 78% of the participants showed reliable effects, which is similar to (and well within the confidence intervals of) point estimates from our previous experiments, which found 84% of participants with reliable effects. It thus appears that a moderate distraction from the face stimuli will somewhat reduce the effect overall but that the SFE is still robust enough to elicit reliable effects in the majority of individual participants. Stronger distraction by high perceptual load, however, will both result in overall clearly reduced effects and in reliable effects in a substantially smaller proportion of participants.

These findings have implications for the theoretical understanding of the SFE. In our previous paper (Wiese, Tüttenberg, et al., 2019), we tentatively interpreted this effect as reflecting the integration of visual and affective information. This interpretation was based on (i) the clearly occipito-temporal scalp distribution of the effect, which is in line with generators in the ventral visual stream, (ii) its apparently selective occurrence for personally familiar faces, and (iii) its reduction with image repetition, which is in line with a contribution of affective information. The present findings, however, seem difficult to integrate with this view. The processing of affective information is often assumed to be automatic (Morris, Ohman, & Dolan, 1999), and implicit face recognition on the basis of affective responses can occur in the absence of overt recognition (Bauer, 1984; Tranel et al., 1995). It thus appears implausible that an ERP effect reflecting the affective component of face recognition should be particularly vulnerable to

load manipulations. Instead, the present data are more compatible with the view that the effect reflects an additional elaboration of perceptual face recognition processes, which is in line with the similar scalp distribution of the N250 and the SFE. This elaborative boost might be restricted to personally familiar faces, as these faces are arguably more important to the participants than celebrities selected by the experimenter. Accordingly, the SFE might reflect the sustained activation of perceptual face representations and access to identity-specific information relevant to any potential interaction. If this identity-specific information does not take priority, e.g., due to demands induced by a competing task, attentional resources are allocated to this more relevant task, resulting in a reduced SFE.

In addition to these theoretical considerations, the present findings are also relevant for the SFE's potential use in applied settings. We have argued before (Wiese, Tüttenberg, et al., 2019) that the SFE might be useful in, e.g., criminal investigations when a suspect is not motivated to indicate their familiarity with a specific person. However, the usefulness of the measure in such applied situations critically depends on the degree to which participants are able voluntarily to suppress the response. One potential strategy might be to deliberately allocate attentional resources away from the face stimuli. The present findings suggest that such a strategy could be successful, as the proportion of individual participants showing a reliable SFE was substantially smaller in the high load condition, both relative to previous findings and the low-load condition in the present study. At the same time, a moderate distraction from the face stimuli, as in the low-load condition of the present study, did not result in a substantial decrease in the proportion of participants showing a reliable SFE. It thus appears that strategies leading to only moderate distraction are unlikely to be successful to suppress the effect. Moreover, it needs to be taken into account that in the present experiments distractors were presented as part of the visual stimuli, i.e., as letters superimposed on the faces. In a more realistic applied scenario, distraction

from the faces would need to be generated by the participants themselves, without any competing cues from the stimuli. It is unclear at present whether such attempts would be successful to suppress the SFE (for related findings, see Bergström, Anderson, Buda, Simons, & Richardson-Klavehn, 2013; Rosenfeld, Soskins, Bosh, & Ryan, 2004).

Finally, in addition to the above discussed SFE and N250 effects, and in contrast to our previous experiments (Wiese, Tüttenberg, et al., 2019), we observed a statistically significant familiarity effect in the N170 time range, with more negative amplitudes for personally familiar relative to unfamiliar faces. This finding is in line with some previous reports (Caharel, Fiori, Bernard, Lalonde, & Rebai, 2006; see also Kloth et al., 2006; Wild-Wall, Dimigen, & Sommer, 2008), but not with others (Butler, Mattingley, Cunnington, & Suddendorf, 2013; Keyes, Brady, Reilly, & Foxe, 2010). It should be noted that differences in N170 due to familiarity observed in the present experiments were small, and that effect sizes were considerably reduced relative to those for later components. With sample sizes typically tested in ERP studies, such relatively small effects will sometimes be significant and sometimes not, simply based on sample variability (see e.g., Cumming, 2012). This factor might at least partly explain the inconsistency in the literature. Importantly, the familiarity effect in the N170 time range observed in the present study does not seem to be specifically linked to this component. As evident in the difference waves (see Figure 3a and b), it more likely reflects the onset of an effect that builds up over time and peaks in the N250 time range. It thus appears possible that an incomplete representation of the perceived face, generated during structural encoding in the N170 time range, is sufficient to initiate the activation of a highly robust familiar face representation. Moreover, as the set of different identities used in the present experiments was very restricted, with only a single familiar and a single unfamiliar face presented to each participant, expectation might have additionally contributed to the early onset of the familiarity effect (Johnston, Overell, Kaufman, Robinson, &

Young, 2016). In any case, when considering experimental effects rather than peaks in the ERP waveform, the recognition of personally familiar faces seems to be characterised by two partially separable neural processes, namely the N250 familiarity effect and the SFE.

Finally, we note again that a key theoretical advantage of our paradigm lies in its ability to examine face recognition in more naturalistic conditions relative to other experimental approaches, while at the same time allowing us to test for a robust neural correlate of recognizing a single identity. However, we acknowledge that this approach limits the possibilities for manipulating experimental factors within-subject. Because it is practically difficult to get very high numbers of highly variable images for each identity, and given the relatively large number of trials needed for ERP analysis, some experimental manipulations will need to be conducted between subjects (particularly as image repetition reduces the SFE, see Wiese et al., 2019). As between-group comparisons typically require larger N to achieve sufficient statistical power (see e.g., Cumming, 2012), it is more difficult to detect small differences between conditions. At the same time, this difficulty may make our result of a reduced SFE with increasing load even more noteworthy.

In conclusion, the present study revealed that both the N250 familiarity effect and the SFE to highly personally familiar faces are clearly observed even when participants' attentional resources are directed away from the face stimuli, and even with a highly resource demanding competing task. It thus appears that familiarity is processed even when participants are severely distracted. Moreover, we provide additional evidence that the N250 familiarity effect and the SFE are functionally distinct, as the N250 appears to be substantially less affected by perceptual load and thus by the availability of attentional resources. We suggest that the SFE reflects an activation boost of perceptual representations and access to identity-specific information for those faces that are of real-life importance to our participants, in preparation for potential interaction.

The degree to which this boost can be voluntarily suppressed when distractors are not presented with the stimuli themselves will be crucial for any potential application and needs to be further examined in future studies.

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Supplementary Material

Experiment 1: High Resource Demands

As evident in figure S1, and as would be expected from ERPs calculated against the common average reference, familiarity and task effects were also observed at dorsal fronto-central to parieto-occipital electrodes, with switched polarities relative to the ventral occipito-temporal positions.
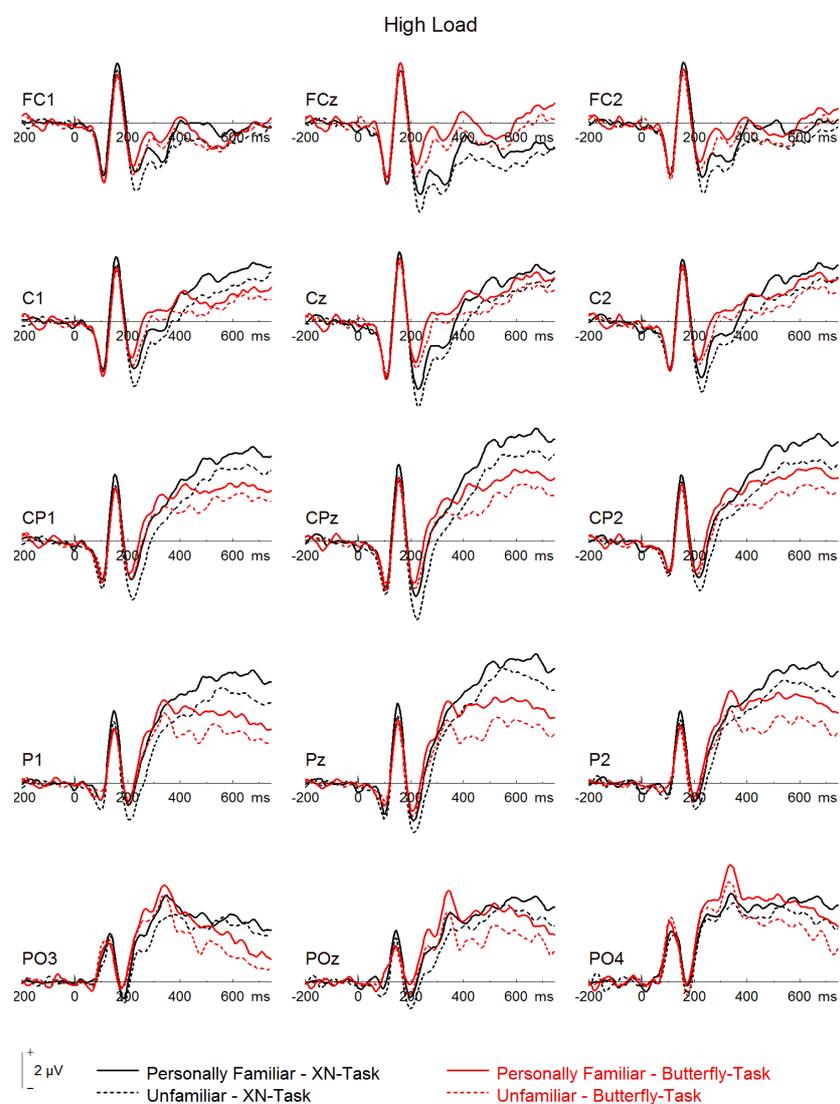

Figure S1. Grand average event-related potentials of Experiment 1 at dorsal electrode sites in the XN- and butterfly task.

Additional analyses were carried out on fronto-central, central, centro-parietal, parietal and parieto-occipital electrode positions in both the N250 (200-300 ms) and SFE (400-600 ms) time windows. For that purpose we calculated repeated-measures ANOVAs with the within-subject factors electrode site (FC, C, CP, P, PO), laterality (1, z, 2 at all sites, except for PO3, POz, PO4, as PO1 and PO2 were not recorded with the present electrode montage), task and familiarity. In the 200-300 ms time window, we observed significant main effects of task, $F(1, 17)$ = 14.079, $p = .002$, $\eta^2_p = .453$, 90% CI [.140, .628], and familiarity, $F(1, 17) = 13.483$, $p = .002$, $\eta^2_p = .442$, 90% CI [.130, .620]. The task effect was further qualified by a laterality by task, $F(2, 34) = 6.220$, $p = .005$, $\eta^2_p = .268$, 90% CI [.056, .420], and a site by laterality by task interaction, $F(8, 136) = 5.051$, $p < .001$, $\eta^2_p = .229$, 90% CI [.093, 286]. No further effects involving the factors task or familiarity were significant.

A corresponding ANOVA in the SFE time window again yielded significant main effects of task, $F(1, 17) = 5.662$, $p = .029$, $\eta^2_p = .250$, 90% CI [.015, .472], and familiarity $F(1, 17) = 18.289$, $p = .001$, $\eta^2_p = .518$, 90% CI [.202, .674]. Moreover, a site by task, $F(4, 68) = 4.806$, $p = .002$, $\eta^2_p = .220$, 90% CI [.057, .318], and a site by laterality by task interaction, $F(8, 136) = 4.587$, $p < .001$, $\eta^2_p = .212$, 90% CI [.079, .268] were found. Again, no further effects involving task or familiarity reached significance.

Experiment 2: Low Resource Demands

ERPs at dorsal electrodes from Experiment 2 are depicted in figure S2. A repeated-measures ANOVA in the 200-300 ms time window revealed a significant main effect of familiarity, $F(1, 17) = 44.338$, $p < .001$, $\eta^2_p = .723$, 90% CI [.470, .813], as well as interactions of

laterality by task, $F(2, 34) = 8.954$, $p = .001$, $\eta^2_p = .345$, 90% CI [.114, .489], laterality by familiarity, $F(2, 34) = 6.380$, $p = .004$, $\eta^2_p = .273$, 90% CI [.060, .425], and site by laterality by familiarity, $F(8, 136) = 3.437$, $p = .001$, $\eta^2_p = .168$, 90% CI [.043, .218]. No further effects involving task or familiarity were significant.
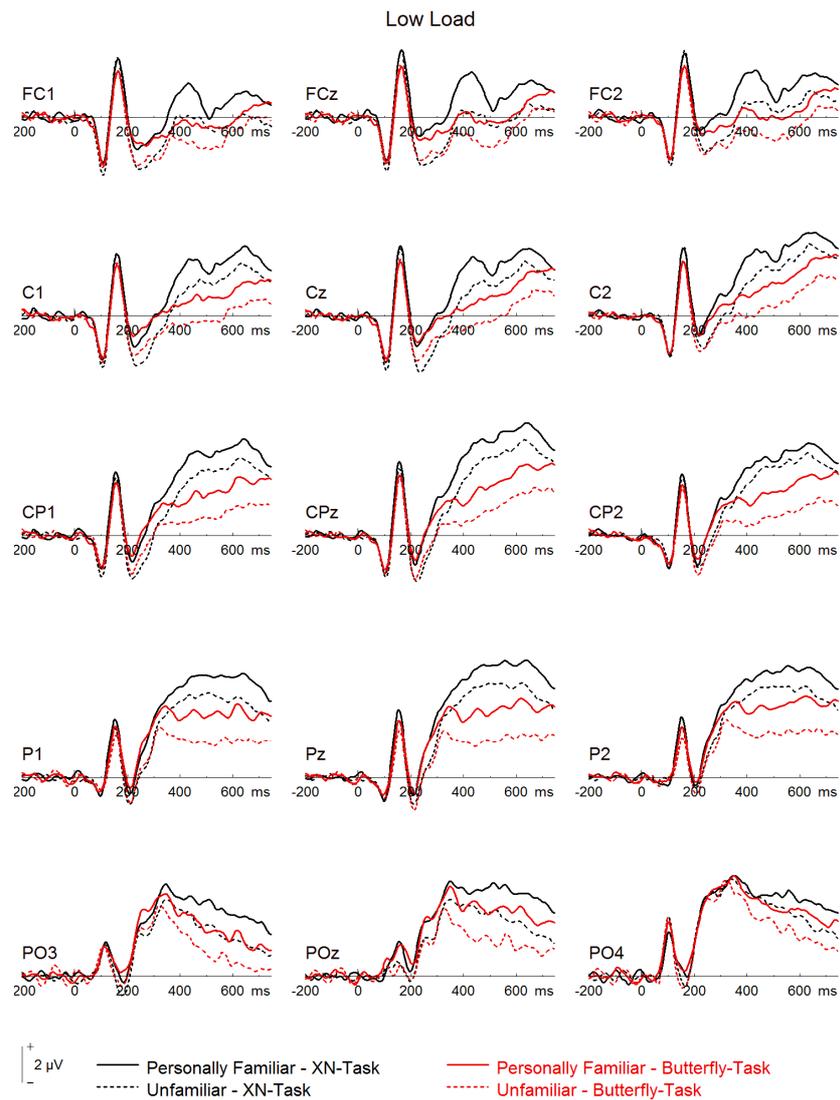

Figure S2. Grand average event-related potentials of Experiment 2 at dorsal electrode sites in the XN- and butterfly task.

A repeated-measures ANOVA in the 400-600 ms time window yielded main effects of task, $F(1, 17) = 34.795$, $p < .001$, $\eta^2_p = .672$, 90% CI [.393, .778], and familiarity, $F(1, 17) = 22.212$, $p < .001$, $\eta^2_p = .566$, 90% CI [.255, 707]. In addition, significant interactions of site by task, $F(4, 68) = 5.155$, $p = .001$, $\eta^2_p = .233$, 90% CI [.067, .331], laterality by familiarity, $F(2, 34) = 4.289$, $p = .022$, $\eta^2_p = .201$, 90% CI [.018, .356], and site by laterality by familiarity, $F(8, 136) = 3.094$, $p = .003$, $\eta^2_p = .154$, 90% CI [.032, .202], were observed.