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Research Report

Developing familiarity during the first eight months of knowing a person: A longitudinal EEG study on face and identity learning

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ABSTRACT

It is well-established that familiar and unfamiliar faces are processed differently, but surprisingly little is known about how familiarity builds up over time and how novel faces gradually become represented in the brain. Here, we used event-related brain potentials (ERPs) in a pre-registered, longitudinal study to examine the neural processes accompanying face and identity learning during the first eight months of knowing a person. Specifically, we examined how increasing real-life familiarity affects visual recognition (N250 Familiarity Effect) and the integration of person-related knowledge (Sustained Familiarity Effect, SFE). Sixteen first-year undergraduates were tested in three sessions, approximately one, five, and eight months after the start of the academic year, with highly variable "ambient" images of a new friend they had met at university and of an unfamiliar person. We observed clear ERP familiarity effects for the new friend after one month of familiarity. While there was an increase in the N250 effect over the course of the study, no change in the SFE was observed. These results suggest that visual face representations develop faster relative to the integration of identity-specific knowledge.

1. Introduction

The recognition of familiar faces in everyday life is vital for appropriate social interaction (Young & Burton, 2017). Reflecting this crucial importance, human observers are highly accurate and efficient at familiar face recognition, even in difficult conditions (Burton, Wilson, Cowan, & Bruce, 1999). At the same time, people often struggle to recognise, or even match simultaneously presented photos of unfamiliar faces for identity (Jenkins, White, Van Montfort, & Burton, 2011). While previous studies have examined this substantial difference in the effectiveness of familiar and unfamiliar face recognition, most have contrasted clearly familiar (e.g., famous) with clearly unfamiliar faces. In real life, however, we are more or less familiar with faces. As only very few studies have conceptualised familiarity as a continuum (Kramer, Young, & Burton, 2018), little is known about how familiarity builds up over time and how novel faces gradually become represented in the brain (see Kovács, 2020). Using a longitudinal design, the present study used event-related brain

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potentials (ERPs) to examine the neural processes accompanying real-life face identity learning during the first eight months of knowing a person.

ERPs reflect voltage changes in the human electroencephalogram, time-locked to events, such as the presentation of a visual stimulus. They consist of positive and negative peaks, which can be assigned to specific neuro-cognitive sub-processes following stimulus presentation. The earliest face-sensitive ERP component, the N170, peaks around 150–190 ms after stimulus presentation and reflects more negative amplitudes for faces than other visual stimuli (Bentin, Allison, Puce, Perez, & McCarthy, 1996). While a substantial number of studies have not observed differences between familiar and unfamiliar faces in this component (e.g., Alzueta, Melcón, Poch, & Capilla, 2019; Bentin & Deouell, 2000; Eimer, 2000; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002; Tanaka, Curran, Porterfield, & Collins, 2006; Wiese, Tüttenberg, et al., 2019; Zimmermann & Eimer, 2013), others have reported either larger (Barragan-Jason, Cauchoix, & Barbeau, 2015; Caharel, Ramon, & Rossion, 2014; Wild-Wall, Dimigen, & Sommer, 2008) or smaller (Huang et al., 2017; Marzi & Viggiano, 2007) N170 amplitudes for familiar relative to unfamiliar faces. Together, these results suggest that familiarity effects in the N170 are small at best and only inconsistently observed across studies.

By contrast, clear familiarity effects, with more negative amplitudes for familiar relative to unfamiliar faces, have been consistently demonstrated starting 200–300 ms after stimulus onset (e.g., Andrews, Burton, Schweinberger, & Wiese, 2017; Bentin & Deouell, 2000; Gosling & Eimer, 2011; Olivares, Iglesias, Saavedra, Trujillo-Barreto, & Valdés-Sosa, 2015; Saavedra, Iglesias, & Olivares, 2010; Wiese, Tüttenberg, et al., 2019). This N250 familiarity effect is assumed to reflect the activation of stored visual representations of familiar faces (Schweinberger & Burton, 2003). Interestingly, more familiar identities elicit stronger responses relative to less familiar faces (Alzueta et al., 2019; Andrews et al., 2017; Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019). Moreover, the effect is sensitive to face learning, as pre-experimentally unfamiliar faces elicit a familiarity response following a single brief learning session (e.g., Andrews et al., 2017; Kaufmann, Schweinberger, & Burton, 2009; Tanaka et al., 2006; Zimmermann & Eimer, 2013). However, while previous learning studies using the N250 effect have investigated the initial acquisition of novel faces, it is unclear how the underlying newly established face representations develop over time. In real life, we meet those who become our friends and colleagues repeatedly, which allows us to learn how different their faces can look in different circumstances. It is known that exposure to such within-person variability is critical for face learning (Kramer, Jenkins, Young, & Burton, 2017; Ritchie & Burton, 2017). In other words, participants need to learn how an individual's appearance varies in changing conditions to form a robust representation that incorporates the idiosyncratic variability of the person and allows recognition from a wide range of instances. It therefore appears plausible that continuous exposure in varying circumstances will result in further refinement of newly established facial representations, presumably strengthening the N250 effect.

In addition to having restricted exposure to a new face to single or very few episodes, previous research has typically examined face learning in lab-based studies, using static images or relatively low-variability video material. While stimuli and presentation format used in these studies have provided tight experimental control, they at the same time arguably lack ecological validity and allow only modest inference to learning under more naturalistic conditions. Therefore, more recent research has started to investigate how real-life exposure to new faces affects the underlying neuro-cognitive representations as a result of increasing familiarity. For instance, a recent fMRI study has demonstrated that three 10-min real-life interactions over two weeks were sufficient to induce activation changes in the right hemispheric face processing network (fusiform face area, occipital face area, posterior superior temporal sulcus, amygdala) and hippocampus in response to a previously unfamiliar person (Sliwinska et al., 2022). Moreover, the social interactions resulted in improved image-matching accuracy for the newly learnt person following the second 10-min session. Similarly, a recent EEG study observed an enhancement of face familiarity representations as a result of three 1-h familiarisation sessions over the course of three consecutive days (Ambrus, Eick, Kaiser, & Kovács, 2021). Such representations were only weak following two weeks of media familiarisation and absent after brief perceptual familiarisation, stressing the importance of real-life exposure for the formation of robust representations. Finally, longer-term face-learning, involving 4 h of exposure each week in separate encounters with the newly learnt person over eight weeks, has been found to lead to stronger identity-specific EEG responses at occipito-temporal electrodes (Campbell & Tanaka, 2021). Overall, while previous research has demonstrated changes in the neuro-cognitive representation of a newly learnt person over several weeks, more research is needed to understand whether and how face representations further develop after this initial phase of knowing a person. In other words, it is largely unclear up to what point visual representations of personally familiar faces become more robust and easier to access with more exposure, and from what point on additional exposure will not have a beneficial effect on face representations, effectively ending face learning.

In addition to establishing visual familiarity, recognising a person also involves accessing identity-specific semantic, episodic and affective information (e.g., when meeting a colleague, what the person's specific tasks are, when the person was last met, and whether we like the person or not) to ensure an appropriate interaction. Recent research has demonstrated an ERP correlate which presumably reflects this aspect of person recognition. Specifically, the ERP familiarity effect for highly familiar faces further increases following the N250 time window and peaks 400–600 ms following stimulus onset (Wiese, Tüttenberg, et al., 2019). This Sustained Familiarity Effect (SFE) increases with the degree of familiarity (Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019), and its scalp distribution is highly similar to the N250 effect, suggesting a generator in the ventral visual pathway. Interestingly, however, the two effects respond differently to experimental manipulations (Wiese, Ingram, et al., 2019; Wiese, Tüttenberg, et al., 2019), implying that they reflect at least partially different processes (see Wiese, Anderson, et al., 2022). As visual familiarity should be established in the N250 time range, the SFE presumably represents the top-down modulation of earlier visual face recognition stages, reflecting the integration of visual information with additional person-related knowledge. Of note, other research has also found the most robust familiarity effects in the SFE time range (Ambrus, Kaiser, Cichy, & Kovács, 2019; Dalski, Kovács, & Ambrus, 2022; Dobs, Isik, Pantazis, & Kanwisher, 2019; Karimi-Rouzbahani, Ramezani, Woolgar, Rich, & Ghodrati, 2021; Li, Burton, Ambrus, & Kovács, 2022). However, it is as yet largely unclear how the SFE builds up over time when more information about a person becomes accumulated.

Recently, we investigated how new people become familiar over the course of two years. Using a cross-sectional design, we tested Year 1, Year 2, and Year 3 undergraduate university students approximately two months after the start of the academic year (translating into roughly two, 14, and 26 months of familiarity, respectively) with images of a friend they had met at university (Popova & Wiese, 2022). While two months of familiarity were sufficient to demonstrate a clear N250 effect, reflecting the establishment of robust face representations, the SFE, and thus the integration of visual with additional person-related knowledge, was initially weak. Importantly, both effects increased with more pronounced familiarity after 14 months, but reached a plateau at this point, as we did not observe any differences between Year 2 and Year 3 students. As the first year of familiarity with a person therefore seems to be critical for the establishment of both visual representations and person-related knowledge, the present study was designed to investigate face and person learning during this time window.

More specifically, the current study examined how increasing familiarity through real-life exposure affects the neural face processing at both visual and integrational processing stages. Using a longitudinal design, we tested a group of first-year undergraduate students at Durham University approximately one, five, and eight months after the start of the academic year. Participants were tested with images of a friend they had met at university and of an unfamiliar identity. Importantly, while familiar identities had been unfamiliar prior to the start of their studies at Durham, participants were exposed to the faces of their new friends in their everyday life throughout the following eight months. As previous work has demonstrated an N250 familiarity effect after brief lab-based learning, we expected that this effect would be evident from the first testing session. Moreover, as our previous study implied a steep increase of the N250 in the initial period of knowing a person (Popova & Wiese, 2022), we predicted that the effect would become more pronounced from Session 1 to Session 2. Moreover, we were particularly interested in whether the N250 familiarity effect would further increase in Session 3 or whether visual face representations would be fully established at five months of familiarity. Regarding the SFE, we expected no further increase in the familiarity effect after the N250 time range in Session 1. This prediction was based on our previous finding of a small SFE for a friend known for approximately two months (Popova & Wiese, 2022). Moreover, we assumed that the SFE would gradually build up over the following sessions, with larger effects in Session 2 than in Session 1, as well as in Session 3 relative to Session 2. These analyses and hypotheses were pre-registered prior data collection (see https://osf.io/e258k).

2. Method

We report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study.

2.1. *Participants*

The target sample size was determined in a power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), assuming a similar SFE as the one reported for university friends known for approximately two months in a previous study (Popova & Wiese, 2022; paired-sample t-test, one-tailed, $dz = .72$, $1 - \beta = .85$; see https://osf.io/e258k), which suggested $N = 16$[1]. Twenty-four first-year undergraduate students at Durham University were recruited for this study, eight of whom (six female, two male) did not complete all three testing sessions, mostly because they were no longer in close contact to their friend chosen for Session 1 (see below). The final sample therefore consisted of 16 participants (14 female, one male, and one non-binary; age $M = 18.4$, $SD = .6$; 14 right- and two left-handed). All participants had normal or corrected-to-normal vision, did not have neurological or skin conditions/wounds on their head, and were not taking psychoactive medication. They provided informed written consent to participate and received course credits or a monetary reward of £8/h as compensation for their time. The study was approved by Durham University's Department of Psychology ethics committee.

2.2. *Stimuli*

The stimuli consisted of images of friends the participants had met at Durham University at the beginning of the academic year and photos of unfamiliar people. Each participant provided 40 naturally varying "ambient" images of their friend per testing session, resulting in 120 different images per identity (ID). Different unfamiliar IDs were used during each session which matched the familiar ID with respect to gender, ethnicity, approximate age, hair colour and style. The unfamiliar stimuli consisted of 40 images of 43 different unfamiliar IDs (some of which were reused with different participants). Using GIMP, photos were cropped to include the full head, adjusted in size and copied to a frame of 190×285 pixels, converted to grayscale, and matched for luminance using the SHINE toolbox (Willenbockel et al., 2010, see Fig. 1 for examples). Ten images of butterflies were used to create a task demand.

[1] Please note that a more conventional power of .8 would have resulted in $N = 14$.

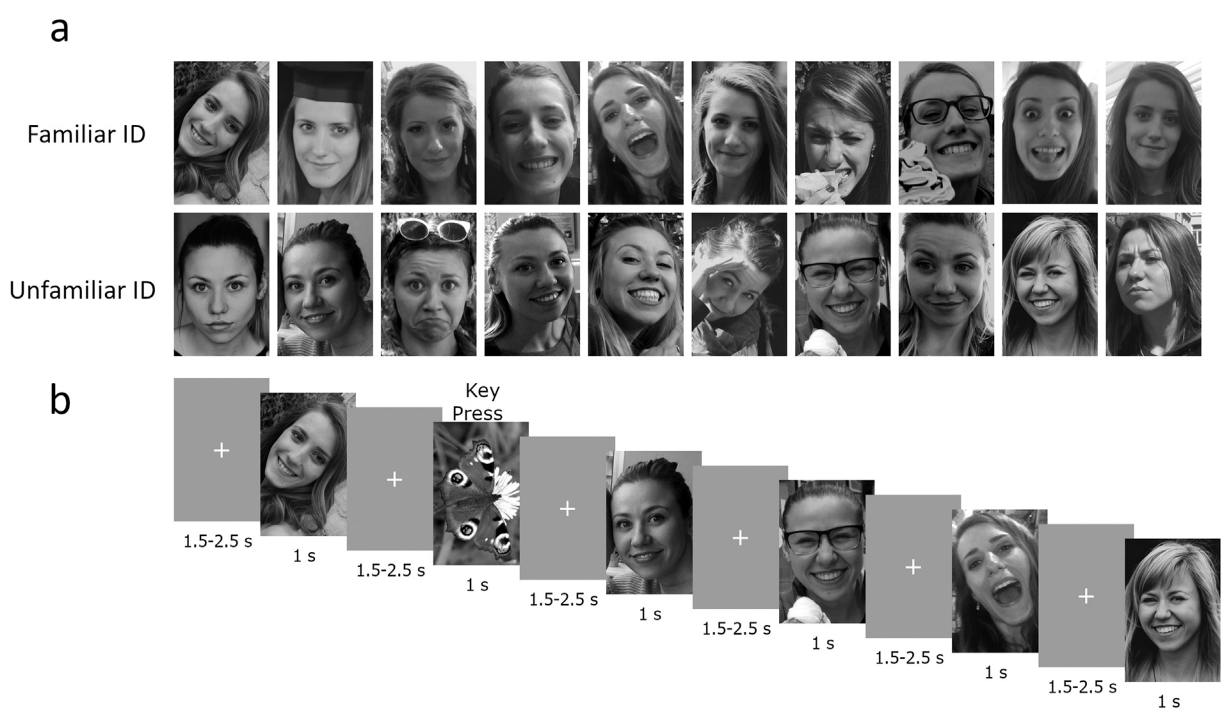

Fig. 1 – a) Example ambient images of two identities. b) Trial structure of the experiment. Images are published with the permission of the depicted persons.

2.3. *Procedure*

The experiment consisted of three EEG sessions. The participants were tested within a two-week time period approximately one ($M = 36.6$ days, $SD = 3.2$), five ($M = 138.4$ days, $SD = 3.9$), and eight months ($M = 249.6$ days, $SD = 4.4$) after the start of the academic year. All recordings took place in an electrically shielded room (Global EMC™) in the EEG lab of Durham University's Psychology Department. The participants were seated 80 cm from a computer monitor with their head placed in a chinrest. Each EEG session consisted of a single 6-min block of stimulus presentation. Forty images each of a familiar and an unfamiliar ID along with 10 butterfly images were shown in a randomised order (Fig. 1). The pictures were presented using E-prime (Psychology Software Tools, Pittsburgh, PA) at a visual angle of $3.6° \times 5.4°$ on a uniform grey background in the centre of the screen for 1000 ms. Trials were separated by a fixation cross varying in duration between 1500 and 2500 ms (2000 ms on average). Participants were instructed to press a button with their right index finger in response to butterflies with emphasis on both accuracy and speed.

Each EEG session was followed by a short rating task assessing familiarity with and emotional responses towards the identities. Participants were presented with eight randomly selected images of each ID and asked to judge how likely they were to recognise the person in an image on a 1–5 scale from 'highly unlikely' to 'highly likely'. Arousal and valence were rated on a scale of 1 *(very arousing/very positive valence)* to 5 *(not arousing at all/very negative valence)* using the Self-Assessment Manikin (SAM) scale (Bradley & Lang, 1994). Participants were also asked how often they see (visual interaction) and talk to the person (social contact), with response options never, once or twice a year, once or twice a month, once or twice a week, or every day. While people only seem to have moderate insight into their face recognition abilities for pre-experimentally unfamiliar faces (see Bobak, Mileva, & Hancock, 2019; Palermo et al., 2017), participants in the present experiment knew their university friends for at least one month. We therefore do not consider missed identifications in the experiment despite high recognisability ratings as likely, particularly as participants provided the familiar face images for their experiment themselves.

2.4. *EEG recording and analysis*

64-channel EEG (EEGo, ANT Neuro, Enschede, The Netherlands) was recorded with a sampling rate of 1024 Hz from sintered Ag/Ag–Cl electrodes. CPz was used as the recording reference and AFz as the ground electrode. Blinks were corrected using BESA Research Software (Version 6.3; Grafelfing, Germany). Data were segmented into epochs between −200 and 1000 ms relative to stimulus onset with the first 200 ms serving as a baseline. Artefact rejection was implemented using a 100 μV amplitude threshold and a 75 μV gradient criterion. The remaining trials were re-referenced to the common average reference and averaged for the different experimental conditions. In line with analysis procedures from previous studies (Popova & Wiese, 2022; Wiese, Tüttenberg, et al., 2019), mean amplitudes from 200 to 400 ms (N250) and 400–600 ms (SFE) were calculated at occipito-temporal electrodes TP9 and TP10. Given the inconsistency of N170 familiarity effects (see above), we report analyses of this component (and of an N250-corrected SFE) in the

Supplementary Materials. The average number of accepted trials across all three testing sessions was 37.7 (±3.6 SD, min = 25) for familiar identities and 37.7 (±3.2 SD, min = 26) for unfamiliar faces.

Repeated-measures Analyses of Variance (ANOVA) with within-subject factors hemisphere (left, right), session (1, 2, 3), and familiarity (friend, unfamiliar ID) were run separately for the two time ranges. This was paralleled by planned paired-sample *t*-tests investigating the differences in familiarity effects (unfamiliar − familiar faces) between and within sessions. To test for the presence of an SFE over and above the familiarity effect observed in the N250 time window, additional planned comparisons directly comparing the two effects within each session were calculated (see Popova & Wiese, 2023). We report effect sizes with appropriately-sized confidence intervals (CIs): 90% CIs for η^2_p[2] (calculated using an online calculator https://effect-size-calculator.herokuapp.com) and 95% CIs for d_{unb} (calculated using ESCI, Cumming, 2012). Furthermore, bootstrapping analyses (Di Nocera & Ferlazzo, 2000) were run to test whether familiarity effects can be reliably detected in individual participants. For this purpose, single-trial EEG epochs of individual participants were randomly reassigned to two “familiarity” conditions with 10,000 iterations. Reliable effects were assumed if the true individual familiarity effects at TP9 and TP10 were larger than 95% of the random re-samplings (Wiese, Tüttenberg, et al., 2019).

To fully explore the data, paired-sample *t*-tests were conducted for the two time ranges of interest for Session 1 and Session 2 for all participants who completed both sessions (N = 18), and additional analyses were calculated including only female participants (N = 14). We further ran mass univariate analyses for the within-session comparisons (friend *vs* unfamiliar identity) by calculating paired-sample *t*-tests for each time point and channel, and controlling for multiple comparisons using the False Discovery Rate (FDR) method (Benjamini & Hochberg, 1995). To detect familiarity effects which were consistent across or exclusive for specific testing sessions, we then used FDR-corrected *p*-values to calculate exclusive disjunctions as well as conjunctions between sessions across all channels and time points. Additionally, we calculated d_{unb} as an effect size measure for each timepoint and channel, and for each of the three sessions separately.

The study procedures and analysis plans were preregistered on the Open Science Framework prior to data collection (see https://osf.io/e258k). All EEG and behavioural data, as well as analysis code, are publicly available on the Open Science Framework platform (https://osf.io/wt9ua/). The conditions of our ethical approval do not permit the public archiving of the photos of the facial identities used in this study and the images cannot be shared with anyone outside the author team. Images of selected individuals who have provided their explicit written consent are used as examples in Fig. 1.

[2] We use 90% confidence intervals here because F-tests are one-sided. This means that the 90% CI always excludes zero if the effect is statistically significant, while the 95% CI does not (see e.g. , Lakens, 2013).

3. Results

3.1. *Event-related potentials*

Visual inspection of the grand average ERPs revealed more negative amplitudes for the familiar relative to the unfamiliar identities in the 200–400 ms (N250) and 400–600 ms (SFE) time ranges (see Fig. 2a). These differences were evident from Session 1 and appeared to become more pronounced over sessions in both time ranges of interest.

An ANOVA in the N250 time range revealed a significant main effect of familiarity, $F(1, 15) = 39.5$, $p < .001$, $\eta^2_p = .725$, 90% CI [.450, .817]. Paired-sample *t*-tests (see Table 1) revealed significantly more negative amplitudes for the friend relative to the unfamiliar face in all three sessions. The main effect of session was non-significant, $F(2, 30) = .85$, $p = .440$, $\eta^2_p = .053$, 90% CI [0, .18]. The ANOVA further yielded a trend for an interaction of session by familiarity, $F(2, 30) = 2.62$, $p = .089$, $\eta^2_p = .149$. Planned comparisons to test our main hypotheses of familiarity effect changes between sessions revealed a trend towards an increase between Session 1 to Session 2 (note that $p = .034$ for the directional alternative hypothesis of increased familiarity effects in Session 2 relative to Session 1). However, there was no noticeable difference between Session 2 and 3. An additional non-pre-registered test compared the effects between Sessions 1 and 3 and revealed a significantly larger effect in Session 3 relative to Session 1.

An ANOVA in the SFE time range revealed a significant main effect of familiarity, $F(1, 15) = 45.6$, $p < .001$, $\eta^2_p = .753$, 90% CI [.495, .835]. Follow-up tests (see Table 1) revealed that, relative to unfamiliar faces, the friend elicited significantly more negative amplitudes in all three sessions. The main effect of session, $F(2, 30) = .68$, $p = .516$, $\eta^2_p = .043$, 90% CI [0, .16], and the session by familiarity interaction were non-significant, $F(2, 30) = .40$, $p = .675$, $\eta^2_p = .026$. Planned comparisons were run to examine potential between-session differences in the familiarity effects and there were no significant differences between any of the sessions.

To compare the familiarity effects against each other, three within-group planned comparisons were run (see Table 1). While in Session 1, the SFE was significantly higher than the N250, in Session 2, the two familiarity effects did not differ, and in Session 3, there was a trend towards a larger SFE.

Bootstrapping analysis for the N250 time window revealed reliable effects in 6/16 participants in Session 1, $p = .38$, 95% CI [.19, .61]. In both Sessions 2 and 3, reliable effects were reported in 9/16 participants, $p = .56$, 95% CI [.33, .77]. Out of the six participants who showed reliable effects in Session 1, four participants demonstrated reliable effects in all three sessions and two participants demonstrated reliable effects in one of the other two sessions. Bootstrapping for the SFE time range revealed reliable familiarity effects in 8/16 participants in Sessions 1 and 2, $p = .50$, 95% CI [.28, .72]. In Session 3 reliable effects were detected in 10/16 participants, $p = .63$, 95% CI [.39, .82]. Out of the eight participants who showed reliable effects in Session 1, four demonstrated reliable effects in the following two sessions and the other four demonstrated a reliable effect in one of the other two sessions.

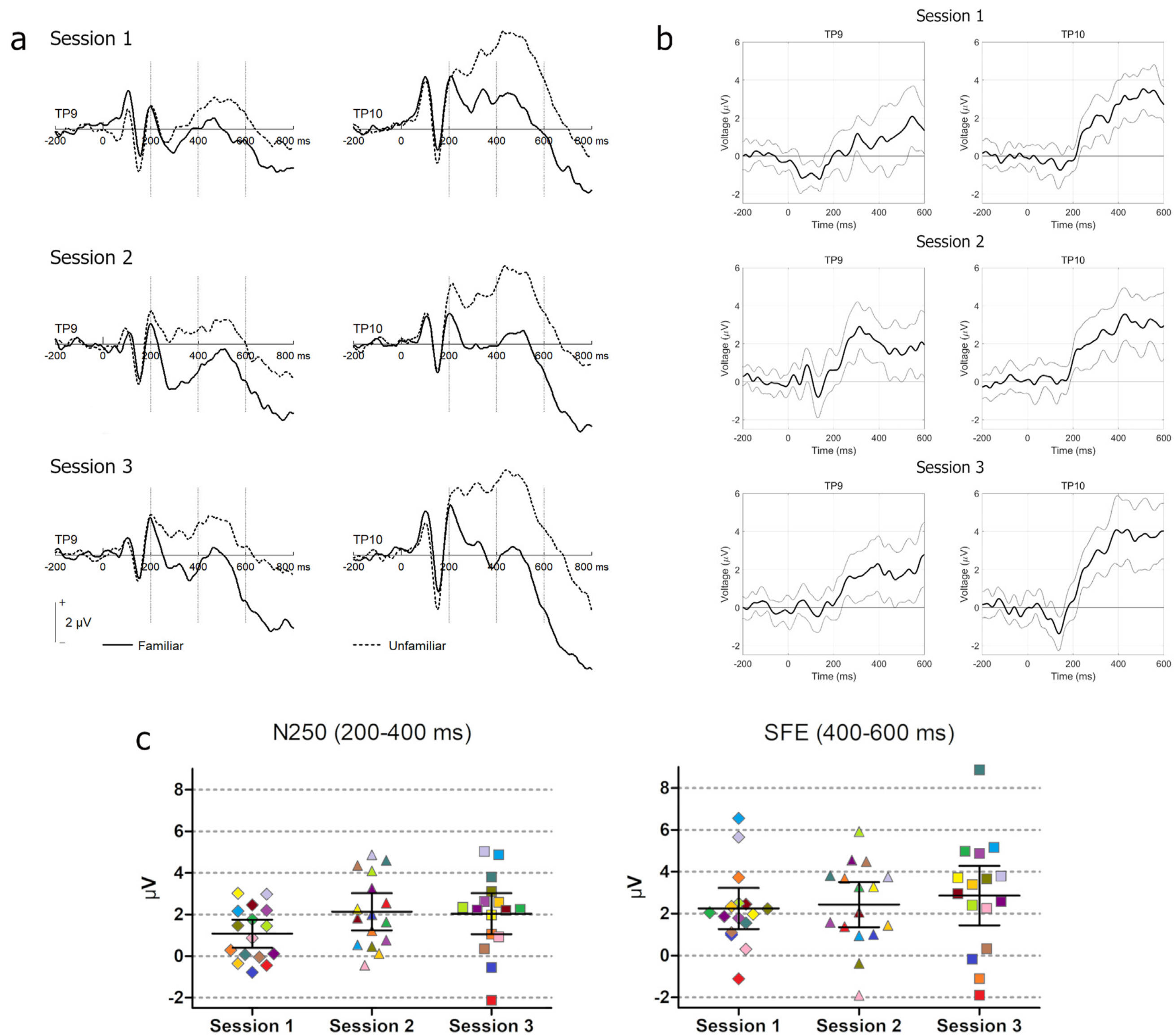

Fig. 2 – a) Grand average event-related potentials (ERPs) at left and right occipito-temporal channels TP9 and TP10 for familiar and unfamiliar IDs for each session. b) Mean (and 95% CIs; dashed lines) difference between familiar and unfamiliar IDs at TP9 and TP10. c) Individual (symbols) and mean familiarity effects with 95% CIs (solid lines) for the N250 and SFE time ranges, colour-coded for individual participants.

3.2. *Rating task*

In the rating task (see Table 2 and Supplementary Materials for a full report), the friend was rated as significantly higher in visual familiarity, arousal, and frequency of interaction, as well as more positive in valence, relative to the unfamiliar ID (all $p < .002$). There was a trend towards a significant difference in the frequency of interaction between Session 1 and 3, suggesting fewer interactions reported in Session 3, $p = .063$, $r = .559$. There were no significant between-session differences for any of the other ratings (all $p > .249$).

3.3. *Exploratory analyses*

Exploratory analyses were run including all participants who only completed both Sessions 1 and 2. A paired-sample t-test in the N250 time window revealed a significant increase in the familiarity effect from Session 1 to Session 2, $M_{diff} = 1.21$, 95% CIs [.15, 2.26], $t(17) = 2.40$, $p = .028$, $d_{unb} = .77$, 95% CIs [.09, 1.50]. There were no significant differences in the SFE time range, $M_{diff} = .30$, 95% CIs [−1.04, 1.64], $t(17) = .47$, $p = .642$, $d_{unb} = .14$, 95% CIs [−.46, .75].

Additional analyses including only the female participants from the final sample ($N = 14$) revealed a significant increase in the N250 effect from Session 1 to Session 2, $M_{diff} = 1.30$ µV, 95% CIs [.05, 2.56], $t(13) = 2.24$, $p = .043$, $d_{unb} = .81$, 95% CIs [.03, 1.66], and from Session 1 to Session 3, $M_{diff} = 1.20$ µV, 95% CIs [.38, 2.01], $t(13) = 3.16$, $p = .008$, $d_{unb} = .69$, 95% CIs [.19, 1.26]. There was no significant difference between Session 2 and 3, $M_{diff} = .11$ µV, 95% CIs [−1.38, 1.60], $t(13) = .16$, $p = .879$, $d_{unb} = .05$, 95% CIs [−.66, .77]. In the SFE time range, there were no significant differences between Session 1 and 2,

Table 1 – Results of paired-samples *t*-tests. S1 = Session 1, S2 = Session 2, S3 = Session 3. All *df* = 15.

ERP measure	Effect	M_{diff}	95% CI	t	*p*	d_{unb}	95% CI
N250	S1: friend *vs* unfam	1.07	[.40, 1.75]	3.36	.004	.27	[.09, .47]
	S2: friend *vs* unfam	2.13	[1.23, 3.04]	5.04	<.001	.73	[.36, 1.17]
	S3: friend *vs* unfam	2.04	[1.06, 3.03]	4.42	.001	.56	[.25, .92]
	S1 *vs* S2	1.05	[-.09, 2.19]	1.97	.067	.67	[-.05, 1.44]
	S2 *vs* S3	.09	[-1.19, 1.37]	.15	.885	.05	[-.62, .72]
	S1 *vs* S3	.97	[.18, 1.75]	2.63	.019	.58	[.10, 1.10]
SFE	S1: friend *vs* unfam	2.24	[1.26, 3.23]	4.85	<.001	.60	[.28, .96]
	S2: friend *vs* unfam	2.43	[1.35, 3.51]	4.80	<.001	.68	[.32, 1.10]
	S3: friend *vs* unfam	2.86	[1.44, 4.28]	4.28	.001	.74	[.32, 1.22]
	S1 *vs* S2	.18	[-1.14, 1.50]	.30	.771	.09	[-.54, .72]
	S2 *vs* S3	.43	[-1.31, 2.18]	.53	.606	.17	[-.50, .86]
	S1 *vs* S3	.62	[-.81, 2.04]	.92	.373	.25	[-.32, .84]
N250 *vs* SFE	S1	1.17	[.33, 2.01]	2.98	.009	.70	[.18, 1.28]
	S2	.30	[-.36, .96]	.97	.349	.15	[-.17, .49]
	S3	.82	[-.05, 1.69]	2.00	.064	.34	[-.02, .72]

Table 2 – Mean/Median ratings for the two identities. Familiarity, valence, arousal, and interaction with each identity were assessed on a scale from 1 to 5 (familiarity: 1 = very low familiarity to 5 = very high familiarity; valence: 1 = very positive to 5 = very negative; arousal: 1 = very arousing to 5 = not arousing at all; interaction: 1 = never, 2 = once or twice a year, 3 = once or twice a month, 4 = once or twice a week, 5 = every day).

		Familiarity		Arousal		Valence		Interaction	
		M	*SD*	*M*	*SD*	*M*	*SD*	*Mdn*	*IQR*
Familiar ID	Session 1	5.00	.00	2.19	.66	1.38	.81	5	.00
	Session 2	4.94	.25	2.44	1.15	1.63	1.09	5	.25
	Session 3	5.00	.00	2.44	.73	1.44	.63	5	1.00
Unfamiliar ID	Session 1	1.69	1.30	4.13	.89	2.75	.45	1	.00
	Session 2	1.56	1.03	4.25	.93	2.81	.40	1	.00
	Session 3	1.63	.89	4.06	1.06	2.81	.54	1	.00

M_{diff} = .14 μV, 95% CIs [−1.38, 1.67], *t*(13) = .16, *p* = .842, d_{unb} = .07, 95% CIs [−.60, .74], Session 2 and 3, M_{diff} = .40 μV, 95% CIs [−1.63, 2.43], *t*(13) = .43, *p* = .678, d_{unb} = .15, 95% CIs [−.58, .89], and Session 1 and 3, M_{diff} = .54 μV, 95% CIs [−1.11, 2.19], *t*(13) = .71, *p* = .490, d_{unb} = .21, 95% CIs [−.40, .83].

Exploratory FDR-corrected mass univariate analyses of the within-group contrast of familiar *vs* unfamiliar identities revealed no systematic differences between the two identities before 200 ms (see Fig. 3a). Across all three sessions, the familiarity effect appeared more prominent over the right hemisphere with no pronounced differences observed over the left hemisphere. The analyses largely confirmed our observation of less pronounced familiarity effects in the N250 time window for Session 1 relative to the two later sessions, as we observed earlier and longer-lasting effects at TP10/P10 in Sessions 2 and 3. Familiarity effects in Session 2 were also more widespread across the scalp, with additional effects over central and parietal channels (presumably reflecting the opposite end of the dipole underlying the occipito-temporal effects, see Fig. 3d). In Session 3, the familiarity effect was more focused but very strongly pronounced at the right occipito-temporal channels.

Fig. 3b shows the exclusive disjunction of FDR-corrected significant effects when comparing the different sessions. These comparisons further illustrate the above observations of more pronounced centro-parietal effects in Session 2 relative to the other two sessions (see Fig. 3b). Importantly, they also show the more pronounced effects in the N250 time range at right occipito-temporal channels in the two later relative to the first session (S1 *vs* S2, S1 *vs* S3). A logical conjunction, showing significant effects common to the respective sessions, demonstrated significant effects in the SFE time range at occipito-temporal channels P10 and TP10 in all combinations of the three sessions (see Fig. 3c). For the earlier N250 time range, there was an overlap in the activity at TP10/P10 in Sessions 2 and 3, starting at approximately 300 ms.

The mass univariate and mass effect size analyses (see Fig. 3d) further suggest strong familiarity effects following the SFE time window, i.e., from 600 to 800 ms. To follow up on this observation, we compared the familiarity effects between sessions in this time range. While there were no significant differences between Sessions 1 and 2, M_{diff} = .87, 95% CIs [−.97, 2.72], *t*(15) = 1.01, *p* = .330, d_{unb} = .34, 95% CIs [−.36, 1.07], and Sessions 2 and 3, M_{diff} = .84, 95% CIs [−1.06, 2.75], *t*(15) = .94, *p* = .362, d_{unb} = .30, 95% CIs [−.35, .96], larger familiarity effects were observed in Session 3 relative to Session 1, M_{diff} = 1.71, 95% CIs [.48, 2.95], *t*(15) = 2.96, *p* = .001, d_{unb} = .71, 95% CIs [.18, 1.30].

4. Discussion

Using a longitudinal design, the present study investigated how familiarity develops during the first eight months of

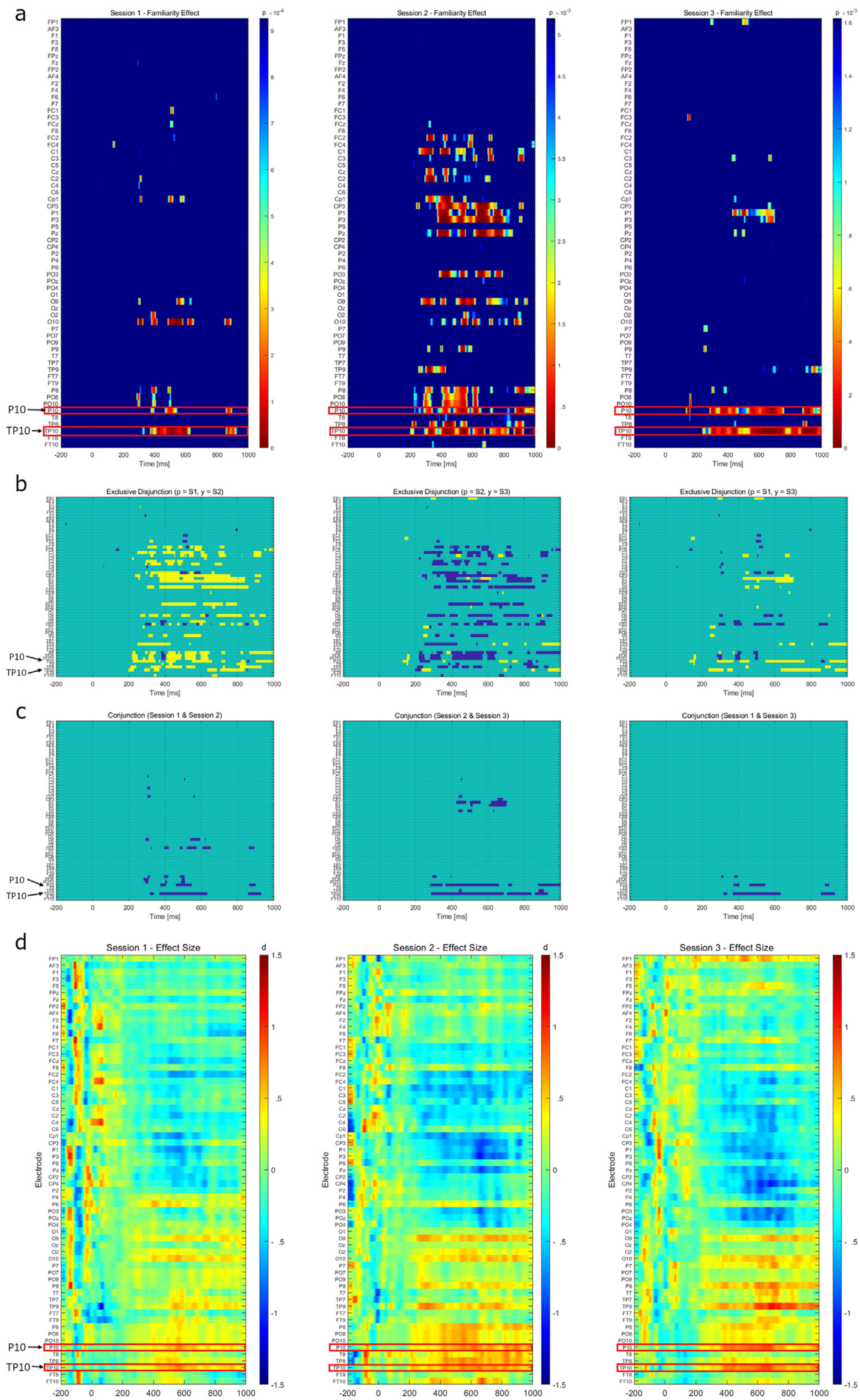

Fig. 3 — a) FDR-corrected mass univariate analyses for the familiar-unfamiliar comparison for each session. b) Exclusive disjunction of significant effects comparing the three sessions. c) Conjunction of significant effects across sessions. d) Mass effect size (d_{unb}) for familiar *vs* unfamiliar faces for each session.

getting to know a person. For this purpose, we used ERPs to examine how increasing familiarity affects visual (N250 familiarity effect) and later integrational (SFE) processing stages of face recognition. Clear familiarity effects were evident after approximately one month of knowing a new person. While we found evidence for further refinement of the visual face representations (in the N250 effect) beyond the first month of familiarity, no noticeable change in the later integrational stages (SFE) was detected over the time span covered by the present study.

As expected, we observed a clear N250 familiarity effect in Session 1 indicating that robust face representations were evident after a month of familiarity. The quick establishment of visual representations is in line with previous research which has reported similar learning effects after a single laboratory-based learning session (Andrews et al., 2017; Kaufmann et al., 2009; Tanaka et al., 2006; Zimmermann & Eimer, 2013) and following short real-life exposure (Ambrus et al., 2021; Popova & Wiese, 2023; Sliwinska et al., 2022). Of note, the effect size we found after one month of familiarity (d_{unb} = .27) was somewhat lower than the effect observed in our previous study after two months of familiarity (d_{unb} = .43) (Popova & Wiese, 2022), which may suggest that the additional month of exposure early in the friendship contributed to more refined face representations. However, the present effect falls within the confidence interval of the previous one, rendering sample variability a plausible alternative interpretation.

Importantly, we observed an increase in the N250 effect over the course of the study. Accordingly, it appears as if one month of exposure was not sufficient for the visual representations to have fully developed. Specifically, we found a significant increase of the effect from Session 1 to 3 (d_{unb} = .58) while the differences between Session 1 and Session 2 (d_{unb} = .67) and Session 2 and 3 (d_{unb} = .05) were non-significant. We note that these findings are based on a small and female-dominant sample. Moreover, the effect size for the Session 1 and 2 comparison was of a moderate to large size, suggesting that the interpretation of this comparison as a null effect may be premature. Both the exploratory analysis including all participants who completed the first two sessions, and the analysis testing only female participants yielded a significant increase in the N250 time window. Together, these results seem to suggest that there might be an increase of the N250 over the first five rather than eight months of knowing a person, while the pre-registered relevant statistical comparison was not significant (p = .067). Therefore, the results from the current study regarding the specific trajectory of development of visual face representations are inconclusive and need to be further examined in future work.

Interestingly, the N250 familiarity effects elicited in Session 2 (d_{unb} = .73) and Session 3 (d_{unb} = .56) seem comparable in size to the effects elicited by highly personally familiar faces (e.g., d_{unb} = .65 in Popova & Wiese, 2022; d_{unb} = .55 in Wiese, Hobden, et al., 2022). Previous research has demonstrated that the strength of face representations depends on the quality and quantity of exposure to within-person variability (Burton, Kramer, Ritchie, & Jenkins, 2016; Kramer et al., 2018). In line with these studies, the N250 increase observed here also complements previous findings suggesting that neural correlates of face representations are modulated by level of familiarity (Andrews et al., 2017; Popova & Wiese, 2022; Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019). Hence, it appears as if sufficient variability is experienced during the first eight months of familiarity, and given frequent exposure, that the visual face representations develop substantially during this time period and reach the level of highly familiar faces. The present results therefore seem to refine our previous conclusions of fully established face and person representations within 14 months of familiarity (Popova & Wiese, 2022) by suggesting that *visual* representations are fully established earlier. As discussed in more detail below, however, the full integration of identity-specific information appears to develop at a slower pace.

Of note, we found a clear SFE in Session 1, suggesting that one month of familiarity is sufficient for the formation of robust person-related representations. Unexpectedly, the SFE at one month of familiarity was larger than the effect in the N250 time range (see e.g., Fig. 2b). However, the SFE in the present study (d_{unb} = .60) was similar to the one observed in our previous study at two months of familiarity (d_{unb} = .53), and well within the previous effect's 95% confidence interval (Popova & Wiese, 2022). Importantly, on the basis of our previous study in which we had observed a significant increase in the SFE between two and 14 months of familiarity (Popova & Wiese, 2022), we hypothesised an increase in the SFE with prolonged familiarity. Contrary to this hypothesis, we did not detect a significant increase over the first eight months of knowing a person. The effect at eight months of familiarity (d_{unb} = .74) was smaller than the one previously observed for personally highly familiar people (e.g., d_{unb} = .92 in Wiese, Hobden, et al., 2022; d_{unb} = 1.08 in Wiese, Tüttenberg, et al., 2019) and friends known for approximately one year (d_{unb} = .95 in Popova & Wiese, 2022), suggesting that the integration of identity-specific information had not yet developed to the level of highly familiar identities.

We see two potential, and not mutually exclusive explanations for the absence of increasing SFEs over the course of the present study. Firstly, the SFE might develop slowly, and gradual increases in the eight months of the present study may be too small to be statistically detectable. The effect might then develop further after the last testing session of the present and before the second time point in our previous study, i.e., between eight and 14 months of knowing a person. This suggestion is in line with a numerical increase of reliable effects in the bootstrapping analysis between Sessions 2 and 3 and with a gradual increase in the SFE effect size from Session 1 to 3. Secondly, precisely how friends were selected by the participants differed between the two studies. Here, the participants picked their friend at the beginning of the academic year, and they might have not remained as close with them for the whole time span covered by the present study. By contrast, the participants in the 14 months group of Popova and Wiese (2022) selected a close university friend *at the time of testing*, and it therefore remains possible that the SFE develops quicker when tested with closer friends. We note, however, that interaction and familiarity ratings in the present study were at or close to ceiling in all three sessions.

Together, these results suggest that the development of visual and person-identity representations follows different trajectories. While at one month of familiarity the SFE in the present study was over and above the N250, at five months of familiarity the magnitude of the effects was very similar. Finally, at eight months there was a trend for a larger SFE relative to the N250, and the SFE appeared to be building up. These results suggest that the first month of familiarity is highly informative for the initial formation of both visual and identity representations. Subsequently, the N250 effect appears to build up to the level of highly familiar identities within the first eight months of familiarity. The SFE, on the other hand, appears to develop only slowly over this time period, resulting in no statistically reliable increase, while being fully developed after 14 months.

Previous research has investigated neural correlates of different levels of familiarity (e.g., Campbell, Louw, Michniak, & Tanaka, 2020; Natu and O'Toole, 2011; Ramon & Gobbini, 2018; Wiese, Hobden, et al., 2022) but not much is known about how face and identity representations are established in the first place, and how familiarity accumulates over time. Recently, Kovács (2020) proposed a model based on neuroimaging data, which suggests changes in activation patterns as a result of increasing familiarity. In the case of personally familiar faces, these changes affect not only the core face network (fusiform/inferior occipital/superior temporal regions, inferior frontal gyrus) but also brain regions processing semantic knowledge (anterior temporal lobe), episodic memory (precuneus/posterior cingulate cortex, medial temporal lobe), personality (temporoparietal junction, inferior parietal lobule, medial prefrontal cortex, anterior cingulate cortex), and emotions (amygdala). Previous models (see Gobbini & Haxby, 2007) have assumed that this "extended network" activity feeds back into the core system, and therefore to visual representations, and it appears to be this boost of core system activation that is reflected in the SFE (given its similar scalp distribution relative to the N250 effect). Crucially, as detailed above, the present results add information about how these processes build up over time and therefore contribute to our theoretical understanding of face and identity learning.

Our results also add novel information to questions of potential applicability. Previous work has used ERP effects, and particularly the SFE, to examine whether it is possible to reliably detect familiarity in individual participants, even when such familiarity is not explicitly acknowledged (Wiese, Anderson, et al., 2022; Wiese, Tuttenberg, et al., 2019). This previous work has found high sensitivity (with typical hit rates between .8 and .95 and false alarm rates below .05), but it remained largely unclear how long a facial identity has to be known to elicit a reliable effect. The proportion of reliable effects in the present study was clearly below those observed in previous experiments using highly familiar faces (with hit rates increasing from .5 in Sessions 1 and 2 to .625 in Session 3), which suggests that eight months are not sufficient to detect familiarity with comparably high sensitivity. This finding is in line with previous results suggesting that such sensitivity at the individual participant level may take substantially longer to develop (Popova & Wiese, 2022).

As a potential limitation, we note that while our approach enabled us to examine familiarity in an ecologically valid way over long time periods, the exact quantity and quality of exposure to the learnt identities over the course of the study remains unclear. To provide more precise information, future studies may therefore try to either control or measure the interactions more accurately (see Campbell & Tanaka, 2021, for a similar naturalistic learning approach in which the minimum exposure was controlled). In the present study, however, a more fine-grained measure of everyday contact, e.g., in the form of contact diaries, would have been very difficult to implement in a reasonably sized group of participants over the time period we studied here. The current experiment was further limited by the reduced number of participants who completed all three sessions. While we did meet our target sample size[3], we experienced a high drop-out rate with a third of the participants withdrawing over the course of the study (and with the highest drop-out between Sessions 1 and 2). The main reason for dropping out of the experiment was no longer being friends with the identity used in Session 1. This demonstrates that naturalistic longitudinal designs are challenging to implement, as it is difficult for participants to foresee whether they would remain friends with someone they have only known for a few weeks. In addition, our sample does not allow to draw strong conclusions for non-female participants. While previous research has reported more accurate face recognition in female as compared to male participants (Lewin & Herlitz, 2002; Sommer, Hildebrandt, Kunina-Habenicht, Schacht, & Wilhelm, 2013), more systematic research is needed to investigate potential gender differences in ERP correlates of naturalistic face learning. Despite these limitations, we believe that ecologically valid procedures are needed to study face and identity learning with personally relevant identities, as only such studies will allow to apprehend the deep familiarisation processes happening in everyday life encounters—leading to the rich semantic, affective, and episodic identity-specific information that shapes our personal relationships.

In conclusion, the present study investigated the changes neural correlates of familiarity undergo during the first eight months of knowing a person. Our findings suggest that one month of exposure is sufficient for initial robust face and identity representations to be established. Moreover, our results imply that visual face representations develop over the first eight months of knowing a person, as we detected evidence for an increase in the N250 effect from one to eight months of familiarity. By contrast, we found no reliable increase in the SFE over the course of our study, suggesting that the integration of identity-specific representations takes longer than eight months of familiarity. These findings extend our knowledge of how new identities become familiar in everyday life by providing crucial timing information for face and identity learning.

Author contributions

Tsvetomila Popova: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration;

[3] Please note that our power analysis was calculated based on a one-tailed paired-sampled *t*-test. We, however, conducted two-tailed tests. For a two-tailed power analysis with power of .85, the required sample size would have been 20 participants.

Visualization; Roles/Writing - original draft; Writing - review & editing.

Holger Wiese: Conceptualization; Formal analysis; Investigation; Methodology; Resources; Supervision; Roles/Writing - original draft; Writing - review & editing.

Open practices section

The study in this article earned Open Data and Preregistered badges for transparent practices. The study procedures and analysis plans were preregistered on the Open Science Framework prior to data collection (see https://osf.io/e258k). All EEG and behavioural data, as well as analysis code, are publicly available on the Open Science Framework platform (https://osf.io/wt9ua).

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Declaration of competing interest

We declare no conflict of interest.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cortex.2023.04.008.

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