Biological Psychology 170 (2022) 108312

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

The time it takes to truly know someone: Neurophysiological correlates of face and identity learning during the first two years

Tsvetomila Popova, Holger Wiese *

Durham University, United Kingdom

ARTICLE INFO

Keywords:
Face learning
Familiarity
Event-related potentials
N250
Sustained familiarity effect

ABSTRACT

How long does it take to truly know a person? To answer this question, we investigated how event-related brain potential (ERP) correlates of facial familiarity (N250) and the integration of identity-specific knowledge (Sustained Familiarity Effect, SFE) develop over time. Sixty undergraduate students from three year groups were tested with images of a university friend (with two, 14, and 26 months of familiarity for Year 1, Year 2, and Year 3 students), a highly familiar friend from home, and an unfamiliar identity. While clear ERP familiarity effects for home friends were observed in all groups, university friends yielded a clear N250 effect but only a small SFE in Year 1. Importantly, both effects significantly increased for university friends from Year 1 to Year 2, but not afterwards. Our results demonstrate that neural representations of visual familiarity and identity-specific knowledge build up over time and are fully developed by 14 months of familiarity.

1. Introduction

The accurate and efficient recognition of a person's face as well as the retrieval of identity-specific semantic, episodic, and affective information are of vital importance, as they guide our behaviour towards other people in everyday life (Young & Burton, 2017). There are, however, remarkable differences in these abilities depending on familiarity. While for instance recognising or matching pictures of unfamiliar faces is often surprisingly error-prone in seemingly ideal conditions (e.g. Bruce, Henderson, Greenwood, Hancock, Burton & Miller, 1999; for a review, see Johnston & Edmonds, 2009), the recognition of faces we know well is typically highly reliable, even in challenging situations (e.g. Burton, Wilson, Cowan & Bruce, 1999). Yet, despite considerable research, it is unclear what exactly constitutes familiarity. Critically, it remains unknown how long it takes to know a person well enough for highly efficient recognition. Familiarity is arguably a continuum, and gradual differences are likely to affect how a face is processed. So how long does it take to truly know someone? To answer this question, we investigated how familiarity increases in real life during the first two years of knowing a person. Using event-related brain potentials (ERPs), we focused on both the visual recognition of a face and the integration of additional identity-specific information.

Recognising a person from their face is typically thought to consist of several distinct stages. Theoretical accounts distinguish an earlier stage at which a face is recognised as familiar from a subsequent stage at which semantic, episodic, and affective information about the person is accessed and integrated (see Bruce & Young, 1986; Gobbini & Haxby, 2007; Schweinberger & Burton, 2003). The excellent temporal resolution of EEG marks the technique as ideal for studying this type of cognitive architecture and thus face and person recognition (Ambrus, Kaiser, Cichy & Kovács, 2019; Campbell, Louw, Michniak & Tanaka, 2020; Yan & Rossion, 2020); see Olivares, Iglesias, Saavedra, Trujillo-Barreto & Valdés-Sosa, 2015, for a review), and previous ERP studies have observed consistent effects of visual familiarity with a face within 200–300 ms after the presentation of a face stimulus. In this time range, both images of celebrities (Bentin & Deouell, 2000; Gosling & Eimer, 2011; Saavedra et al., 2010; Wiese et al., in press) and personally familiar faces (Pierce, Scott, Boddington, Droucker, Curran & Tanaka, 2011; Wiese, Anderson, Beierholm, Tüttenberg, Young & Burton, 2022; Wiese, Tüttenberg, et al., 2019) elicit more negative amplitudes than unfamiliar faces. This so-called N250 familiarity effect is largest at occipito-temporal electrodes and is typically interpreted as reflecting access to visual representations of known faces (Schweinberger & Burton, 2003). Importantly, the N250 is also sensitive to face learning, as familiarity effects have been reported in response to pre-experimentally unfamiliar faces after a single lab-based learning session (Andrews, Burton, Schweinberger & Wiese, 2017; Kaufmann et al., 2009; Tanaka, Curran, Porterfield & Collins, 2006; Zimmermann & Eimer, 2013).

* Correspondence to: Department of Psychology, Durham University, South Road, Durham DH1 3LE, United Kingdom.
E-mail address: holger.wiese@durham.ac.uk (H. Wiese).

https://doi.org/10.1016/j.biopsycho.2022.108312
Received 8 November 2021; Received in revised form 4 February 2022; Accepted 9 March 2022
Available online 12 March 2022
0301-0511/© 2022 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

While these findings can provide information about how quickly a face is initially learned, they do not capture real-life learning over longer periods. In real life, familiarity builds up gradually over multiple encounters, and representations of newly learned faces are presumably refined through repeated exposure in varying circumstances (Burton, Kramer, Ritchie & Jenkins, 2016; Kramer et al., 2018). However, it is not known for how long learning continues and at what point additional exposure stops providing further benefit, effectively ending face learning.

As noted above, the process of recognising a person goes beyond visual recognition (Bruce & Young, 1986). In line with this, the ERP familiarity effect further increases after the N250 time window and peaks between 400 and 600 ms (Wiese, Tüttenberg, et al., 2019). Due to its occipito-temporal scalp distribution and modulation by level of familiarity (Wiese et al., in press), this so-called Sustained Familiarity Effect (SFE) has been interpreted to represent the integration of visual with additional identity-specific information. Currently, however, not much is known about the SFE, and it remains to be addressed what level of familiarity is necessary to elicit the effect. Moreover, it is unclear whether the integrational processes reflected in the SFE increase in magnitude with the accumulation of more knowledge or whether they saturate at some point. These questions are difficult to examine using traditional learning paradigms where the focus is typically on the visual aspect of face learning. Accordingly, to more clearly understand how identity-specific information is integrated, experiments should test learning through real-life social interactions in which knowledge gradually builds up over much longer time periods.

Some studies have investigated the acquisition of person-related knowledge in lab-based learning sessions (Kaufmann et al., 2009; Paller, Gonsalves, Grabowecky, Bozic & Yamada, 2000; Wiese & Schweinberger, 2015). Taylor et al. (2016) trained participants with novel, computer-generated pictures of faces that were either paired with semantic (e.g. name or occupation) or physical information (e.g. about their eye colour). Critically, faces learned with semantic information elicited more positive amplitudes relative to the perceptual condition at mid-parietal electrodes in a time-range similar to the SFE. This P600f effect might be interpreted as the positive end of the same dipole that generates the SFE. However, it should be noted that Taylor and colleagues (2016) did not observe differences between their experimental conditions at right occipito-temporal channels (see also Eimer, 2000) where the SFE is maximal. Thus, while the two effects may reflect partly similar processes, their generating structures appear somewhat different, and it therefore appears unlikely that they are fully identical.

To investigate how long it takes to truly know a person, the present study examined how familiarity develops through natural exposure in everyday life (see Ambrus, Eick, Kaiser & Kovács, 2021, and Campbell & Tanaka, 2021, for a similar approach). Using a cross-sectional design, we tested undergraduate students in their first, second, and third year of study approximately two months after the start of the academic year. Participants were presented with images of a close friend from their hometown and a friend known from university (translating into approximately two, 14, and 26 months of familiarity, respectively). Home and university friends were chosen because they likely do not differ systematically with respect to visually-derivable characteristics (such as age, gender, attractiveness etc.), while at the same time varying with respect to their level of familiarity. In other words, while accumulated exposure should be similar for home friends, it should systematically increase for university friends across year groups. We expected significant effects of visual recognition, with more negative N250 amplitudes for home and university friends relative to unfamiliar faces, in all groups. More importantly, we tested whether the N250 familiarity effect would increase in magnitude from Year 1 to Year 2. Regarding the SFE, in Year 1, we expected a smaller effect for university friends relative to home friends, as less identity-specific information should be available for the former compared to the latter identities. We further hypothesised that the SFE in response to university friends would increase from Year 1 to Year 2. Finally, we were particularly interested in whether the SFE would additionally grow from Year 2 to Year 3 or whether it would be fully developed after 14 months of knowing a person.

2. Method

2.1. Participants

The sample consisted of 60 undergraduate students at Durham University, 20 from their first year of study (Year 1; 19 female, age $M = 18.4$, $SD = 0.7$), 20 from Year 2 (19 female, age $M = 19.5$, $SD = 0.8$), and 20 from Year 3 (16 female, age $M = 21.1$, $SD = 1.8$). The sample size for each group was determined using G*Power (Faul, Erdfelder, Lang & Buchner, 2007). This power analysis was targeted at detecting the smallest effect of interest, which was the SFE for university friends in Year 1. For this contrast, we assumed half the SFE effect size relative to the one reported for personally highly familiar faces by Wiese et al. (2019) (paired-sample t-test, one-tailed, $dz = 0.8$, $1 - \beta = 0.95$). This analysis suggested 19 participants, which was increased to 20 for counterbalancing reasons (see below). Data were collected over two consecutive academic years to ensure a sufficiently large sample. All participants had normal or corrected-to-normal vision and did not take any central-acting medication. Fifty-six participants were right-handed and four were left-handed according to a modified version of the Edinburgh Handedness Inventory (Oldfield, 1971). All participants provided written informed consent and received either course credit or a monetary compensation of £ 8 per hour. The study was approved by Durham University's Psychology ethics committee.

2.2. Stimuli

Prior to the experiment, participants provided 50 photos (i.e. naturally varying "ambient" images) each of a friend known from university and of a friend from home (i.e. not known from university),[1] with the exception of six participants who were close friends (known from university) with an identity that was already in the stimulus set and therefore only provided images for the home friend (i.e. two university friend IDs were used for two participants, and two additional IDs for three participants). Accordingly, a total of 114 different identities was used. Consent of the depicted people was obtained via email. Eight images of butterflies were used as target stimuli. Photos were cropped around the faces, resized to a 190 × 285 pixels frame, converted to greyscale, and matched for luminance using the SHINE toolbox (Willenbockel, Sadr, Fiset, Horne, Gosselin & Tanaka, 2010; see Fig. 1a).

2.3. Procedure

Year 1 students were tested, on average, 47.0 days ($SD = 10$), Year 2 students 54.6 days ($SD = 10.9$), and Year 3 students 60.8 days ($SD = 5.4$) after the start of the academic year. The participants were seated in an electrically shielded room (Global EMC™) with their heads in a chin rest 80 cm from a monitor. Participants were paired so that the home friend for one participant was used as an unfamiliar face for another participant, and vice versa.

The experiment consisted of a single block of 166 trials, in which all 50 images of the home friend, all 50 images of the university friend, 50 images of an unfamiliar person, and 16 images of butterflies were presented in random order using E-prime (Psychology Software Tools, Pittsburgh, PA). Each photo was displayed in the centre of the screen at a

[1] Please note that previous experiments have found highly comparable results when stimuli are provided by the participants or by the experimenters, i.e. when the particular images are known before the experiment or not (Wiese et al., 2019).

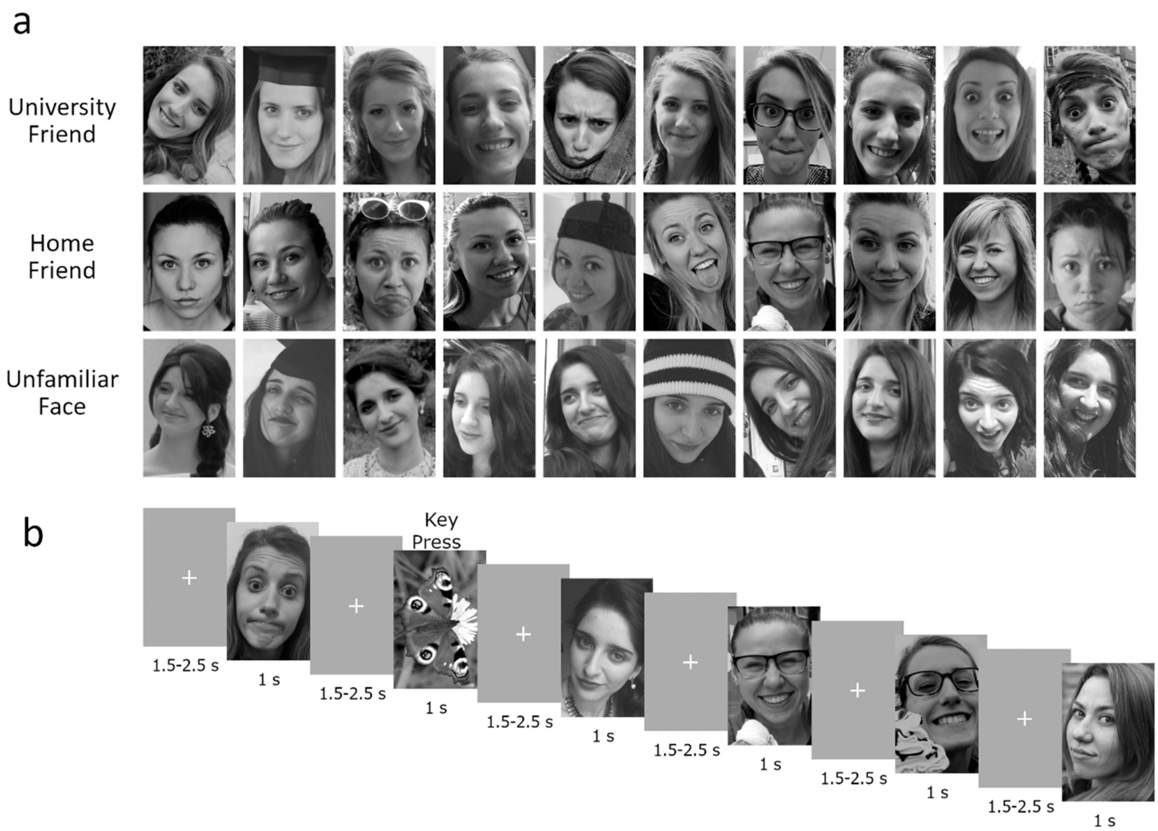

Fig. 1. a) Example ambient images from three identities (IDs). Images are published with the permission of the depicted persons. b) Trial structure of the experiment.

visual angle of 3.6° x 5.4° for 1000 ms and followed by a fixation cross with 1500–2500 ms presentation time (2000 ms on average). We chose this longer stimulus presentation time relative to some previous studies even though it introduces a higher probability of blink artifacts, because it eliminates offset potentials in later analysis time windows and is arguably more ecologically valid. Participants were instructed to press a button with their right index finger in response to images of butterflies (Fig. 1b). This task arguably captures face recognition in a more naturalistic way than explicit familiarity judgments, as recognising highly familiar faces in real life is largely independent of deliberate identity processing and does not require an overt response (see Wiese et al., 2022).

The main experiment was followed by a short rating task. For each of the three identities, participants saw eight randomly selected images, which were presented simultaneously on the screen, and were asked to indicate 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)* to 5 *(not arousing at all/very negative)* 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.

2.4. EEG Recording and Analysis

64-channel EEG was recorded from DC to 200 Hz with a sampling rate of 1024 Hz using sintered Ag/Ag-Cl electrodes (EEGo, ANT Neuro, Enschede, Netherlands). AFz served as ground and CPz was used as the recording reference. BESA Research Software (Version 6.3; Grafelfing, Germany) was used for blink correction. Data were segmented into epochs from − 200–1000 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 separately for each experimental condition. Following analysis procedures from previous studies (Wiese, Tüttenberg, et al., 2019), mean amplitudes from 200 to 400 ms (N250) and 400–600 ms (SFE) were calculated at TP9 and TP10 (see Supplementary Material for additional analyses of N170, N250-corrected SFE, and P600f). The average number of accepted trials was 47.8 (± 3.2 SD, min = 33) for university friends, 47.4 (± 4.2 SD, min = 22) for home friends, and 47.8 (± 3.7 SD, min = 27) for unfamiliar faces.

Mixed-model Analyses of Variance (ANOVA) with within-participant factors hemisphere (right, left) and familiarity (university friend, home friend, unfamiliar face) and the between-participant factor year group (Year 1, Year 2, Year 3) were run separately for N250 and SFE measures. We report effect sizes with appropriately sized confidence intervals (CIs): 90% CIs for η^2_p were calculated using an online calculator (https://effect-size-calculator.herokuapp.com); Cohen's d was bias-corrected (d_{unb}) and calculated for repeated measures t-tests using the mean standard deviation rather than the standard deviation of the difference as denominator, while the pooled standard deviation was used for independent t-tests (Cumming, 2012). 95% CIs for d_{unb} were calculated using ESCI (Cumming, 2012).

Familiarity effects were further examined in individual participants using a bootstrapping approach (Di Nocera & Ferlazzo, 2000) by randomly reassigning single-trial EEG epochs to "familiarity" conditions with 10,000 iterations. Effects were defined as reliable if the true individual differences between familiarity conditions were larger than 95% of the random re-assignments.

Finally, to fully explore the data, we additionally ran mass univariate analyses for the critical within-group (familiarity effects for university vs. home friends for Year 1, 2, and 3 separately) as well as between-group comparisons (familiarity effects for home and university friends between Year 1 and Year 2, as well as Year 2 and Year 3; see

Supplementary Material for a full analysis of all contrasts). For that purpose, paired or independent t-tests were calculated for each time point and channel. To not attenuate the exploratory nature of these analyses, we did not apply corrections for multiple comparisons. We note that any potential unpredicted result from exploratory analyses needs replication before it can be seen as valid (see e.g. Wagenmakers, Wetzels, Borsboom, van der Maas & Kievit, 2012).

Procedures and analyses were not pre-registered, but all inclusion and exclusion criteria were established before data collection. All study data and analysis code will be uploaded to the Open Science Framework platform (https://osf.io/g9kvw/). Face stimuli cannot be made publicly available for data protection reasons but photos of selected individuals who have provided their written consent are included as examples.

3. Results

Visual inspection of the grand average ERPs revealed more negative amplitudes for the university and home friends relative to the unfamiliar faces in the 200–400 ms (N250) and 400–600 ms (SFE) time ranges (see Fig. 2), which was most clearly evident at occipito-temporal electrodes (Fig. 2c). Critically, the SFE appeared more pronounced for home than university friends in Year 1 students, but not in the two other groups.

An ANOVA in the N250 time range revealed a significant interaction of familiarity by year group, $F(4, 114) = 2.52, p = .045, \eta_p^2 = .081$, 90% CI [.001,.143]. Paired-sample t-tests (see Table 1) for Year 1 revealed significantly more negative amplitudes for university friends relative to unfamiliar faces, and for home friends relative to unfamiliar faces. University and home friends did not differ significantly. In Year 2, there were again significant differences between university friends and unfamiliar faces, and home friends and unfamiliar faces. Here, more negative amplitudes for the university relative to the home friends were observed. Analyses for Year 3 revealed again more negative amplitudes for university friends relative to unfamiliar faces, and for home friends versus unfamiliar faces. University and home friends did not differ. Testing for between-group differences in the N250 familiarity effect (unfamiliar – familiar faces), an independent-samples t-test yielded a significant increase for the university friend from Year 1 to Year 2, but no differences between Year 2 and Year 3. For home friends, there were no differences, neither between Year 1 and Year 2, nor between Year 2 and Year 3.

An ANOVA in the SFE time range again yielded a significant familiarity by year group interaction, $F(4, 114) = 3.22, p = .015, \eta_p^2 = .102$, 90% CI [.011,.169]. Follow-up t-tests (see Table 1) in Year 1 revealed significantly more negative amplitudes for university friends relative to unfamiliar faces, and for home friends versus unfamiliar faces. Importantly, and in line with our a priori predictions, more negative amplitudes for home relative to university friends were observed. In Year 2, relative to unfamiliar faces, analyses revealed more negative amplitudes for both university, and home friends, which in turn did not differ. Similarly, analyses of Year 3 revealed more negative amplitudes for both university friends, and home friends relative to unfamiliar faces, while the two familiar faces did not differ significantly. To test our prediction of an increase of the SFE for the university student from Year 1 to Year 2 and to explore whether the effect further increases from Year 2 to Year 3, two independent-samples t-tests were conducted. As predicted, the SFE in Year 2 was significantly higher than in Year 1. At the same time, there was no significant difference between Year 2 and Year 3. For the home friend, no significant differences were observed, neither between Year 1 and Year 2, nor between Year 2 and Year 3.

Bootstrapping analysis for the N250 time range in the Year 1 group revealed reliable familiarity effects in 8/20 participants, Proportion (P) = .40, 95% CI [.22,.61], for both home and university friends versus unfamiliar faces. In Year 2, reliable familiarity effects were observed in 10/20 participants, P = .50, 95% CI [.30,.70], for home friends relative to unfamiliar faces, and in 14/20 participants, P = .70, 95% CI [.48,.86], for university friends in comparison to unfamiliar faces. In Year 3, reliable effects were detected in 11/20 participants, P = .55, 95% CI [.34,.74], for home friends versus unfamiliar faces, and in 16/20 participants, P = .80, 95% CI [.58,.92], for university friends versus unfamiliar faces.

Bootstrapping analysis for the SFE time range in Year 1 revealed reliable familiarity effects in 11/20 participants, P = .55 95% CI [.34,.74], for home friends versus unfamiliar faces, and in 7/20 participants, P = .35, 95% CI [.18,.57], for university friends versus unfamiliar faces. In Year 2, reliable familiarity effects were reported in 13/20 participants, P = .65, 95% CI [.43, 82], for home friends relative to unfamiliar faces, and in 16/20 participants, P = .80, 95% CI [.58,.92], for university friends in comparison to unfamiliar faces. In Year 3, reliable effects were reported in 16/20 participants, P = .80, 95% CI [.58,.92], for home friends versus unfamiliar faces, and in 19/20 participants, P = .95, 95% CI [.76,.99], for university friends versus unfamiliar faces.

Mass univariate analyses of the within-group contrast of home versus university familiarity effects for Year 1, Year 2, and Year 3 separately largely confirmed findings from our mean amplitude analysis above. In Year 1, clear differences, reflecting stronger familiarity effects for home friends, were observed between 400 and 600 ms after stimulus onset (see Fig. 3a). These effects were observed not only at left and right occipito-temporal channels, but also (polarity-reversed, see Fig. 2c and Supplementary Material) over central and parietal channels, likely reflecting the opposite end of the same underlying dipole. Corresponding effects were not observed in Year 2 or Year 3.

Similarly, exploratory mass univariate tests of the between-group comparisons largely confirmed the results of the confirmatory analysis reported above (see Fig. 3b). Specifically, clearly larger familiarity effects for university friends were observed in Year 2 relative to Year 1. Although most clearly observed in the 400–600 ms time window, these effects started earlier (app. 300 ms after stimulus onset), and, in some channels, lasted until the end of the recording epoch. Differences between the Year 1 and 2 were less pronounced for home friends. Finally, no systematic differences were observed between familiarity effects observed in Year 2 and Year 3.

In the rating task (see Table 2 and Supplementary Materials for a full report), the two familiar identities were rated as significantly higher in visual familiarity, arousal, and frequency of visual interaction and social contact, as well as more positive in valence in comparison to the unfamiliar identities (all $p < .001$). Interestingly, visual familiarity ratings for the university friend significantly increased from Year 1 to Year 2, $t(38) = 2.13$, $p = .040$, $d_{unb} = 0.66$, 95% CI [0.03, 1.31], and valence scores became significantly more positive, $t(38) = 2.08$, $p = .044$, $d_{unb} = 0.65$, 95% CI [0.02, 1.29]. Corresponding effects were not observed for the home friend or between Year 2 and Year 3 groups (all $p > .175$, all $d_{unb} < 0.43$; see Supplementary Material). The Year 1 group rated their home friends as significantly more arousing relative to their university friends, $t(19) = 5.60$, $p < .001$, $d_{unb} = 1.54$, 95% CI [0.84, 2.35], but no significant differences were observed in the other two groups. All year groups reported seeing (visual interaction) and talking (social interaction) to their university friends significantly more frequently than their home friends (all $p < .013$; all $r > 0.539$). Finally, none of the differences between unfamiliar and familiar faces in the rating task correlated with ERP familiarity effects (see Table 3).

4. Discussion

To investigate how long it takes to truly know a person, the current study examined how neurophysiological correlates of face and person recognition change with increasing familiarity. We were particularly interested in ERP effects reflecting visual face recognition (i.e. N250 familiarity effect) and the integration of visual with additional identity-specific knowledge (SFE). Our results show robust visual representations after two months of knowing a person. Critically, we further demonstrate that both visual representations of facial identity and of person-related knowledge build up with increasing levels of familiarity and

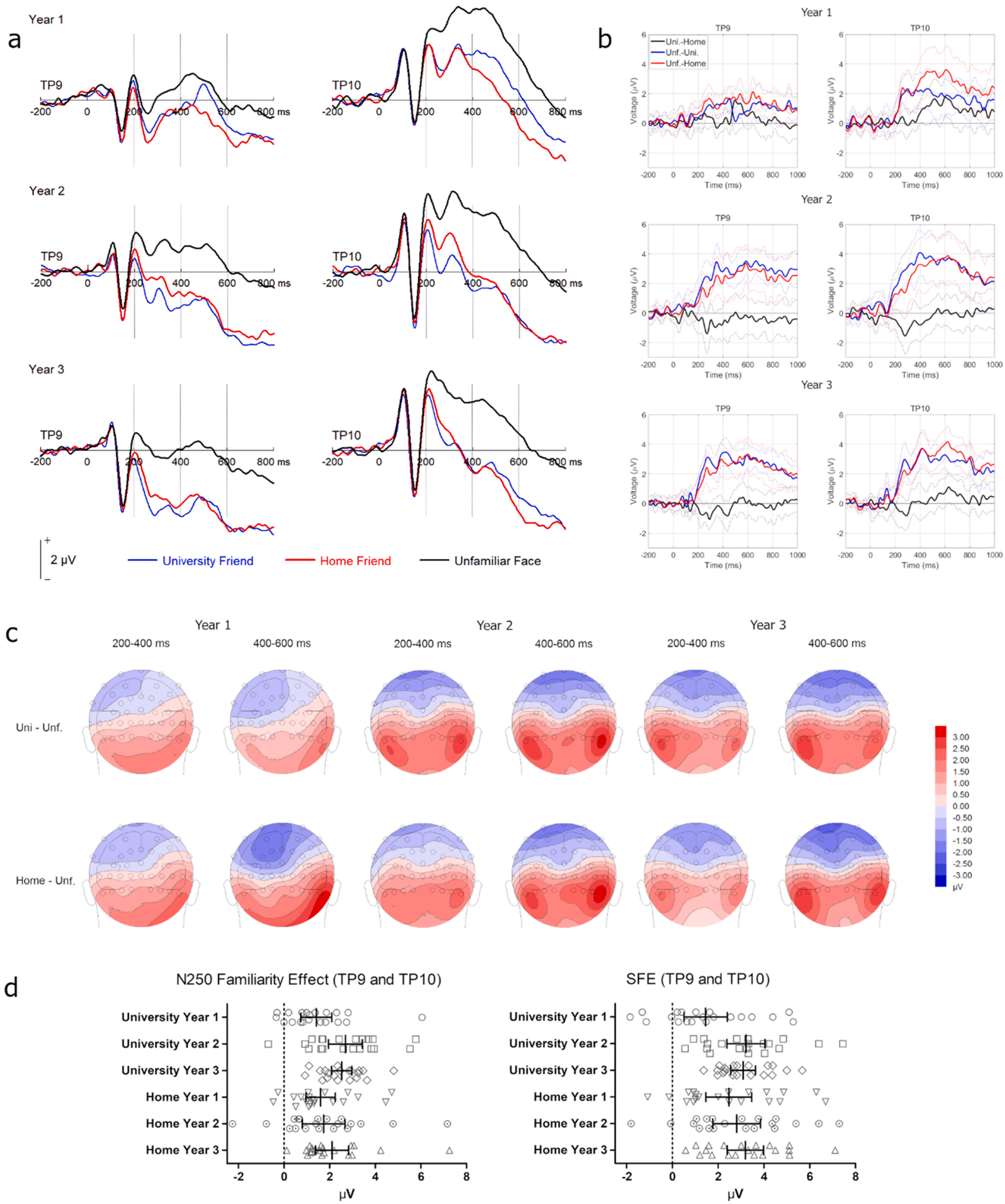

Fig. 2. a) Grand average event-related potentials (ERPs) at left and right occipito-temporal channels TP9 and TP10 for university friends, home friends, and unfamiliar faces for each year group. b) Mean (and 95% CIs; dashed lines) difference between conditions (university minus home, unfamiliar minus university, unfamiliar minus home) at TP9 and TP10. C) Scalp-topographical voltage maps (unfamiliar face minus university friend, unfamiliar face minus home friend) for the N250 (200–400 ms) and SFE (400–600 ms) time windows (spherical spine interpolation, 110° equidistant projections). D) Individual (symbols) and mean familiarity effects with 95% CIs (solid lines) for university and home friends for Year 1, Year 2, and Year 3 in the N250 and SFE time ranges. Note the clear increase in the N250 effect and SFE from Year 1 to Year 2 for university friends only.

Table 1
Results of independent and paired-samples t-tests. Y1 = Year 1, Y2 = Year 2, Y3 = Year 3.

ERP measure	Effect	M_{diff}	95% CI	df	*t*	*p*	d_{unb}	95% CI
N250	Y1: uni vs unfam	1.42	[0.74, 2.09]	19	4.40	< 0.001	0.43	[0.20, 0.69]
	Y1: home vs unfam	1.60	[0.95, 2.25]	19	5.19	< 0.001	0.50	[0.26, 0.77]
	Y1: uni vs home	0.18	[− 0.25, 0.61]	19	0.88	.390	0.06	[− 0.08, 0.21]
	Y2: uni vs unfam	2.69	[1.95, 3.43]	19	7.60	< 0.001	0.65	[0.40, 0.94]
	Y2: home vs unfam	1.74	[0.80, 2.68]	19	3.89	.001	0.46	[0.19, 0.76]
	Y2: uni vs home	0.95	[0.04, 1.86]	19	2.19	.041	0.24	[0.01, 0.48]
	Y3: uni vs unfam	2.53	[2.09, 2.97]	19	11.98	< 0.001	0.76	[0.51, 1.07]
	Y3: home vs unfam	2.10	[1.38, 2.83]	19	6.09	< 0.001	0.65	[0.37, 0.98]
	Y3: uni vs home	0.43	[− 0.28, 1.14]	19	1.26	.223	0.13	[− 0.08, 0.35]
	Uni: Y1 vs Y2	1.27	[0.30, 2.24]	38	2.66	.011	0.82	[0.19, 1.48]
	Uni: Y2 vs Y3	0.16	[− 0.67, 1.00]	38	0.39	.698	0.12	[− 0.50, 0.74]
	Uni: Y1 vs Y3	1.11	[0.33, 1.89]	38	2.88	.006	0.89	[0.25, 1.56]
	Home: Y1 vs Y2	0.14	[− 0.96, 1.24]	38	0.26	.799	0.08	[− 0.54, 0.70]
	Home: Y2 vs Y3	0.36	[− 0.78, 1.51]	38	0.64	.523	0.20	[− 0.82, 0.42]
	Home: Y1 vs Y3	0.50	[− 0.43, 1.44]	38	1.09	.284	0.34	[− 0.28, 0.97]
SFE	Y1: uni vs unfam	1.45	[0.51, 2.40]	19	3.22	.004	0.53	[0.17, 0.92]
	Y1: home vs unfam	2.46	[1.46, 3.47]	19	5.16	< 0.001	0.84	[0.44, 1.30]
	Y1: uni vs home	1.01	[0.19, 1.83]	19	2.59	.018	0.35	[0.06, 0.65]
	Y2: uni vs unfam	3.21	[2.38, 4.05]	19	8.06	< 0.001	0.95	[0.59, 1.38]
	Y2: home vs unfam	2.81	[1.77, 3.85]	19	5.65	< 0.001	0.90	[0.49, 1.37]
	Y2: uni vs home	0.40	[− 0.47, 1.27]	19	0.96	.348	0.11	[− 0.13, 0.36]
	Y3: uni vs unfam	3.09	[2.55, 3.63]	19	11.93	< 0.001	1.53	[1.02, 2.15]
	Y3: home vs unfam	3.19	[2.39, 3.98]	19	8.38	< 0.001	1.35	[0.85, 1.96]
	Y3: uni vs home	0.10	[− 0.63, 0.83]	19	0.28	.780	0.04	[− 0.25, 0.33]
	Uni: Y1 vs Y2	1.76	[0.54, 2.98]	38	2.92	.006	0.91	[0.27, 1.57]
	Uni: Y2 vs Y3	0.12	[− 0.84, 1.08]	38	0.26	.798	0.08	[− 0.54, 0.70]
	Uni: Y1 vs Y3	1.64	[0.58, 2.69]	38	3.15	.003	0.98	[0.33, 1.65]
	Home: Y1 vs Y2	0.35	[− 1.05, 1.74]	38	0.50	.619	0.16	[− 0.46, 0.78]
	Home: Y2 vs Y3	0.38	[− 0.89, 1.64]	38	0.60	.551	0.19	[− 0.43, 0.81]
	Home: Y1 vs Y3	0.72	[− 0.51, 1.96]	38	1.18	.244	0.37	[− 0.25, 1.00]

are fully developed by 14 months of knowing a person.

In line with previous work demonstrating that visual familiarity is established quickly, e.g. in a single experimental session (Andrews et al., 2017; Kaufmann et al., 2009; Tanaka et al., 2006; Zimmermann & Eimer, 2013), we observed a clear N250 familiarity effect at the earliest time point measured in this study, after just under two months of familiarity. Importantly, we also found a significant increase of the effect for the university friend from Year 1 to Year 2, indicating additional learning after the first two months of knowing a person. This was consistent with visual familiarity ratings, which also revealed a significant increase. At the same time, no significant differences were detected between Year 2 and 3. Hence, while two months of familiarity are sufficient to establish robust, image-independent face recognition, the underlying representations keep getting refined with regular exposure and appear to be fully developed by 14 months of familiarity.

Although N250 familiarity effects for home and university friends were highly similar in Year 1 and Year 3, we unexpectedly observed more negative amplitudes in the N250 for university relative to home friends in Year 2. This finding may suggest that the N250 not exclusively reflects the cumulative level of familiarity, but that more recent contact is relatively more important (as participants reported seeing and interacting with their university friends more often than with their home friends). However, because this difference was not predicted and the pattern was not evident in the group analysis of Year 3, it needs to be replicated before any firm conclusions can be drawn. If the effect turns out to be replicable, it might suggest that even well-established face representations are not completely stable over time but can become less robust if they are not accessed regularly.

As expected, we further observed a relatively small but significant SFE for the university friend in Year 1. Its size ($d_{unb} = 0.53$) was smaller than the effect elicited by highly familiar faces reported by Wiese et al. (2019) ($d_{unb} = 1.08$) and Wiese, Hobden, et al. (in press) ($d_{unb} = 0.92$) but similar to those reported for somewhat less familiar identities, such as favourite celebrities ($d_{unb} = 0.66$). Importantly, the effect was also significantly smaller than the SFE elicited by the home friend in this year group. This is consistent with the assumption that participants had more identity-specific information for their home friend, as the university friend had only been known for two months. Furthermore, and as hypothesised, we observed a significant increase in the magnitude of the effect from Year 1 to Year 2 for the university friend, resulting in similar SFEs for the two familiar identities from Year 2 on. These observations suggest that the first year of familiarity is critical for the development of the SFE, as the effect appears to plateau afterwards. It seems that, while we continue to acquire new information about our friends beyond the first year, this additional information does not substantially affect the corresponding neural representations. What we initially learn about a new person reflects novel and therefore highly relevant information. Arguably, once this basic information is acquired, new semantic facts will mostly refine our already established knowledge. Our findings therefore suggest that the level of familiarity at which a person-related representation is no longer substantially expanded is reached during the first 14 months, given regular contact.

The discussion in previous paragraphs assumes that the processes in the analysed ERP time windows at least partly reflect different processes. This assumption appears justified as the difference curve for highly familiar faces (see e.g. Fig. 2b, but also Wiese et al., 2019; Wiese, Hobden, et al., in press; Wiese et al., 2022) typically shows two peaks. Critically, we have demonstrated that the earlier (N250) and later (SFE) parts of the familiarity effect respond differently to experimental manipulations (e.g. Wiese, Ingram, Elley, Tüttenberg, Burton & Young, 2019). However, complementing our initial analysis strategy, we further applied a mass univariate approach that is data- rather than hypothesis-driven, and therefore does not make any a priori assumptions about the timing or location of effects. This analysis largely confirmed the procedures and results discussed above by (i) not suggesting systematic familiarity effects earlier than 200 ms, while at the same time suggesting (ii) that familiarity effects after 600 ms get weaker towards the end of the epoch, (iii) that the difference between university and home friends in Year 1 is most clearly observed between 400 and 600 ms (i.e. in our SFE time window), and (iv) that the most substantial between-group difference is observed for university friends between Year 1 and Year 2.

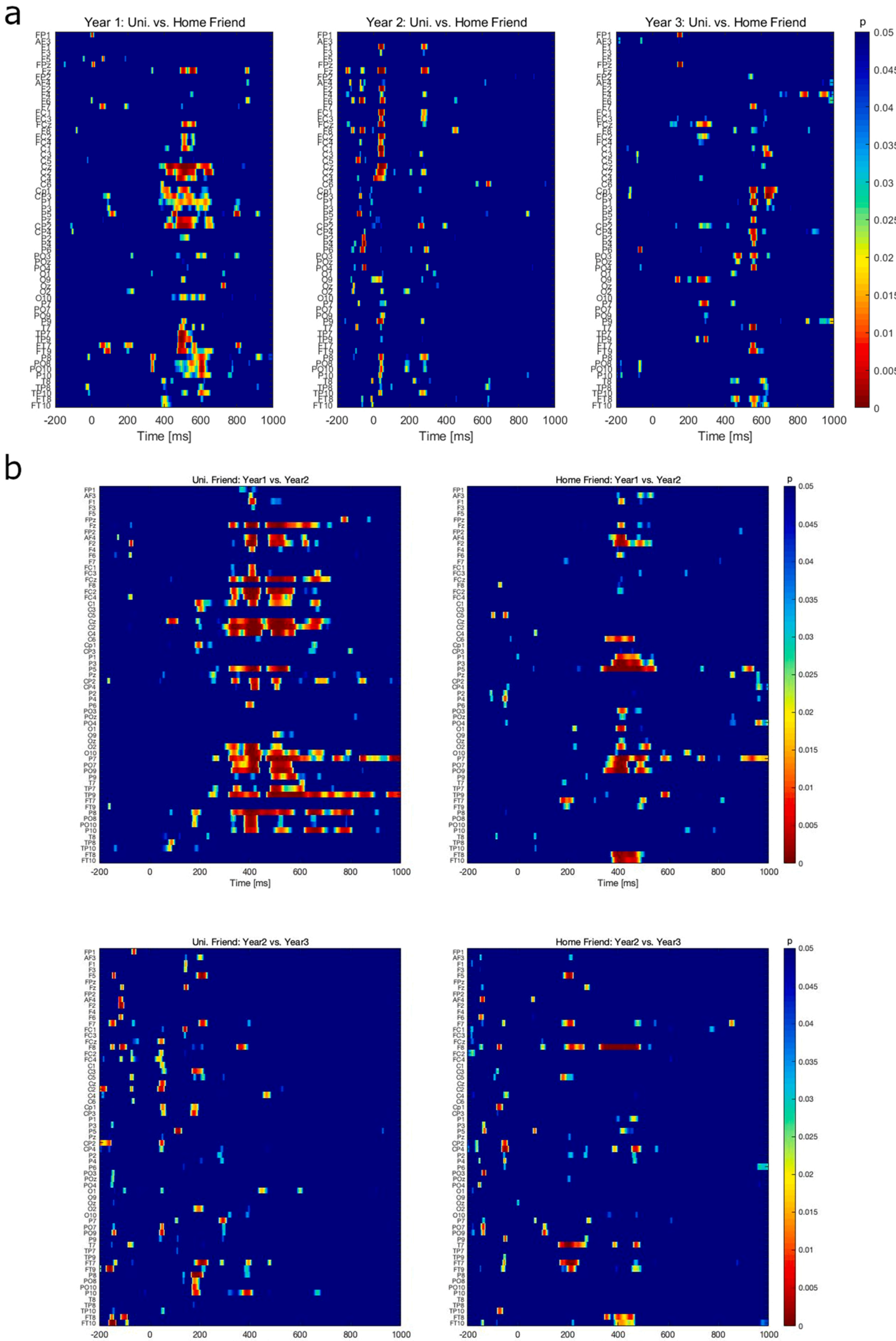

Fig. 3. Mass univariate analyses (a) for the within-group comparisons of home versus university friend familiarity effects, and (b) the between-group comparisons between Year 1 and Year 2, as well as Year 2 and Year 3 for home and university friend familiarity effects separately.

Table 2
Mean/Median ratings for the identities used in the experiment. Familiarity, emotional response towards, and interaction with the 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; visual interaction & social contact: 1 = never, 2 = once or twice a year, 3 = once or twice a month, 4 = once or twice a week, 5 = every day).

		Familiarity *M SD*	Valence *M SD*	Arousal *M SD*	Visual Interaction *Mdn* IQR	Social Contact *Mdn* IQR
University Friend	Year 1	4.55 0.94	1.65 0.49	2.60 0.60	5 0.00	5 0.00
	Year 2	5.00 0.00	1.30 0.57	2.10 0.97	5 0.00	5 0.00
	Year 3	5.00 0.00	1.10 0.31	1.80 1.06	5 1.00	5 0.00
Home Friend	Year 1	4.80 0.89	1.45 1.23	1.65 0.59	3 1.00	4 1.00
	Year 2	5.00 0.00	1.10 0.31	1.65 0.87	3 0.25	4 2.00
	Year 3	5.00 0.00	1.10 0.31	2.05 1.19	2 1.00	4 1.25
Unfamiliar Face	Year 1	2.20 1.37	2.90 0.31	4.35 0.99	1 0.00	1 0.00
	Year 2	1.95 1.15	2.90 0.64	4.05 0.76	1 0.00	1 0.00
	Year 3	1.80 1.15	3.15 0.49	4.15 0.88	1 0.00	1 0.00

Table 3
Spearman's rank order correlations between the familiarity effects (unfamiliar – university, unfamiliar – home) for the ERPs and the ratings.

	N250				SFE			
	University friend		Home friend		University friend		Home friend	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Familiarity	-0.145	.268	-0.054	.684	-0.149	.254	.011	.932
Valence	.179	.170	.106	.418	.227	.082	.090	.495
Arousal	-0.047	.721	-0.165	.207	.122	.353	-0.180	.168
Visual Interaction	-0.217	.096	-0.023	.862	-0.120	.361	-0.066	.616
Social Contact	-0.078	.555	.090	.494	-0.060	.649	.142	.279

Bootstrapping results in the SFE time range generally supported previous findings of reliable effects in the clear majority of participants (Wiese, Tüttenberg, et al., 2019; Wiese et al., 2022). In Year 1, however, the proportion of reliable effects for home friends was surprisingly low and fell outside the confidence interval of previous studies or indeed of Year 2 and Year 3 in the present study. The SFE depends on the level of familiarity with an identity (see Wiese, Hobden, et al., in press), and accordingly a potential explanation for this finding might be that home friends in Year 1 were less familiar relative to the other participant groups. While it is unfortunately unclear precisely how long and how well home friends were known, this interpretation is at least partly in line with our rating results, which show slightly lower familiarity ratings for home friends in Year 1 relative to the other groups. We note that, if home friends were slightly less familiar in Year 1, this appears to make our finding of within-group differences between home and university friends in this group even more robust.

The current findings advance our understanding by providing novel information about establishing and refining face and person representations. Previous studies on face learning have largely focused on *what* information is learned from a face (e.g. structural versus surface reflectance information; Itz, Schweinberger, Schulz & Kaufmann, 2014; O'Toole et al., 1999), but relatively little is known about *when*, or more precisely over what period of time, learning takes place. The present results cannot provide an exact answer to this question. They indicate, however, that both visual exposure and the accumulation of identity-specific knowledge substantially affect neural representations between two and 14 months after first meeting a new person, but not afterwards. How exactly these representations develop during the first year of familiarity, and whether visual and other person-related representations follow a different learning trajectory in this time range will need to be addressed in future studies. Moreover, future studies might choose test sessions at earlier time points to examine the initial establishment of face and person representations and might choose longitudinal experiments to investigate learning in a within-participants design.

Of relevance for future studies, the current approach demonstrates that studying the neurophysiological correlates of face and person learning as it happens "in the wild" is viable and represents an important addition to purely laboratory-based studies. However, while gaining substantial ecological validity, this more naturalistic approach also has limitations. For instance, it is difficult to obtain an objective measure of how well exactly our participants have known their friends at the time of testing, both with respect to amount and intensity of contact, and it is unclear precisely how long the home friends were known in the present study. While it is likely that long-term familiarity varied to some extent in the present data, our result of stable familiarity effects for university friends after one year suggests that this variability should not have a substantial influence as long as home friends were known for more than a year. Moreover, our results are limited by the knowledge that is available about the specific ERP markers used here. In particular, we interpret the SFE as reflecting identity-specific semantic knowledge, as both episodic memory (see Wiese et al., 2019) and valence (see Wiese, Hobden, et al., in press) are not substantially modulating the effect. However, in the absence of direct empirical evidence, it remains possible that other factors, such as differences in arousal or visual familiarity, drive the SFE. While we have discussed the latter possibility in detail elsewhere (see Wiese et al., 2022), we note that we did not detect any correlations between rating results and the SFE in the present study, which at least implies no strong influence of these variables on the ERP effect. While future work will hopefully help to reduce the restrictions discussed here, we believe that accepting them for now is clearly preferable relative to the alternative of *exclusively* conducting lab-based work on face and identity learning, as learning over time periods such as those examined in the present study is very difficult to study in a strictly controlled laboratory setting.

In summary, the present study tracked the neurocognitive changes face and person representations undergo over the course of two years. Our results indicate that two months of familiarity are sufficient to establish a stable visual representation of a face. At the same time, the integration of personal knowledge with visual information is initially relatively weak and develops to the level of a highly familiar identity within 14 months. Crucially, both types of representations are refined after the initial two months, which suggests that the first year of familiarity is critical for their complete development. We conclude that two months of familiarity are sufficient for robust face recognition, but that it may take up to more than one year to truly know a person.

Author Contributions

H. Wiese developed the study concept. Both authors contributed to the study design. T. Popova performed the data collection, data analysis and interpretation under the supervision of H. Wiese. Both authors drafted and revised the manuscript and approved its final version for submission.

Funding

This work was supported by a Ph.D. studentship from the Department of Psychology at Durham University awarded to T. Popova.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.biopsycho.2022.108312.

References

Ambrus, G. G., Eick, C. M., Kaiser, D., & Kovács, G. (2021). Getting to know you: emerging neural representations during face familiarization. *Journal of Neuroscience*. https://doi.org/10.1523/JNEUROSCI.2466-20.2021

Ambrus, G. G., Kaiser, D., Cichy, R. M., & Kovács, G. (2019). The neural dynamics of familiar face recognition. *Cerebral Cortex, 29*(11), 4775–4784. https://doi.org/10.1093/cercor/bhz010

Andrews, S., Burton, A. M., Schweinberger, S. R., & Wiese, H. (2017). Event-related potentials reveal the development of stable face representations from natural variability. *Quarterly Journal of Experimental Psychology, 70*(8), 1620–1632. https://doi.org/10.1080/17470218.2016.1195851

Bentin, S., & Deouell, L. Y. (2000). Structural encoding and identification in face processing: ERP evidence for separate mechanisms. *Cognitive Neuropsychology, 17* (1–3), 35–55. https://doi.org/10.1080/026432900380472

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Bruce, V., Henderson, Z., Greenwood, K., Hancock, P. J. B., Burton, A. M., & Miller, P. (1999). Verification of face identities from images captured on video. *Journal of Experimental Psychology: Applied, 5*(4), 339–360. https://doi.org/10.1037/1076-898X.5.4.339

Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology, 77*(3), 305–327. https://doi.org/10.1111/j.2044-8295.1986.tb02199.x

Burton, A. M., Kramer, R. S. S., Ritchie, K. L., & Jenkins, R. (2016). Identity from variation: representations of faces derived from multiple instances. *Cognitive Science, 40*(1), 202–223. https://doi.org/10.1111/cogs.12231

Burton, A. M., Wilson, S., Cowan, M., & Bruce, V. (1999). Face recognition in poor-quality video: evidence from security surveillance. *Psychological Science, 10*(3), 243–248. https://doi.org/10.1111/1467-9280.00144

Campbell, A., Louw, R., Michniak, E., & Tanaka, J. W. (2020). Identity-specific neural responses to three categories of face familiarity (own, friend, stranger) using fast periodic visual stimulation. *Neuropsychologia, 141*, Article 107415. https://doi.org/10.1016/j.neuropsychologia.2020.107415

Campbell, A., & Tanaka, J. W. (2021). When a stranger becomes a friend: Measuring the neural correlates of real-world face familiarisation. *Visual Cognition, 29*(10), 689–707. https://doi.org/10.1080/13506285.2021.2002993

Cumming, G. (2012). Understanding The New Statistics: Effect Sizes. *Confidence Intervals, and Meta-Analysis*. Routledge,.

Di Nocera, F., & Ferlazzo, F. (2000). Resampling approach to statistical inference: Bootstrapping from event-related potentials data. *Behavior Research Methods, Instruments, & Computers, 32*(1), 111–119. https://doi.org/10.3758/BF03200793

Eimer, M. (2000). Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology, 111*(4), 694–705. https://doi.org/10.1016/S1388-2457(99)00285-0

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/bf03193146

Gobbini, M. I., & Haxby, J. V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia, 45*(1), 32–41. https://doi.org/10.1016/j.neuropsychologia.2006.04.015

Gosling, A., & Eimer, M. (2011). An event-related brain potential study of explicit face recognition. *Neuropsychologia, 49*(9), 2736–2745. https://doi.org/10.1016/j.neuropsychologia.2011.05.025

Itz, M. L., Schweinberger, S. R., Schulz, C., & Kaufmann, J. M. (2014). Neural correlates of facilitations in face learning by selective caricaturing of facial shape or reflectance. *NeuroImage, 102*, 736–747. https://doi.org/10.1016/j.neuroimage.2014.08.042

Johnston, P. R. A., & Edmonds, A. J. (2009). Familiar and unfamiliar face recognition: a review. *Memory, 17*(5), 577–596. https://doi.org/10.1080/09658210902976969

Kaufmann, J. M., Schweinberger, S. R., & Burton, A. M. (2009). N250 ERP correlates of the acquisition of face representations across different images. *Journal of Cognitive Neuroscience, 21*(4), 625–641. https://doi.org/10.1162/jocn.2009.21080

Kramer, R. S. S., Young, A. W., & Burton, A. M. (2018). Understanding face familiarity. *Cognition, 172*, 46–58. https://doi.org/10.1016/j.cognition.2017.12.005

O'Toole, A. J., Vetter, T., & Blanz, V. (1999). Three-dimensional shape and two-dimensional surface reflectance contributions to face recognition: an application of three-dimensional morphing. *Vision Research, 39*(18), 3145–3155. https://doi.org/10.1016/S0042-6989(99)00034-6

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia, 9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Olivares, E. I., Iglesias, J., Saavedra, C., Trujillo-Barreto, N. J., & Valdés-Sosa, M. (2015). Brain signals of face processing as revealed by event-related potentials. *Behavioural Neurology, 2015*, Article e514361. https://doi.org/10.1155/2015/514361

Paller, K. A., Gonsalves, B., Grabowecky, M., Bozic, V. S., & Yamada, S. (2000). Electrophysiological correlates of recollecting faces of known and unknown individuals. *NeuroImage, 11*(2), 98–110. https://doi.org/10.1006/nimg.1999.0521

Pierce, L. J., Scott, L., Boddington, S., Droucker, D., Curran, T., & Tanaka, J. (2011). The N250 brain potential to personally familiar and newly learned faces and objects. *Frontiers in Human Neuroscience*, 5. https://doi.org/10.3389/fnhum.2011.00111

Saavedra, C., Iglesias, J., & Olivares, E. I. (2010). Event-related potentials elicited by the explicit and implicit processing of familiarity in faces. *Clinical EEG and Neuroscience, 41*(1), 24–31. https://doi.org/10.1177/155005941004100107

Schweinberger, S. R., & Burton, A. M. (2003). Covert recognition and the neural system for face processing. *Cortex, 39*(1), 9–30. https://doi.org/10.1016/S0010-9452(08)70071-6

Tanaka, J. W., Curran, T., Porterfield, A. L., & Collins, D. (2006). Activation of preexisting and acquired face representations: the N250 event-related potential as an index of face familiarity. *Journal of Cognitive Neuroscience, 18*(9), 1488–1497. https://doi.org/10.1162/jocn.2006.18.9.1488

Taylor, J., Shehzad, Z., & McCarthy, G. (2016). Electrophysiological correlates of face-evoked person knowledge. *Biological Psychology, 118*, 136–146. https://doi.org/10.1016/j.biopsycho.2016.05.011

Wagenmakers, E. J., Wetzels, R., Borsboom, D., van der Maas, H. L. J., & Kievit, R. A. (2012). An agenda for purely confirmatory research. *Perspectives on Psychological Science, 7*(6), 632–638. https://doi.org/10.1177/1745691612463078

Wiese, H., Anderson, D., Beierholm, U., Tüttenberg, S. C., Young, A. W., & Burton, A. M (2022). Detecting a viewer's familiarity with a face: evidence from event-related brain potentials and classifier analyses. *Psychophysiology, 59*(1), Article e13950. https://doi.org/10.1111/psyp.13950

Wiese, H., Hodben, G., Silibek, E., Mattignac, V., Flack, T. R., Ritchie, K. L., … Burton, A. M. (2021). Familiarity is familiarity is familiarity: event-related brain potentials reveal qualitatively similar representations of personally familiar and famous faces. *J. Exp. Pshycol.*. https://doi.org/10.1037/xlm0001063

Wiese, H., Ingram, B. T., Elley, M. L., Tüttenberg, S. C., Burton, A. M., & Young, A. W. (2019). Later but not early stages of familiar face recognition depend strongly on attentional resources: evidence from event-related brain potentials. *Cortex, 120*, 147–158. https://doi.org/10.1016/j.cortex.2019.06.004

Wiese, H., & Schweinberger, S. R. (2015). Getting connected: both associative and semantic links structure semantic memory for newly learned persons. *The Quarterly Journal of Experimental Psychology, 68*(11), 2131–2148. https://doi.org/10.1080/17470218.2015.1008526

Wiese, H., Tüttenberg, S. C., Ingram, B. T., Chan, C. Y. X., Gurbuz, Z., Burton, A. M., … Young, A. W. (2019). A robust neural index of high face familiarity. *Psychological Science, 30*(2), 261–272. https://doi.org/10.1177/0956797618813572

Willenbockel, V., Sadr, J., Fiset, D., Horne, G. O., Gosselin, F., & Tanaka, J. W. (2010). Controlling low-level image properties: the SHINE toolbox. *Behavior Research Methods, 42*(3), 671–684. https://doi.org/10.3758/BRM.42.3.671

Yan, X., & Rossion, B. (2020). A robust neural familiar face recognition response in a dynamic (periodic) stream of unfamiliar faces. *Cortex, 132*, 282–295. https://doi.org/10.1016/j.cortex.2020.08.016

Young, A. W., & Burton, A. M. (2017). Recognizing Faces. *Current Directions in Psychological Science, 26*(3), 212–217. https://doi.org/10.1177/0963721416688114

Zimmermann, F. G. S., & Eimer, M. (2013). Face learning and the emergence of view-independent face recognition: An event-related brain potential study. *Neuropsychologia, 51*(7), 1320–1329. https://doi.org/10.1016/j.neuropsychologia.2013.03.028