Neurophysiological correlates of face and identity learning through naturalistic exposure

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Abstract

Differential processing of familiar and unfamiliar faces is now well-established but surprisingly little is known about how familiarity develops over time. The aim of this thesis was to track the neural processes which accompany short- and long-term face and person learning, under more naturalistic conditions than those of previous, laboratory-based research. Using event-related brain potentials, the experiments examined how real-life learning affects the visual face representations (N250 familiarity effect) and the integration of person-related knowledge (Sustained Familiarity Effect, SFE). Chapter 2 revealed an increase in the N250 and the SFE from two to 14 months of familiarity but not afterwards, indicating that the first year of familiarity is critical for the development of the neural representations of visual familiarity and identity-specific knowledge. Chapter 3 tracked the development of these two effects during the first eight months of knowing a person and found a clear N250 and SFE at one month of knowing someone. While the N250 was fully established by five months of familiarity, indicating that the visual representations were fully developed substantially earlier than 14 months, no significant increase in the SFE was observed during the examined eight-month period, suggesting that the integration of identity-specific information needs longer to get fully established. Chapter 4 investigated face learning following a single brief real-life encounter and observed a significant N250 effect after a 10-minute interaction with an unfamiliar person, suggesting that 10 minutes are sufficient to establish initial visual representations. In sum, the present research suggests that image-independent visual face representations are initially established very quickly and get fully developed within the first five months of knowing a person. The integration of person-related knowledge, on the other hand, first emerges after one month of familiarity and gradually develops to the level of highly familiar identities by 14 months. These findings substantially improve our understanding of how we get to know people in everyday life by providing vital information about the time course of this process.

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Declaration

The author confirms that none of the material presented in this thesis has been submitted elsewhere for any other qualification and is the author's own work unless referenced otherwise.

Publication note

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Statement of Copyright

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1. General Introduction

According to one of the most popular theoretical frameworks in the field of face recognition, humans are considered to be face experts due to the constant exposure to faces in everyday life (Carey et al., 1997; Diamond & Carey, 1986; Gauthier & Tarr, 2002; Tanaka, 2001). This theory is supported by the accuracy and effortlessness with which familiar faces are successfully recognised even in very challenging conditions (e.g. Burton et al., 1999; Demanet et al., 2007; Hole et al., 2002). However, this face expertise seems to be restricted to familiar faces (Young & Burton, 2018), as unfamiliar face recognition is substantially more error-prone even in seemingly ideal conditions (e.g. Bruce et al., 1999; Burton et al., 2010). As every face that is now familiar was once unfamiliar, previous research has looked at face learning to gain insights into the changes occurring at the neuro-cognitive level which come with increasing familiarity. However, currently not much is known about the neural correlates of short- and long-term face learning, and even less about the later stages that integrate visual with person-related semantic, episodic, and affective information, all vital for appropriate social interaction with others.

The experiments presented here have studied the transition from unfamiliar to familiar face processing over short and prolonged time periods, and under more naturalistic conditions relative to previous, laboratory-based work. The purpose of this literature review is to provide an overview of the different functional stages of face recognition and the event-related brain potential (ERP) components related to them, and to justify the need for longer-term and more ecologically valid experimental methods. In addition to theoretical advancements, the findings of the present thesis could have real-life applications, as a better understanding of the neuro-cognitive processes of face perception and learning is important for forensic settings (e.g. eyewitness testimony, situations in which explicit indication of personal familiarity is not possible etc.).

1.1. Familiar and unfamiliar face recognition

A fundamental difference between familiar and unfamiliar faces is the ease with which familiar faces are recognised quickly and accurately from highly variable images (Burton et al., 1999), over long time intervals (Bahrick et al., 1975), and even in the absence of conscious awareness (Morrison et al., 2000). This does not generalise to unfamiliar faces as participants often struggle to even match simultaneously presented images of unknown faces that were taken in the same pose, only minutes apart (Bruce et al., 1999; Burton et al., 2010; see Johnston & Edmonds, 2009 for a review). Such high error rates for unfamiliar faces have also been observed outside of the laboratory when matching a photo ID to a live person (Kemp et al., 1997), and even trained police and passport officers perform as poorly as naïve student samples (Burton et al., 1999; White, Kemp, et al., 2014). A seminal paper by Jenkins and colleagues (2011) which used an image-sorting procedure very clearly demonstrated these striking differences between familiar and unfamiliar face recognition. They presented participants with 20 highly variable images of each of two Dutch celebrities and asked them to sort the photos into piles based on perceived identity without knowing how many identities were actually present. Participants who were not familiar with the celebrities severely overestimated the number of identities, with a median number of piles of 7.5 (range = 3-16), while Dutch participants who were familiar with the celebrities performed perfectly.

Observations like these have led researchers to suggest that qualitatively different processes are underlying familiar and unfamiliar face recognition (Hancock et al., 2000; Ramon & Gobbini, 2018; Young & Burton, 2017, 2018). Familiar face processing is assumed to rely on structural codes, called face recognition units (FRUs; Bruce & Young, 1986) that develop gradually and become more abstract, i.e. independent of a particular image of the person (Young et al., 1985). A key difference between familiar and unfamiliar faces is the varied exposure to familiar faces, as they have been seen numerous times and in different conditions, e.g. from varying angles, with different lighting, with different facial expressions, at different ages, with changes in hairstyles and make-up etc. Repeated exposure to someone helps establish “stability from variation” by learning which aspects of a face are stable across encounters while also providing information about ways in which the face varies (Bruce, 1994). This allows the formation of representations which are abstract from a specific encounter and the continuous refinement of these representations as a result of exposure enables recognition across a huge variation of image exemplars.

Such representations, however, are not available for unfamiliar faces. Unfamiliar face recognition depends mainly on pictorial codes that contain image-specific visual information of the initial exposure to the face. This makes recognition strongly dependent on the specific situation in which the face was first seen (Young et al., 1985). As a consequence, photos which closely match the original encounter can be easily recognised but even small changes in viewpoint, lighting, facial expressions etc., can severely affect recognition (Hancock et al., 2000). Face learning reflects this transition from error-prone image matching to the effortless recognition of the several thousand familiar faces we know (Jenkins et al., 2018), each of which used to be an unfamiliar face and has successfully undergone a shift in representations.

1.2. Face learning

1.2.1. Telling faces together and telling faces apart

Face learning reflects the establishment of face representations which allow for successful recognition of a person across substantial image variation. There are two markers of successful face recognition – (i) accurately reconciling new instances of the familiar face as belonging to the *same* identity, while (ii) at the same time not perceiving exemplars of *other* identities as the familiar identity. This has highlighted two aspects of face learning - “telling people apart” and “telling people together”

(Jenkins et al., 2011). Originally, research has strongly focused on the first aspect which looks at between-people variability and the unique features of the facial identity promoting differentiation between identities. However, more recent studies have also started to focus on the second aspect of face learning and try to understand the consequences of these within-person differences instead of eliminating/minimising them by using standardised images or representing an identity with a single image. Interestingly, participants are more likely to judge photos depicting the same person as belonging to different identities than to group images of different people together (Andrews et al., 2015; Jenkins et al., 2011). Therefore, the main problem of face recognition is not differentiating between people (“telling people apart”) but accurately identifying highly variable photos as belonging to the same person (“telling people together”). Photos of the same person can look very different and sometimes this difference exceeds the variability in images of two different people (Adini et al., 1997). Importantly, faces have idiosyncratic variability, as the way facial appearance varies across instances is individual for each face (Burton et al., 2011, 2016), and learning about someone’s variability fails to translate into improved recognition performance with another person (Dowsett et al., 2016).

1.2.2. Theoretical accounts of face learning

Researchers have proposed two different but not mutually exclusive accounts of the nature of face representations formed as a result of face learning. According to the averages account, face learning involves averaging together different instances of a given identity which cancels out any random variation specific to any particular exemplar and preserves only information which is stable across images (Burton et al., 2005). According to this view, a robust average representation will be formed in which any transient differences, which is seen as “noise”, would be filtered out (e.g. variations due to lighting, viewing angles, facial expressions, facial expressions, hairstyle) while information diagnostic to the facial identity which appears in all encounters will be present. Previous research has suggested that when presented with a set of images, individuals extract the mean of the set and form an average representation of that person (Kramer et al., 2015). Further support for this theory comes from the improved accuracy of computational models when recognising an average relative to an individual image (Jenkins & Burton, 2008; Robertson et al., 2015), even when the averages are generated from poor-quality images (Ritchie, White, et al., 2018). Moreover, improved matching performance is observed when a photo is matched to an average rather than an individual photo and this is the case both for familiar and unfamiliar faces (White, Burton, et al., 2014). These authors, however, reported even better performance when a photo was matched to an array of five individual images relative to an average (White, Burton, et al., 2014). In addition, no advantage for averages is observed when participants are matching images to a live target (Ritchie et al., 2020) and an iconic image of a celebrity is perceived as a better representation of what the person looks like than an average (Ritchie, Kramer, et al., 2018). Hence, currently, the evidence regarding the averaging account is inconclusive.

An alternative but related model suggests that rather than treating information related to individual variability as “noise”, such variability contains important identity-related information that is stored in the representation (Burton et al., 2016). According to the exemplar-based model, different instances of the face are stored individually in a representation, and face recognition involves comparing the current visual input to previously stored instances of the face with higher numbers of stored instances resulting in higher recognition rates (e.g. Longmore et al., 2008, 2017). While the concept of averages proposes the formation of abstract face representations during face learning, the exemplar-based model suggests that multiple instances of the face are stored within the representations. The exemplar-based theory also highlights the importance of exemplar variation during face learning as a higher number of encounters increases the likelihood that there will be a close match between an incoming image and an old encounter.

1.2.3. Within-person variability

Faces can look very different in different pictures, and exposure to this within-person variability is critical for face learning (Kramer et al., 2017; Ritchie & Burton, 2017). Namely, one needs to learn how an individual's appearance varies to form a robust representation that generalises to a wide range of images. This was evident in Jenkins et al.'s (2011) study, as only the participants that were familiar with the Dutch celebrities were able to perceive the highly variable photos of each identity as belonging together. Additionally, higher familiarity with a celebrity increases the number of images which are judged to serve as a good representation of what the famous person looks like (Ritchie, Kramer, et al., 2018). Previous face learning studies have also demonstrated that exposure to multiple images facilitates face learning (Andrews et al., 2015, 2017; Dowsett et al., 2016; Kramer et al., 2015; Liu et al., 2015; Longmore et al., 2008, 2017; Matthews & Mondloch, 2018; Menon et al., 2015; Sweeney & Lampinen, 2012).

While previous research has demonstrated that the duration of the exposure has an impact on face learning, as viewing faces for longer leads to an increase in matching accuracy (Memon et al., 2003), the degree of variability also plays an important role in face learning. Ritchie and Burton (2017) demonstrated improved identification following exposure to a highly variable set of images (images with variability related to different facial expressions, angles, lighting, ageing, hairstyle etc.) than to images with low variability (still images taken from a single video with variability limited to different angles and expressions) while the duration of exposure was kept constant between the two conditions. Similarly, Murphy and colleagues (2015) observed better recognition of novel images following exposure to 96 naturally varying images relative to the repetition of the same six images, while duration exposure was identical. Furthermore, one-minute exposure to high variability (changes as a result of different camera angles, lighting, expression but also clothes, hairstyle and make-up) leads to more robust and durable representations relative to one-minute exposure to no (a single image) or limited variability (changes limited to camera angle, pose, and facial expressions) (Corpuz & Oriet, 2022). Therefore, experience with variation appears to be a key aspect of face learning.

Within-person variability has been studied using “ambient” images, i.e. everyday photos of “natural” variability that simultaneously differ on multiple dimensions, which include the appearance of the face itself, for instance, by varying hairstyles, facial expressions, gaze, viewing angle, but also environmental factors such as background and lighting (Jenkins et al., 2011; see Figure 1.1 for examples). Such highly variable stimuli allow researchers to investigate whether robust representations have been established, as successful recognition across a wide range of images is necessary to conclude that a face has been learnt (Jenkins et al., 2011; Kramer et al., 2017).

Figure 1.1. Example of ambient images of two identities. Published with permission of the depicted persons.

1.3. Models of face processing

In real life, however, the differences between familiar and unfamiliar people go beyond visual face representations and getting to know a person involves more than just perceptual familiarisation. Recognising a person does not end with visual processing of the face but also involves access to relevant person-related information. In everyday life, we learn faces through social interaction and acquire semantic information about people, share episodic memories, and develop affective responses.

The process of face and person recognition is often conceptualised as a sequence of several functionally distinct stages. The arguably most influential model is Bruce & Young's (1986) model of face recognition (see Figure 1.2). In the first step called structural encoding facial descriptions are generated. This is followed by the differentiation between familiar and unfamiliar faces conducted by the face recognition units. Here, the encoded representations of perceived stimuli are compared to stored face representations. If there is a close match between the visual input and a stored face representation, the face is classified as familiar and relevant semantic and episodic information is retrieved through accessing so-called person identity nodes. Finally, if available, the name of the identity is retrieved. While this model has been revised and modified over the years (Burton et al., 1990; Haxby et al., 2000; Kovács, 2020; Schweinberger & Burton, 2003; Schweinberger & Neumann, 2016), subsequent models have followed the general structure of Bruce & Young's (1986) famous model which has shaped face recognition research over the past few decades.

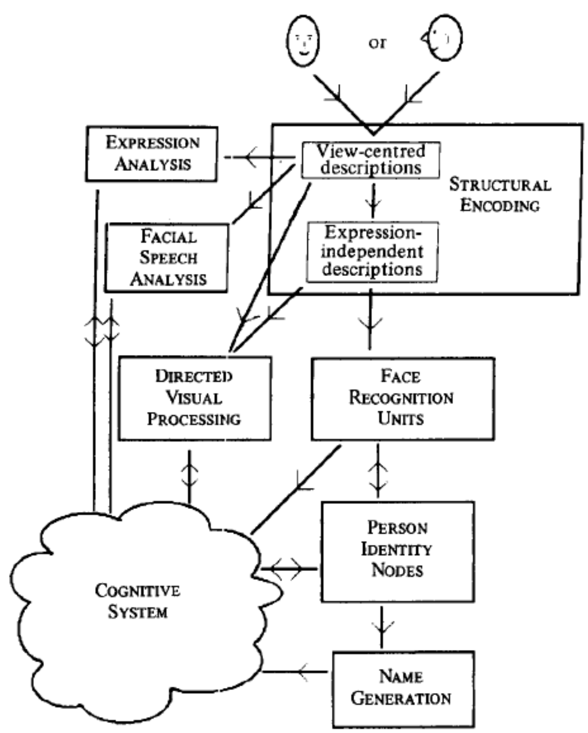


Figure 1.2. A functional model for face recognition (Bruce & Young, 1986).

Neuroscientific research using functional Magnetic Resonance Imaging (fMRI) has suggested that a widely distributed network of brain areas is involved in face processing. Haxby and colleagues (2000) distinguished between (i) a core system consisting of the posterior superior temporal sulcus and inferior occipital and fusiform gyri which processes visual appearances and is assumed to be selective for faces, and (ii) an extended system which allows the access to additional information about the identity. The extended system, which is not face-specific, incorporates areas involved in emotional processing (amygdala, insula, striatum) and the encoding of person-related knowledge such as personality traits (anterior paracingulate), intentions and mental states (posterior superior temporal sulcus/temporoparietal junction), and semantic (anterior temporal cortex) and episodic information (precuneus/posterior cingulate) (Gobbini & Haxby, 2007; see Figure 1.3). While this model distinguishes between these two systems, it also highlights interactions between them, as information is passed back from the extended to the core system via feedback loops.

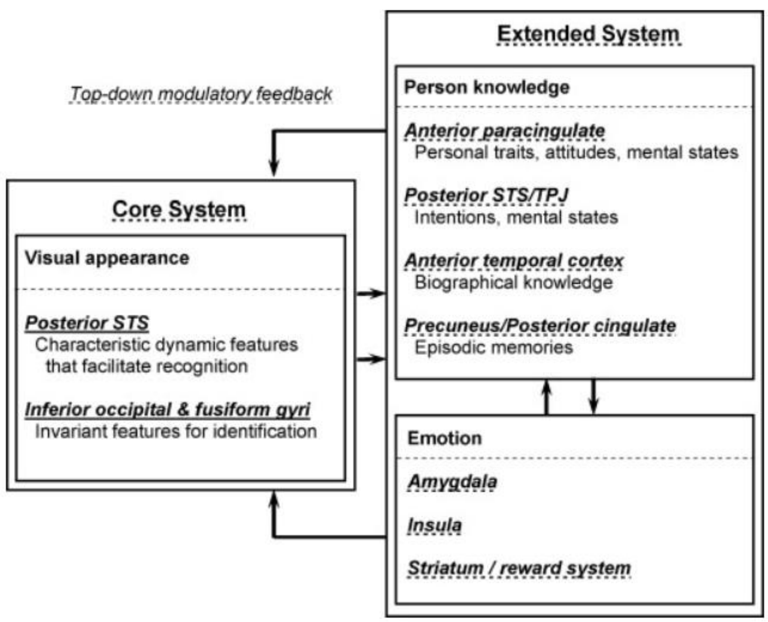


Figure 1.3. A model of the distributed human neural system for face perception (Gobbini & Haxby, 2007; Haxby et al., 2000).

Recently, Kovács (2020) proposed a modified version of this model which focuses on how a person becomes familiar in everyday life (see Figure 1.4). According to this model, the first step is visual familiarisation followed by the accumulation of person-related knowledge, and eventually, highly accurate and effortless recognition in the case of highly familiar faces. As someone becomes more familiar, the available information regarding the person gradually becomes more elaborate, leading to increased activation across the face-identification network. Different types of familiarity, i.e. purely perceptual familiarity, famous faces, and personally familiar identities, all activate the same neural network but at a different level. Only highly familiar faces, such as well-known celebrities and personally familiar people, activate identity-specific representations within long-term memory areas (precuneus/posterior cingulate and the medial temporal lobe), and only personally familiar faces elicit an identity-specific response in the areas related to emotions (amygdala). Importantly, this model highlights that traditional laboratory-based familiarisation procedures fail to elicit the network-wide response which people who are known for much longer evoke.

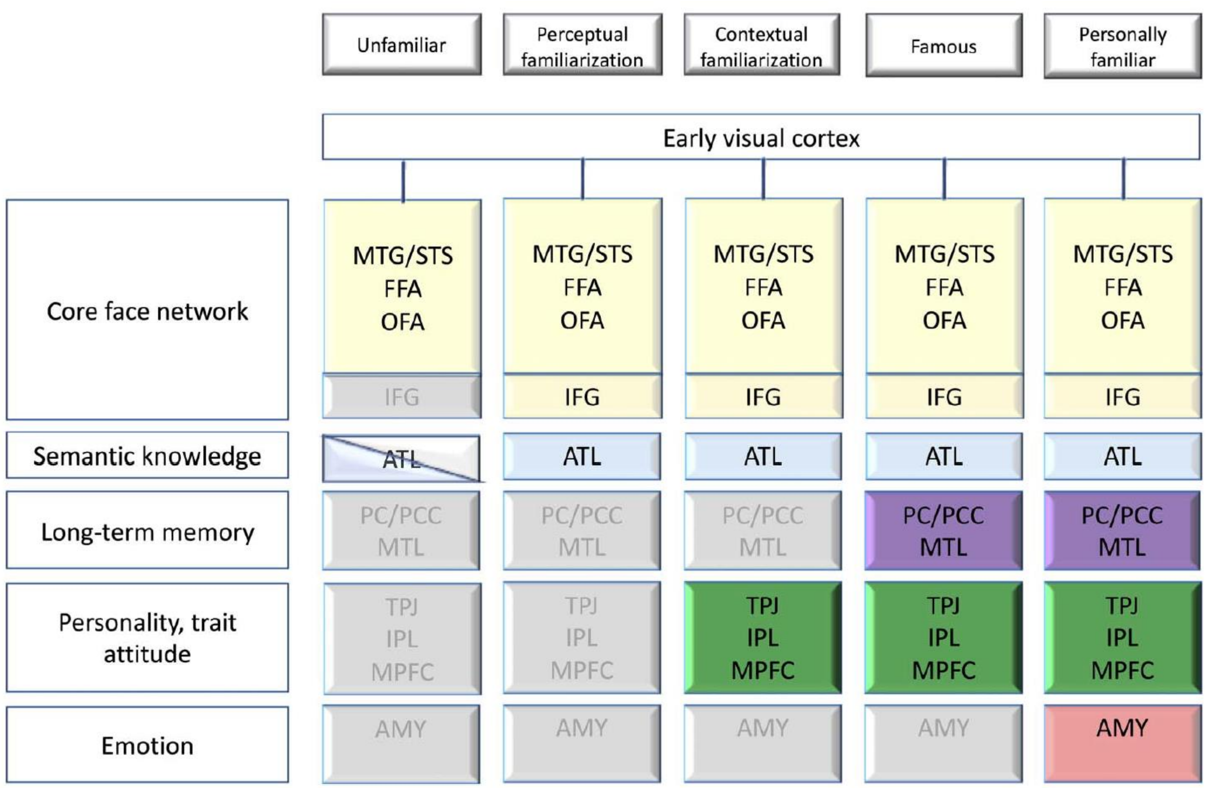


Figure 1.4. A model of person identity-specific changes in the brain as a person becomes familiar (Kovács, 2020).

1.4. EEG and the neural correlates of face recognition

Due to its excellent spatial resolution, fMRI has improved our understanding of the brain areas involved in face recognition and the connectivity between brain regions, but its low temporal resolution prevents us from gaining precise information regarding the sequence of the various face recognition stages (Ambrus et al., 2019; Campbell et al., 2020; Olivares et al., 2015; Yan & Rossion, 2020). Since it takes less than a quarter of a second to identify a visual input as a face and to recognise a face as familiar (e.g. Gosling & Eimer, 2011), event-related brain potentials (ERPs) are ideally suited to study face recognition and provide insights into its different functional stages. ERPs are derived from scalp-recorded electroencephalography (EEG) and reflect post-synaptic potentials that are time-locked to a particular event (Woodman, 2010), in face perception research usually the presentation of a face image. As ERPs are small, a large number of simultaneously active neurons with the same orientation needs to be summed together (Jackson & Bolger, 2014). The resulting ERPs comprise of positive and negative voltage deflections, called components, which represent particular stages of stimulus processing. The EEG's temporal resolution in the millisecond range enables researchers to investigate the sequence of sub-processes involved in face recognition (Luck, 2014), and determine for instance at what stage the differences between familiar and unfamiliar faces emerge. ERPs studies have refined face perception models and provided vital information regarding its timing (Schweinberger & Neumann, 2016).

1.4.1. The N170 – detection of a face-like stimulus

EEG research has identified several ERP components sensitive to faces (see Schweinberger & Neumann, 2016; see Figure 1.5). The earliest face-selective component, the N170, peaks approximately

160-190 ms after the presentation of a face, as faces elicit more negative waves in this time range over occipito-temporal brain regions than other objects (Bentin et al., 1996). The N170 has been assumed to reflect structural encoding (Eimer, 2000b, 2011), or the detection of a face-like pattern (Schweinberger & Burton, 2003; Schweinberger & Neumann, 2016). In line with both interpretations, some studies have not observed differences between familiar and unfamiliar faces in this component (Alzueta et al., 2019; Bentin & Deouell, 2000; Eimer, 2000a; Schweinberger et al., 2002; Tanaka et al., 2006; Wiese, Tüttenberg, et al., 2019). However, there are some discrepancies regarding N170's sensitivity to familiarity. Some studies have reported a larger N170 for familiar relative to unfamiliar faces (Barragan-Jason et al., 2015; Caharel et al., 2002, 2005, 2014; Wild-Wall et al., 2008), while other studies have detected differences in the opposite direction (Huang et al., 2017; Marzi & Viggiano, 2007). Due to these inconsistencies and the small effects observed when the component is modulated by familiarity, there is overall more support for the conclusion that reliable neural differences between familiar and unfamiliar faces emerge later (but see Caharel & Rossion (2021) for a different conclusion).

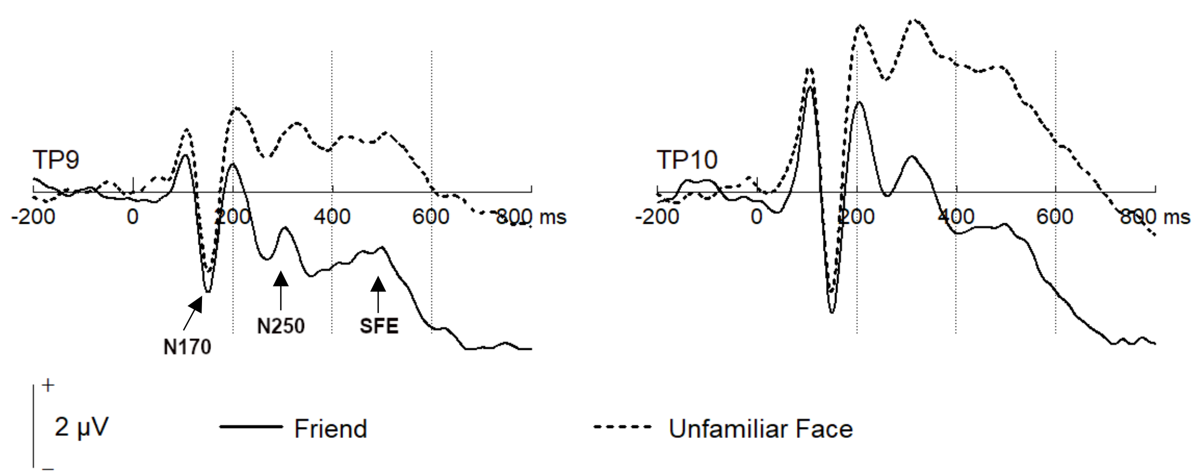


Figure 1.5. Illustration of ERP face recognition components. N170, N250, and SFE in response to highly variable images of a friend known for just over a year and of an unfamiliar face, plotted at the occipito-temporal channels TP9 and TP10. Dotted lines separate the time ranges selected for the calculation of mean amplitudes for the N250 and SFE components. Data from Chapter 2.

1.4.2. N250 familiarity effect

1.4.2.1. The N250 – accessing visual representations of familiar faces

More consistent familiarity effects are observed in the N250 familiarity effect, a negative deflection at occipito-temporal electrodes which peaks at around 250 ms and begins about 200 ms after stimulus onset. Relative to unfamiliar faces, more negative amplitudes have been reported in response to celebrities (Andrews et al., 2017; Bentin & Deouell, 2000; Gosling & Eimer, 2011; Saavedra et al., 2010; Wiese, Hobden, et al., 2022), personally highly familiar faces (Wiese, Ingram, et al., 2019; Wiese, Tüttenberg, et al., 2019), and the participant's own face (Tanaka et al., 2006). This so-called N250 familiarity effect has been interpreted to represent access to stored representations of the visual characteristics of familiar faces (Schweinberger & Burton, 2003; Schweinberger & Neumann, 2016) and has shown sensitivity to explicit person identification, as ERPs successfully separated 'definitely known' from 'merely familiar' faces (Gosling & Eimer, 2011). Increased negativity has also been reported for familiar faces preceded by an image of the same (primed) relative to a different (unprimed) face, an effect known as the N250r ("r" for repetition; Begleiter et al., 1995; Herzmann et al., 2004; Schweinberger et al., 1995, 2004), presumably reflecting facilitated access to face representations as a result of pre-activation by the prime stimulus. Despite showing some degree of image specificity, the N250r component has also been reported in response to a repetition of different images of the same person, suggesting that the effect is not fully image-dependent but at least partly related to facial identity (Schweinberger et al., 2002).

The N250 and N250r effects also do not depend heavily on the availability of attentional resources as their magnitude is similar in low and highly distracting conditions, suggesting that visual face recognition can successfully occur in very attention-demanding conditions (Neumann et al., 2011; Neumann & Schweinberger, 2008; Wiese, Ingram, et al., 2019). Moreover, it appears to be independent of voluntary control, as the N250 was elicited when participants overtly denied they knew a familiar person (Wiese, Anderson, et al., 2022), and in the absence of conscious awareness, as familiarity effects have been reported in patients with developmental prosopagnosia without overt recognition of the familiar faces (Eimer et al., 2012). Additionally, the level of familiarity appears to have a graded effect on the magnitude of the familiarity effect, as the largest N250 effects have been reported for the participants' own face, followed by close friends, and then favourite celebrities (Alzueta et al., 2019; Wiese, Hobden, et al., 2022). The modulation of the effect by degree of familiarity makes the N250 a good candidate to explore the development of familiarity during learning.

1.4.2.2. N250 for experimentally learnt faces

Of particular relevance, the N250 familiarity effect is also sensitive to face learning. Tanaka and colleagues (2006) reported an N250 familiarity effect for pre-experimentally unfamiliar faces after a single learning session, and the magnitude of the effect was similar to the N250 elicited by own-face images. However, as identical pictures were used at the learning and testing stages, it cannot be concluded that robust representations have been established, as evidence of recognition across different exemplars is needed to determine that a transition to generalisable face representations has occurred (Jenkins et al., 2011). By contrast, clear face learning was demonstrated by Kaufmann et al. (2009), as watching videos of initially unfamiliar faces was sufficient to later elicit the N250 familiarity effect in response to similar but previously unseen images of the learnt faces. Furthermore, there was an increase in the magnitude of the N250 effect over blocks, suggesting that further learning improved the stored face representations. Hence, the face representations formed during learning were robust enough to allow for the recognition of previously unseen images of a person, and continuous exposure led to further refinement of these representations.

The transition from unfamiliar to familiar face processing was also examined by Zimmermann and Eimer (2013) by using the N250r and focusing on pictorial versus structural codes. They presented participants with two consecutive images of pre-experimentally unfamiliar faces per trial, and these images showed either the same or a different person in either the same or a different view. The images depicted faces either in full frontal view or half profile view at an angle of approximately 35˚. During the first half of the experiment, an N250r was elicited only on same-identity same-view trials (i.e. for image repetition). However, during the second half, the effect extended to view-change trials of the same identity. Therefore, over the course of the experiment, face learning was reflected by this transition from view-dependent (pictorial codes) to view-independent (structural codes) repetition effects, as the representations were robust enough to generalise to other viewpoints. Overall, these studies demonstrate that the N250 time range is sensitive to face learning, as more negative amplitudes have been found in response to pre-experimentally unfamiliar faces after just one brief learning session.

In real life, however, face learning and familiar face recognition occur under different circumstances. In everyday life, faces are learnt through exposure to the individual's unique within-person variability, and this exposure is key for acquiring stable representations which allow people to accurately and effortlessly recognise numerous faces in highly variable conditions (Jenkins & Burton, 2011; Ritchie & Burton, 2017). These representations are gradually built up and refined through repeated exposure over several occasions. However, face learning experiments usually consist of a single learning session which involves limited exposure to natural variability by either using only a single image during face learning (e.g. Tanaka et al., 2006) or very similar images with variation restricted to viewing angle and/or facial expressions (e.g. Kaufmann et al., 2009; Zimmermann & Eimer, 2013). This makes the process qualitatively different from the phenomenon we are trying to study (Kramer et al., 2017) and is seen as one of the main reasons behind the slow progress of the field (Burton, 2013). Another key discrepancy between the process of interest and how it is studied in the laboratory is related to the recognition stage. In real life, faces are arguably not only never encountered in precisely the same way twice, as they always look different due to environmental factors (e.g. lighting, background) or individual changes (e.g. facial expressions, gaze, health, make-up), but familiar faces are successfully recognised over substantial variation (Burton et al., 2011). Laboratory studies, however, often repeat similar or identical image(s) which fails to mimic real-life face recognition. Furthermore, a face has to be recognised across a wide range of images in order to conclude that stable representations have been formed (Jenkins et al., 2011). Therefore, using test stimuli that are identical/similar to the 'learning phase' images does not enable researchers to conclude that a face has reliably been learnt.

Andrews and colleagues (2017) implemented a more ecologically valid method than previous ERP face learning studies to investigate whether the N250 effect would be elicited when participants learnt and were then tested with highly variable "ambient" images. The participants were instructed to sort 20 "ambient" images of two unfamiliar faces into two separate piles, one for each identity. This "guided" sorting task resulted in incidental learning (see also Andrews et al., 2015), as an N250 effect with more negative amplitudes for recently learnt relative to novel identities was observed in a subsequent ERP session. Importantly, N250 amplitudes were identical for novel images of the learnt identities relative to those that were used during learning. Therefore, the representations formed during this learning procedure were robust enough to incorporate novel, never-before-seen "ambient" images of the identities. However, despite using a more ecologically valid method than previous studies, Andrews et al.'s (2017) study does not tell us much about everyday face learning.

The experimental procedures used by Andrews and colleagues (2017) differ from real-life face learning in key aspects. While participants were simultaneously presented with 20 images of each of the identities, in everyday life one is exposed to a single instance of the person at any given time. Furthermore, during a given social encounter, even though the face undergoes a range of changes in viewing angle, distance, facial expressions etc., people perceive the face as consistently showing the same person (Bruce, 1994), arguably because of the gradual nature of change and object constancy - our more general experience that a visual object at a given location does not change identity from one moment to the next. This should make forming a stable representation of the identity easier than tasks in which participants have to identify which instances belong to the particular person before they are integrated into a new representation. However, as Andrews et al. (2017) presented participants with images that were taken on many different occasions, this study more closely resembles long-term face learning where we are exposed to day-to-day variability (e.g. in make-up or health) in addition to the changes that can be observed during a single encounter (e.g. in viewing angle or emotional expression). Therefore, it is still unclear whether a single interaction with a previously unfamiliar person can produce reliable learning effects.

In research, familiarity is commonly approached as a binary category, comparing famous/experimentally learnt to unfamiliar faces (Kramer et al., 2018). In real life, however, familiarity is a continuum ranging from superficial visual familiarity (e.g. the person we see sometimes on the bus) to long-term friendships or other close relationships. The different levels of familiarity have an impact on performance in behavioural tasks and can be modelled computationally (Clutterbuck & Johnston, 2002; Kramer et al., 2018). However, it is largely unclear as yet whether and how these more fine-grained differences are reflected in the ERP familiarity effects. Some studies have demonstrated that the N250 effect is modulated by degree of familiarity. In addition to successfully establishing image-independent representations of the newly learnt identities, Andrews et al. (2017) still reported a larger N250 familiarity effect for celebrities suggesting the representations for the experimentally learnt identities were weaker compared to highly overlearnt faces. Similarly, researchers have reported a graded effect of familiarity on both N250 and N250r (Alzueta et al., 2019; Herzmann et al., 2004; Wiese, Hobden, et al., 2022). While these findings overall suggest that more familiar faces elicit stronger ERP effects, we do not yet know over what time window the underlying representations develop following their initial establishment, and at what point subsequent exposure no longer leads to additional refinement of the representations.

1.4.3. Sustained Familiarity Effect (SFE)

Models of face processing have highlighted a stage following visual recognition, in which relevant semantic, episodic, and affective information about the person is retrieved and integrated (Bruce & Young, 1986; Ellis & Lewis, 2001; Gobbini & Haxby, 2007; Schweinberger & Burton, 2003). While the N250 familiarity effect has been replicated in many studies, face recognition research has been less consistent about later stages related to identity processing. An ERP effect which has been linked to the semantic processing of people is the N400 which was originally reported in the field of word processing when semantically inconsistent words elicit a negative effect over the central-parietal areas around 400 ms (Kutas & Hillyard, 1980). Subsequent research on face processing has reported a similar effect between 300 and 600 ms after stimulus onset when semantic (e.g. prime and target sharing the same occupation) and associative (e.g. prime and target celebrities co-occurring together) priming reduces the effect (for a review see Wiese, 2011). Furthermore, the effect's topography is similar for face images and written names of celebrities supporting the interpretation that the N400 effect is linked to post-perceptual stages of identity processing rather than visual recognition (Schweinberger, 1996).

Recently, Wiese, Tüttenberg, et al. (2019) reported a robust and reliable index of familiarity following the N250 time range (see Figure 1.5), presumably reflecting the stage of person rather than face recognition. This so-called Sustained Familiarity Effect (SFE) peaked between 400 and 600 ms after stimulus onset and was modulated by degree of familiarity, as the SFE was strongest for personally highly familiar identities (~4 μV), smaller but clearly present for personally less familiar people (university lecturers), and absent for celebrities chosen by the experimenters. Subsequent research, however, demonstrated that this effect was not restricted to personally familiar faces, as celebrities could also elicit the effect as long as the viewers were sufficiently familiar with them (Wiese, Hobden, et al., 2022). The SFE is larger than previous candidates for a robust index of familiarity and can be reliably observed in most individual participants (~84% of the participants). Its scalp distribution is highly similar to the N250 familiarity effect, suggesting a generator in the ventral visual pathway. Extending the findings from the initial study, more recent work found again that familiarity has a graded effect on the SFE, as the effect was observed to be largest for the participants' own face, followed by personally highly familiar identities, favourite celebrities, and disliked celebrities (Wiese, Hobden, et al., 2022). These observations led to the suggestion that the SFE might reflect the integration of visual information with additional person-related knowledge (affective, semantic, episodic information), which is vital for appropriate social interactions, presumably reflecting feedback loops from semantic and affective to perceptual brain regions, highlighted in models of face recognition (Gobbini & Haxby, 2007; Schweinberger & Burton, 2003; see Figure 1.3).

Despite the similarities in scalp distributions, the N250 and the SFE appear to reflect functionally at least partly distinct processes rather than one long-lasting familiarity effect. This assumption is based on observations that the two effects respond differently to experimental manipulations. For instance, while the SFE is modulated by attentional load (Wiese, Ingram, et al., 2019) and image repetition (Wiese, Tüttenberg, et al., 2019), these manipulations do not affect the N250 familiarity effect. A recent study using a cross-experiment multivariate classification of EEG data also reported that the familiarity responses in these two time ranges were modulated differentially by task demands (Dalski, Kovács, Wiese, et al., 2022). This is in line with the observation that difference curves of familiar versus unfamiliar faces typically show two peaks, as the familiarity effect ramps up sharply at around 200 ms, with an initial peak between 200 and 300 ms, followed by a dip around 400 ms, and then additionally increases and peaks again between 400 and 600 ms (Wiese, Anderson, et al., 2022; Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019). It, therefore, appears that the two effects are not completely independent, but the SFE reflects processing in addition to the earlier N250 effect.

Other EEG studies have also reported the most prominent and robust differences between familiar and unfamiliar faces in this later time range. Using multivariate representational similarity analysis, Ambrus and colleagues (2019) observed identity representations for familiar celebrities from 400 ms onwards. Additionally, Karimi-Rouzbahani et al. (2021) observed a peak for the familiarity effects elicited in response to the participant's own face and close personally familiar identities 400 ms after stimulus exposure. Using a cross-experiment and cross-participant decoding analysis, Dalski, Kovács, and Ambrus (2022) reported familiarity effects from 270 to 630 ms with a peak between 330 and 500 ms. Li and colleagues (2022) demonstrated that the level of familiarity of famous faces can be reliably decoded between 400 and 600 ms after stimulus presentation. The consistency of these findings across studies adopting different analytical procedures and using faces differing in level and type of familiarity demonstrates the robustness of the general finding.

Currently, however, relatively little is known about the SFE and the later stages of face or identity processing. While the effect is modulated by degree of familiarity (Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019), it remains to be addressed how familiar the person needs to be for a reliable effect to be elicited, how the magnitude of the effect changes with increasing familiarity, and whether it reaches a plateau after a while. Additionally, the relationship between the SFE and N250 familiarity effect remains somewhat unclear. For instance, while Wiese, Tüttenberg, and colleagues (2019) reported an SFE in response to images of university lecturers, no significant N250 familiarity effect was observed.

Nevertheless, the development of the SFE cannot be studied using face learning paradigms which traditionally focus on the visual aspect of learning faces. While some have tried to investigate the impact of semantic information on post-N250 face recognition stages (e.g. Kaufmann et al., 2009; Paller et al., 2000; Wiese & Schweinberger, 2015), a single learning session in laboratory settings cannot mimic real-life identity learning. In everyday life, we get to know people through social interaction, and learning to recognise a new person over time is typically accompanied by a gradual increase in semantic, affective, and episodic information (Kovács, 2020). Representations of this additional person-related information may build up on a different timescale relative to visual face representations.

1.5. Real-life learning

More recent work has started to address the limitations of previous research by incorporating naturalistic face learning to investigate the effect of real-life exposure to a pre-experimentally unfamiliar person on neuro-cognitive representations. A recent fast periodic visual stimulation EEG study tracked the neural changes as a result of two months of familiarisation “in the wild”, which involved at least four hours of exposure per week on two separate occasions (Campbell & Tanaka, 2021). Accordingly, the identities were learnt through everyday life interaction and exposure to within-person variability, and were encountered on different days and in different settings. Real-life familiarisation resulted in increased face identity responses for the newly familiar faces over the occipito-temporal area relative to the pre-familiarisation session, while a comparable change was neither observed for a face which remained unfamiliar nor for the participant’s own face.

Moreover, a recent study investigating the impact of different types of familiarisation observed an enhancement of face familiarity representations from 400 ms after stimulus exposure following three one-hour sessions of real-life interaction (playing a quiz game with a previously unfamiliar person) over three consecutive days (Ambrus et al., 2021). Meanwhile, the representations acquired during a two-week media familiarisation task (watching a TV show) were weaker relative to those formed during real-life exposure, while no changes were observed following the brief perceptual exposure (image sorting task). While these findings might point towards the importance of rich, real-life familiarisation for the establishment of robust face representations, the differences in exposure time between the conditions limit the conclusions which can be drawn, and it is therefore unclear what precisely drives the differences between conditions.

Additionally, a recent fMRI study demonstrated that even shorter naturalistic exposure is sufficient for face learning to occur (Sliwinska et al., 2022). In this study, real-life learning consisted of three 10-minute interactions over the course of two weeks. The first two sessions involved a few minutes of a general conversation followed by a Rock Paper Scissors game with the actor, while in the final session, the actor and the participant discussed the fMRI procedure. There was no difference in the neural response to the actor and a foil in the first fMRI scan which was carried out before the first learning session when both identities were unfamiliar. Importantly, however, the three real-life interactions resulted in a sustained neural response in the face-processing network in the right hemisphere (fusiform face area, occipital face area, posterior superior temporal sulcus, amygdala) and the right hippocampus for the learnt person, while a decrease in the activity of these areas was reported for the foil identity. Additionally, these fMRI results were accompanied by behavioural differences, with improved image matching of the newly learnt face following the second interaction.

While these studies demonstrate that ecologically more valid paradigms can successfully be implemented and used to improve our understanding of how people become familiar in real-life, our knowledge of how familiarity initially develops and then increases over time is still rather limited. Sliwinska and colleagues' (2022) study shows that faces are learnt quickly even in more naturalistic conditions, but it is still unclear what the minimal exposure resulting in learning effects is, and whether a single real-life interaction can lead to face learning. Additionally, while Campbell and Tanaka (2021) found newly formed identity representations following two months of regular exposure to a pre-experimentally unfamiliar person, it is not clear how the representations develop afterwards and at what point the identity representations are fully established. More research looking at the long-term development of familiarity is needed to improve our understanding of how familiar faces, which differ in the levels of perceptual exposure but also the availability of semantic, episodic, and affective information, are represented in the brain. These questions are not only of theoretical importance but could have a potential impact on applied situations, and in particular the forensic field by informing eyewitness testimony practices and by potentially providing an objective measurement of familiarity (see Wiese, Anderson, et al., 2022).

1.6. Present thesis

The aim of this thesis is to investigate face and identity learning from short to long time periods using naturalistic exposure. The three studies outlined below were designed to more closely capture the transition from unfamiliar to familiar face recognition, focus on the boundary conditions and developmental trajectories of face and identity learning, as well as examine the relationship between the two processes. The experiments introduce a novel (quasi-)experimental approach by examining how participants learn new identities via naturalistic exposure in everyday life situations with exposure ranging from five minutes (Chapter 4) to just over two years (Chapter 2). The methods used in these studies enable us to overcome most of the challenges to studying personal familiarity in naturalistic settings (e.g. Ramon & Gobbini, 2018), as the used identities were learnt through exposure to natural within-person variability. Moreover, in the two long-term learning experiments, the participants were exposed to their friends in everyday life and acquired semantic information about, shared episodic memories with, and developed affective responses towards their friends.

Chapter 2 examines the changes face and identity representations undergo over the course of two years. Using a cross-sectional design, Year 1, 2, and 3 undergraduate students were tested approximately two months after the start of the academic year with images of friends known from university (translating into two, 14, and 26 months of familiarity) and photos of long-known friends from their hometowns. We show two novel results: 1) the neural identity representations are relatively weak after two months of knowing a person, and 2) the neural representations of visual familiarity and identity-specific knowledge increase following the first two months and are fully developed by 14 months of familiarity. These results add a first estimate of the time it takes to learn about new people to our current knowledge of face and identity learning and suggest that it takes up to approximately one year for both face and identity representations to be fully refined.

Chapter 3 investigates what happens during the first year of familiarity with a person which seems to be critical for the formation of face and identity representations. Using a longitudinal design, we investigated how ERP familiarity effects develop during the first eight months of knowing someone by testing first-year undergraduate students with images of a friend met at university approximately one, five, and eight months after the start of the academic year. Clear ERP familiarity effects were evident after one month of familiarity. While there was a significant increase in the N250 effect over the time span of the study, we did not observe an increase in the SFE time range. These results further refine our findings from Chapter 2 of fully developed N250 at 14 months of familiarity by demonstrating that visual face representations are indeed fully developed substantially earlier - within about five months of knowing a person. The integration of identity-specific knowledge, on the other hand, takes longer to get fully established, presumably between eight and 14 months.

In Chapter 4, we tested how long it takes to build an initial representation of a new face under naturalistic conditions. In a series of three experiments, participants interacted with a ‘to-be-learnt’ identity which was followed by an EGG session in which the ERPs in response to highly variable previously unseen images of the newly learnt identity and an unfamiliar face were recorded. Robust representations were present after a 30-minute and a 10-minute social interaction, and a trend was reported following a five-minute exposure. A further control experiment confirmed that the observed learning effects resulted from the brief social interaction before the testing session rather than from learning during the EEG session. These results suggest that in everyday life situations, we learn faces easily and quickly, as the initial representations seem to build up within the first five to 10 minutes of a real-life encounter. The findings support the abstract rather than instance-based account of face learning as while the participants were exposed to the new person during one single encounter, the N250 familiarity effect was elicited in response to images taken in widely different environmental conditions and containing long-term changes in the faces.

Overall, the experiments presented in this thesis give a first estimate of the time it takes to get to know someone in everyday life. They demonstrate that robust visual representations (as reflected in the N250 familiarity effect) are established very quickly – within the first 10 minutes of meeting a new person, and get fully developed by five months of knowing someone. The integration of identity-related knowledge (as reflected in the SFE), on the other hand, first emerges within one month of exposure and develops to the level of highly familiar people by 14 months of familiarity.

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

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.

2.1. 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 et al., 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 et al., 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 et al., 2019; Campbell et al., 2020; Yan & Rossion, 2020; see Olivares et al., 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, Hobden, et al., 2022) and personally familiar faces (Pierce et al., 2011;

Wiese, Anderson, et al., 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 et al., 2017; Kaufmann et al., 2009; Tanaka et al., 2006; Zimmermann & Eimer, 2013). 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 et al., 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 400-600 ms (Wiese, Tüttenberg, et al., 2019). Due to its occipito-temporal scalp distribution and modulation by level of familiarity (Wiese, Hobden, et al., 2022), 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 et al., 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 et al., 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.

2.2. Method

2.2.1. 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 et al., 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, Tüttenberg, et al. (2019) (paired-sample t-test, one-tailed, dz = 0.8, $1 - \beta = .95$). 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.

2.2.2. 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 x 285 pixels frame, converted to greyscale, and matched for luminance using the SHINE toolbox (Willenbockel et al., 2010; see Figure 2.1a).

[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).

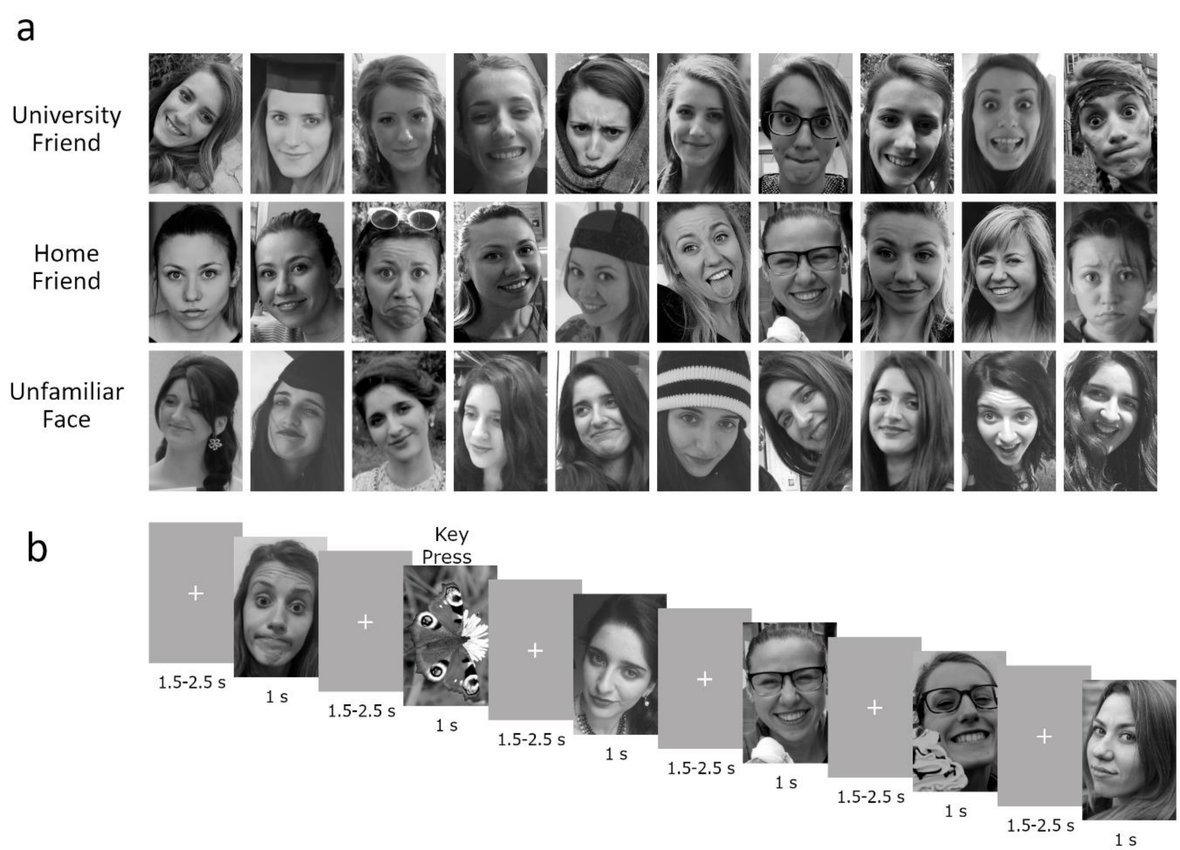


Figure 2.1. Exemplary stimuli and procedure. a) Example ambient images from three identities (IDs). Images are published with the permission of the depicted persons. b) Trial structure of the experiment.

2.2.3. 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^{TM}) 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 visual angle of 3.6° x 5.4° for 1,000 ms and followed by a fixation cross with 1,500-2,500 ms presentation time (2,000 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 (Figure 2.1b). 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, Anderson, 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.

2.2.4. 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 to 1,000 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 200-400 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 n^2_p were calculated using an online calculator (https://effect-size-calculator.herokuapp.com); Cohen'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 et al., 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.

2.3. 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 Figure 2.2), which was most clearly evident at occipito-temporal electrodes (Figure 2.2c). Critically, the SFE appeared more pronounced for home than university friends in Year 1 students, but not in the two other groups.

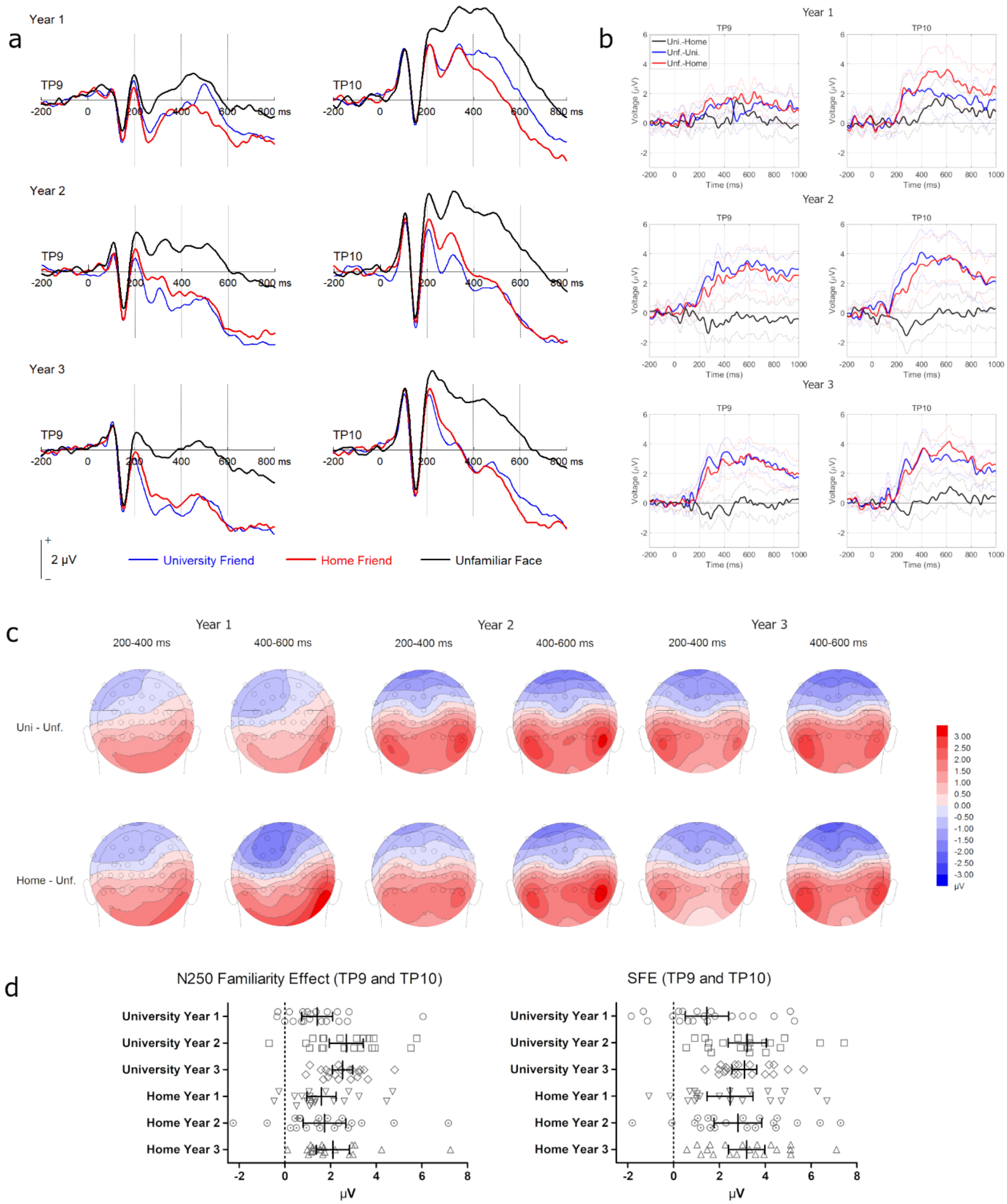


Figure 2.2. ERP results. a) Grand average ERPs at left and right occipito-temporal channels TP9 and TP10 for university friends, home friends, and unfamiliar faces for each year group. b) Mean (and 95% CIs; dashed lines) difference between conditions (university minus home, unfamiliar minus university,

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 (400-600ms) 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.

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 2.1) 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 2.1) 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.

Table 2.1. 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	<.001	0.43	[0.20, 0.69]
	Y1: home vs unfam	1.60	[0.95, 2.25]	19	5.19	<.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	<.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	<.001	0.76	[0.51, 1.07]
	Y3: home vs unfam	2.10	[1.38, 2.83]	19	6.09	<.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	<.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	<.001	0.95	[0.59, 1.38]
	Y2: home vs unfam	2.81	[1.77, 3.85]	19	5.65	<.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	<.001	1.53	[1.02, 2.15]

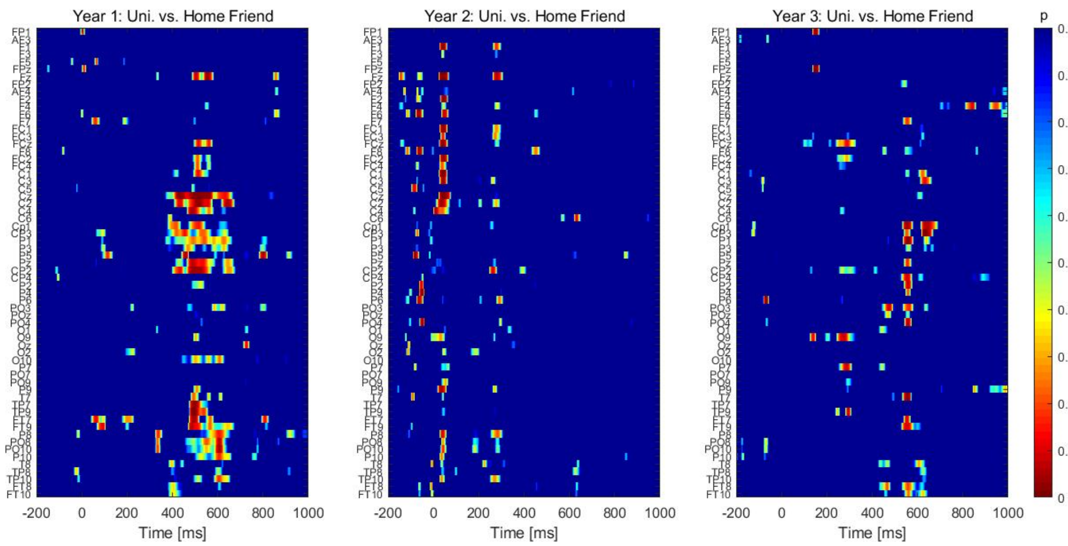
Y3: home vs unfam	3.19	[2.39, 3.98]	19	8.38	<.001	1.35	[0.85, 1.96]
Y3: uni vs home	0.10	[-0.63, 0.83]	19	0.28	.780	0.04	[-0.25, 0.33]
Uni: Y1 vs Y2	1.76	[0.54, 2.98]	38	2.92	.006	0.91	[0.27, 1.57]
Uni: Y2 vs Y3	0.12	[-0.84, 1.08]	38	0.26	.798	0.08	[-0.54, 0.70]
Uni: Y1 vs Y3	1.64	[0.58, 2.69]	38	3.15	.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]

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 Figure 2.3a). These effects were observed not only at left and right occipito-temporal channels, but also (polarity-reversed, see Figure 2.2c 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.

a


Year 1: Uni. vs. Home Friend
Year 2: Uni. vs. Home Friend
Year 3: Uni. vs. Home Friend
Time [ms]
-200 0 200 400 600 800 1000
p
0.05 0.045 0.04 0.035 0.03 0.025 0.02 0.015 0.01 0.005 0

b

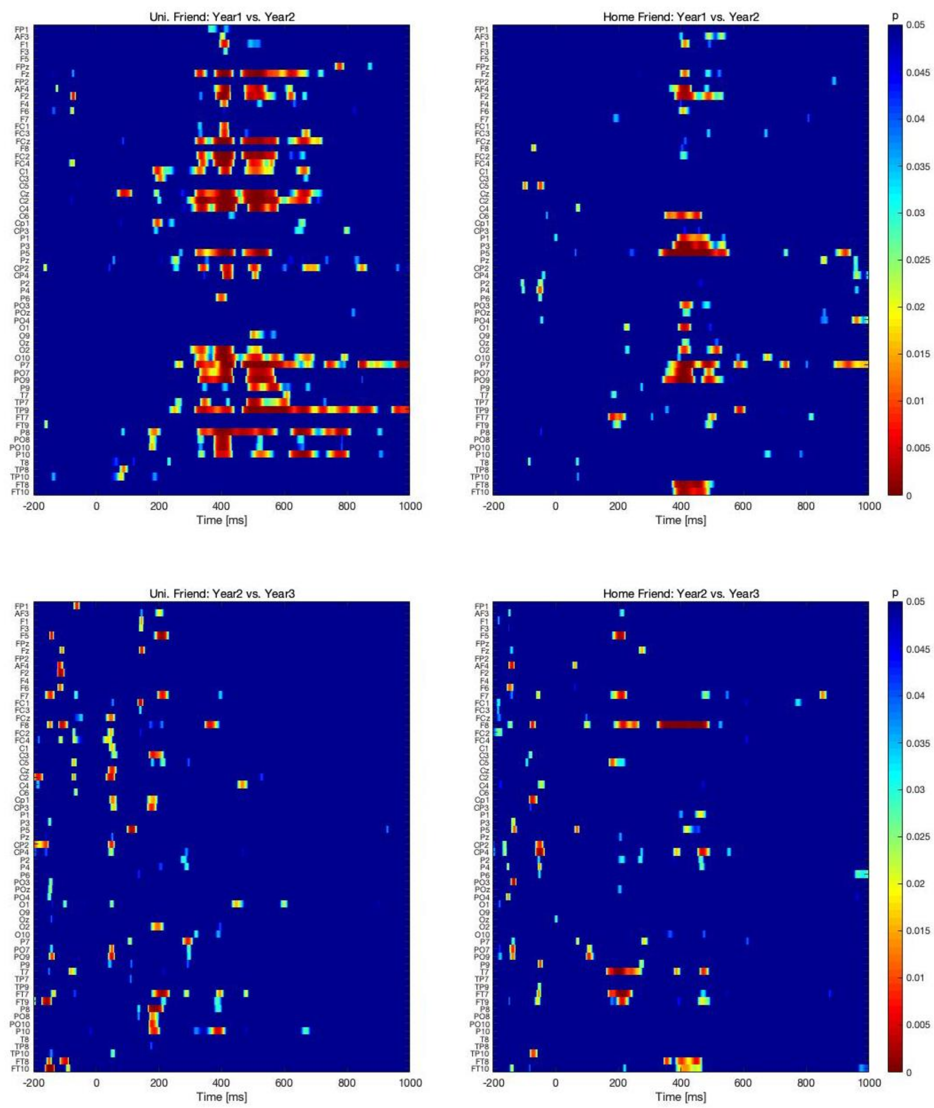

Uni. Friend: Year1 vs. Year2
Home Friend: Year1 vs. Year2
Uni. Friend: Year2 vs. Year3
Home Friend: Year2 vs. Year3
Time [ms]
-200 0 200 400 600 800 1000
p
0.05 0.045 0.04 0.035 0.03 0.025 0.02 0.015 0.01 0.005 0

Figure 2.3. 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.

Similarly, exploratory mass univariate tests of the between-group comparisons largely confirmed the results of the confirmatory analysis reported above (see Figure 2.3b). 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 2.2 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 $r > .539$). Finally, none of the differences between unfamiliar and familiar faces in the rating task correlated with ERP familiarity effects (see Table 2.3).

Table 2.2. 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		Valence		Arousal		Visual Interaction		Social Contact	
		M	*SD*	*M*	*SD*	*M*	*SD*	*Mdn*	IQR	*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 2.3. 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	-.145	.268	-.054	.684	-.149	.254	.011	.932
Valence	.179	.170	.106	.418	.227	.082	.090	.495
Arousal	-.047	.721	-.165	.207	.122	.353	-.180	.168
Visual Interaction	-.217	.096	-.023	.862	-.120	.361	-.066	.616
Social Contact	-.078	.555	.090	.494	-.060	.649	.142	.279

2.4. 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 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, Tüttenberg, et al. (2019) (d_{unb} = 1.08) and Wiese, Hobden, et al. (2022) (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. Figure 2.2b, but also Wiese, Anderson, et al., 2022; Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019) 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, et al., 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 200ms, while at the same time suggesting (ii) that familiarity effects after 600ms 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 600ms (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.

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, Anderson, 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., 2022), 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 current 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 et al., 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 studies 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, Tüttenberg, et al., 2019) and valence (see Wiese, Hobden, et al., 2022) 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, Anderson, 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.

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

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 a significant increase in the N250 effect after five months but not afterwards, no change in the SFE was observed over the course of the study. These results suggest that visual face representations develop fully within five months of knowing a person while the integration of identity-specific knowledge takes longer to get fully established.

3.1. 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 et al., 1999). At the same time, people often struggle to recognise, or even match simultaneously presented photos of unfamiliar faces for identity (Jenkins et al., 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 et al., 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 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 et al., 1996). While a substantial number of studies have not observed differences between familiar and unfamiliar faces in this component (e.g. Alzueta et al., 2019; Bentin & Deouell, 2000; Eimer, 2000; Schweinberger et al., 2002; Tanaka et al., 2006; Wiese, Tüttenberg, et al., 2019; Zimmermann & Eimer, 2013), other have reported either larger (Barragan-Jason et al., 2015; Caharel et al., 2014; Wild-Wall et al., 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 et al., 2017; Bentin & Deouell, 2000; Gosling & Eimer, 2011; Olivares et al., 2015; Saavedra et al., 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 et al., 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 et al., 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-minute 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-minute session. Similarly, a recent EEG study observed an enhancement of face familiarity representations as a result of three one-hour familiarisation sessions over the course of three consecutive days (Ambrus et al., 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 four hours 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 et al., 2019; Dalski, Kovács, & Ambrus, 2022; Dobs et al., 2019; Karimi-Rouzbahani et al., 2021; Li et al., 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).

3.2. 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.

3.2.1. Participants

The target sample size was determined in a power analysis using G*Power (Faul et al., 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 = 0.72, 1 – β = 0.85; see https://osf.io/e258k), which suggested N=16[2]. 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* = 0.6; 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.

3.2.2. Stimuli

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

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 x 285 pixels, converted to grayscale, and matched for luminance using the SHINE toolbox (Willenbockel et al., 2010, see Figure 3.1 for examples). Ten images of butterflies were used to create a task demand.

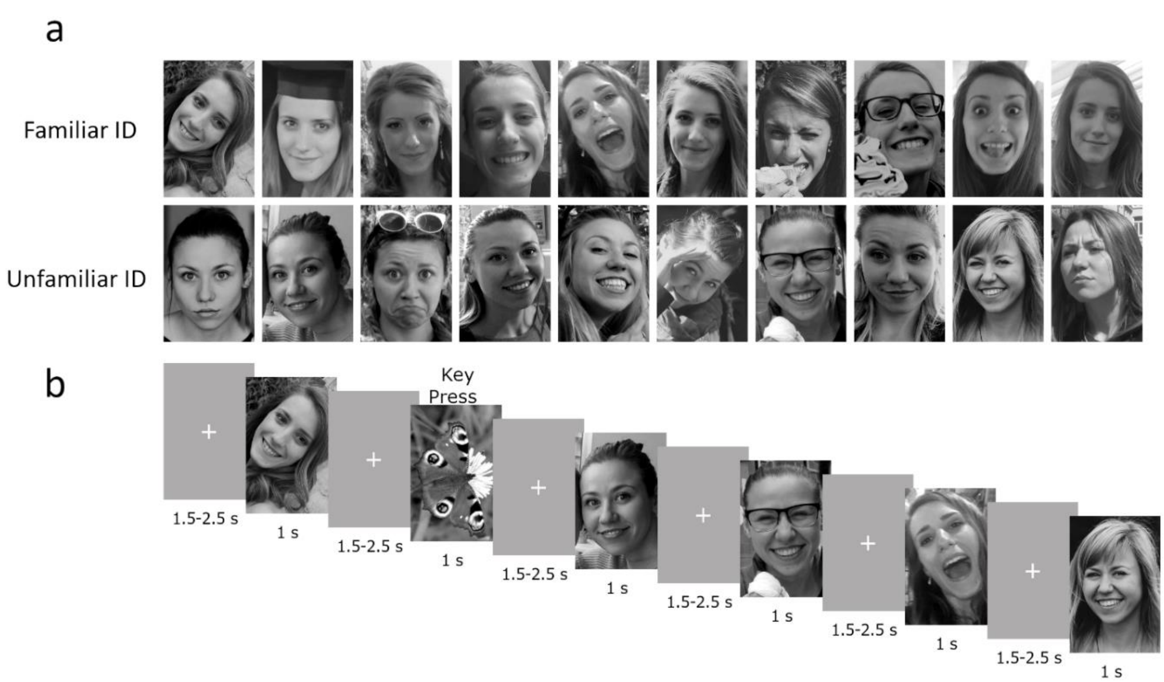


Figure 3.1. Exemplary stimuli and procedure. a) Example ambient images of two identities. b) Trial structure of the experiment. Images are published with the permission of the depicted persons.

3.2.3. 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 six-minute 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 (Figure 3.1). The pictures were presented using E-prime (Psychology Software Tools, Pittsburgh, PA) at a visual angle of 3.6° x 5.4° on a uniform grey background in the centre of the screen for 1,000 ms. Trials were separated by a fixation cross varying in duration between 1,500-2,500 ms (2,000 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 et al., 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.

3.2.4. 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 1,000 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 200-400 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 n^2_p[3] (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 versus 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.

Procedures, confirmatory analyses, and all inclusion and exclusion criteria were pre-registered before data collection (https://osf.io/e258k). All EEG and behavioural data 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

[3] 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).

be shared with anyone outside the author team. Images of selected individuals who have provided their explicit written consent are used as examples in Figure 3.1.

3.3. Results

3.3.1. 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 Figure 3.2a). These differences were evident from Session 1 and appeared to become more pronounced over sessions in both time ranges of interest.

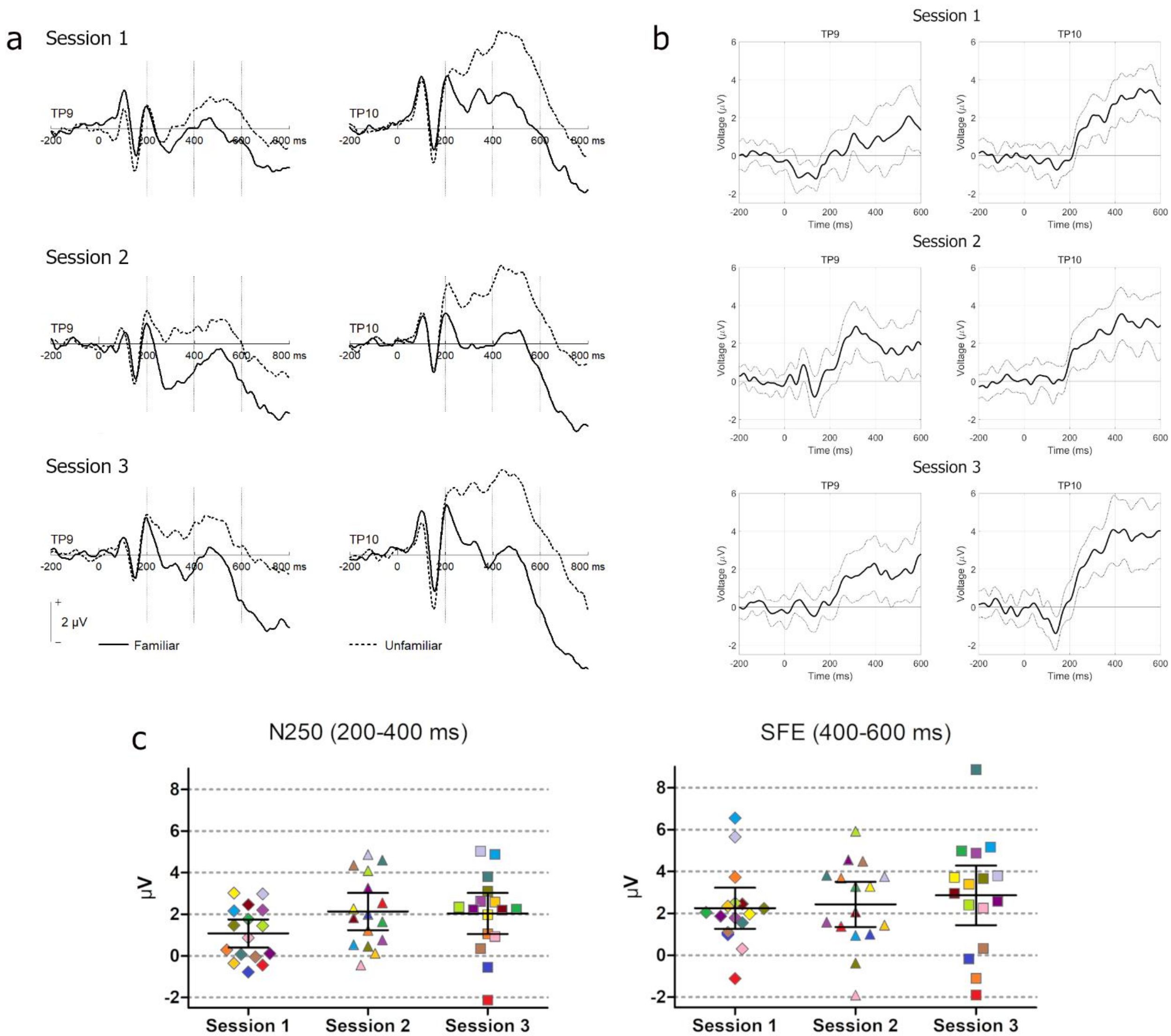


Figure 3.2. ERP results. a) Grand average event-related potentials (ERPs) at left and right occipito-temporal channels TP9 and TP10 for familiar and unfamiliar IDs for each session. b) Mean (and 95% CIs; dashed lines) difference between familiar and unfamiliar IDs at TP9 and TP10. c) Individual (symbols) and mean familiarity effects with 95% CIs (solid lines) for the N250 and SFE time ranges, colour-coded by individual participant .

An ANOVA in the N250 time range revealed a significant main effect of familiarity, $F(1, 15) = 39.5$, $p < .001$, $\eta_p^2 = .725$, 90% CI [.450, .817]. Paired-sample t-tests (see Table 3.1) 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, $F(2, 30) = 0.85$, $p = .440$, $\eta_p^2 = .053$, 90% CI [0, 0.18]. The ANOVA further yielded a trend for an interaction of session by familiarity, $F(2, 30) = 2.62$, $p = .089$, $\eta_p^2 = .149$. 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, $F(1, 15) = 45.6$, $p < .001$, $\eta_p^2 = .753$, 90% CI [.495, .835]. Follow-up tests (see Table 3.1) revealed that, relative to unfamiliar faces, the friend elicited significantly more negative amplitudes in all three sessions. The main effect of session, $F(2, 30) = 0.68$, $p = .516$, $\eta_p^2 = .043$, 90% CI [0, 0.16], and the session by familiarity interaction were non-significant, $F(2, 30) = 0.40$, $p = .675$, $\eta_p^2 = .026$. 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 3.1). 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.

Table 3.1. 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	[0.40, 1.75]	3.36	.004	0.27	[0.09, 0.47]
	S2: friend vs unfam	2.13	[1.23, 3.04]	5.04	<.001	0.73	[0.36, 1.17]
	S3: friend vs unfam	2.04	[1.06, 3.03]	4.42	.001	0.56	[0.25, 0.92]
	S1 vs S2	1.05	[-0.09, 2.19]	1.97	.067	0.67	[-0.05, 1.44]
	S2 vs S3	0.09	[-1.19, 1.37]	0.15	.885	0.05	[-0.62, 0.72]

	S1 vs S3	0.97	[0.18, 1.75]	2.63	.019	0.58	[0.10, 1.10]
SFE	S1: friend vs unfam	2.24	[1.26, 3.23]	4.85	<.001	0.60	[0.28, 0.96]
	S2: friend vs unfam	2.43	[1.35, 3.51]	4.80	<.001	0.68	[0.32, 1.10]
	S3: friend vs unfam	2.86	[1.44, 4.28]	4.28	.001	0.74	[0.32, 1.22]
	S1 vs S2	0.18	[-1.14, 1.50]	0.30	.771	0.09	[-0.54, 0.72]
	S2 vs S3	0.43	[-1.31, 2.18]	0.53	.606	0.17	[-0.50, 0.86]
	S1 vs S3	0.62	[-0.81, 2.04]	0.92	.373	0.25	[-0.32, 0.84]
N250 vs SFE	S1	1.17	[0.33, 2.01]	2.98	.009	0.70	[0.18, 1.28]
	S2	0.30	[-0.36, 0.96]	0.97	.349	0.15	[-0.17, 0.49]
	S3	0.82	[-0.05, 1.69]	2.00	.064	0.34	[-0.02, 0.72]

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 other two of the 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 yielded reliable effects in Session 1, four demonstrated reliable effects in the following two sessions and the rest demonstrated a reliable effect in one of the other two sessions.

3.3.2. Rating task

In the rating task (see Table 3.2 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).

Table 3.2. 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	0.00	2.19	0.66	1.38	0.81	5	0.00
	Session 2	4.94	0.25	2.44	1.15	1.63	1.09	5	0.25
	Session 3	5.00	0.00	2.44	0.73	1.44	0.63	5	1.00
Unfamiliar ID	Session 1	1.69	1.30	4.13	0.89	2.75	0.45	1	0.00
	Session 2	1.56	1.03	4.25	0.93	2.81	0.40	1	0.00
	Session 3	1.63	0.89	4.06	1.06	2.81	0.54	1	0.00

3.3.3. Exploratory analyses

Exploratory analyses were run including all participants who 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 [0.15, 2.26], *t*(17) = 2.40, *p* = .028, d_{unb} = 0.77, 95% CIs [0.09, 1.50]. There were no significant differences in the SFE time range, M_{diff} = 0.30, 95% CIs [-1.04, 1.64], *t*(17) = 0.47, *p* = .642, d_{unb} = 0.14, 95% CIs [-0.46, 0.75].

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 [0.05, 2.56], *t*(13) = 2.24, *p* = .043, d_{unb} = 0.81, 95% CIs [0.03, 1.66], and from Session 1 to Session 3, M_{diff} = 1.20 µV, 95% CIs [0.38, 2.01], *t*(13) = 3.16, *p* = .008, d_{unb} = 0.69, 95% CIs [0.19, 1.26]. There was no significant difference between Session 2 and 3, M_{diff} = 0.11 µV, 95% CIs [-1.38, 1.60], $t(13) = 0.16$, $p = .879$, d_{unb} = 0.05, 95% CIs [-0.66, 0.77]. In the SFE time range, there were no significant differences between Session 1 and 2, M_{diff} = 0.14 µV, 95% CIs [-1.38, 1.67], $t(13) = 0.16$, $p = .842$, d_{unb} = 0.07, 95% CIs [-0.60, 0.74], Session 2 and 3, M_{diff} = 0.40 µV, 95% CIs [-1.63, 2.43], $t(13) = 0.43$, $p = .678$, d_{unb} = 0.15, 95% CIs [-0.58, 0.89], and Session 1 and 3, M_{diff} = 0.54 µV, 95% CIs [-1.11, 2.19], $t(13) = 0.71$, $p = .490$, d_{unb} = 0.21, 95% CIs [-0.40, 0.83].

Exploratory FDR-corrected mass univariate analyses of the within-group contrast of familiar versus unfamiliar identities revealed no systematic differences between the two identities before 200 ms (see Figure 3.3a). 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 Figure 3.3d). In Session 3, the familiarity effect was more focused but very strongly pronounced at the right occipito-temporal channels.

Figure 3.3b 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 Figure 3.3b). 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 Figure 3.3c). 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 Figure 3.3d) further suggest strong familiarity effects following the SFE time window, i.e. from 600-800 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} = 0.87, 95% CIs [-0.97, 2.72], $t(15) = 1.01$, $p = .330$, d_{unb} = 0.34, 95% CIs [-0.36, 1.07], and Sessions 2 and 3, M_{diff} = 0.84, 95% CIs [-1.06, 2.75], $t(15) = 0.94$, $p = .362$, d_{unb} = 0.30, 95% CIs [-0.35, 0.96], larger familiarity effects were observed in Session 3 relative to Session 1, M_{diff} = 1.71, 95% CIs [0.48, 2.95], $t(15) = 2.96$, $p = .001$, d_{unb} = 0.71, 95% CIs [0.18, 1.30].

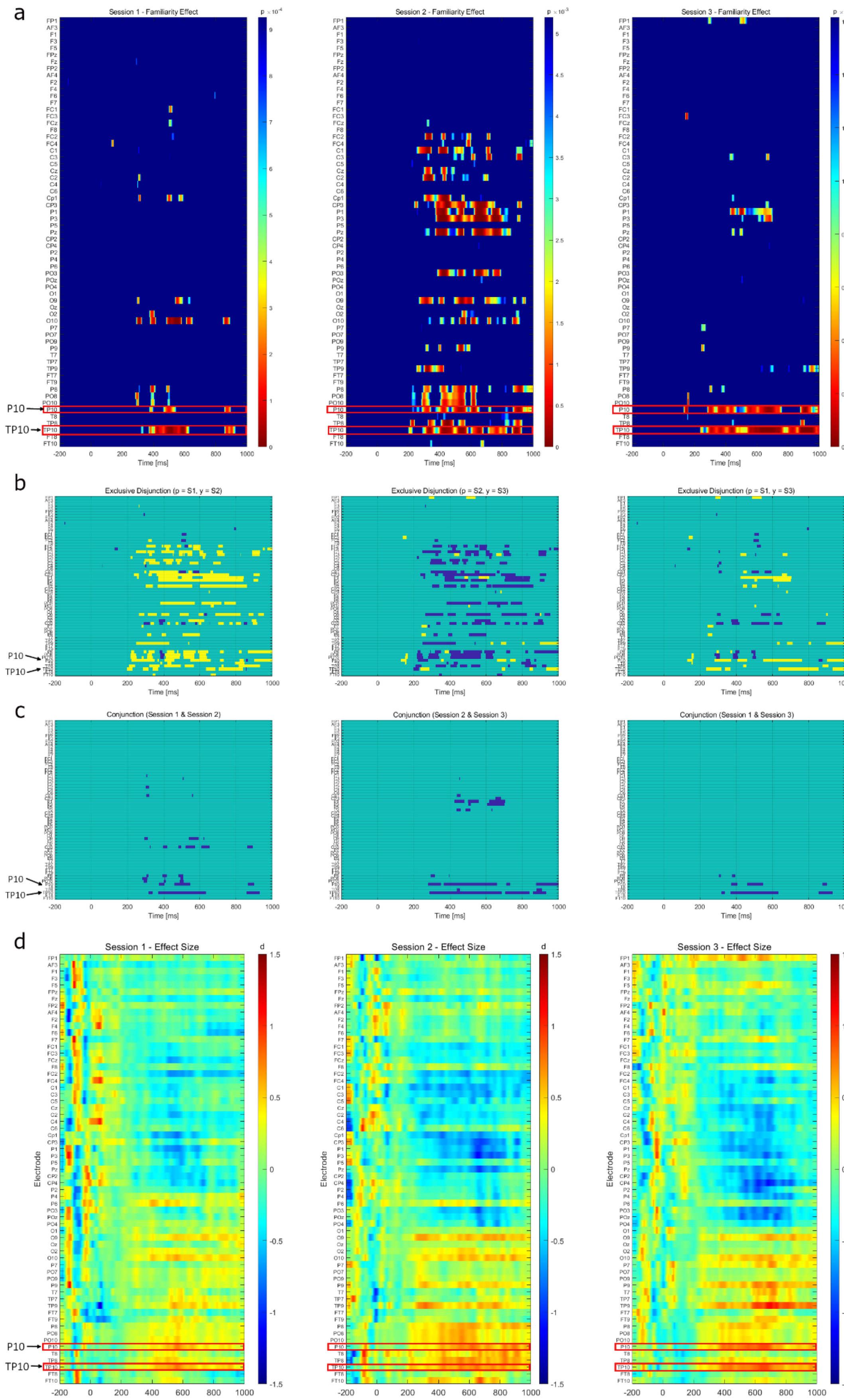

a
Session 1 - Familiarity Effect
Session 2 - Familiarity Effect
Session 3 - Familiarity Effect
Time [ms]
P10
TP10
b
Exclusive Disjunction (p = S1, y = S2)
Exclusive Disjunction (p = S2, y = S3)
Exclusive Disjunction (p = S1, y = S3)
c
Conjunction (Session 1 & Session 2)
Conjunction (Session 2 & Session 3)
Conjunction (Session 1 & Session 3)
d
Session 1 - Effect Size
Session 2 - Effect Size
Session 3 - Effect Size
Electrode
Time [ms]
d

Figure 3.3. Mass univariate and effect analyses. 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.

3.4. Discussion

Using a longitudinal design, the present study investigated how familiarity develops during the first eight months of 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 observed further refinement of the visual face representations (in the N250 effect) beyond the first month of familiarity, no reliable 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} = 0.27) was somewhat lower than the effect observed in our previous study after two months of familiarity (d_{unb} = 0.43) (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} = 0.58) and a trend for a (non-significant) increase from Session 1 to 2 with a moderate to large effect size (d_{unb} = 0.67), while no noticeable difference was detected between Session 2 and 3 (d_{unb} = 0.05). We note that this finding is based on a small and female-dominant sample. However, unlike the comparison between Session 1 and 2, the N250 comparison between Session 2 and 3 was far from being significant (*p* = .885), and the effect size was very small, which suggests that adding a realistic number of participants would unlikely change this result. Moreover, while we cannot completely exclude the possibility that the absence of a further increase was related to the difference in reported interactions between Session 2 and Session 3, we consider this interpretation unlikely, as this difference is very small (reflecting a single participant's rating changing from the highest possible to the next highest score). These results more likely point towards refinement of the visual representations within the first five months of familiarity, but not afterwards. Although only a non-significant trend was observed in the confirmatory group-level analysis between Sessions 1 and 2, our interpretation is further supported by the increase in reliable effects at the individual participant level observed in the bootstrapping analysis. In addition, 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 justify our interpretation of complete development of visual face representations over the first five months of knowing a person, at least in female participants.

Interestingly, and in line with above interpretation, the N250 familiarity effect elicited in Session 2 (d_{unb} = 0.73) seems comparable in size to the effects elicited by highly personally familiar faces (e.g. d_{unb} = 0.65 in Popova & Wiese, 2022; d_{unb} = 0.55 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 et al., 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 five months of familiarity and given frequent exposure, the visual face representation 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 substantially 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. Figure 3.2b). However, the SFE in the present study (d_{unb} = 0.60) was similar to the one observed in our previous study at two months of familiarity (d_{unb} = 0.53), 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} = 0.74) 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 & 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 due to an increase in the N250 time range. 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 plateau at the level of highly familiar identities by five months of familiarity. The SFE, on the other hand, appears to develop only slowly over the first eight months of knowing someone, 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 et al., 2020; Natu & 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 representation, 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, Tüttenberg, 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 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 naturistic 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, 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 et al., 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 fully develop after five months of frequent exposure, as we detected evidence for an increase in the N250 effect over the first five 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.

4. How quickly do we learn new faces in everyday life? Neurophysiological evidence for face identity learning after a brief real-life encounter.

Abstract

Faces learnt in a single experimental session elicit a familiarity effect in event-related brain potentials (ERPs), with more negative amplitudes for newly learnt relative to unfamiliar faces in the N250 component. However, no ERP study has examined face learning following a brief real-life encounter, and it is not clear how long it takes to learn new faces in such ecologically more valid conditions. To investigate these questions, the present study examined whether robust image-independent representations, as reflected in the N250 familiarity effect, could be established after a brief unconstrained social interaction by analysing the ERPs elicited by highly variable images of the newly learnt identity and an unfamiliar person. Significant N250 familiarity effects were observed after a 30-minute (Experiment 1) and a 10-minute (Experiment 2) encounter, and a trend was observed after five minutes of learning (Experiment 3), demonstrating that 5-10 minutes of exposure were sufficient for the initial establishment of image-independent representations. Additionally, the magnitude of the effects reported after 10 and 30 minutes was comparable suggesting that the first 10 minutes of a social encounter might be crucial, with extra 20 minutes from the same encounter not adding further benefit for the initial formation of robust face representations.

4.1. Introduction

When identifying known people from their faces, the human brain highly efficiently resolves a problem of considerable complexity, as we accurately recognise familiar faces from novel, never-before-seen images, even in highly challenging circumstances (e.g. Burton et al., 1999; Demanet et al., 2007; Hole et al., 2002). At the same time, the recognition or even simultaneous matching of unfamiliar faces in seemingly ideal conditions is often challenging (e.g. Bruce et al., 1999; White et al., 2014). These well-established findings beg the question of what makes familiar and unfamiliar face recognition so different, and part of the answer seems to be that we know what our friends, relatives, and colleagues look like in a wide variety of circumstances (e.g. with varying lighting, viewing angles, facial movements, but also varying hair/beard styles, make-up, weight, or health), while this kind of information is usually not available for somebody we have just met (Young & Burton, 2017, 2018). More formally, we have memory representations that are abstract from any particular instance, and therefore activated by a wide range of never-before-seen images, for familiar but not for unfamiliar faces, which allows efficient and image-independent recognition of the former but not the latter (Bruce, 1994; Kramer et al., 2018). But how are these familiar face representations initially established? Every familiar face has been unfamiliar and seen for the first time at some point in the past. Moreover, we constantly meet new people and have to regularly form new face representations which then allow recognition at a later time. At present, the neural processes underlying face learning, and particularly the time it takes to establish a novel, image-independent representation are not well understood. Here, we used event-related brain potentials (ERPs) to examine the temporal dynamics of face learning, as measured by the neural response to novel images of newly learnt and unfamiliar faces, and more specifically the amount of time during a first encounter that is needed for image-independent recognition.

Current theoretical work on face recognition and learning emphasises qualitative differences underlying familiar and unfamiliar face processing (Young & Burton, 2017, 2018). Unfamiliar face recognition is thought to strongly rely on so-called pictorial codes or representations, which closely resemble the appearance of a face in the specific situation it was seen. Recognition is therefore closely tied to this original encounter (Young et al., 1985), and, as a result, images that closely match this specific instance are well recognised, but even small deviances can have detrimental effects on recognition (e.g. Burton et al., 2010; Longmore et al., 2008). However, exposure to highly variable images of the same face, e.g. taken from different viewpoints, with different emotional expressions, and/or in different lighting conditions, enables people to learn which aspects remain stable across images (Burton et al., 2005) and how different the same face can look due to environmental factors or changes in the face itself (Burton et al., 2016; Jenkins et al., 2011). Repeated exposure to highly variable images of a face thus enables the transition from pictorial to so-called structural codes which are abstract (in the sense that they do *not* represent a specific image) and allow the successful reconciliation of highly variable exemplars as belonging to the same identity (Young et al., 1985). Therefore, getting to know a face's idiosyncratic variability appears to be a crucial aspect of face learning (Jenkins et al., 2011; Kramer et al., 2017). In support of this theoretical argument, it has been found that a wider range of within-person variability facilitates face learning. For instance, exposure to high-variability images (which capture both situational changes such as different facial expressions, distance from the camera, or different head angles, and longer-term changes due to ageing, health, hairstyle, camera characteristics etc.) results in more effective learning relative to low-variability images (stills taken from a single video which capture only situational changes) (Ritchie & Burton, 2017). However, it is as yet unclear how much exposure to a new face is necessary to learn someone's idiosyncratic variability well enough for image-independent recognition to occur.

ERP studies on face recognition have consistently shown that familiar faces elicit more negative amplitudes than unfamiliar identities at occipito-temporal electrode sites starting at approximately 200 ms after stimulus onset (e.g. Bentin & Deouell, 2000; Gosling & Eimer, 2011; Saavedra et al., 2010). This so-called N250 familiarity effect is typically assumed to reflect access to long-term visual face representations, but, importantly, pre-experimentally unfamiliar faces can elicit this effect following a learning task (Andrews et al., 2017; Kaufmann et al., 2009; Tanaka et al., 2006; see also Zimmermann & Eimer, 2013). In many cases, however, these experiments have relied on low-variability stimuli, such as images or videos with relatively small or highly controlled changes in viewpoint or facial expressions (e.g. Kaufmann et al., 2009; Tanaka et al., 2006; Zimmermann & Eimer, 2013), therefore reducing a critical aspect of face learning (Kramer et al., 2017; Ritchie & Burton, 2017). The extent to which the observed effects represented the activation of fully image-independent representations is therefore somewhat unclear. In an attempt to overcome this limitation, Andrews and colleagues (2017) presented participants simultaneously with 20 different, highly variable images of two 'to-be-learnt' identities that were taken on many different occasions. Clear N250 effects were observed after a brief exposure to these stimuli, and importantly, these effects were highly similar when using the same images as presented during learning or completely novel images of the learned identities at test. However, while introducing substantial within-person variability to the learning and testing phases, the high variability of the stimuli used in this study arguably more closely resembled learning a face from a number of different occasions. As noted above, while many dimensions of facial variability change during a given real-life encounter (such as facial expressions, gaze, viewing angle), other aspects (such as weight, age, health, hairstyle, make-up etc.) remain more stable. As yet, it remains unknown whether the variability experienced during a single brief encounter is sufficient to form a robust representation that enables the recognition of novel, highly variable instances of the face.

Interestingly, researchers have started to study exposure to real-life variability by using more naturalistic learning procedures. For instance, recent studies found stronger neural responses for previously unfamiliar people following four hours of real-life exposure over eight weeks (Campbell & Tanaka, 2021) and after three real-life one-hour learning sessions over three consecutive days (Ambrus et al., 2021). Recently, an fMRI study demonstrated that even shorter real-life exposure can lead to face learning (Sliwinska et al., 2022). In this study, participants interacted with a pre-experimentally unfamiliar person in three ten-minute sessions spread across two weeks. The authors report improved accuracy in image matching of newly learnt faces after the second session. Moreover, significant changes in right-hemispheric cortical face-processing areas (fusiform face area, occipital face area, posterior superior temporal sulcus, amygdala) and the hippocampus were observed following the last interaction. These studies demonstrate that ecologically more valid experimental paradigms can be used to advance our understanding of the establishment of new face representations. However, as noted above, it still remains unclear whether a single social encounter can produce a learning response.

Relatedly, the time course of face learning has not been systematically examined. Previous studies have demonstrated neural correlates of face learning after single lab-based learning sessions, but the minimal exposure time necessary to form robust image-independent representations in more naturalistic circumstances has not been established. It has been demonstrated that the N250 effect is modulated by the degree of familiarity, as the effect elicited by well-known celebrities is larger relative to recently learnt faces (Andrews et al., 2017), and personally highly familiar faces elicit a stronger N250 compared to famous people (Wiese, Hobden, et al., 2022). However, the trajectory of how the effect builds up over time, and particularly the time point at which it first emerges, remain unclear.

Of note, familiarity effects in ERPs are not restricted to the N250 time range. Previous work has shown that the ERP familiarity effect for highly familiar faces further increases following the N250 time range and peaks between 400-600 ms (Wiese, Tüttenberg, et al., 2019). We have suggested that this so-called Sustained Familiarity Effect (SFE) reflects the integration of visual with additional person-related semantic and/or episodic information, as, on the one hand, the scalp distribution of the SFE and the N250 effect are very similar, but on the other hand the SFE is differentially modulated by experimental manipulations (Wiese, Ingram, et al., 2019) and therefore functionally not identical to the N250.

Recently, we (Popova & Wiese, 2022) reported that two months of familiarity were sufficient to elicit a familiarity effect in the SFE time window but the magnitude of the effect was substantially smaller than in previous studies on personally highly familiar faces, and not significantly larger than the N250 effect. So far, no studies have examined the SFE following brief, initial learning of a new face. However, in line with our interpretation of the SFE, we would not expect that a brief interaction with a pre-experimentally unfamiliar person results in increased ERP familiarity effects following the N250 time range.

The present experiments investigated whether an N250 familiarity effect, reflecting the activation of image-independent face representation, can be established following brief naturalistic exposure to a pre-experimentally unfamiliar identity. For this purpose, we presented participants with a previously unfamiliar person in a short one-to-one social encounter followed by an EEG test session in which novel, naturally varying "ambient" images (see Figure 4.1 for examples) of the newly learnt and of an unfamiliar identity were presented. During learning, participants were exposed to within-person variability on those dimensions in which parameter values naturally shift during an initial encounter (e.g. different viewing angles, facial expressions, eye gaze, speech movements etc.), while other sources of variability remained constant (e.g. lighting, age, health, weight, make-up, hairstyle etc.). Our experiments, therefore, examined whether variability in the former dimensions was sufficient to enable recognition from photos that vary on the latter dimensions as well, which would support the abstract nature of the underlying representations. In Experiment 1, participants interacted with the 'to-be-learnt' person for 30 minutes which resulted in significant N250 familiarity effects. In an attempt to estimate the minimum exposure necessary to elicit learning effects, we then reduced the duration of the learning phase to ten minutes in Experiment 2 and five minutes in Experiment 3. While 10 minutes were sufficient to elicit effects comparable to Experiment 1, only marginal effects were detected after a five-minute interaction. A final experiment was conducted as a control which confirmed that the observed effects indeed resulted from the social interaction prior to testing rather than learning during the EEG session.

4.2. Experiment 1: 30-minute learning phase

4.2.1. 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.

Participants

Required sample size was estimated in a power analysis using G*Power (Faul et al., 2007) based on the difference between newly learnt and unfamiliar faces in a previous study (Andrews et al., 2017; late N250 effect for the learnt/different condition, TP9/TP10 only; paired-sample test, two-sided, dz = 0.84, $1 - \beta = .95$), which suggested a sample size of N = 21. Our actual sample consisted of 24 students at Durham University (15 female, nine male; age *M* = 20.5, *SD* = 1.3). One additional participant was excluded due to technical problems during EEG recording. All participants were right-handed according to a modified version of the Edinburgh Handedness Inventory (Oldfield, 1971), had normal or corrected-to-normal vision, and did not take central-acting medication. They gave written informed consent to participate and received course credit or a monetary reward of £7.50/h. The study was approved by the ethics committee of Durham University’s Department of Psychology.

Stimuli

The stimuli consisted of 50 naturally varying “ambient” images showing the faces of each of four ‘to-be-learnt’ identities (three female, one male; the confederates) and four additional unfamiliar identities that were pairwise matched for gender, approximate age, and approximate hair colour and style. All depicted persons were fully informed about the purposes of the experiment and voluntarily provided images of themselves which were cropped around the head, resized to 190 x 285 pixels (corresponding to approximately 5 x 7.5cm image size on the screen), converted to grayscale, and matched for luminance using the SHINE toolbox (Willenbockel et al., 2010; see Figure 4.1 for examples). Eight images of butterflies were used as targets to create a task demand. Confederates were recruited from the student research assistants working in the Durham Psychology EEG lab at the time of the experiment. Three confederates were year two and year three undergraduate Psychology students (unlike our participants who were mostly year one students), and the fourth confederate was a postgraduate student. All participants were unfamiliar with the assigned confederates in all cases.

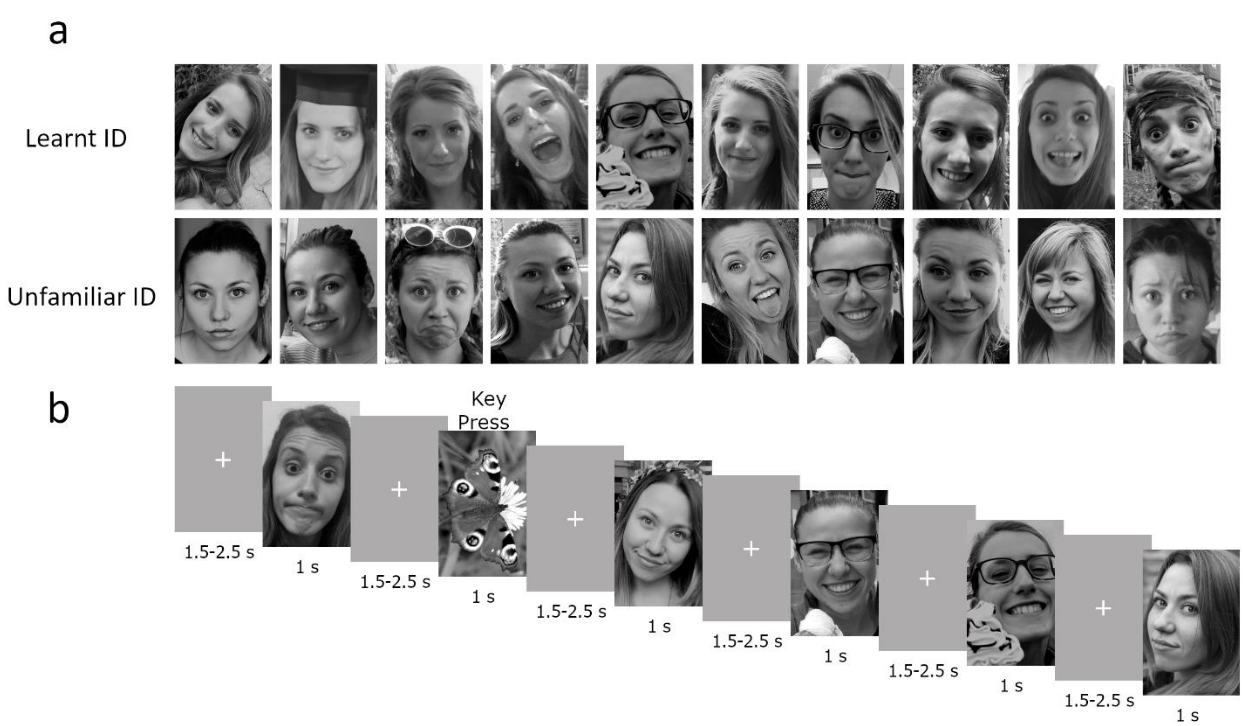


Figure 4.1. Exemplary stimuli and procedure. a) Examples of ambient images from two identities. b) Trial structure of the experiment. Images are published with the permission of the depicted persons.

Procedure

The study consisted of a learning phase and a subsequent EEG test session. One of the four confederates was randomly chosen as the to-be-learnt person for each of the participants, who were told that they would have a chat with one of the research assistants from the lab. Participants were also told prior to the learning session that they would later be presented with images of faces and that some of these faces might be familiar. During the learning phase, the confederate interacted with the participant for 30 minutes in a naturalistic face-to-face conversation. This was carried out in a room close to the EEG laboratory, with only the participant and the confederate present. To allow for a more naturalistic conversational situation, the discussion during the learning phase was not scripted and no specific instruction to watch the face was given to the participant. However, confederates had to ensure that their face was visible. Typical conversation topics included the participants' experiences at university (e.g. with their colleges, societies, sports teams etc.), how they find their course, hobbies, where they are from, or their living situation. As would be expected in a natural conversation, both the participants and confederates asked for and provided information about these topics. Accordingly, participants learned identity-specific information about the confederates during the interaction.

Immediately following the learning phase, participants were directly taken to the EEG laboratory (not allowing any further interaction with the confederate), prepared for EEG recording (taking approximately 15 minutes), and seated in an electrically shielded chamber (Global EMC^{TM}) with their head resting on a chinrest 80 cm from a computer monitor. Fifty photos each of the newly learnt confederate and of the unfamiliar person from the same pair, as well as 16 trials with pictures of butterflies were presented in random order (Figure 4.1). Accordingly, in this and all following experiments, each participant was presented with images of two different identities. The images were presented using E-prime (Psychology Software Tools, Pittsburgh, PA) at a visual angle of 3.6° x 5.4° on a uniform grey background in the centre of the screen for 1,000 ms. Trials were separated by a 1,500-2,500 ms fixation cross (2,000 ms on average). Participants were instructed to watch the screen at all times and to press a button in response to images of butterflies using the right index finger. Both accuracy and speed were emphasised. The EEG part of the experiment took approximately six minutes.

The main experiment was followed by a short rating task assessing the visual recognisability of the identities. The participants were simultaneously presented with eight randomly selected images of each of the two identities and asked how likely they would recognise the person on a scale of 1 *(highly unlikely)* to 5 *(highly likely)*.

EEG recording and Analysis

64-channel EEG (EEGo, ANT Neuro, Enschede, The Netherlands) was recorded using sintered Ag/Ag-Cl electrodes at a sampling rate of 1024 Hz from DC to 200 Hz. AFz was used as the ground electrode and CPz served as the recording reference. Blinks were corrected using the algorithm implemented in BESA Research Software (Version 6.3; Grafelfing, Germany). Data were segmented into epochs from -200 to 1,000 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 two experimental conditions. The average number of trials was 47 (±4.3 SD, min = 34) for learnt and 47 (±4.3 SD, min = 33) for unfamiliar faces.

Similar to previous work on face learning (see Andrews et al., 2017), early (200-300 ms) and late (300-400 ms) N250 time windows were analysed at occipito-temporal electrodes TP9 and TP10. Moreover, the SFE was analysed between 400-600 ms at the same electrodes (see Wiese, Tüttenberg, et al., 2019). As we had no a priori hypotheses about the lateralisation of potential learning effects, paired-sample t-tests on data averaged across left- and right-hemispheric electrodes were run separately for each time range to test our hypotheses of learning effects with more negative amplitudes for newly learnt relative to unfamiliar faces. Repeated-measures ANOVAs with an additional hemisphere factor and analyses of the N170 time range are reported in Supplementary materials. Following an estimation approach in data analysis (e.g. Cumming, 2012), effect sizes and appropriately-sized confidence intervals (CIs) are reported throughout. Cohens' d was bias-corrected (d_{unb}) and calculated using the mean standard deviation rather than the standard deviation of the difference as the denominator and 95% CIs for d_{unb} were calculated using ESCI (Cumming, 2012). To compare the magnitude of familiarity effects against each other, we ran three paired-sample t-tests for familiarity effects in the three consecutive time windows. As we expected no significant differences, we additionally ran Bayesian tests to gain potential evidence for the null hypothesis. Finally, to fully explore the data, we ran mass univariate tests comparing learnt and unfamiliar face conditions at all electrodes and time points.

The study procedure and analyses were not pre-registered before data collection. All study data and analysis code are publicly available on the Open Science Framework platform (https://osf.io/mz6qb/). 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 Figure 4.1.

4.2.2. Results

The learnt identity was rated significantly higher in visual recognisability relative to the unfamiliar identity, M_{diff} = 2.67, 95% CI [2.14, 3.19], $t(23) = 10.54$, $p < .001$, d_{unb} = 2.79[4] (Table 4.1).

[4] Please note ESCI only provides CIs when the d value is between -2 and 2 (see Cumming, 2012; p. 306-307).

Table 4.1. Mean ratings for visual recognisability for the learnt ID and the unfamiliar ID. Visual familiarity was assessed on a scale from 1 (very low familiarity) to 5 (very high familiarity).

	Learnt ID		Unfamiliar ID	
	M	*SD*	*M*	*SD*
Experiment 1: 30 min	4.17	0.92	1.50	0.93
Experiment 2: 10 min	3.62	0.99	1.50	0.83
Experiment 3: 5 min	2.88	1.41	2.00	1.23
Experiment 4: Control	1.85	0.99	1.71	0.87

Visual inspection of the grand average ERPs suggested more negative amplitudes for the newly learnt in comparison to the unfamiliar face in all analysed time windows (Figure 4.2 - 30 min). A t-test in the 200-300 ms time range yielded a trend in this direction, M_{diff} = 0.58 µV, 95% CI [-0.05, 1.21], $t(23)$ = 1.90, p = .070, d_{unb} = 0.14, 95% CI [-0.01, 0.31]. A corresponding test conducted in the 300-400 ms range demonstrated significantly more negative amplitudes for the learnt identities relative to the unfamiliar faces, M_{diff} = 0.74 µV, 95% CI [0.02, 1.46], $t(23)$ = 2.13, p = .044, d_{unb} = 0.17, 95% CI [0.01, 0.33]. Similarly, in the 400-600 ms window (SFE) ERP amplitudes for the learnt faces were more negative than for the unfamiliar faces, M_{diff} = 0.90 µV, 95% CI [0.07, 1.72], $t(33)$ = 2.26, p = .034, d_{unb} = 0.25, 95% CI [0.02, 0.49].

There were no significant differences between the familiarity effects in the early and late N250, M_{diff} = 0.16 µV, $t(23)$ = 0.67, p = .511, d_{unb} = 0.10, early N250 and the SFE, M_{diff} = 0.32 µV, $t(23)$ = 1.54, p = .137, d_{unb} = 0.18, and the late N250 and the SFE, M_{diff} = 0.16 µV, $t(23)$ = 0.77, p = .452, d_{unb} = 0.08. Bayesian tests provided moderate support for the null hypothesis for the early versus late N250, BF_{01} = 3.81, error % = 0.03, and late N250 versus SFE comparisons, BF_{01} = 3.58, error % = 0.03. For the early N250 versus SFE comparison, there was weak support for the null, BF_{01} = 1.65, error % = 0.03.

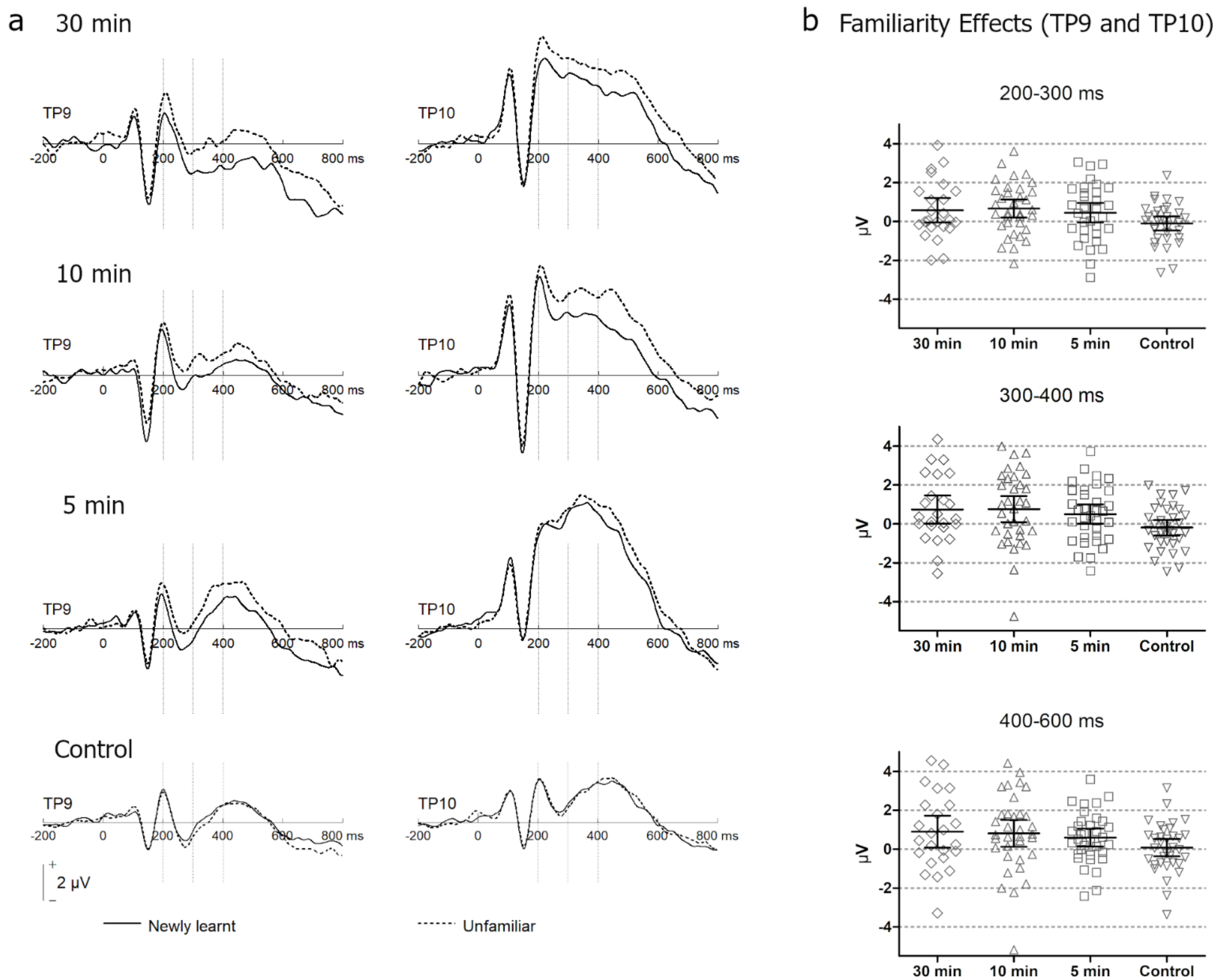


Figure 4.2. ERP results. a) Grand average ERPs (30 min: N = 24; 10 min: N = 34; 5 min: N = 34; Control: N = 34) at left and right occipito-temporal channels TP9 and TP10 for the newly learnt vs. unfamiliar faces for all experiments. b) Individual familiarity effects (symbols) and mean familiarity effects with 95% CIs (solid lines) shown separately for the three time ranges of interest.

4.3. Experiment 2: 10-minute learning phase

4.3.1. Method

Participants

We tested 34 under- and postgraduate students at Durham University (27 female, seven male; age *M* = 21 years, *SD* = 5.1; 29 right-, five left-handed). This sample size was determined in a power analysis based on the late N250 effect observed in Experiment 1 (paired-sample test, one-tailed, dz = 0.44, $1 - \beta = .8$) using G*Power (Faul et al., 2007). Selection criteria and compensation were identical to Experiment 1. The study was approved by Durham University's Department of Psychology ethics committee.

Stimuli and procedure

Stimuli consisted of 50 images of each of six identities (four female, two male; four undergraduate and two postgraduate research assistants in the EEG lab at the time of testing), which were pairwise matched for gender. Each participant was tested with one pair, with one identity as the 'to-be-learnt' person while the other was used as the unfamiliar face. As both members of a pair were learnt by different participants, the same images were used in the learnt and the unfamiliar conditions across participants. Each identity served as the 'to-be-learnt' person for at least three participants. Stimulus editing was identical to Experiment 1.

The experimental procedure, as well as EEG recording and data analysis, were analogous to Experiment 1, with the exception that the learning phase was reduced to 10 minutes. Moreover, due to UK Covid-19 regulations, and specifically the requirement to wear face masks indoors, the learning sessions for Experiment 2 were conducted outside the Durham Psychology Department. The average number of trials was 48 (±3.3 SD, min = 36) for learnt and 48 (±2.3 SD, min = 43) for unfamiliar faces.

4.3.2. Results

The learnt identity was rated as significantly more visually recognisable than the unfamiliar identity, M_{diff} = 2.12, 95% CI [1.71, 2.53], *t*(33) = 10.51, *p* < .001, d_{unb} = 2.28 (Table 4.1).

ERP results are depicted in Figure 4.2 – 10 min. Similar to Experiment 1, the newly learnt face elicited more negative amplitudes than the unfamiliar face in the 200-300 ms time range, M_{diff} = 0.67 µV, 95% CI [0.20, 1.13], *t*(33) = 2.91, *p* = .006, d_{unb} = 0.20, 95% CI [0.06, 0.35], in the 300-400 ms time range, M_{diff} = 0.76 µV, 95% CI [0.10, 1.42], *t*(33) = 2.34, *p* = .026, d_{unb} = 0.24, 95% CI [0.03, 0.46], as well as in the 400-600 ms time window, M_{diff} = 0.82 µV, 95% CI [0.13, 1.51], *t*(33) = 2.40, *p* = .022, d_{unb} = 0.31, 95% CI [0.05, 0.59].

There were no significant differences between early and late N250, M_{diff} = 0.09 µV, *t*(33) = 0.57, *p* = .575, d_{unb} = 0.06, early N250 and the SFE, M_{diff} = 0.15 µV, *t*(33) = 0.67, *p* = .506, d_{unb} = 0.09, and late N250 and the SFE, M_{diff} = 0.55 µV, *t*(33) = 0.32, *p* = .749, d_{unb} = 0.03. These results were further supported by Bayesian tests which revealed moderate support for the null hypothesis for the early versus late N250, BF_{01} = 4.69, error % = 0.04, early N250 versus SFE, BF_{01} = 4.41, error % = 0.04, and late N250 versus SFE comparisons, BF_{01} = 5.19, error % = 0.04.

4.4. Experiment 3: five-minute learning phase

4.4.1. Method

Participants

We tested 34 under- and postgraduate students at Durham University (30 female, four male; age *M* = 19.3 years, *SD* = 2; 32 right-, two left-handed). Selection criteria and compensation were identical to Experiment 1. Two participants had taken part in Experiment 2 but interacted and were tested with different identities. The study was approved by Durham University's Department of Psychology ethics committee.

Stimuli and procedure

Stimuli consisted of 50 images of each of four female identities (undergraduate research assistants in the EEG lab at the time of testing) who were paired up as in Experiment 2. Familiarity was balanced across participants, and each identity served as the 'to-be-learnt' person for at least eight participants. Stimulus editing was identical to Experiment 1.

The experimental procedure, as well as EEG recording and data analysis, were analogous to Experiment 1, but the learning phase was reduced to five minutes. As in Experiment 2, learning sessions took part outside the Durham Psychology building. The average number of trials was 46 (±3.9 SD, min = 35) for learnt and 46 (±4.0 SD, min = 36) for unfamiliar faces.

4.4.2. Results

The learnt identity was rated significantly higher in recognisability relative to the unfamiliar identity, M_{diff} = 0.88, 95% CI [0.38, 1.39], $t(33) = 3.54$, $p = .001$, d_{unb} = 0.65, 95% CI [0.26, 1.07] (Table 4.1).

Visual inspection of the grand average ERPs again revealed more negative amplitudes for the newly learnt face in comparison to the unfamiliar face in all time windows of interest (see Figure 4.2 - 5 min). However, the effect appeared somewhat reduced relative to Experiments 1 and 2. Analysis in the N250 time range yielded trends towards familiarity effects, both in the 200-300ms, M_{diff} = 0.45 µV, 95% CI [-0.05, 0.95], $t(33) = 1.81$, $p = .079$, d_{unb} = 0.15, 95% CI [-0.02, 0.33], and in the later 300-400 ms time range, M_{diff} = 0.50 µV, 95% CI [-0.004, 1.00], $t(33) = 2.02$, $p = .052$, d_{unb} = 0.17, 95% CI [-0.001, 0.35]. There was a significant familiarity effect in the later 400-600 ms time range, M_{diff} = 0.59 µV, 95% CI [0.13, 1.05], $t(33) = 2.61$, $p = .014$, d_{unb} = 0.25, 95% CI [0.05, 0.45].

Further analyses revealed no significant differences between the effects in the early and late N250, M_{diff} = 0.05 µV, *t*(33) = 0.38, *p* = .709, d_{unb} = 0.03, early N250 and the SFE, M_{diff} = 0.14 µV, *t*(33) = 0.65, *p* = .521, d_{unb} = 0.10, and the late N250 and the SFE, M_{diff} = 0.09 µV, *t*(33) = 0.55, *p* = .584, d_{unb} = 0.07. There was moderate support for the null hypothesis for the early versus late N250, BF_{01} = 5.09, error % = 0.04, early N250 versus SFE, BF_{01} = 4.48, error % = 0.04, and late N250 versus SFE comparisons, BF_{01} = 4.72, error % = 0.04.

4.5. Experiment 4: control experiment

4.5.1. Method

Participants

The sample consisted of 34 under- and postgraduate students at Durham University (27 female, six male, one non-binary; age *M* = 19.0 years, *SD* = 1.3; 30 right-, four left-handed). Two additional participants were excluded due to technical problems during EEG recording. Selection criteria and compensation were identical to Experiment 1. The study was approved by Durham University's Department of Psychology ethics committee.

Stimuli and procedure

The stimuli were identical to Experiment 3. The experimental procedure was analogous to Experiment 3 but there was no learning phase, and accordingly, all identities were unfamiliar to the participants. Each participant was randomly assigned to one version of the experiment, in which one specific pair of "learnt" and unfamiliar IDs from Experiment 3 was presented. Data was then analysed as if the "learnt" ID had been familiarised, although in fact both identities were unfamiliar. The ID combinations and the number of times each ID appeared in the two conditions were identical to

Experiment 3 (see Experiment 2 in Wiese et al., 2019, for an analogous procedure). EEG recording and data analysis were identical to Experiment 1. The average number of trials was 48 (±4.0 SD, min = 30) for "learnt" and 47 (±3.7 SD, min = 33) for "unfamiliar" faces.

4.5.2. Results

As expected, there was a non-significant difference in visual recognisability between the two identities, M_{diff} = 0.15, 95% CI [-0.08, 0.38], $t(33) = 1.30$, $p = .201$, d_{unb} = 0.15, 95% CI [-0.08, 0.40] (Table 4.1).

Visual inspection of the grand average ERPs did not suggest any differences between the identities in any of the time windows (see Figure 4.2 - Control). Analyses confirmed this observation by revealing no significant differences between the conditions in the 200-300 ms, M_{diff} = 0.10 µV, $t(33)$ = 0.59, $p = .562$, d_{unb} = 0.04, 300-400 ms, M_{diff} = 0.19 µV, $t(33) = 1.01$, $p = .322$, d_{unb} = 0.06, and 400-600 ms time ranges, M_{diff} = 0.08 µV, $t(33) = 0.36$, $p = .724$, d_{unb} = 0.03. Additionally, we ran Bayesian tests to examine our a priori prediction of non-significant differences between the two conditions which revealed a moderate support for the null hypothesis in the 200-300 ms, BF_{01} = 4.64, error % = 0.04, 300-400 ms, BF_{01} = 3.42, error % = 0.04, and 400-600 ms time windows, BF_{01} = 5.13, error % = 0.04.

4.6. Exploratory Analysis

To fully explore the data beyond the predicted effects at a priorly defined electrode positions and time windows, mass univariate analyses of the within-participant comparisons of learnt versus unfamiliar faces were run for each time point and channel for all four experiments (see Figure 4.3). The strongest familiarity effects were observed in the 10-minute condition (Experiment 2). Systematic differences between the newly learnt and the unfamiliar identities began approximately 200 ms after stimulus presentation. In Experiment 3, stronger familiarity effects were observed over the central and parietal channels, presumably reflecting the opposite end of the dipole underlying occipito-temporal effects. No systematic differences were observed in our control experiment (Experiment 4). We note that (i) given the exploratory nature of the approach, the results reported here should be replicated before any strong conclusions can be made, particularly as (ii) none of these effects survived a correction for multiple comparisons using the False Discovery Rate procedure (Benjamini & Hochberg, 1995).

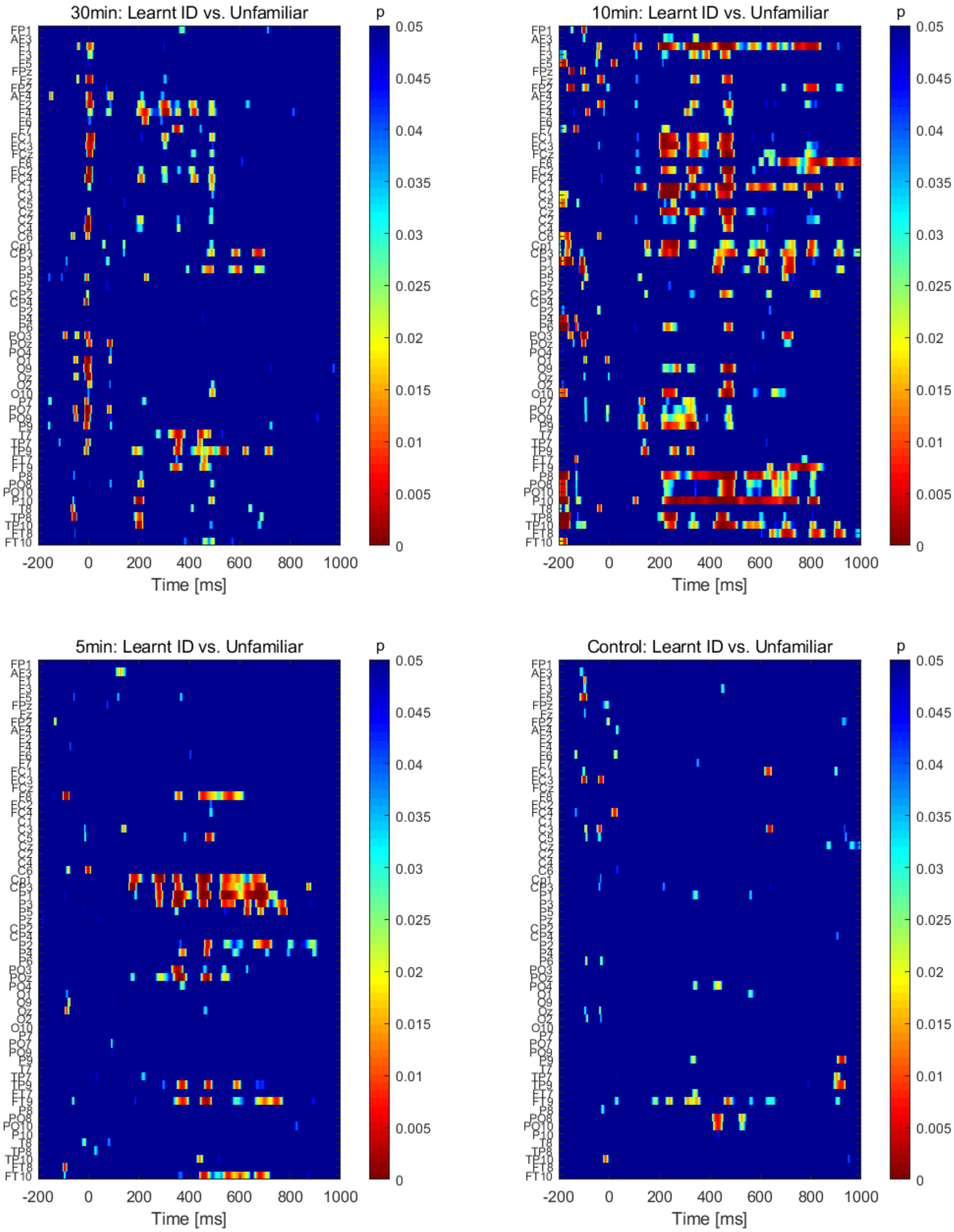


Figure 4.3. Mass univariate analyses for the within-group comparisons for each experiment.

4.7. Discussion

The present series of experiments investigated how much time it takes to form a new image-independent face representation in real-life interactions with a new person. Using ERPs and the N250 familiarity effect as an index of visual familiarity, we examined whether robust, image-independent recognition could be established following a brief real-life encounter in response to novel, highly variable images of the newly learnt person. Significant learning effects were observed after a 30-minute (Experiment 1) and a 10-minute (Experiment 2) social encounter, while only trends were found in the N250 following a five-minute interaction (Experiment 3). These findings suggest that initial face representations build up within 5-10 minutes in everyday life encounters, and accordingly that we learn new faces very easily and quickly. Additionally, no difference between conditions was detected in a control experiment (Experiment 4), confirming that the observed effects in Experiments 1-3 indeed resulted from the social interaction before testing rather than from learning during the test sessions.

The current results substantially extend previous lab-based research (Andrews et al., 2017; Kaufmann et al., 2009; Tanaka et al., 2006; Zimmermann & Eimer, 2013) by demonstrating face learning under more naturalistic conditions. Importantly, while in the present study within-person variability during learning was restricted to the specific conditions of a single encounter (e.g. providing no changes in lighting, make-up, or hair), the images used at test were taken in widely different environmental conditions. Moreover, test images also depicted longer-term changes in the faces themselves, and on the basis of these two factors, it seems reasonable to conclude that test images contained substantially more variability relative to the learning session. Our finding of clear learning from limited variability under these testing conditions has important theoretical implications.

Theoretical models on face learning and recognition have formulated two different but not mutually exclusive views about the type of information stored in a newly established face representation. Burton and colleagues (2005) suggested that forming a new representation can be conceptualised as an averaging process across different instances. More specifically, the authors suggested that by averaging across different instances of the face, random variability (e.g. caused by different lighting, facial expressions, viewing angles etc.) would be filtered out, while information crucial to the identity of the face should be present in all instances, and should therefore emerge during the averaging process. In later work, Burton and colleagues (2016) have argued that variability should not be treated as noise but instead contains important identity-specific information. For instance, how a specific face appears to change with different light is not random but depends strongly on the individual shape and surface reflectance information. While the former average-based view construes face representations as abstract from any specific instance, the latter view implies that multiple instances or "snapshots" of a given facial identity are stored in a face representation, and that recognition occurs if a stimulus is similar to any of these instances.

The present results seem to be easier to integrate with an abstract rather than an instance-based account. As noted above, participants in the present study were exposed to the new face in only one specific situation, and yet recognised it from widely varying images. It therefore appears that participants had extracted information during the learning session that allowed recognition in very different circumstances. Crucially, as the newly learnt face had never been experienced in the conditions reflected in the test stimuli, participants could not possibly have an instance-based representation of these particular conditions. For instance, the participants could not have a snapshot of what the face looked like in lighting different from the learning situation because they had never seen the face in different lighting. Accordingly, we suggest that some form of invariant facial information was extracted in the learning session.

To our knowledge, this is the first study looking at the time course of real-life face learning. Our findings suggest that the establishment of robust, image-independent representations that allow for recognition from novel everyday images occurs during the first five to 10 minutes of a social interaction.

Interestingly, the magnitude of the effects observed after 10 and 30 minutes was comparable suggesting that the variability experienced throughout the first 10 minutes is informative, while additional time from the same encounter does not provide detectable further benefit. It therefore appears that the variability experienced in the two conditions was very similar despite the difference in exposure duration. In other words, the different viewing angles, expressions etc. observed in the initial five to 10 minutes of exposure provided sufficient within-person variability to build an initial representation, while longer exposure to the person presumably repeated these views and did not contribute novel information to enhance learning. This suggestion is consistent with previous research which has highlighted enhanced learning following exposure to high as opposed to low variability while exposure duration was kept constant (Murphy et al., 2015; Ritchie & Burton, 2017).

It has to be noted that we only observed a trend in the earlier N250 time window (200-300 ms), which would have been significant had we decided to run one-sided tests before data analysis (which would have been possible, as we had clear a priori predictions about the direction of the effect). Moreover, the familiarity effect then became significant in the following late N250 time window (300-400 ms). In combination, this suggests to us that learning effects were present in the N250 time range in Experiment 1. Aa a potential explanation for the observed trend, we note that fewer participants (N = 24) were tested relative to the following experiments (N = 34). We started our study with assumptions about effect sizes and statistical power derived from previous experiments (Andrews et al., 2017), which we then adapted based on the results of Experiment 1. It thus seems plausible that the observed trend would have been significant with larger N (as in Experiments 2-4).

While reliable learning effects were detected following a single session of real-life familiarisation in the present study, the observed N250 effects were smaller than those elicited by well-known celebrities (Andrews et al., 2017; Gosling & Eimer, 2011), personally highly familiar faces (Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019), and friends known for about two months (Popova

& Wiese, 2022). Accordingly, while five to 10 minutes of social interaction appear sufficient for the initial establishment of face representations, more exposure to someone's idiosyncratic variability, presumably ideally spread out across several different encounters, is needed to strengthen these representations to the level of highly familiar faces. Recently, face recognition research has been shifting from a binary approach to familiarity, which compares familiar to unfamiliar faces, towards investigating how different levels of familiarity are represented in the brain (e.g. Ambrus et al., 2021; Andrews et al., 2017; Bobes et al., 2019; Li et al., 2022; Ramon & Gobbini, 2018; Wiese, Tüttenberg, et al., 2019; Wiese, Hobden, et al., 2022). The present results add to these findings and support theoretical accounts that conceptualise familiarity as a gradual rather than a bi-valent, dichotomous category (Kovács, 2020; Kramer et al., 2018).

As expected, brief exposure to a pre-experimentally unfamiliar person did not result in a clear SFE over and above the effect in the earlier time windows. While there was a significant difference between the newly learnt identity and the unfamiliar face in the SFE time window, the magnitude of the effect was substantially smaller than the SFE in response to highly familiar faces (Popova & Wiese, 2022; Wiese, Anderson, et al., 2022; Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019). It appears that the N250 learning effects in the present study continue into the later time window but unlike previous studies with highly familiar identities, the difference between familiar and unfamiliar faces does not increase, indicating that no substantial additional processing is taking place following visual recognition. This is consistent with the finding that moderately familiar faces, such as university lecturers (Wiese et al., 2019) or celebrities picked by the experimenters (Wiese et al., 2022) do not elicit a prominent SFE, and that the effect is only small in magnitude after approximately two months of personal familiarity (Popova & Wiese, 2022), i.e. after substantially more exposure than tested in any experiment of the present study. The present finding is also in line with the assumption that the SFE reflects the integration of visual with additional semantic and/or episodic knowledge. Although some identity-specific knowledge will be available following an initial brief interaction, it can arguably be only sparse, and may either be insufficient or insufficiently integrated with visual information to elicit the effect. Accordingly, substantially more prolonged and repeated exposure is needed to observe a clear SFE (Popova & Wiese, 2022).

Relatedly, our results can be interpreted in the context of a recent neuroscientific account (Kovács, 2020), which suggests that face and identity learning is accompanied by establishing representations not only in core face processing regions (such as the inferior occipital lobe and the lateral fusiform gyrus), but also in anterior temporal regions (reflecting semantic knowledge), the medial temporal lobe (for episodic memory), the temporo-parietal junction and the inferior parietal lobe (for personality traits and attitudes), as well as the insula and amygdala (for emotional responses). Critically, this account differentiates various categories of familiarisation, ranging from purely visual over contextual to closer personal familiarity. According to this system, face learning in the present study would arguably be categorised as at least contextual familiarisation, which is suggested to contain (some) semantic, episodic, and personality information about the to-be-learnt person. As noted above, however, familiarity effects in later time ranges associated with semantic and episodic processing were not prominent. Moreover, purely image-based, i.e. visual familiarisation has been shown to result in the same basic ERP effect – with more negative amplitudes for learnt relative to unfamiliar faces in the N250 time range (Andrews et al., 2017), arguing against the idea that familiarity as reflected in the N250 effect depends on a specific type of familiarisation (see also Wiese, Hobden, et al., 2022). In conclusion, it appears that a single, brief interaction with a new person is insufficient to establish contextual representations as suggested by Kovács (2020).

Our findings also seem to deviate to some extent from those of Ambrus and colleagues (2021), who reported that personal familiarisation resulted in stronger effects relative to purely perceptual learning. It should be noted, however, that, in addition to the different familiarisation procedures, the amount of exposure was substantially larger in the personal condition of Ambrus et al. (2021), which arguably reflects a quantitative rather than a qualitative difference for various types of familiarisation. Relatedly, while in our study familiarity effects were observed between 200 and 400 ms, Ambrus and colleagues (2021) found evidence for familiar face representations only after 400 ms. At present, it is unclear what underlies these differences between studies. One might speculate that the shorter learning time in the present study relative to Ambrus et al. (2021; one hour on each of three consecutive days) explains the absence of a clear SFE. As noted above, however, even two months of familiarity are not sufficient to elicit the full effect (see Popova & Wiese, 2022), which renders this possibility unlikely to us. A further potentially important difference between studies lies in the substantial image repetition in Ambrus et al. (2021). Image repetition generally decreases ERP familiarity effects (see Wiese, Anderson, et al., 2022; Wiese, Tüttenberg, et al., 2019), and it may also reduce the sensitivity to detect such effects with other EEG-based methods.

As outlined in previous paragraphs, the present findings advance our current understanding of how face representations develop and show that a more ecologically valid experimental approach can be used to overcome limitations of purely laboratory-based face learning studies (e.g. Burton, 2013). It should be noted that this increased ecological validity is particularly reflected in the learning phase of our experiments as it consisted of a naturalistic conversation, including natural distances and face sizes for the learner. Images used at test contained natural within-person variability but were presumably presented at a smaller visual angle than during naturalistic interactions. Nevertheless, our findings have potential implications for more applied fields, and in particular, for research interested in the reliability of eyewitness testimony, as they contribute knowledge about the degree of familiarity necessary for reliable identification. However, any potential implications are limited by several important factors. While we reported clear familiarity effects immediately following a brief exposure, the time between initially meeting a person for the first time and the need to recognise this person later is usually much longer in applied scenarios. It is unclear how stable the familiarity effects observed in the present experiments are over time, and initial evidence suggests that newly learnt faces are likely forgotten within 24 hours without additional training (Kramer, 2021).

As a limitation, we further note that it is unclear how much time our participants spent looking at the 'to-be-learnt' face. Confederates had to ensure that their faces were visible, but no specific instructions were given to the participants regarding the social encounter. We purposefully did not provide the participant/confederate pairs with a task that might have enforced focusing on the face to allow for a more naturalistic interaction. Therefore, it is not possible to decide on the basis of the present results whether the similar effects observed in the 10- and 30-minute conditions were caused by a similar amount of time spent looking at the 'to-be-learnt' person or whether additional fixations in the longer condition did not provide additional useful information. Future studies are needed to clarify these questions.

In conclusion, the present study is the first to present electrophysiological evidence for the minimal time of exposure to a new person that allows the recognition of their face from novel images. We found evidence for image-independent face recognition after five- to 10-minute interactions with a stranger, while 20 additional minutes of exposure did not result in learning effects over and above those observed after ten minutes. These findings provide new insights into the time course of face learning and the initial formation of robust image-independent representations. Moreover, our results seem to support the formation of abstract rather than instance-based representations after an initial encounter with a new facial identity.

5. General Discussion

5.1. Summary of experimental work

The aim of this thesis was to investigate how familiarity develops in real life. This was achieved by adopting short- and longer-term face and identity learning procedures, in which familiarity ranged from five minutes to just over two years. In all experiments, the new identities were learnt in naturalistic settings through exposure to within-person variability and person-related knowledge. The first two experimental chapters investigated long-term learning of identities which were continuously and frequently encountered in everyday life. The final experimental chapter focused on short-term learning in which familiarity was limited to a single, brief social interaction. The recognition stage in all experiments consisted of the presentation of highly variable images in order to test the robustness of any new representations. Event-related brain potentials (ERPs) were used to examine how increasing familiarity affects visual face recognition (N250 familiarity effect) and the integration of visual with additional person-related knowledge (Sustained Familiarity Effect, SFE).

Chapter 2 investigated the development of face and identity representations during the first two years of familiarity cross-sectionally. Year 1, 2, and 3 undergraduate students were tested with images of a friend they had met at university and photos of a close friend from home, approximately two months after the start of the academic year, translating into two, 14, and 26 months of familiarity for the university friend for Year 1, 2, and 3, respectively. As expected, two months of knowing a person were sufficient for the establishment of robust face representations (as measured with the N250). The identity-specific representations (as measured with the SFE) at two months of familiarity, on the other hand, were weak and substantially smaller than those elicited in response to someone known for much longer (i.e. the friend from home). Importantly, both types of representations got further refined with increasing familiarity, from two to 14 months of knowing a person. At 14 months of familiarity, they appeared to be fully developed, with no significant increase occurring afterwards. While in long-term friendships the exposure to new visual and person-related information, arguably, continues beyond the first year of familiarity, this new information does not appear to result in substantial changes to the already-established representations. These findings suggest that the first year of familiarity is therefore crucial for the formation of both visual and identity representation.

Consequently, Chapter 3 focused on how familiarity develops during the first eight months after meeting someone. Using a longitudinal design, a group of first-year undergraduate students were tested approximately one, five, and eight months after the start of the academic year with images of a friend they had met at university. Familiarity effects were present in the N250 at the earliest time point of the study – after one month of familiarity. Additionally, a clear SFE was observed suggesting that one month of familiarity is sufficient for the establishment of robust identity-related representations. While this conclusion may appear to contrast with the findings in Chapter 2, the effect size of the SFE was very similar to the one reported at two months of familiarity in the cross-sectional study, and clearly within its confidence intervals. Importantly, further refinement of the visual face representations (as examined using the N250) was observed following the first month of knowing a person, and these representations appeared to be fully developed at five months of familiarity. In contrast, no substantial increase in the SFE was observed over the time span of the study, suggesting that the integration of visual with identity-relevant knowledge builds up more slowly and that the full development takes longer than eight months of familiarity. These results further refine the findings from Chapter 2 and extend our knowledge of the times course over which people become familiar in daily life.

Finally, Chapter 4 focused on brief real-life learning to investigate how quickly we learn faces in an initial real-life encounter. In a series of three experiments, participants interacted with a pre-experimentally unfamiliar person. This was followed by an EEG testing session in which they were presented with never-before-seen images of the newly learnt person and of an unfamiliar identity.

Importantly, while within-person variability during learning was limited to the differences which can be observed during a single encounter (e.g. different facial expressions, gaze, speech movement, views), the images used at the recognition stage contained additional environment-related variability (e.g. lighting, camera characteristics) and longer-term changes (e.g. differences in weight, health, hairstyle). Therefore, the images used at test arguably contained more variability than what was experienced during the learning stage, providing a robust test for the flexibility of the newly acquired representations. Clear N250 familiarity effects were present after a 30-minute and a 10-minute encounter, and a trend was evident after a five-minute interaction. Moreover, the magnitude of the effects reported after 10 and 30 minutes of face learning was very similar, suggesting that 20 extra minutes from the same first encounter with a person do not further refine the visual face representations. A final control experiment was conducted in which the ERPs elicited by the images used in the five-minute experiment were recorded with no learning session prior to testing, so both identities presented were unfamiliar to the participants. The clear absence of any difference between identities strongly suggests that the learning effects reported in the first three experiments were due to the interaction before the testing session, and not related to learning based on the images presented during the EEG session. These studies suggest that a brief five to 10-minute interaction is sufficient for the formation of robust visual representations, and the differences in variability observed at learning and test provide support for the abstract nature of the newly acquired representations. This series of studies therefore provides novel insights into the initial establishment of face representations in naturalistic conditions.

Together, these experiments demonstrate that face learning occurs quickly in everyday life, as a 10-minute social encounter is enough for the formation of face representations. However, a single brief interaction is not sufficient for the full development of the N250 familiarity effect, and even after one to two months of familiarity, the visual face representations are not fully developed. Face learning appears to end around five months after first meeting a person, given frequent exposure, at which point the representations reach the level of highly familiar faces. An initial integration of visual with additional person-related information develops over the first month of knowing someone, and then gradually builds up until it reaches a plateau between eight and 14 months of familiarity.

5.2. How do the present studies relate to and extend previous work?

5.2.1. What have we learnt about face and person learning?

This thesis presents the first experiments systematically looking at the time course of face and person learning in everyday life. Previous research largely focused on the different cognitive stages (e.g. Bruce & Young, 1986; Schweinberger & Neumann, 2016) and brain areas (e.g. Gobbini & Haxby, 2007; Haxby et al., 2000) involved in familiar face processing and the differences between different types of familiarity (e.g. Alzueta et al., 2019; Bobes et al., 2019; Natu & O'Toole, 2011; Ramon & Gobbini, 2018; Sugiura, 2014; Wiese et al., 2022). However, not much is known about when the initial face and identity representations are first established and how they develop over time. Recently, Kovács (2020) proposed a model of how people become familiar based on neuroimaging data. This model suggests that person-related information emerges gradually in the brain with increasing familiarity and leads to changes in the core face network and the extended system. The present experiments provide critical information about the time course of this process by focusing on the development of visual representations and the integration of person-related knowledge.

The series of experiments in Chapter 4 demonstrates that the visual face representations emerge after an initial social interaction with an unfamiliar person in as little as 10 minutes. These findings are consistent with previous EEG research which has demonstrated visual recognition following a single laboratory-based learning session (Andrews et al., 2017; Kaufmann et al., 2009; Tanaka et al., 2006; Zimmermann & Eimer, 2013). They also extend recent work adopting real-life learning procedures (Ambrus et al., 2021; Sliwinska et al., 2022) by showing that a single, brief naturalistic interaction is sufficient to learn a new face. In an attempt to find the minimum exposure time which results in the establishment of visual representations flexible enough to generalise to novel, highly variable images, the effect of exposure duration on the acquired representations was also explored. Interestingly, no clear difference in the magnitude of the effect was observed between 10- and 30-minute exposures. In everyday life, faces are learnt through exposure to within-person variability (Bruce, 1994; Burton, 2013; Jenkins & Burton, 2011; Ritchie & Burton, 2017). It appears that the first 10 minutes of the encounter provided rich and diagnostic information about how the face varies, and additional exposure during this initial interaction did not produce any meaningful benefits. Despite not observing further refinement of the representations with prolonged exposure, the acquired representations after 10 minutes were not fully developed and had not reached the same level as those for highly familiar faces. The N250 effects reported here were smaller than those elicited by highly familiar faces (e.g. Andrews et al., 2017; Wiese et al., 2019, 2022) and presumably, the limited within-person variability present during this single interaction with the newly learnt person did not enable the participants to efficiently recognise the face from all of the highly variable instances presented at the testing session. An additional study, testing behavioural recognition following a 10-minute interaction, would be necessary to confirm these speculations and shed more light on how well the ambient images were recognised. Overall, however, Chapter 4 suggests that a naturalistic 10-minute interaction is sufficient for the initial development of visual face representations, but that more experience with the face is necessary to further refine them.

Chapter 3 and Chapter 2 examined face learning over substantially longer time periods – eight months and two years, respectively, and investigated how the visual representations develop following their initial establishment. Both studies observed robust visual representations at their earliest testing timepoint – one (Chapter 3) and two (Chapter 2) months of familiarity. Interestingly, the effect size for the N250 effect recorded at one month of familiarity (d_{unb} = 0.27) was similar to the one observed after a brief 10-minute interaction (d_{unb} = 0.22[5])[6]. While the visual representations develop very quickly during the initial social encounter, the additional exposure during the first month which involves seeing the person on many separate and variable occasions (as our participants reported daily exposure to their new friend) does not appear to contribute much to the development of the effect. Therefore, the first interaction with a new person seems to provide exposure to variability that is highly diagnostic of the facial identity, and subsequent exposure during the following month seems to result in substantially slower learning. Importantly, however, in Chapter 4 testing took place immediately following the learning task. It is possible that the representations acquired during the brief exposure would be less robust after a month as previous research has shown a steep decline in face recognition performance of a newly learnt face in the first 24 hours following the learning session (Kramer, 2021). Presumably, while subsequent exposure following the first interaction does not result in an immediate substantial increase of the familiarity effect, it likely promotes the stability of the representation and its retention in long-term memory. An additional study with multiple learning and testing sessions on different days could further test the initial acquisition of face respresentations. The N250 observed at 2 months of familiarity (d_{unb} = 0.43), on the other hand, was bigger than the familiarity effect recorded at one month. Thus, it appears that the additional month of exposure contributed to more refined representations, and that with frequent interactions, the visual representations are slowly but gradually becoming stronger over time. While, presumably, the variability experienced between 10 minutes and one month, on one hand, and one and two months, on the other hand, would be very similar, the N250 correlate might not be as sensitive to keep track of this small but constant accumulation of visual familiarity resulting in no visible increase in the effect over the first month but a slight increase from one to two months.

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[5] The effect size d_{unb} was averaged across the 200-300 ms and 300-400 ms time windows.
[6] The between-experiment comparisons should be interpreted with caution due to wide confidence intervals for the d_{unb} in all studies.

Additionally, Chapter 3 and Chapter 2 demonstrated that the visual representations keep getting refined following the first one and two months of familiarity. In Chapter 2, we observed an increase in the N250 effect between two (d_{unb} = 0.43) and 14 months (d_{unb} = 0.65) at which point the visual representations were fully established as there was no subsequent increase from 14 to 26 months (d_{unb} = 0.76) of familiarity. Chapter 3 then refined these conclusions by showing a significant increase in the visual representations over the first eight months of familiarity. This was evident in a trend for a significant increase in the familiarity effect from one to five months and no difference between five and eight months, pointing towards a refinement of the visual representations within the first five months of familiarity but not afterwards. In line with this interpretation, the visual representations at five months of familiarity (d_{unb} = 0.73) had reached the level of highly familiar faces (Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019) and of friends known for about 14 months. These findings suggest that face learning ends at five months of familiarity, given regular exposure[7]. Therefore, it appears that the first five months of getting to know someone provide enough within-person variability to build representations which allow the reliable and robust recognition of the person from highly variable images. While visual exposure to the newly-learnt person continues beyond these five months and the visual representations need to accommodate for changes in visual appearance which take place over longer time periods (e.g. ageing, weight fluctuations), subsequent exposure presumably changes the representation but does not extend it. In other words, we may not continue to add more “snapshots” of what the person looks like to the representation but instead, those which are no longer useful are replaced. As an analogy, a computer folder containing images increases in size with the addition of extra images, but if images are instead replaced with new ones, the content changes but the size of the folder remains the same. Overall, these findings suggest that the initial development of visual face

[7] This is the best estimation, given the present data. Future research will hopefully clarify if face learning really ends at five months of familiarity.

representations occurs very quickly - during the first encounter with the new person, and then fully develops during the first five months of getting to know that person.

In real life, getting to know someone does not only consist of perceptual familiarisation, as faces are learnt in parallel to person-related semantic/episodic knowledge. Personally familiar faces activate a wide neural network in a more elaborate way than purely experimentally learnt faces (Kovács, 2020; Ramon & Gobbini, 2018). The studies in this thesis therefore also explored the integration of visual with additional person-related knowledge as an important aspect of the transition from a stranger to a friend. This was possible in Chapters 2 and 3 because of the use of personally familiar, socially relevant identities that were seen on a regular basis, which allowed us to examine the development of familiarity in real life. Previous research has largely relied on comparisons between different types of familiarity (e.g. personally familiar versus famous identities) to reach conclusions regarding the impact of the level of familiarity on the brain (e.g. Ambrus et al., 2021; Andrews et al., 2017; Caharel et al., 2002; Karimi-Rouzbahani et al., 2021; Wiese et al., 2019). The experiments presented in Chapter 2 and Chapter 3 which track how the ERP correlates of familiarity change over time substantially extend our current knowledge of the impact that the degree of familiarity has on identity representations by investigating the development of familiarity for the same type of identities both cross-sectionally (Chapter 2) and longitudinally (Chapter 3).

The findings suggest that the person-identity representations which involve the integration of relevant semantic, episodic, and affective information take longer to initially emerge relative to the visual representations. This is based on the observation from Chapter 4 of robust familiarity effects following a brief learning procedure only in the earlier N250 time range related to visual familiarity with no subsequent increase in the effect in the later face-processing stages. While during the naturalistic interaction which was part of the learning phase of the study, the participants would have acquired some person-related knowledge about the newly learnt person, this information was either not sufficient or not sufficiently integrated to substantially affect the later (SFE) stages related to semantic and episodic processing (d_{unb} = 0.31). In contrast, the representations observed after one month of familiarity (d_{unb} = 0.60) were substantially stronger indicating that after one month of knowing a person a sufficient amount of person-related knowledge has been accumulated. Similarly to the visual representations, at this point, the SFE is not as robust as the effect elicited by highly familiar people (Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019) and the refinement of this later processing stage continues with subsequent exposure. It appears that the build-up of person-related information is very rapid over the first two months of familiarity but slows down afterwards. This is based on the lack of increase in the SFE over the course of the study reported in Chapter 3. Hence, the initial exposure to person-related information during the first one/two months is highly informative and readily integrated with the visual representations, but subsequent information only builds up the representation very slowly. The integration of person-related knowledge then reaches a plateau by 14 months of familiarity. This demonstrates that similarly to face learning, identity learning does not continue indefinitely, and representations do not get substantially refined with continuous exposure.

The present experiments investigated the time course over which visual and person-related information develops with increasing familiarity. Taking into account the conclusions discussed above, in Figure 5.1., I propose a model which collates the findings from all three studies conducted as part of this thesis. This model follows the process of getting to know someone from the very first meeting with a new person to a long-term friendship. Overall, the present results suggest that while the first five months are crucial for the full development of robust face representations, the integration of person-related knowledge to the level of highly familiar faces takes just over a year.

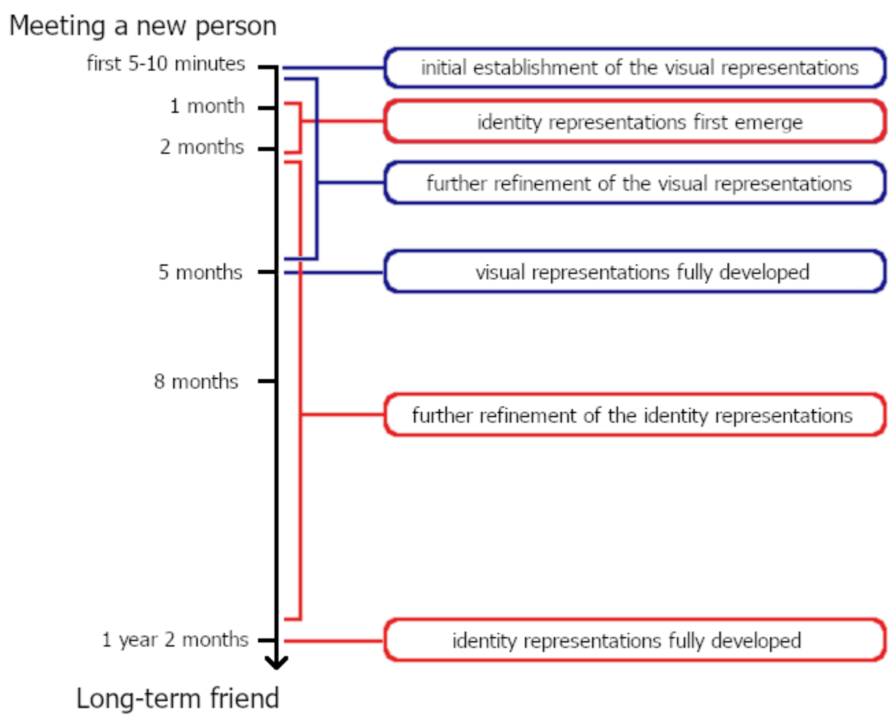

Figure 5.1. Proposed model of the time course of face and identity learning in everyday life.

5.2.2. What have we learnt about the ERP correlates associated with familiar face recognition?

In addition to the discussed theoretical contributions of how people become familiar in everyday life, the experiments reported here contribute to our understanding of the ERP correlates related to familiar face processing. They provide information regarding the minimal exposure and degree of familiarity necessary for the effect to be elicited and the trajectory of the development of the two effects. The N250 is very sensitive to face learning and a single 10-minute exposure is sufficient for the initial establishment of robust face representations. This supports the conclusions of previous laboratory-based ERP studies (Andrews et al., 2017; Kaufmann et al., 2009; Tanaka et al., 2006; Zimmermann & Eimer, 2013). For the SFE, on the other hand, prolonged acquisition of information related to the new friend is needed to reliably elicit the effect (in the sense of an enhanced amplitude difference following the N250 time window), which is in line with previous research failing to observe an SFE for only moderately familiar people, i.e. lecturers and disliked celebrities (Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019). It appears that one month of daily real-life exposure is enough to elicit a clear SFE. Both effects are modulated by familiarity in a gradual rather than binary manner, as quantifiable differences were observed between the different levels of familiarity, supported by the effect sizes which generally increased with familiarity from 10 minutes to 14 months.

The results also indicate that the two ERP familiarity effects follow different trajectories of development. Both develop substantially initially, but in the case of the N250, this happens during the first exposure, while the SFE first emerges after approximately one month of interaction. The development of both effects then slows down in the following months resulting in only gradual refinement of the familiarity effects. The N250 further develops during the first five months and then reaches a plateau, while the SFE keeps increasing following the full development of the N250 and reaches a plateau after just over one year of close familiarity. This difference in the temporal course of development of these two effects contributes to the argument that despite the similar scalp topography, these two effects reflect two at least partly different processes. Wiese and colleagues (2019) interpreted the SFE to reflect the integration of visual with additional person-related knowledge. While the specificity of this effect to faces and the exact processes that underlie the SFE are beyond the scope of the current work, the pattern of results of the present experiments is consistent with the current understanding of what the SFE represents.

The question regarding the neural basis of the two effects remains open. The occipito-temporal scalp distribution of these two familiarity effects suggests a neural generator in the ventral visual stream but the low spatial resolution of EEG prevents inferences regarding the precise anatomical locations of the effects (e.g. Olivares et al., 2015). On the other hand, fMRI's excellent spatial resolution has been very useful in the localisation of the processes underlying familiar face processing. Based on models of face perception, the core and extended face systems are expected to underpin these familiarity effects (Gobbini & Haxby, 2007; Haxby et al., 2000), with more familiar faces activating the areas from the extended network to a higher extent (Kovács, 2020). The fusiform gyrus is often seen as the main generator of the N250 effect (Kaufmann et al., 2009), while a recent study demonstrated that the right occipital face area plays a causal role in the differentiation between familiar and unfamiliar faces (Eick et al., 2021). The SFE, on the other hand, due to its late peak and modulation by degree of familiarity, is likely to incorporate post-perceptual processing carried out in the extended face network and fed back to the core face-processing network. This is consistent with the present findings which observed an increase in the SFE following the full development of the N250 effect.

5.3. Methodological and practical implications

Previous neuroscientific research on face learning and recognition has largely ignored two key aspects of the real-life phenomenon. First, studies have largely relied on artificial or tightly controlled stimuli, thereby neglecting the importance of within-person variability for both learning and recognition stages (e.g. Burton, 2013). Second, they have used laboratory-based familiarisation procedures which cannot produce the same widespread neural representations of identities learnt in real life over long time periods (Kovács, 2020). As a result, past research can only provide limited information about how we really get to know people in everyday life. Recently, studies looking at face learning have started to address these limitations by implementing short- (Ambrus et al., 2021; Sliwinska et al., 2022) and long-term (Campbell & Tanaka, 2021) real-life learning procedures. The experiments in this thesis continue this shift towards more ecologically valid paradigms by introducing three different (quasi-)experimental procedures studying face learning as it happens in real life. The current results demonstrate that such procedures are feasible to implement and can provide novel insights into the transition from unfamiliar to familiar face processing.

These findings also have potential real-life implications for forensic settings. Eyewitness testimony is very challenging and error-prone because it involves recognising a person, quite often seen only briefly, in different settings to which they were first encountered and often across substantial (sometimes deliberate) variations in appearance (e.g. Steblay et al., 2003; Wells et al., 1998). Improved understanding of the initial development of visual representations, and in particular, the minimal exposure leading to recognition from multiple highly variable images of the newly learnt person is of interest to and can inform eyewitness testimony practices. However, any potential practical implications of the results from Chapter 4 are, at the moment, limited by several key factors. First, the visual representations were tested shortly after the brief exposure. In applied settings, the delay between exposure and the need to recognise the person is substantially longer, and currently it is unclear how stable the effects are over time. Second, in the study, the learning phase consisted of a brief one-to-one social encounter. More research is needed to track the development of face representations in busy environments in which people are likely to be more distracted. Additionally, in applied settings, people often need to identify someone with whom they have not interacted, so future research needs to investigate whether social interaction contributes to the initial establishment of the visual representations observed in the present experiments.

Objective and reliable measures of familiarity elicited without an overt response could be used in settings in which someone might want to conceal familiarity with a specific individual or might not be capable of communicating familiarity (e.g. small children or individuals with locked-in syndrome or dementia). While the effects reported in the N250 correlate are usually small, the SFE is a good candidate as the effect is robust and highly reliable in individual participants (Wiese, Anderson, et al., 2022; Wiese, Tüttenberg, et al., 2019). Additionally, the SFE is present even when an individual is trying to actively deny familiarity (Wiese, Anderson, et al., 2022) and allows a high specificity regarding the exact time range and electrode sites at which the effect will be the strongest. The present findings, however, demonstrate that the effect is not as robust and sensitive during the first year of familiarity. In Chapter 2, the proportion of reliable effects in individual participants increased from P = .35 at two to P = .80 at 14 months of familiarity. Therefore, to be able to detect familiarity effects in individual participants with reasonable accuracy, the identity needs to be known for at least 14 months. Additionally, before the SFE can be used as an index of familiarity with populations unable to overtly report familiarity, additional research is needed to investigate whether the effect is as reliable in other age groups, as, for instance, age-related deficits have been observed in the N250r in healthy older participants (Wiese et al., 2017).

5.4. Limitations and directions for future research

A limitation of the present thesis and the more ecologically valid paradigms used here is the lack of control regarding the quality and quantity of exposure. It is challenging to obtain an objective measurement of familiarity for friends known for a long time (Chapter 2) and to precisely track exposure over long time periods (Chapter 3). Additionally, while in Chapter 4 the exposure duration to the person was timed, it is unclear exactly how much time the participants spent looking at the face of the person and what sort of information they learnt about the face during the social encounter. It also remains unknown how the different types of non-visual identity-specific information (episodic, semantic, affective) contribute to the development and magnitude of the identity representations. While long-term face and identity learning is difficult to investigate in strict laboratory conditions, there are strengths and limitations for both purely laboratory-based and more ecologically valid approaches, and a combination of both is needed to shed light on how faces become familiar.

Another limitation of the current work is that it does not take into account individual differences in face learning. It is well-established that face recognition ability is a continuum, ranging from very poor recognition in people with prosopagnosia to excellent recognition abilities in super-recognisers (e.g.

White & Burton, 2022). Therefore, there will be differences between participants in their face learning skills, with some being better and some worse than average learners. Similarly, there will be variability between learnt identities, as characteristics such as the distinctiveness (Kaufmann & Schweinberger, 2012) or attractiveness of a face (Wiese et al., 2014) make some faces easier to learn than others. Additionally, prior experience is likely to also have an impact, as, for instance, people more easily remember faces which resemble someone they already know (Hancock, 2021). The investigation of these sources of variability was beyond the scope of the present experiments due to the sample sizes, which are typical for ERP research but too small to test for the additional factors discussed here. It, however, represents an interesting avenue for future work and a logical next step for the face learning studies from Chapter 4.

Another interesting question which emerges from the current work is about the stability of the established face and identity representation in the absence of further exposure. As briefly discussed earlier, an improved understanding of the process of forgetting has crucial implications for forensic settings. Additionally, a change in the N250 and SFE over time in the absence of additional exposure can shed some light on the nature of face and identity representations. For instance, in Chapter 2, one of the groups observed a larger N250 for friends with whom the participants reported interacting more frequently at the time of testing. This suggests that recency of exposure, in addition to the cumulative level of familiarity, might also play a role in the robustness of the representations. This pattern was not present for the SFE time range suggesting that the neural representations of identity-specific knowledge are more robust over time than the visual representations in the absence of frequent interactions. However, as this observation was not predicted and not present in the other year group, more support for this conclusion is needed.

5.5. Conclusions

In sum, the current thesis presented novel (quasi-)experimental approaches to study the neural basis of short- and long-term face and identity learning in a more ecologically valid way as compared to previous laboratory-based studies. The results presented here improve our knowledge of how people become familiar in everyday settings and add a time dimension to our theoretical understanding of face and identity learning, focusing on both the visual representations (as reflected in the N250 familiarity effect) and the integration of person-related knowledge (as reflected in the SFE). In addition to these theoretical contributions, the present findings have also potential real-life implications for forensic settings. Future research should investigate the impact of individual differences on face and identity learning and the developmental trajectory of face and identity representations in the absence of subsequent exposure.

6. Appendices

6.1. Chapter 2. Supplementary Material

Performance

Due to technical issues during testing, the behavioural responses of one participant were not recorded. For the remaining participants, accuracy was close to ceiling during the butterfly detection task, hit rate = .99, *SD* = .02, false alarm rate < .01, *SD* = .005. The mean reaction time for correct responses was 503 ms, SD = 63.6.

Event-related potentials

A mixed-model ANOVA for the N170 (140-180 ms) with within-participant factors hemisphere and familiarity and a between-participant factor year group yielded a significant main effect of familiarity, $F(2, 114) = 3.22$, $p = .044$, $\eta_p^2 = .053$, 90% CI [.001, .123], while the familiarity by year group interaction was non-significant, $F(4, 114) = 0.43$, $p = .790$, $\eta_p^2 = .015$, 90% CI [.000, .032]. Relative to unfamiliar faces, university friends elicited significantly more negative amplitudes, M_{diff} = 0.42 µV, 95% CI [0.08, 0.76], $t(59) = 2.47$, $p = .017$, d_{unb} = 0.13, 95% CI [0.02, 0.24], and a corresponding trend was observed for home friends, M_{diff} = 0.32 µV, 95% CI [-0.04, 0.68], $t(59) = 1.78$, $p = .081$, d_{unb} = 0.10, 95% CI [-0.01, 0.22]. University and home friends did not differ, M_{diff} = 0.10 µV, 95% CI [-0.23, 0.43], $t(59) = 0.63$, $p = .532$, d_{unb} = 0.03, 95% CI [-0.07, 0.14]. The familiarity effect in the N170 time range for university friends and the corresponding trend for home friends might suggest that familiarity can be observed before the N250 time range (i.e. earlier than 200ms). Of note, however, the observed effects were very small and were only statistically significant (or close to significant) when all 60 participants were entered into the analysis. Due to inconsistencies regarding the N170's sensitivity to familiarity in previous research and the very small effects observed here, we conclude that the first reliable and clear familiarity signal occurs in the N250 time range.

An ANOVA in the N250 time range revealed significant main effects of familiarity, $F(2, 114) = 72.57$, $p < .001$, $\eta_p^2 = .560$, 90% CI [.455, .629], and hemisphere, $F(1, 57) = 26.00$, $p < .001$, $\eta_p^2 = .313$, 90% CI [.152, .447], while the year group main effect was non-significant, $F(2, 57) = 0.65$, $p = .525$.

An ANOVA in the SFE time range yielded significant main effects of familiarity, $F(2, 114) = 88.38$, $p < .001$, $\eta_p^2 = .608$, 90% CI [.510, .671], hemisphere, $F(1, 57) = 11.87$, $p = .001$, $\eta_p^2 = .172$, 90% CI [.047, .311], and year group, $F(2, 57) = 3.38$, $p = .041$, $\eta_p^2 = .106$, 90% CI [.002, .221].

A measure of the SFE which was corrected for potential differences in the earlier time range was calculated by subtracting N250 amplitudes from the SFE (N250-corrected SFE; see Wiese, Hobden, et al., 2022). A mixed-model ANOVA revealed significant main effects of familiarity, $F(2, 114) = 24.32$, $p < .001$, $\eta_p^2 = .299$, 90% CI [.180, .393], and hemisphere, $F(1, 57) = 14.63$, $p < .001$, $\eta_p^2 = .204$, 90% CI [.067, .343], and a significant hemisphere by familiarity interaction, $F(2, 114) = 5.87$, $p = .004$, $\eta_p^2 = .093$, 90% CI [.019, .175]. The main effect of year group, $F(2, 57) = 1.69$, $p = .193$, $\eta_p^2 = .056$, 90% CI [.000, .153], and the year group by familiarity interaction, $F(4, 114) = 0.67$, $p = .614$, $\eta_p^2 = .023$, 90% CI [.000, .051], were non-significant. Relative to unfamiliar faces, analyses revealed significantly more negative amplitudes for university, $M_{diff} = 0.37$ µV, 95% CI [0.08, 0.66], $t(59) = 2.57$, $p = .013$, $d_{unb} = 0.18$, 95% CI [0.04, 0.32], and home friends, $M_{diff} = 1.01$ µV, 95% CI [0.72, 1.30], $t(59) = 6.97$, $p < .001$, $d_{unb} = 0.48$, 95% CI [0.32, 0.65]. Additionally, home friends elicited significantly more negative amplitudes than university friends, $M_{diff} = 0.64$ µV, 95% CI [0.34, 0.93], $t(59) = 4.3$, $p < .001$, $d_{unb} = 0.30$, 95% CI [0.15, 0.45]. The observed main effect of familiarity suggests additional processing of identity information in the later time window, over and above the processes reflected in the N250. At the same time, this analysis did not yield a significant interaction with year group, which might be interpreted as suggesting that the differences between year groups occurred mostly in the N250 time range and were then carried over into the later time window.

We note, however, that such an interpretation cannot explain that in Year 1 university and home friends did not differ in the N250, whereas home friends elicited more negative amplitudes in the SFE. We, therefore, conclude that the uncorrected SFE reveals important findings, which would have been missed by an exclusive focus on corrected data.

Finally, to analyse P600f, mean amplitudes from 400-600ms were calculated at Pz (see Figure 6.1a and 6.1b). A mixed-model ANOVA revealed a significant main effect of familiarity, $F(2, 114) = 29.24$, $p < .001$, $\eta_p^2 = .339$, 90% CI [.218, .431], while the familiarity by year group interaction was non-significant, $F(4, 114) = 1.66$, $p = .165$, $\eta_p^2 = .055$, 90% CI [.000, .106]. Analyses revealed more positive amplitudes for university friends relative to unfamiliar faces, $M_{diff} = 0.93$ µV, 95% CI [0.59, 1.28], $t(59) = 5.43$, $p < .001$, $d_{unb} = 0.44$, 95% CI [0.26, 0.62], and for home friends versus unfamiliar faces, $M_{diff} = 1.35$ µV, 95% CI [0.97, 1.72], $t(59) = 7.17$, $p < .001$, $d_{unb} = 0.64$, 95% CI [0.43, 0.85]. Additionally, home friends elicited significantly more positive amplitudes than university friends, $M_{diff} = 0.41$ µV, 95% CI [0.04, 0.79], $t(59) = 2.21$, $p = .031$, $d_{unb} = 0.18$, 95% CI [0.02, 0.35]. As the crucial interaction of familiarity by year group was not significant, this analysis supports our suggestion of non-identical processes underlying the P600f and the SFE.

Exploratory mass univariate analyses of the within-group contrasts of university and home friends versus unfamiliar faces confirmed our main findings of less pronounced familiarity effects for university friends in the Year 1 group relative to those observed for home friend and the effects elicited by university friends in the two other groups (see Figure 6.1c). No systematic differences between the two familiarity effects were observed in the Year 2 and 3 groups.

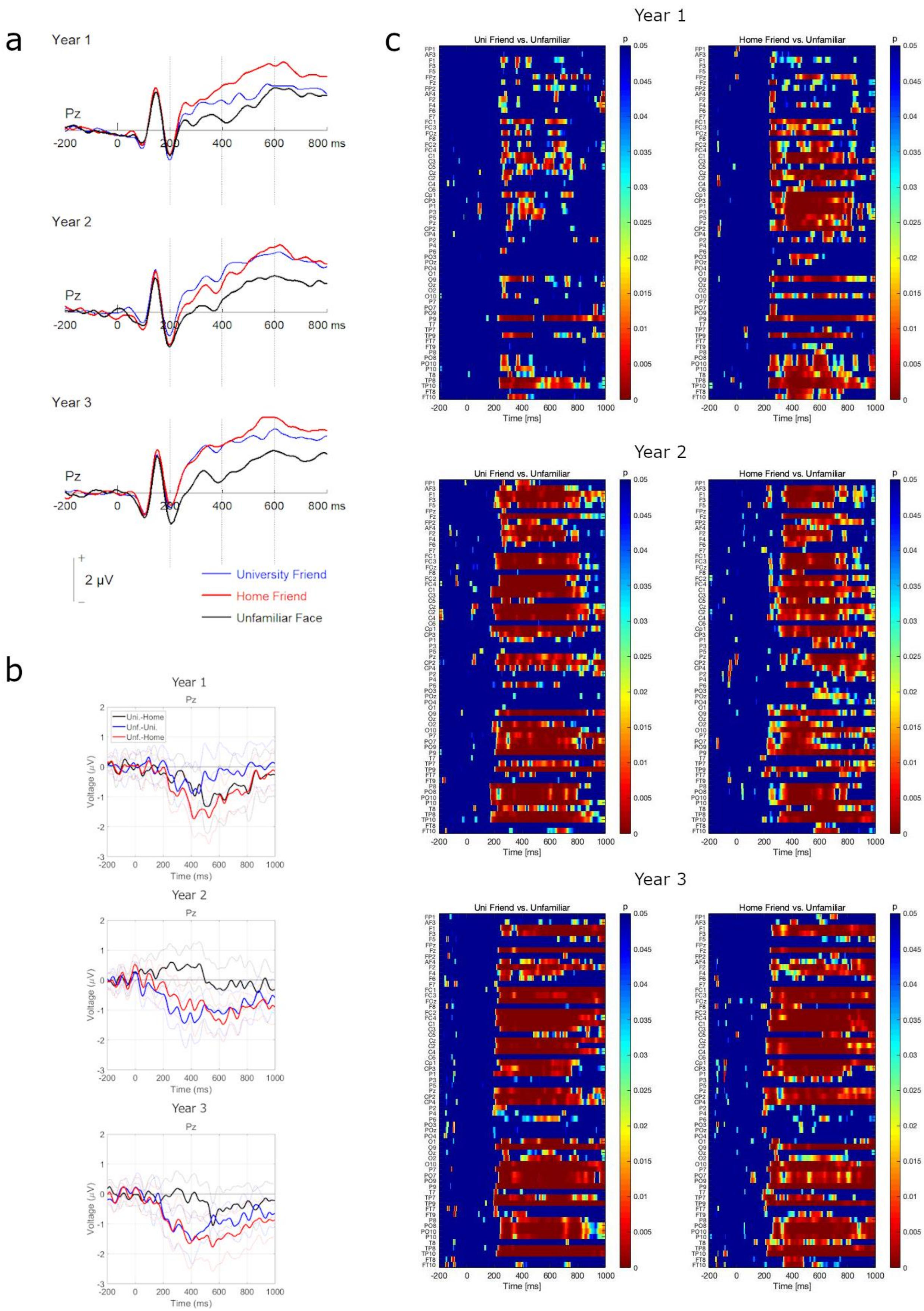
a
Year 1
Pz
-200
0
200
400
600
800 ms
Year 2
Year 3
2 µV
University Friend
Home Friend
Unfamiliar Face
b
Year 1
Pz
Uni.-Home
Unf.-Uni.
Unf.-Home
Voltage (µV)
Time (ms)
Year 2
Year 3
c
Year 1
Uni Friend vs. Unfamiliar
Home Friend vs. Unfamiliar
Time [ms]
p
Year 2
Year 3

Figure 6.1. Exploratory ERP results. a) Grand average event-related potentials at mid-parietal electrode Pz 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 Pz. c) Mass univariate analyses for the within-group comparisons for each year group.

Rating task

See Table 6.1 for a list of all tests run on the ratings for familiarity, valence, and arousal and Table 6.2 for visual and social interaction.

Table 6.1. Results for familiarity, valence, and arousal. ESCI only provides CIs for d values between -2 and 2 (see Cumming, 2012; p. 306-307).

		df	*t*	*p*	d_{unb}	95% CIs
Familiarity	Year 1 Uni vs Home	19	0.82	.425	0.26	-0.39, 0.93
	Year 1 Uni vs Unfam	19	5.79	< .001	1.93	1.06, 2.92
	Year 1 Home vs Unfam	19	7.26	< .001	2.17	
	Year 2 Uni/Home vs Unfam	19	11.90	< .001	3.61	
	Year 3 Uni/Home vs Unfam	19	12.43	< .001	3.77	
	Uni: Year 1 vs Year 2/Year3	38	2.13	.040	0.66	0.03, 1.31
	Home: Year 1 vs Year 2/Year 3	38	1.00	.324	0.31	-0.31, 0.94
Valence	Year 1 Uni vs Home	19	0.75	.464	0.20	-0.35, 0.77
	Year 1 Uni vs Unfam	19	8.75	< .001	2.94	
	Year 1 Home vs Unfam	19	5.25	< .001	1.55	0.81, 2.39
	Year 2 Uni vs Home	19	1.71	.104	0.42	-0.09, 0.95
	Year 2 Uni vs Unfam	19	8.72	< .001	2.53	
	Year 2 Home vs Unfam	19	11.57	< .001	3.44	
	Year 3 Uni vs Unfam	19	17.96	< .001	4.81	
	Year 3 Home vs Unfam	19	15.16	< .001	4.81	
	Uni: Year 1 vs Year 2	38	2.08	.044	0.65	0.02, 1.29
	Uni: Year 2 vs Year 3	38	1.38	.176	0.43	-0.19, 1.06
	Home: Year 1 vs Year 2/Year 3	38	1.23	.226	0.38	-0.24, 1.01
Arousal	Year 1 Uni vs Home	19	5.60	< .001	1.54	0.84, 2.35
	Year 1 Uni vs Unfam	19	6.72	< .001	2.06	
	Year 1 Home vs Unfam	19	10.28	< .001	3.19	
	Year 2 Uni vs Home	19	2.02	.058	0.47	-0.02, 0.98

	Year 2 Uni vs Unfam	19	7.07	< .001	2.15	
	Year 2 Home vs Unfam	19	9.04	< .001	2.81	
	Year 3 Uni vs Home	19	2.03	.056	0.21	-0.01, 0.45
	Year 3 Uni vs Unfam	19	9.65	< .001	2.33	
	Year 3 Home vs Unfam	19	8.39	< .001	1.93	1.21, 2.79
	Uni: Year 1 vs Year 2	38	1.97	.057	0.61	-0.02, 1.25
	Uni: Year 2 vs Year 3	38	0.94	.355	0.30	-0.33, 0.92
	Home: Year 2 vs Year 3	38	1.21	.234	0.38	-0.25, 1.01

Table 6.2. Results for visual interaction and social contact.

		U	*p*	r	95% CIs
Visual Interaction	Year 1 Uni vs Home		< .001	.923	
	Year 1 Uni vs Unfam		< .001	.896	
	Year 1 Home vs Unfam		< .001	.750	
	Year 2 Uni vs Home		< .001	.868	
	Year 2 Uni vs Unfam		< .001	.950	
	Year 2 Home vs Unfam		< .001	.950	
	Year 3 Uni vs Home		< .001	.850	
	Year 3 Uni vs Unfam		< .001	.950	
	Year 3 Home vs Unfam		< .001	.950	
	Uni: Year 1 vs Year 2	188.0	.758	-0.09	-0.35, 0.23
	Uni: Year 2 vs Year 3	148.0	.165	0.31	0.02, 0.54
	Home: Year 1 vs Year 2	144.5	.134	-0.26	-0.54, 0.03
	Home: Year 2 vs Year 3	116.5	.023	0.39	0.09, 0.66
Social Contact	Year 1 Uni vs Home		.006	.581	
	Year 1 Uni vs Unfam		< .001	.923	
	Year 1 Home vs Unfam		< .001	.950	
	Year 2 Uni vs Home		.012	.539	
	Year 2 Uni vs Unfam		< .001	.950	
	Year 2 Home vs Unfam		< .001	.950	
	Year 3 Uni vs Home		< .001	.777	
	Year 3 Uni vs Unfam		< .001	.950	
	Year 3 Home vs Unfam		< .001	.950	
	Uni: Year 1 vs Year 2	200.0	1.000	0.00	-0.30, 0.28
	Uni: Year 2 vs Year 3	179.0	.583	0.15	-0.17, 0.41
	Home: Year 1 vs Year 2	178.0	.565	0.10	-0.25, 0.40
	Home: Year 2 vs Year 3	160.0	.289	0.18	-0.13, 0.50

6.2. Chapter 3. Supplementary Material

Performance

In all three sessions, during the butterfly detection task, accuracy was close to ceiling, hit rate = 0.996, SD = .02, false alarm rate < .002, *SD* =.01. The mean reaction time for correct responses was 472 ms, *SD* = 70.8.

Event-related potentials

Repeated-measures ANOVA in the 140-180 ms time range with within-subject factors session (1, 2, 3), hemisphere (left, right), and familiarity (friend, unfamiliar ID) was run to investigate for any familiarity effects in the N170. There was a significant main effect of familiarity with more negative amplitudes reported in response to the unfamiliar face, M_{diff} = 0.29 µV, 95% CIs [0.01, 0.58], $F(1, 15) = 4.78$, $p = .045$, $\eta_p^2 = .242$, 90% CI [.003, .475] while the session by familiarity interaction was non-significant, $F(2, 30) = 1.39$, $p = .265$, $\eta_p^2 = .085$.

We further explored the data by analysing the N250-corrected SFE (calculated by subtracting the N250 amplitudes from the SFE to correct for potential differences in the earlier time range; see (Wiese, Hobden, et al., 2022). There was a significant main effect of familiarity with more negative amplitudes elicited in response to familiar IDs relative to non-familiar faces, M_{diff} = 0.76 µV, 95% CIs [0.38, 1.15], $F(1, 15) = 17.6$, $p < .001$, $\eta_p^2 = .541$, 90% CI [.202, .694]. There was also a significant hemisphere by familiarity interaction with bigger familiarity effects reported over the right hemisphere, M_{diff} = 0.92 µV, 95% CIs [0.43, 1.42], $F(1, 15) = 15.8$, $p = .001$, $\eta_p^2 = .514$, 90% CI [.175, .678]. The main effect of session, $F(2, 30) = 2.53$, $p = .096$, $\eta_p^2 = .144$, and the session by familiarity interaction, $F(2, 30) = 1.20$, $p = .314$, $\eta_p^2 = .074$, were non-significant.

Rating task

See Table 6.3 for a list of all tests run on the ratings for familiarity, valence, and arousal and Table 6.4 for frequency of interaction.

Table 6.3. Results for familiarity, valence, and arousal. All df = 15. ESCI only provides CIs for d values between -2 and 2 (see Cumming, 2012; p. 306-307). S1 = Session 1, S2 = Session 2, S3 = Session 3, Fam = Familiar, Unfam = Unfamiliar.

		t	*p*	d_{unb}	95% CIs
Familiarity	S1: Fam vs Unfam	10.18	< .001	3.41	
	S2: Fam vs Unfam	13.18	< .001	4.27	
	S3: Fam vs Unfam	15.25	< .001	5.12	
	Fam: S1/S3 vs S2	1.00	.333	0.34	-0.36, 1.05
	Unfam: S1 vs S2	0.32	.757	0.10	-0.56, 0.77
	Unfam: S2 vs S3	0.32	.751	0.06	-0.33, 0.46
	Unfam: S1 vs S3	0.15	.882	0.05	-0.67, 0.78
Valence	S1: Fam vs Unfam	5.37	< .001	2.00	
	S2: Fam vs Unfam	4.07	.001	1.37	0.57, 2.30
	S3: Fam vs Unfam	5.37	< .001	2.22	
	Fam: S1 vs S2	0.89	.388	0.25	-0.33, 0.84
	Fam: S2 vs S3	0.68	.509	0.20	-0.41, 0.82
	Fam: S1 vs S3	0.37	.718	0.08	-0.38, 0.55
	Unfam: S1 vs S2/S3	0.44	.669	0.14	-0.52, 0.81
Arousal	S1: Fam vs Unfam	8.35	< .001	2.36	
	S2: Fam vs Unfam	5.68	< .001	1.64	0.86, 2.57
	S3: Fam vs Unfam	4.47	< .001	1.69	0.76, 2.77
	Fam: S1 vs S2	0.81	.432	0.25	-0.39, 0.92
	Fam: S1 vs S3	1.00	.333	0.34	-0.36, 1.08
	Unfam: S1 vs S2	0.52	.609	0.13	-0.38, 0.65
	Unfam: S2 vs S1	0.64	.530	0.18	-0.39, 0.76
	Unfam: S1 vs S3	0.27	.791	0.06	-0.40, 0.53

Table 6.4. Results for frequency of interaction.

	p	r
S1: Fam vs Unfam	< .001	.955
S2: Fam vs Unfam	< .001	.926
S3: Fam vs Unfam	< .001	.906
Fam: S1 vs S2	.625	.250
Fam: S2 vs S3	.250	.433
Fam: S1 vs S3	.063	.559

6.3. Chapter 4. Supplementary Material

Performance

Experiment 1: Due to technical issues during testing, the behavioural responses of the participants were not recorded. Please note that the participants' accuracy during the butterfly detection task in the other three experiments was close to ceiling with very low false alarm rates.

Experiment 2: The responses of five participants were not recorded due to technical issues. For the remaining 29 participants, accuracy was close to ceiling during the butterfly detection task, hit rate = .99, *SD* = .02, false alarm rate < .01, *SD* = .004. The mean reaction time for correct responses was 508 ms, SD = 81.2.

Experiment 3: Technical issues prevented the recording of the data of one participant. For the remaining participants, the accuracy at ceiling levels, hit rate = 1.00, *SD* = .00, false alarm rate < .01, *SD* = .003, with a mean reaction time for correct responses of 508 ms, SD = 60.3.

Experiment 4: The responses of one participant were not recorded because of technical issues. For the remaining participants, accuracy was close to ceiling, hit rate = .99, *SD* = .03, false alarm rate < .001, *SD* = .002. The mean reaction time for correct responses was 473 ms, SD = 65.2.

Event-related potentials

To further explore the data, repeated-measures Analysis of Variance (ANOVA) with the within-participants factors hemisphere (left, right) and familiarity (newly learnt, unfamiliar) were run for the N170 correlate (140-180 ms) for each experiment. Additionally, we investigated the effect of hemisphere by running repeated-measures ANOVA separately for the early (200-300 ms) and late N250 time ranges (300-400 ms), as well as for the SFE (400-600 ms).

Experiment 1

An ANOVA in the N170 time window revealed a non-significant main effect of familiarity, *F*(1, 23) = 1.07, *p* = .312, η_p^2 = .044, and a non-significant hemisphere by familiarity interaction, *F*(1, 23) = 0.94, *p* = .342, η_p^2 = .039.

There was a non-significant hemisphere by familiarity interaction in the early N250 time range, *F*(1, 23) = 0.09, *p* = .768, η_p^2 = .004, the later N250 time range, *F*(1, 23) = 1.15, *p* = .295, η_p^2 = .048, and the SFE time window, *F*(1, 23) = 0.55, *p* = .465, η_p^2 = .023.

Experiment 2

In the N170 time window, there was a significant main effect of familiarity with more negative amplitudes elicited by the newly learnt face, M_{diff} = 0.35 µV, 95% CIs [0.01, 0.70], *F*(1, 33) = 4.28, *p* = .047, η_p^2 = .115, 90% CI [.001, .287]. The hemisphere by familiarity interaction was non-significant, *F*(1, 33) = 0.50, *p* = .483, η_p^2 = .015.

The hemisphere by familiarity interaction was non-significant in the 200-300 ms, *F*(1, 33) = 0.08, *p* = .775, η_p^2 = .003, and 300-400 ms time ranges, *F*(1, 33) = 0.55, *p* = .466, η_p^2 = .016. Analysis in the later 400-600 ms window, however, yielded a significant interaction, *F*(1, 33) = 4.23, *p* = .048, η_p^2 =.114, 90% CI [.001, .285], with larger familiarity effects over the right hemisphere.

Experiment 3

There was a non-significant main effect of familiarity in the N170 time window, *F*(1, 33) = 1.80, *p* = .189, η_p^2 = .052. The hemisphere by familiarity interaction was also non-significant, *F*(1, 33) = 0.25, *p* = .619, η_p^2 = .008.

The hemisphere by familiarity interaction was non-significant in the early N250, $F(1, 33) = 1.66$, $p = .206$, $\eta_p^2 = .048$, late N250, $F(1, 33) = 2.77$, $p = .105$, $\eta_p^2 = .078$, and the SFE, $F(1, 33) = 0.10$, $p = .752$, $\eta_p^2 = .003$.

Experiment 4

An ANOVA in the N170 time range revealed a non-significant main effect of familiarity, $F(1, 33) = 0.19$, $p = .669$, $\eta_p^2 = .006$. An additional Bayes repeated-measure ANOVA provided moderate support for the null hypothesis, $BF_{01} = 3.76$, error % = 4.10. The hemisphere by familiarity interaction was non-significant, $F(1, 33) = 0.004$, $p = .948$, $\eta_p^2 = .0001$.

A non-significant hemisphere by familiarity interaction was found in the early N250, $F(1, 33) = 0.46$, $p = .504$, $\eta_p^2 = .014$, and late N250 time windows, $F(1, 33) = 0.39$, $p = .536$, $\eta_p^2 = .012$, and the SFE, $F(1, 33) = 0.45$, $p = .509$, $\eta_p^2 = .013$.

7. References

Adini, Y., Moses, Y., & Ullman, S. (1997). Face recognition: The problem of compensating for changes in illumination direction. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *19*(7), 721–732. https://doi.org/10.1109/34.598229

Alzueta, E., Melcón, M., Poch, C., & Capilla, A. (2019). Is your own face more than a highly familiar face? *Biological Psychology*, *142*, 100–107. https://doi.org/10.1016/j.biopsycho.2019.01.018

Ambrus, G. G., Eick, C. M., Kaiser, D., & Kovács, G. (2021). Getting to know you: Emerging neural representations during face familiarization. *Journal of Neuroscience*, *41*(26), 5687–5698. 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

Andrews, S., Jenkins, R., Cursiter, H., & Burton, A. M. (2015). Telling faces together: Learning new faces through exposure to multiple instances. *Quarterly Journal of Experimental Psychology*, *68*(10), 2041–2050. https://doi.org/10.1080/17470218.2014.1003949

Bahrick, H. P., Bahrick, P. O., & Wittlinger, R. P. (1975). Fifty years of memory for names and faces: A cross-sectional approach. *Journal of Experimental Psychology: General*, *104*(1), 54–75. https://doi.org/10.1037/0096-3445.104.1.54

Barragan-Jason, G., Cauchoix, M., & Barbeau, E. J. (2015). The neural speed of familiar face recognition. *Neuropsychologia*, *75*, 390–401. https://doi.org/10.1016/j.neuropsychologia.2015.06.017

Begleiter, H., Porjesz, B., & Wang, W. (1995). Event-related brain potentials differentiate priming and recognition to familiar and unfamiliar faces. *Electroencephalography and Clinical Neurophysiology*, *94*(1), 41–49. https://doi.org/10.1016/0013-4694(94)00240-L

Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society: Series B (Methodological)*, *57*(1), 289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological Studies of Face Perception in Humans. *Journal of Cognitive Neuroscience*, *8*(6), 551–565. https://doi.org/10.1162/jocn.1996.8.6.551

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

Bobak, A. K., Mileva, V. R., & Hancock, P. J. (2019). Facing the facts: Naive participants have only moderate insight into their face recognition and face perception abilities. *Quarterly Journal of Experimental Psychology*, *72*(4), 872–881. https://doi.org/10.1177/1747021818776145

Bobes, M. A., Lage-Castellanos, A., Olivares, E. I., Perez Hidalgo-Gato, J., Iglesias, J., Castro-Laguardia, A. M., & Valdes-Sosa, P. (2019). ERP Source Analysis Guided by fMRI During Familiar Face Processing. *Brain Topography*, *32*(4), 720–740. https://doi.org/10.1007/s10548-018-0619-x

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. (1994). Stability from variation: The case of face recognition the M.D. Vernon memorial lecture. *The Quarterly Journal of Experimental Psychology Section A*, *47*(1), 5–28. https://doi.org/10.1080/14640749408401141

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. (2013). Why has research in face recognition progressed so slowly? The importance of variability. *Quarterly Journal of Experimental Psychology*, *66*(8), 1467–1485. https://doi.org/10.1080/17470218.2013.800125

Burton, A. M., Bruce, V., & Johnston, R. A. (1990). Understanding face recognition with an interactive activation model. *British Journal of Psychology*, *81*(3), 361–380. https://doi.org/10.1111/j.2044-8295.1990.tb02367.x

Burton, A. M., Jenkins, R., Hancock, P. J. B., & White, D. (2005). Robust representations for face recognition: The power of averages. *Cognitive Psychology*, *51*, 256–284. https://doi.org/10.1016/j.cogpsych.2005.06.003

Burton, A. M., Jenkins, R., & Schweinberger, S. R. (2011). Mental representations of familiar faces. *British Journal of Psychology*, *102*(4), 943–958. https://doi.org/10.1111/j.2044-8295.2011.02039.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., White, D., & McNeill, A. (2010). The Glasgow Face Matching Test. *Behavior Research Methods*, *42*(1), 286–291. https://doi.org/10.3758/BRM.42.1.286

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

Caharel, S., Courtay, N., Bernard, C., Lalonde, R., & Rebaï, M. (2005). Familiarity and emotional expression influence an early stage of face processing: An electrophysiological study. *Brain and Cognition*, *59*(1), 96–100. https://doi.org/10.1016/j.bandc.2005.05.005

Caharel, S., Poiroux, S., Bernard, C., Thibau, F., Lalonde, R., & Rebai, M. (2002). ERPs associated with familiarity and degree of familiarity during recognition. *International Journal of Neuroscience*, *112*(12), 1499–1512. https://doi.org/10.1080/00207450290158368

Caharel, S., Ramon, M., & Rossion, B. (2014). Face Familiarity Decisions Take 200 msec in the Human Brain: Electrophysiological Evidence from a Go/No-go Speeded Task. *Journal of Cognitive Neuroscience*, *26*(1), 81–95. https://doi.org/10.1162/jocn_a_00451

Caharel, S., & Rossion, B. (2021). The N170 is Sensitive to Long-term (Personal) Familiarity of a Face Identity. *Neuroscience*, *458*, 244–255. https://doi.org/10.1016/j.neuroscience.2020.12.036

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*, 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

Carey, S., De Schonen, S., Ellis, H. D., Bruce, V., Cowey, A., Ellis, A. W., & Perrett, D. I. (1997). Becoming a face expert. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *335*(1273), 95–103. https://doi.org/10.1098/rstb.1992.0012

Clutterbuck, R., & Johnston, R. A. (2002). Exploring Levels of Face Familiarity by Using an Indirect Face-Matching Measure. *Perception*, *31*(8), 985–994. https://doi.org/10.1068/p3335

Corpuz, R. L., & Oriet, C. (2022). Within-person variability contributes to more durable learning of faces. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, *76*(4), 270–282. https://doi.org/10.1037/cep0000282

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

Dalski, A., Kovács, G., & Ambrus, G. G. (2022). Evidence for a General Neural Signature of Face Familiarity. *Cerebral Cortex*, *32*(12), 2590–2601. https://doi.org/10.1093/cercor/bhab366

Dalski, A., Kovács, G., Wiese, H., & Ambrus, G. G. (2022). Characterizing the shared signals of face familiarity: Long-term acquaintance, voluntary control, and concealed knowledge. *Brain Research*, *1796*, 148094. https://doi.org/10.1016/j.brainres.2022.148094

Demanet, J., Dhont, K., Notebaert, L., Pattyn, S., & Vandierendonck, A. (2007). Pixelating Familiar People in the Media: Should Masking Be Taken at Face Value? *Psychologica Belgica*, *47*(4), Article 4. https://doi.org/10.5334/pb-47-4-261

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

Diamond, R., & Carey, S. (1986). Why faces are and are not special: An effect of expertise. *Journal of Experimental Psychology: General*, *115*, 107–117. https://doi.org/10.1037/0096-3445.115.2.107

Dobs, K., Isik, L., Pantazis, D., & Kanwisher, N. (2019). How face perception unfolds over time. *Nature Communications*, *10*(1), 1258. https://doi.org/10.1038/s41467-019-09239-1

Dowsett, A. J., Sandford, A., & Burton, A. M. (2016). Face learning with multiple images leads to fast acquisition of familiarity for specific individuals. *Quarterly Journal of Experimental Psychology*, *69*(1), 1–10. https://doi.org/10.1080/17470218.2015.1017513

Eick, C. M., Ambrus, G. G., & Kovács, G. (2021). Inhibition of the occipital face area modulates the electrophysiological signals of face familiarity: A combined cTBS-EEG study. *Cortex*, *141*, 156–167. https://doi.org/10.1016/j.cortex.2021.03.034

Eimer, M. (2000a). 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

Eimer, M. (2000b). The face-specific N170 component reflects late stages in the structural encoding of faces. *NeuroReport*, *11*(10), 2319. https://doi.org/10.1097/00001756-200007140-00050

Eimer, M. (2011). The Face-Sensitive N170 Component of the Event-Related Brain Potential. In A. J. Calder, G. Rhodes, M. H. Johnson, & J. V. Haxby (Eds.), *The Oxford Handbook of Face Perception* (Vol. 28, pp. 329–344). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199559053.013.0017

Eimer, M., Gosling, A., & Duchaine, B. (2012). Electrophysiological markers of covert face recognition in developmental prosopagnosia. *Brain*, *135*(2), 542–554. https://doi.org/10.1093/ brain/awr347

Ellis, H. D., & Lewis, M. B. (2001). Capgras delusion: A window on face recognition. *Trends in Cognitive Sciences*, *5*(4), 149–156. https://doi.org/10.1016/S1364-6613(00)01620-X

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

Gauthier, I., & Tarr, M. J. (2002). Unraveling mechanisms for expert object recognition: Bridging brain activity and behavior. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 431–446. https://doi.org/10.1037/0096-1523.28.2.431

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

Hancock, P. J. B. (2021). Familiar faces as islands of expertise. *Cognition*, *214*, 104765. https://doi.org/10.1016/j.cognition.2021.104765

Hancock, P. J. B., Bruce, V., & Burton, A. M. (2000). Recognition of unfamiliar faces. *Trends in Cognitive Sciences*, *4*(9), 330–337. https://doi.org/10.1016/S1364-6613(00)01519-9

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*(6), 223–233. https://doi.org/10.1016/S1364-6613(00)01482-0

Herzmann, G., Schweinberger, S. R., Sommer, W., & Jentzsch, I. (2004). What's special about personally familiar faces? A multimodal approach. *Psychophysiology*, *41*(5), 688–701. https://doi.org/10.1111/j.1469-8986.2004.00196.x

Hole, G. J., George, P. A., Eaves, K., & Rasek, A. (2002). Effects of Geometric Distortions on Face-Recognition Performance. *Perception*, *31*(10), 1221–1240. https://doi.org/10.1068/p3252

Huang, W., Wu, X., Hu, L., Wang, L., Ding, Y., & Qu, Z. (2017). Revisiting the earliest electrophysiological correlate of familiar face recognition. *International Journal of Psychophysiology*, *120*, 42–53. https://doi.org/10.1016/j.ijpsycho.2017.07.001

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

Jackson, A. F., & Bolger, D. J. (2014). The neurophysiological bases of EEG and EEG measurement: A review for the rest of us: Neurophysiological bases of EEG. *Psychophysiology*, *51*(11), 1061–1071. https://doi.org/10.1111/psyp.12283

Jenkins, R., & Burton, A. M. (2008). 100% Accuracy in Automatic Face Recognition. *Science*, *319*(5862), 435–435. https://doi.org/10.1126/science.1149656

Jenkins, R., & Burton, A. M. (2011). Stable face representations. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1571), 1671–1683. https://doi.org/10.1098/rstb.2010.0379

Jenkins, R., Dowsett, A. J., & Burton, A. M. (2018). How many faces do people know? *Proceedings of the Royal Society B: Biological Sciences*, *285*(1888), 20181319. https://doi.org/10.1098/rspb.2018.1319

Jenkins, R., White, D., Van Montfort, X., & Burton, A. M. (2011). Variability in photos of the same face. *Cognition*, *121*(3), 313–323. https://doi.org/10.1016/j.cognition.2011.08.001

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

Karimi-Rouzbahani, H., Ramezani, F., Woolgar, A., Rich, A., & Ghodrati, M. (2021). Perceptual difficulty modulates the direction of information flow in familiar face recognition. *NeuroImage*, *233*, 117896. https://doi.org/10.1016/j.neuroimage.2021.117896

Kaufmann, J. M., & Schweinberger, S. R. (2012). The faces you remember: Caricaturing shape facilitates brain processes reflecting the acquisition of new face representations. *Biological Psychology*, *89*(1), 21–33. https://doi.org/10.1016/j.biopsycho.2011.08.011

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

Kemp, R., Towell, N., & Pike, G. (1997). When Seeing should not be Believing: Photographs, Credit Cards and Fraud. *Applied Cognitive Psychology*, *11*(3), 211–222. https://doi.org/10.1002/(SICI)1099-0720(199706)11:3<211::AID-ACP430>3.0.CO;2-O

Kovács, G. (2020). Getting to Know Someone: Familiarity, Person Recognition, and Identification in the Human Brain. *Journal of Cognitive Neuroscience*, *32*(12), 2205–2225. https://doi.org/10.1162/jocn_a_01627

Kramer, R. S. S. (2021). Forgetting faces over a week: Investigating self-reported face recognition ability and personality. *PeerJ*, *9*, e11828. https://doi.org/10.7717/peerj.11828

Kramer, R. S. S., Jenkins, R., Young, A. W., & Burton, A. M. (2017). Natural variability is essential to learning new faces. *Visual Cognition*, *25*(4–6), 470–476. https://doi.org/10.1080/13506285.2016.1242522

Kramer, R. S. S., Ritchie, K. L., & Burton, A. M. (2015). Viewers extract the mean from images of the same person: A route to face learning. *Journal of Vision*, *15*(4), 1–9. https://doi.org/10.1167/15.4.1

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

Kutas, M., & Hillyard, S. A. (1980). Reading Senseless Sentences: Brain Potentials Reflect Semantic Incongruity. *Science*, *207*(4427), 203–205. https://doi.org/10.1126/science.7350657

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*. https://doi.org/10.3389/fpsyg.2013.00863

Lewin, C., & Herlitz, A. (2002). Sex differences in face recognition—Women's faces make the difference. *Brain and Cognition*, *50*(1), 121–128. https://doi.org/10.1016/S0278-2626(02)00016-7

Li, C., Burton, A. M., Ambrus, G. G., & Kovács, G. (2022). A neural measure of the degree of face familiarity. *Cortex*, *155*, 1–12. https://doi.org/10.1016/j.cortex.2022.06.012

Liu, C. H., Chen, W., & Ward, J. (2015). Effects of exposure to facial expression variation in face learning and recognition. *Psychological Research*, *79*(6), 1042–1053. https://doi.org/10.1007/s00426-014-0627-8

Longmore, C. A., Liu, C. H., & Young, A. W. (2008). Learning faces from photographs. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(1), 77–100. https://doi.org/10.1037/0096-1523.34.1.77

Longmore, C. A., Santos, I. M., Silva, C. F., Hall, A., Faloyin, D., & Little, E. (2017). Image dependency in the recognition of newly learnt faces. *Quarterly Journal of Experimental Psychology*, *70*(5), 863–873. https://doi.org/10.1080/17470218.2016.1236825

Luck, S. J. (2014). *An Introduction to the Event-Related Potential Technique*. The MIT Press.

Marzi, T., & Viggiano, M. P. (2007). Interplay between familiarity and orientation in face processing: An ERP study. *International Journal of Psychophysiology*, *65*(3), 182–192. https://doi.org/10.1016/j.ijpsycho.2007.04.003

Matthews, C. M., & Mondloch, C. J. (2018). Improving Identity Matching of Newly Encountered Faces: Effects of Multi-image Training. *Journal of Applied Research in Memory and Cognition*, *7*(2), 280–290. https://doi.org/10.1016/j.jarmac.2017.10.005

Memon, A., Hope, L., & Bull, R. (2003). Exposure duration: Effects on eyewitness accuracy and confidence. *British Journal of Psychology*, *94*(3), 339–354. https://doi.org/10.1348/000712603767876262

Menon, N., White, D., & Kemp, R. I. (2015). Identity-level representations affect unfamiliar face matching performance in sequential but not simultaneous tasks. *The Quarterly Journal of Experimental Psychology*, *68*(9), 1777–1793. https://doi.org/10.1080/17470218.2014.990468

Morrison, D. J., Bruce, V., & Burton, A. M. (2000). Covert face recognition in neurologically intact participants. *Psychological Research*, *63*(2), 83–94. https://doi.org/10.1007/s004260000037

Murphy, J., Ipser, A., Gaigg, S. B., & Cook, R. (2015). Exemplar variance supports robust learning of facial identity. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(3), 577. https://doi.org/10.1037/xhp0000049

Natu, V., & O'Toole, A. J. (2011). The neural processing of familiar and unfamiliar faces: A review and synopsis. *British Journal of Psychology*, *102*(4), 726–747. https://doi.org/10.1111/j.2044-8295.2011.02053.x

Neumann, M. F., Mohamed, T. N., & Schweinberger, S. R. (2011). Face and object encoding under perceptual load: ERP evidence. *NeuroImage*, *54*(4), 3021–3027. https://doi.org/10.1016/j.neuroimage.2010.10.075

Neumann, M. F., & Schweinberger, S. R. (2008). N250r and N400 ERP correlates of immediate famous face repetition are independent of perceptual load. *Brain Research*, *1239*, 181–190. https://doi.org/10.1016/j.brainres.2008.08.039

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*, e514361. https://doi.org/10.1155/2015/514361

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

Palermo, R., Rossion, B., Rhodes, G., Laguesse, R., Tez, T., Hall, B., Albonico, A., Malaspina, M., Daini, R., Irons, J., Al-Janabi, S., Taylor, L. C., Rivolta, D., & McKone, E. (2017). Do People Have Insight into their Face Recognition Abilities? *Quarterly Journal of Experimental Psychology*, *70*(2), 218–233. https://doi.org/10.1080/17470218.2016.1161058

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

Popova, T., & Wiese, H. (2022). The time it takes to truly know someone: Neurophysiological correlates of face and identity learning during the first two years. *Biological Psychology*, *170*, 108312. https://doi.org/10.1016/j.biopsycho.2022.108312

Popova, T., & Wiese, H. (2023). How quickly do we learn new faces in everyday life? Neurophysiological evidence for face identity learning after a brief real-life encounter. *Cortex*, *159*, 205–216. https://doi.org/10.1016/j.cortex.2022.12.005

Ramon, M., & Gobbini, M. I. (2018). Familiarity matters: A review on prioritized processing of personally familiar faces. *Visual Cognition*, *26*(3), 179–195. https://doi.org/10.1080/13506285.2017.1405134

Ritchie, K. L., & Burton, A. M. (2017). Learning faces from variability. *Quarterly Journal of Experimental Psychology*, *70*(5), 897–905. https://doi.org/10.1080/17470218.2015.1136656

Ritchie, K. L., Kramer, R. S. S., & Burton, A. M. (2018). What makes a face photo a ‘good likeness’? *Cognition*, *170*, 1–8. https://doi.org/10.1016/j.cognition.2017.09.001

Ritchie, K. L., Mireku, M. O., & Kramer, R. S. S. (2020). Face averages and multiple images in a live matching task. *British Journal of Psychology*, *111*(1), 92–102. https://doi.org/10.1111/bjop.12388

Ritchie, K. L., White, D., Kramer, R. S. S., Noyes, E., Jenkins, R., & Burton, A. M. (2018). Enhancing CCTV: Averages improve face identification from poor-quality images. *Applied Cognitive Psychology*, *32*(6), 671–680. https://doi.org/10.1002/acp.3449

Robertson, D. J., Kramer, R. S. S., & Burton, A. M. (2015). Face Averages Enhance User Recognition for Smartphone Security. *PLOS ONE*, *10*(3), e0119460. https://doi.org/10.1371/journal.pone.0119460

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. (1996). How Gorbachev primed Yeltsin: Analyses of associative priming in person recognition by means of reaction times and event-related brain potentials. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1383–1407. https://doi.org/10.1037/0278-7393.22.6.1383

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

Schweinberger, S. R., Huddy, V., & Burton, A. M. (2004). N250r: A face-selective brain response to stimulus repetitions. *Neuroreport*, *15*(9), 1501–1505. https://doi.org/10.1097/01.wnr.0000131675.00319.42

Schweinberger, S. R., & Neumann, M. F. (2016). Repetition effects in human ERPs to faces. *Cortex*, *80*, 141–153. https://doi.org/10.1016/j.cortex.2015.11.001

Schweinberger, S. R., Pfütze, E.-M., & Sommer, W. (1995). Repetition priming and associative priming of face recognition: Evidence from event-related potentials. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 722–736. https://doi.org/10.1037/0278-7393.21.3.722

Schweinberger, S. R., Pickering, E. C., Jentzsch, I., Burton, A. M., & Kaufmann, J. M. (2002). Event-related brain potential evidence for a response of inferior temporal cortex to familiar face repetitions. *Cognitive Brain Research*, *14*(3), 398–409. https://doi.org/10.1016/S0926-6410(02)00142-8

Sliwinska, M. W., Searle, L. R., Earl, M., O'Gorman, D., Pollicina, G., Burton, A. M., & Pitcher, D. (2022). Face learning via brief real-world social interactions includes changes in face-selective brain areas and hippocampus. *Perception*, *51*(8), 521–538. https://doi.org/10.1177/03010066221098728

Sommer, W., Hildebrandt, A., Kunina-Habenicht, O., Schacht, A., & Wilhelm, O. (2013). Sex differences in face cognition. *Acta Psychologica*, *142*(1), 62–73. https://doi.org/10.1016/j.actpsy.2012.11.001

Steblay, N., Dysart, J., Fulero, S., & Lindsay, R. C. L. (2003). Eyewitness Accuracy Rates in Police Showup and Lineup Presentations: A Meta-Analytic Comparison. *Law and Human Behavior*, *27*(5), 523–540. https://doi.org/10.1023/A:1025438223608

Sugiura, M. (2014). Neuroimaging studies on recognition of personally familiar people. *Frontiers in Bioscience*, *19*(4), 672. https://doi.org/10.2741/4235

Sweeney, L. N., & Lampinen, J. M. (2012). The effect of presenting multiple images on prospective and retrospective person memory for missing children. *Journal of Applied Research in Memory and Cognition*, *1*(4), 235–241. https://doi.org/10.1016/j.jarmac.2012.08.001

Tanaka, J. W. (2001). The entry point of face recognition: Evidence for face expertise. *Journal of Experimental Psychology: General*, *130*, 534–543. https://doi.org/10.1037/0096-3445.130.3.534

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

Wells, G. L., Small, M., Penrod, S., Malpass, R. S., Fulero, S. M., & Brimacombe, C. A. E. (1998). Eyewitness identification procedures: Recommendations for lineups and photospreads. *Law and Human Behavior*, *22*, 603–647. https://doi.org/10.1023/A:1025750605807

White, D., & Burton, A. M. (2022). Individual differences and the multidimensional nature of face perception. *Nature Reviews Psychology*, *1*(5), 287–300. https://doi.org/10.1038/s44159-022-00041-3

White, D., Burton, A. M., Jenkins, R., & Kemp, R. I. (2014). Redesigning photo-ID to improve unfamiliar face matching performance. *Journal of Experimental Psychology: Applied*, *20*, 166–173. https://doi.org/10.1037/xap0000009

White, D., Kemp, R. I., Jenkins, R., Matheson, M., & Burton, A. M. (2014). Passport Officers' Errors in Face Matching. *PLoS ONE*, *9*(8). https://doi.org/10.1371/journal.pone.0103510

Wiese, H. (2011). The structure of semantic person memory: Evidence from semantic priming in person recognition. *British Journal of Psychology*, *102*(4), 899–914. https://doi.org/10.1111/j.2044-8295.2011.02042.x

Wiese, H., Altmann, C. S., & Schweinberger, S. R. (2014). Effects of attractiveness on face memory separated from distinctiveness: Evidence from event-related brain potentials. *Neuropsychologia*, *56*, 26–36. https://doi.org/10.1016/j.neuropsychologia.2013.12.023

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), e13950. https://doi.org/10.1111/psyp.13950

Wiese, H., Hobden, G., Siilbek, E., Martignac, V., Flack, T. R., Ritchie, K. L., Young, A. W., & Burton, A. M. (2022). Familiarity is familiarity is familiarity: Event-related brain potentials reveal qualitatively similar representations of personally familiar and famous faces. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *48*(8), 1144–1164. 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., Komes, J., Tüttenberg, S., Leidinger, J., & Schweinberger, S. R. (2017). Age-related differences in face recognition: Neural correlates of repetition and semantic priming in young and older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*, 1254–1273. https://doi.org/10.1037/xlm0000380

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

Wild-Wall, N., Dimigen, O., & Sommer, W. (2008). Interaction of facial expressions and familiarity: ERP evidence. *Biological Psychology*, *77*(2), 138–149. https://doi.org/10.1016/j.biopsycho.2007.10.001

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

Woodman, G. F. (2010). A Brief Introduction to the Use of Event-Related Potentials (ERPs) in Studies of Perception and Attention. *Attention, Perception & Psychophysics*, *72*(8). https://doi.org/10.3758/APP.72.8.2031

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

Young, A. W., & Burton, A. M. (2018). Are We Face Experts? *Trends in Cognitive Sciences*, *22*(2), 100–110. https://doi.org/10.1016/j.tics.2017.11.007

Young, A. W., Hay, D. C., McWeeny, K. H., Flude, B. M., & Ellis, A. W. (1985). Matching Familiar and Unfamiliar Faces on Internal and External Features. *Perception*, *14*(6), 737–746. https://doi.org/10.1068/p140737

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