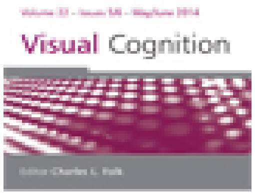

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Familiarity matters: A review on prioritized processing of personally familiar faces

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ABSTRACT
In this review, we synthesize the existing literature investigating personally familiar face processing and highlight the remarkable, enhanced processing efficiency resulting from real-life experience. Highly learned identity-specific visual and semantic information associated with personally familiar face representations facilitates detection, recognition of identity and social cues, and activation of person knowledge. These optimizations afford qualitatively different processing of personally familiar as compared to unfamiliar faces, which manifests on both the behavioural and neural level.

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Personally familiar face processing; detection; recognition; identification; ERPs; fMRI

Faces convey multiple streams of information that play a central role in social communication. Despite the subjective impression of efficient or "expert" perception with faces in general (Diamond & Carey, 1986), there is a clear discrepancy between familiar and unfamiliar faces. People can easily say that someone is unfamiliar based on his or her facial appearance, and can recognize facial expressions in strangers' faces. Processing the unique and invariant identity of faces, however, is markedly better for familiar as compared to unfamiliar faces (Bruce, 1994; Bruce, Henderson, Newman, & Burton, 2001; Burton, Schweinberger, Jenkins, & Kaufmann, 2015; Burton, Wilson, Cowan, & Bruce, 1999; Gobbini & Haxby, 2007; Jenkins, White, Van Montfort, & Burton, 2011; Natu & O'Toole, 2011; Ramon & Van Belle, 2016). Sorting photographs of faces by identity is surprisingly difficult and inaccurate if faces are unfamiliar, and nearly effortless and highly accurate if faces are familiar (Jenkins et al., 2011; see Figure 1a). Unfamiliar face matching is degraded by variation in head position or lighting (Hancock, Bruce, & Burton, 2000; Jenkins & Burton, 2011), suggesting that performance with unfamiliar faces relies to a greater extent on image matching (Hancock et al., 2000; Megreya & Burton, 2006). By contrast, recognition of personally familiar faces is highly accurate even with severely degraded images or videos of low quality (Bruce, 1994; Bruce et al., 2001; Burton et al., 1999; Burton et al., 2015; Gobbini & Haxby, 2007; Guntupalli & Gobbini, 2017; Jenkins et al., 2011; Natu & O'Toole, 2011; Ramon & Van Belle, 2016; Ramon, Vizioli, Liu-Shuang, & Rossion, 2015; Watier & Collin, 2009; see Figure 1b).

The concept of familiarity encompasses several facets that have important implications for face processing. First, *personally* familiar, *visually* familiar, *famous*, and *experimentally learned* faces differ not only in terms of their visual representations stored in memory, but also with regards to the availability of person knowledge, personal relationships, and emotions associated with the identities in question. Only some studies (e.g., for fMRI: Bartels & Zeki, 2000; Bartels & Zeki, 2004; Gobbini, Leibenluft, Santiago, & Haxby, 2004; Leibenluft, Gobbini, Harrison, & Haxby, 2004; Sugiura, Mano, Sasaki, & Sadato, 2011; Taylor et al., 2009), which we review here, have systematically examined differences among these levels of familiarity. Second, even considering only personally familiar others, the degree of familiarity will differ depending on the extent and nature of our personal relationship. Our experience with personally familiar others may range from casual, with minimal associated person knowledge, to extended and

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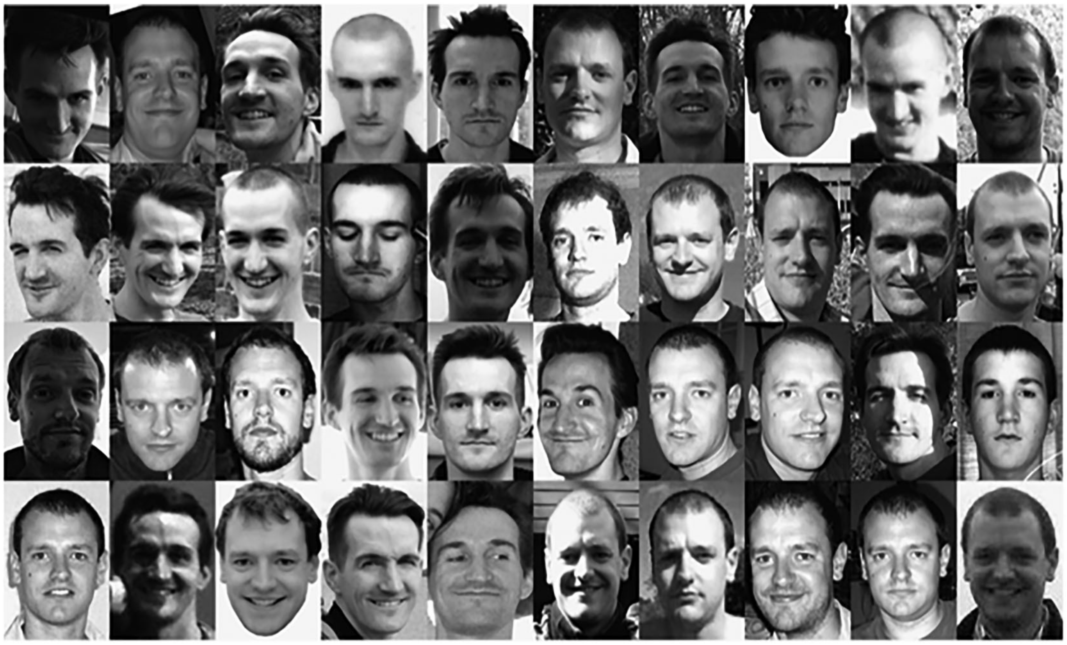

a.

b.

Figure 1. Robustness of personally familiar identity matching. Jenkins et al. (2011) demonstrated that sorting face photos by identity is significantly facilitated by familiarity. Presented with 40 images similar to those shown in (a), unfamiliar observers indicated that these images conveyed seven or eight identities; familiar observers correctly categorized them as belonging to one of the two identities depicted. (b) Examples of stimuli used in a behavioural experiment by Burton et al. (1999). A still from a low-quality video and photograph of the same individual are shown left and right, respectively. Assigning the same identity to videos and photos of personally familiar faces is remarkably robust, and superior to performance shown by unfamiliar observers.

prolonged interaction, with deep and intimate person knowledge.

Here, we focus on studies that have aimed to determine the effects of real-life experience with others, i.e., *personal familiarity*, on face processing. We examine how personal familiarity optimizes processing of faces at multiple levels in the hierarchical and branching human system for face and person perception (Gobbini & Haxby, 2007; Haxby, Hoffman, & Gobbini, 2000). Only familiar faces have associated person knowledge, and activation of such knowledge is stronger for personally familiar faces than for famous faces (Gobbini et al., 2004), and for close than more distant personal relationships (Leibenluft et al., 2004; for a review see Sugiura, 2014). As expressed by Proust in *In Search of Lost Time* (1913):

> Even the simple act which we describe as "seeing someone we know" is, to some extent, an intellectual process. We pack the physical outline of the creature we see with all the ideas we have already formed about him, and in the complete picture of him, which we compose in our minds those ideas have certainly

> the principal place. In the end they come to fill out so completely the curve of his cheeks, to follow so exactly the line of the nose, they blend so harmoniously in the sound of his voice that these seem to be no more than a transparent envelope, so that each time we see the face or hear the voice it is these notions which we recognize and to which we listen.

The behavioural and neuroimaging findings reviewed here demonstrate more robust representations and optimized processing of personally familiar as compared to unfamiliar faces. Similar to long-term learning that optimizes processing one's own language, multimodal experience with personally relevant individuals fine-tunes the human face processing system to facilitate social interactions. This exposure and interaction-dependent optimization can be observed at multiple levels: early visual processing for rapid detection of faces and social cues, later visual processes for view-invariant recognition, and post-perceptual processes for various aspects of social cognition (e.g., activation of person knowledge and construal of another person's current state of mind). All levels of familiarity may lead to similar effects on visual processing, that may differ quantitatively or qualitatively from personally familiar faces, but non-visual processes are qualitatively different for familiar faces. Collectively, the studies reviewed here suggest that real-life familiarity dramatically alters a range of cognitive processes and emphasize that investigation of the human system for face perception should not conflate familiar and unfamiliar face processing.

Investigations that have used personally familiar faces are relatively few compared to those involving unfamiliar, famous, and visually familiar faces. While all are crucial for our understanding of the human face processing system, we propose that investigating processing of highly learned, socially important personally familiar faces is fundamental for understanding the full potential of the human face processing system.

The special status of personally familiar faces

From our own experience and without rigorous scientific inquiry, most of us will appreciate that personally familiar faces are special. Unexpectedly spotting an old schoolmate in a crowded lecture theatre at university years after high school graduation seems effortless, if not involuntary. Personally familiar face recognition and identification is robust despite dramatic changes in viewpoints, viewing distances, image resolution, or changes that occur naturally (Balas, Cox, & Conwell, 2007; Bruce et al., 2001; Bruck, Cavanagh, & Ceci, 1991; Ramon, 2015a), which dramatically impair performance for unfamiliar face identity matching (Hancock et al., 2000). Thus, the subjective impression that we can readily identify unfamiliar individuals based on identity card pictures or in a police line-up (Jenkins & Burton, 2011; White, Kemp, Jenkins, Matheson, & Burton, 2014) appears to be an illusion with serious real-world consequences.

However, the process of recognizing a personally familiar face, even years after not having seen that person, is not merely a visual task. We spend a great deal of our time engaged in social interactions, resulting in detailed and varied knowledge about familiar individuals. This includes biographical information, preferences, social relationships, personality traits, outlook, opinions, and intentions, as well as episodic information and shared memories (Gobbini, 2010; Gobbini et al., 2004; Gobbini & Haxby, 2007; Haxby & Gobbini, 2011; Leibenluft et al., 2004). The immediate retrieval of person knowledge about a familiar other determines our approach to that individual and is a necessary precondition for appropriate and smooth social interactions.

Here we argue that the remarkably robust processing of a personally familiar face arises due to optimization across these various levels of face processing. Highly overlearned, invariant facial representations enable recognition across a range of viewing conditions and efficient retrieval of related person knowledge and emotional responses. Moreover, activation of person knowledge may in turn facilitate visual processing in a top-down manner, e.g., through activation of prior knowledge about the visual appearance of a personally familiar other. In the following we first outline the different types of familiarity that have been used to assess its effects on face processing. Then we review the empirical findings of processing differences due to personal familiarity acquired through repeated real-life interactions. The behavioural evidence is reviewed first, and structured according to task and level of processing assessed, followed by neuroimaging studies (electrophysiology and functional magnetic resonance imaging; fMRI).

The many faces of familiarity

Several lines of research have sought to identify how the apparently effortless act of recognizing personally familiar faces is achieved (e.g., Gobbini & Haxby, 2007; Natu & O'Toole, 2011; Ramon et al., 2015). However, this undertaking is challenging for at least one simple reason: every individual has a different circle of personally familiar faces. That is, certain faces will be highly familiar to one person, but only vaguely familiar, or entirely unfamiliar, to others. From an experimental researcher's point of view this seemingly mundane fact makes research design quite challenging. Investigating processing of personally familiar faces always involves a compromise between the number of stimuli used across participants, rigour of stimulus control, and available cohort size, as well as inter-individual variability regarding the level of familiarity.

For decades researchers have been using faces of famous individuals to gain insights into the effects of familiarity. This approach generally allows for large stimulus sets and the use of identical stimuli across participants (e.g., Fairhall, Anzellotti, Ubaldi, & Caramazza, 2014; Weibert et al., 2016; Yan, Young, & Andrews T, 2017). However, as is the case for personally familiar faces, to account for inter-individual differences in familiarity with famous identities across subjects, the stimulus sets used would either need to be reduced to the shared known famous identities, or be selected based on participants' self-reported familiarity. Leaving aside the issue of inter-individual differences in response criteria, the latter approach would involve data analyses based on different visual input. Many early studies have used iconic images of celebrities or political figures that were famous when media was substantially less available (e.g., Marilyn Monroe, Che Guevara). Previous work has shown that recognition of such famous individuals is more image-, as opposed to identity-, based: they could not be recognized by their childhood pictures (Carbon, 2008). Exposure to more contemporary celebrities involves comparatively more variability in viewing conditions, which in turn minimizes image-based recognition and identification. Nonetheless, even for famous faces learned across a range of images and videos or films nowadays, the visual memory representations formed will be limited to the appearance available through the media. Moreover, the degree of inter-subject variability concerning the familiarity with individual celebrities used is difficult to control and will likely determine the extent to which hypothesized effects are observed.

More importantly, famous faces are not learned in the same way as personally familiar faces: the learning process involves impersonal observation at a distance, mostly through the media, rather than in person. Person knowledge associated with famous faces, as compared to that for personally familiar faces, is in general more rudimentary. In the case of actors, person knowledge can be more variable and is affected by the roles played in different movies. Furthermore, reciprocal feedback characteristic of social interactions, which are typical of frequent and extensive contacts with personally familiar individuals, play no role in learned familiarity with famous faces. Personally familiar faces used in the majority of studies reviewed here involve faces of friends and relatives. Participants have detailed, view-invariant representations (Burton et al., 1999; Pachai, Sekuler, Bennett, Schyns, & Ramon, 2017; Ramon, 2015a), and well-developed person knowledge of these individuals (Idson & Mischel, 2001), and they evoke an individual-specific emotional response (Gobbini et al., 2004). Other personally familiar faces associated with more impoverished person knowledge and limited visual experience (e.g., shop clerks or students who sit in the back of a class) are less relevant for investigating the optimization of face processing that is the focus of this review.

Another line of research has resorted to *experimental familiarization* with initially unfamiliar face stimuli (e.g., Cloutier, Kelley, & Heatherton, 2011; Dubois et al., 1999; Gobbini & Haxby, 2006; Guntupalli, Wheeler, & Gobbini, 2017; Kosaka et al., 2003; Natu & O'Toole, 2015; Rossion, Schiltz, Robaye, Pirenne, & Crommelinck, 2001). This approach has the advantage of high control over both the stimulus material and exposure across participants. However, this type of familiarity differs fundamentally from that which accrues over years of varied exposure and personal interaction in natural settings. Usually, a set of images is learned and participants may engage in memory strategies that they would not normally apply in everyday life. Furthermore, these procedures often use the same images at learning and recognition phases, allowing image-based learning. Finally, those variations characteristic of natural exposure are usually not incorporated in the learning regime: social interactions involve changes in viewing distances, viewpoints, as well as facial motion, which may be crucial components for the formation of a robust representation for recognition, and also for subtle, nuanced variations in facial expression or direction of attention (Chauhan, Visconti di Oleggio Castello, Soltani, & Gobbini, 2017; Gill, Garrod, Jack, & Schyns, 2014; Visconti di Oleggio Castello, Guntupalli, Yang, & Gobbini, 2014). Nevertheless, investigations employing experimental familiarization might shed light on the importance of semantic information associated with faces in terms of facilitated memory recognition (Schwartz & Yovel, 2016; Todorov, Gobbini, Evans, & Haxby, 2007; Verosky, Todorov, & Turk-Browne, 2013), modulation of the evoked potential response (Abdel Rahman, 2011; Heisz & Shedden, 2009; Kaufmann, Schweinberger, & Burton, 2009; Paller et al., 2003; Taylor, Shehzad, & McCarthy, 2016), and brain areas involved as shown with fMRI (Cloutier et al., 2011; Gobbini & Haxby, 2006; Natu & O'Toole, 2015; Todorov et al., 2007; Verosky et al., 2013).

Some studies have used *personally* familiar faces as stimuli, i.e., those that have become familiar through extensive exposure under naturalistic conditions in real life settings (e.g., Arsalidou, Barbeau, Bayless, & Taylor, 2010; Bartels & Zeki, 2000; Bartels & Zeki, 2004; Bobes, Lage Castellanos, Quinones, Garcia, & Valdes-Sosa, 2013; Chauhan et al., 2017; Gobbini et al., 2004; Gobbini et al., 2013; Leibenluft et al., 2004; Nakamura et al., 2000; Ramon, 2015a, 2015b; Ramon et al., 2015; Ramon & Van Belle, 2016; Ramon, Busigny, Gosselin, & Rossion, 2017; Ramon, Caharel, & Rossion, 2011; Taylor et al., 2009; Visconti di Oleggio Castello et al., 2014; Visconti di Oleggio Castello & Gobbini, 2015; Visconti di Oleggio Castello, Halchenko, Guntupalli, Gors, & Gobbini, 2017;Visconti di Oleggio Castello, Wheeler, Cipolli, & Gobbini, 2017; Watier & Collin, 2009). This is the type of face familiarity we cover in this review: the one that develops over years of repeated personal interactions and includes a range of familiar individuals, such as relatives, colleagues, and friends.

Behavioural differences between personally familiar and unfamiliar face processing

Behavioural studies have shown that many aspects of face perception are facilitated when faces are personally familiar. Here we review the behavioural literature, which is organized according to different levels of processing that roughly mirror the face processing stages proposed by Bruce and Young (1986). Face identification involves *detection* of a face, *familiarity recognition*[1] ("I know that person"), *identification* ("It's John!"), and automatic *activation of person knowledge* ("He's an old, but unreliable, friend") and an emotional response. Additionally, *social cues* are decoded, such as direction of attention and facial expression ("He doesn't see me, and he looks distracted").

Behavioural studies investigating the effects of real-life familiarity, in comparison to neurophysiological and neuroimaging studies, are relatively numerous. These have addressed, for example, recognition of identity across views and from low quality still images and videos (Bruce, 1982; Burton et al., 1999), or more generally the robustness of the representation of personally familiar as compared to unfamiliar faces (Gobbini et al., 2013; Ramon et al., 2015; Tong & Nakayama, 1999; Visconti di Oleggio Castello, Wheeler et al., 2017), or to famous and unfamiliar faces (Keyes & Zalicks, 2016; Liccione et al., 2014). Other investigations have focused on the speed of familiar face detection and categorization (Caharel, Ramon, & Rossion, 2014; Gobbini et al., 2013; Ramon et al., 2011; Ramon et al., 2015; Visconti di Oleggio Castello, Wheeler et al., 2017; Visconti di Oleggio Castello & Gobbini, 2015), as well as facilitation of processing socially-salient information. In a study of perception of gaze direction and head angle, perception of eye gaze was detected around 100 ms faster in familiar as compared to unfamiliar faces (Visconti di Oleggio Castello et al., 2014). Finally, others have established familiarity-related differences in face discrimination or perceptual information processing (Chauhan et al., 2017; Ramon, 2015a, 2015b; Ramon & Van Belle, 2016; Visconti di Oleggio Castello & Gobbini, 2015; Watier & Collin, 2009). We review the available behavioural evidence according to the tasks employed across different paradigm and procedures.

Detecting and determining the familiarity of a face

Familiar faces are categorized as being familiar extremely quickly, and reliably faster, than unfamiliar faces are categorized as such (Haan & Kollenburg, 2005). Speeded Go/No-Go paradigms have revealed behavioural familiar face decisions in under 400 ms (Ramon et al., 2011), with a 80 ms advantage over unfamiliar faces. Recently, Visconti di Oleggio Castello and Gobbini (2015) reported that familiar faces can drive a forced choice saccade in as little as 180 ms. The highly learned representations of familiar faces afford more robust and rapid detection when attentional resources are reduced, or even without awareness (Gobbini et al., 2013) (see Figure 2).

Other studies have addressed the type of information that is critical for observers to decide whether faces are familiar or not. Familiar and unfamiliar face categorization under initially visually ambiguous conditions suggest that familiar face recognition requires less high spatial frequency information (Ramon et al., 2015; see Figure 3a). Recordings of eye movements during categorization of familiar and unfamiliar faces indicate that observers sample facial information differently (Van Belle, Ramon, Lefevre, & Rossion, 2010). Observers fixated more on the diagnostic eye region during unfamiliar face processing, while information sampling was comparatively more distributed during processing of familiar faces (see Figure 3b).

Processing of facial identity: familiar face matching, discrimination, identification

The studies reviewed thus far indicate that detecting and determining the familiarity of a face is extremely efficient. Recognition of the *identity* of familiar faces is also highly robust. Personally familiar face *identification* can be highly accurate even after considerable time periods have elapsed, and over a very large range of image variation (Bruck et al., 1991; Burton et al., 2015). Bahrick, Bahrick, and Wittlinger (1975) reported that subjects could identify 90% of their former classmates' faces within 15 years of graduation; after 48 years they still identified 70%. Bruck et al. (1991) reported that individuals could accurately identify former classmates based on high school yearbook images (87% of names provided correct). Moreover, their ability to match classmates' yearbook images with photographs taken 25 years later was highest for very familiar former classmates (78%). Further studies documented that personally familiar face identification is also extremely robust across changes in viewing distance (Ramon, 2015a; see Figure 4) viewpoint, and facial expression (Balas et al., 2007; Bruce, 1982; Keyes & Zalicks, 2016; Liccione et al., 2014). This is contrasts

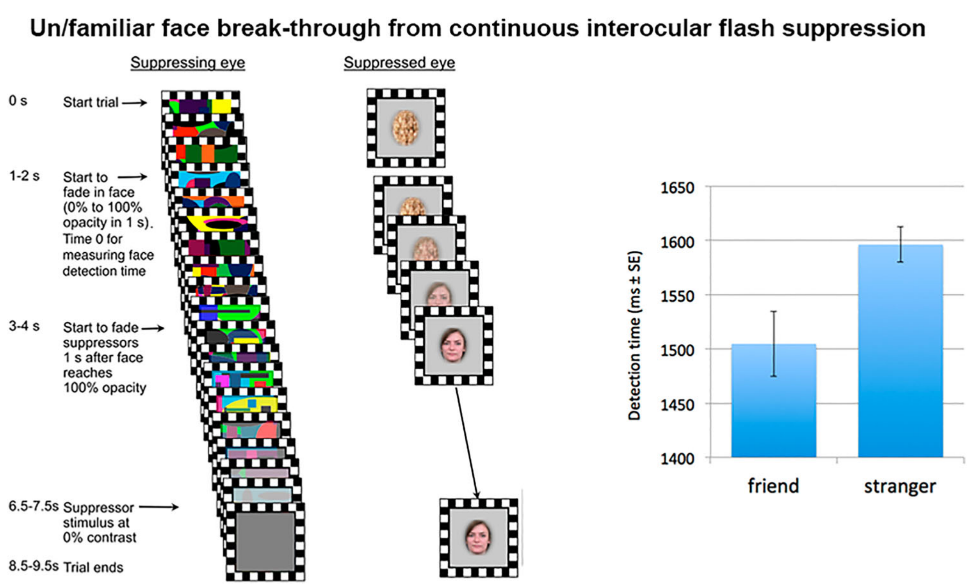

Figure 2. Personally familiar face detection during continuous inter-ocular flash suppression. Using this paradigm, Gobbini et al. (2013) addressed whether familiarity with faces expedites break-through from inter-ocular suppression. One eye was presented different high contrast collages of coloured shapes at 10 Hz. The other eye was presented a phase-scrambled image that faded into an intact face image over 1 s; the intact face remained at full opacity for 1 s, while the suppressing stimuli slowly faded to a grey square. The task required participants to make a manual response as soon as they saw a face and, thus, was orthogonal to face identity and the familiarity of the faces. The authors demonstrated that personally familiar faces break through inter-ocular suppression ~90 ms faster than unfamiliar faces (advantage displayed right) suggesting that face familiarity is processed without awareness. (Reproduced from Gobbini et al., 2013).

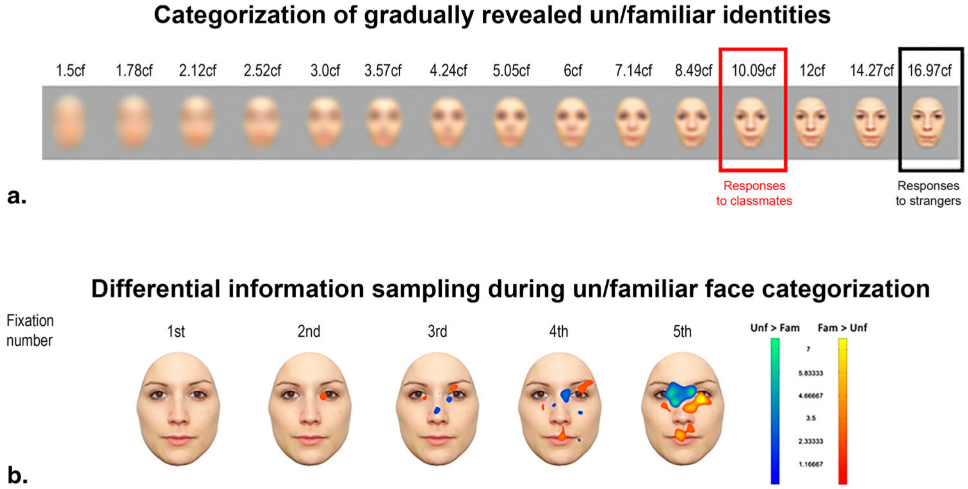

Figure 3. Face recognition is facilitated by personal familiarity and involves familiarity-dependent information sampling. (a) Using a novel dynamic visual stimulation paradigm during fMRI acquisition, Ramon et al. (2015) slowly revealed personally familiar (classmates) and unfamiliar faces. Each identity was initially shown as a severely low-pass filtered image (1.5 cycles per face (c/f)), while consecutively presented stimuli contained parametrically increasing amounts of high spatial frequency information to gradually reveal each identity. Personally familiar face decisions occurred significantly faster than unfamiliar face decisions. (b) Presented with full-face stimuli, individuals sample facial information differently across time, depending on the familiarity of the individual depicted (Van Belle et al., 2010). Fixations on personally familiar faces are increasingly distributed across individual facial features, while unfamiliar face processing involves sampling that is comparatively more restricted to the eye region.

with matching of unfamiliar face images, which can be severely disrupted by image variations such as head angle, lighting, image quality, and expression (Hancock et al., 2000; Jenkins & Burton, 2011).

Other studies have revealed facilitatory effects of personal familiarity on *identity matching* or *face discrimination*. Burton and coauthors (Burton et al., 1999) reported near perfect performance for associating images of familiar individuals with highly degraded CCTV video footage, while unfamiliar subjects performed at chance (Bruce et al., 2001) (see Figure 1b). Individually determined psychophysical thresholds indicate that familiarity broadens the range of spatial frequencies from which information for facial identity processing can be derived for efficient face matching (Watier & Collin, 2009). More efficient processing of available facial information due to personal familiarity has also been observed for face discrimination based on vertically arranged inter-feature relationships (Ramon, 2015b), as well as the overall facial configuration between the eyes and the mouth (Ramon, 2015a). Finally, very recent psychophysical evidence suggests that familiarity selectively enhances sensitivity to horizontal structure of faces (Pachai et al., 2017), which is diagnostic for processing facial identity (Dakin & Watt, 2009; Pachai, Sekuler, & Bennett, 2013).

Overall, the aforementioned behavioural findings suggest that overlearned representations of individuals' facial appearance acquired through repeated and prolonged exposure facilitates visual processing. This in turn makes familiar face processing (detection, recognition, and identification) remarkably robust, accurate, and rapid, compared to processing of unfamiliar faces. Thus, real-life experience with personally meaningful individuals has clear implications for face processing.

Familiarity effects observed with neuroimaging

The behavioural findings reviewed thus far suggest that personally familiar faces indeed have a special status: they are rapidly recognized and identified with high fidelity across various viewing conditions. In the following sections, we first review evidence from electrophysiological studies, which have sought to determine the time course of familiarity-dependent modulation during face processing. This is followed by a review of fMRI studies, conducted to delineate the brain regions involved in personally familiar face processing.

Electrophysiological studies have aimed to determine when personal familiarity modulates event-related potentials (ERPs). Previous studies have

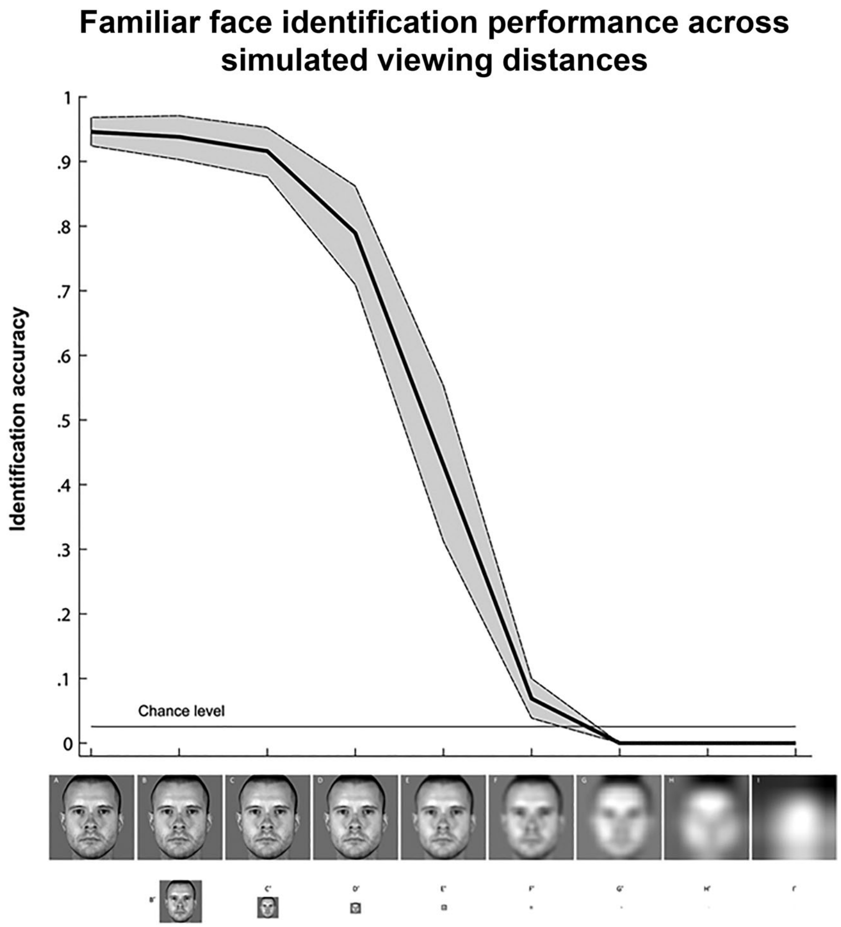

Figure 4. Verbal identification of personally familiar faces across viewing distances. Ramon (2015a) reported that personally familiar faces (departmental colleagues) can be verbally identified across in an extremely robust manner across a wide range of simulated viewing distances (3.3 to 844.8 m using the Laplacian pyramid; Burt & Adelson, 1983). The reduced-size images displayed in the bottom row depict stimuli used in the experiment to simulate viewing distances; the top row displays the visual information projected to the retina.

consistently reported modulation by familiarity for ERPs after 200 ms post stimulus onset (Caharel et al., 2014; Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Todd, Lewis, Meusel, & Zelazo, 2008; Webb et al., 2010; for own-face, learned, and famous face processing see e.g., Gosling & Eimer, 2011; Kaufmann et al., 2009; Miyakoshi, Kanayama, Nomura, Iidaka, & Ohira, 2008; Pierce et al., 2011; Tacikowski, Jednoróg, Marchewka, & Nowicka, 2011; Tanaka, Curran, Porterfield, & Collins, 2006; for a recent review see Huang et al., 2017). Employing a time-sensitive Go/No-Go paradigm in which participants responded to personally familiar or unfamiliar faces, Caharel et al. (2014) reported the earliest differential responses at about 210 ms after stimulus onset at occipito-temporal electrodes.

Empirical findings pertaining to *earlier* components' (<200 ms post stimulus onset) modulation by personal familiarity are on the other hand, less consistent. The N170 (M170 in magnetoencephalography) is the earliest face-preferential response not driven by low-level visual information, which peaks at around 170 ms after stimulus onset at occipito-temporal sites (Bentin & Deouell, 2000; Eimer, 2000; Furey et al., 2006; Rossion et al., 1999; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002). Studies that have found N170/M170 modulation related to personal familiarity have, however, reported variable effects. For instance, some authors observed familiarity-related decreases in the magnitude of this component (Todd et al., 2008), while others reported N170/M170 increases for personally familiar faces (Caharel, Fiori, Bernard, Lalonde, & Rebai, 2006; Caharel et al., 2014; Kloth et al., 2006; Wild-Wall, Dimigen, & Sommer, 2008), or no modulation at all (Keyes, Brady, Reilly, & Foxe, 2010; Kotlewska & Nowicka, 2015).

Studies using famous and unfamiliar faces may point towards potentially promising avenues to help account for these observed discrepancies regarding early ERP components. Recently, Huang et al. (2017) presented individual participants only with those famous face stimuli which they reported as being *most familiar* to them. Based on their observations, the authors concluded that "cognitive discrimination between familiar and unfamiliar faces starts no less than 200 ms after stimulus onset" (Huang et al., 2017, p. 42). Barragan-Jason, Cauchoix, and Barbeau (2015) recently reported familiarity-related processing differences as early as 140 ms after stimulus onset observed using multivariate pattern analyses (MVPA) of data from a Go/No-Go paradigm involving numerous well-known media celebrities. This is compatible with other behavioural evidence indicating early modulation by familiarity (Visconti di Oleggio Castello & Gobbini, 2015). Such findings support the idea that degree of familiarity and/or prior knowledge about to-be-represented identities may determine whether modulation of early ERP components will be observed. Further studies are therefore needed to clarify the impact of differential expectations or task demands, which can dramatically affect performance in healthy and impaired individuals (Ramon, in press), as well as early ERP components (Johnston, Overell, Kaufman, Robinson, & Young, 2016), as well as varying degrees of familiarity.

Regarding later components, notably the N250 and N400, the reported findings are more consistent. Collectively, they suggest reliable familiarity-dependent modulation, which has been interpreted as reflecting activation of representations in long-term memory and semantic processing. Both components' amplitudes are decreased for unfamiliar faces, compared to different types of familiar faces (famous, personally familiar, and experimentally learned faces; Bentin & Deouell, 2000; Caharel, Courtay, Bernard, Lalonde, & Rebai, 2005, 2006; Eimer, 2000; Herzmann et al., 2004; Paller, Gonsalves, Grabowecky, Bozic, & Yamada, 2000; Pfütze, Sommer, & Schweinberger, 2002; Schweinberger et al., 2002; Tanaka et al., 2006). The pattern observed for unfamiliar, famous, and personally familiar faces suggests that the degree of familiarity modulates expression of these components (Herzmann et al., 2004; Huang et al., 2017).

In summary, while the available studies support the idea of familiarity-related processing differences after 210–250 ms post stimulus onset, further electrophysiological investigations are required to account for the discrepant findings reported for earlier components. Studies using novel analytical techniques, different degrees of personal familiarity, a systematic investigation of differences between paradigms and procedures, and individual differences are required to investigate their role in the more variable early processing signatures related to personal familiarity.

Functional neuroimaging studies of face processing, using both Positron Emission Tomography (PET) and fMRI, have consistently shown that faces elicit stronger responses than non-face objects in a distributed network of brain regions. According to the functional model proposed by Haxby et al. (2000), this distributed face processing system can be divided into a core and an extended system, which are considered to have distinct functional roles (see Figure 5a). The model proposes that the core system is involved in the visual analysis of faces, whereas the extended system is involved in extraction of information from faces, such as direction of attention, emotional content, speech processing, and person knowledge.

While the original model stipulated that the core system consisted of the occipital face area (OFA), fusiform face area (FFA), and posterior superior temporal sulcus (pSTS) (Gauthier et al., 2000; Haxby et al., 1994; Haxby et al., 2000; Haxby & Gobbini, 2007; Haxby & Gobbini, 2011; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Sergent & Signoret, 1992), more recently, additional face areas located in the anterior temporal and right inferior frontal cortices (ATFA and rIFFA, respectively) have been included in the core system (Fox, Iaria, & Barton, 2009; Guntupalli et al., 2017; Haxby et al., 1994; Ishai, Ungerleider, & Haxby, 2000; Pitcher, Dilks, Saxe, Triantafyllou, & Kanwisher, 2011; Rajimehr, Young, & Tootell, 2009; Tsao, Moeller, & Freiwald, 2008; Tsao, Schweers, Moeller, & Freiwald, 2008; Vignal, Chauvel, & Halgren, 2000; Visconti di Oleggio Castello, Castello et al., 2017; for reviews see Collins & Olson, 2014; Duchaine & Yovel, 2015) (see Figures 5b and c). The proposal that the ATFA and rIFFA are part of the core system and play a role in the representation of familiarity and identity has been supported further by a recent fMRI study (Visconti di Oleggio Castello, Castello et al., 2017) that applied MVPA to investigate the neural systems that distinguish personally

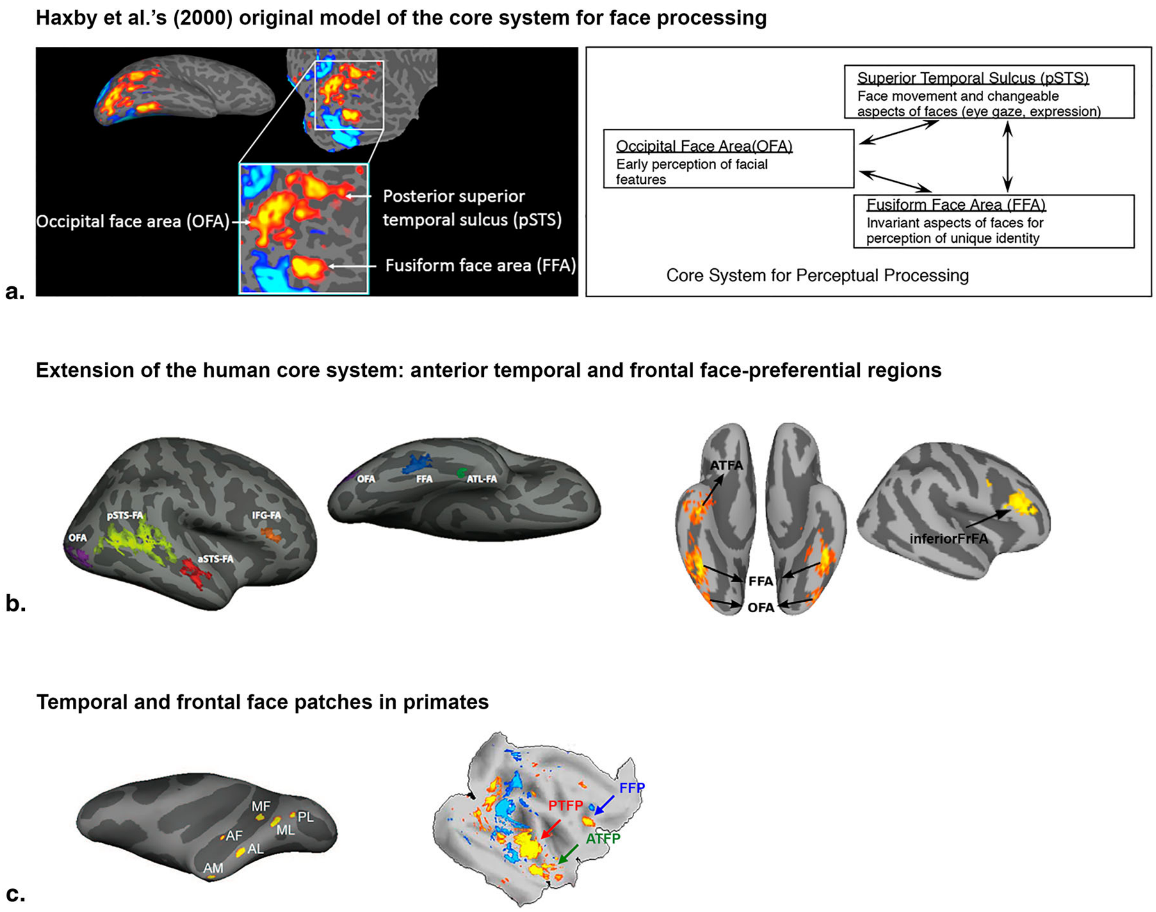

Figure 5. Face-preferential regions in the human and monkey brain. (a) In their original model, Haxby et al. (2000) describe the core system for the visual analysis of faces as comprising the OFA, FFA and pSTS. (b) Subsequent work (left and middle) has identified face-preferential regions in the anterior temporal and right inferior frontal cortices (ATL-FA / ATFA; IFG-FA / Inferior FrFA), considered as components of the core system (Guntupalli et al., 2017; Duchaine & Yovel, 2015). (c) Neuroimaging studies with non-human primates have identified multiple face patches in temporal cortex (left; Freiwald & Tsao, 2010), as well as a frontal face patch (right; Rajimehr et al., 2009); arrows indicate the location of posterior (red) and anterior (green) temporal, as well as frontal (blue) face patches. Abbreviations: AF, anterior frontal; AL, anterior lateral; AM, anterior medial; ATL-FA / ATFA, anterior temporal face area; FFP, frontal face patch; FFA, fusiform face area; IFG-FA or InferiorFrFA, inferior frontal face area; OFA, occipital face area; pSTS, posterior superior temporal sulcus; PTFP, posterior temporal face patch.

familiar from unfamiliar faces. In this fMRI experiment, face familiarity, controlling for identity, could be decoded in the areas of the posterior core system (OFA, FFA, pSTS) and in areas of the anterior temporal lobe and inferior frontal cortex (Guntupalli et al., 2017; Visconti di Oleggio Castello, Castello et al., 2017).

Previous studies have not shown a consistent difference in the overall strength, i.e., univariate neural response to personally familiar and unfamiliar faces in core system areas (Gobbini et al., 2004; Leibenluft et al., 2004; Ramon et al., 2015; for reviews see Gobbini, 2010; Gobbini & Haxby, 2007; Haxby & Gobbini, 2011; and Natu & O'Toole, 2011). Earlier studies had mostly failed to find univariate modulation by personal familiarity in anterior temporal cortex (Gobbini et al., 2004; Leibenluft et al., 2004). However, using a novel dynamic visual stimulation paradigm, Ramon et al. (2015) observed enhanced responses to personally familiar vs. unfamiliar face recognition in both face-preferential and non-face-preferential regions. These included (among others) the bilateral anterior and inferior temporal regions in personally familiar face processing, as well as the amygdala, hippocampus, and perirhinal cortex (see Figure 6). Using the same visual stimulation paradigm in a study of personally familiar and unfamiliar face processing in non-human primates, Landi and Freiwald (2017) recently replicated the familiarity-dependent responses in anterior ventral and medial temporal regions reported by Ramon et al. (2015).

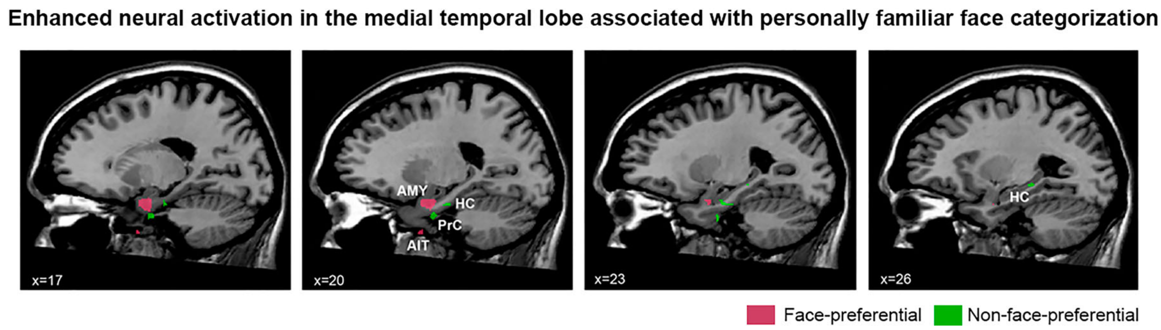

Figure 6. Medial temporal lobe activation is modulated by personal familiarity. Personally familiar, relative to unfamiliar, face categorization was associated with increased activation across various regions, including anterior temporal and medial temporal lobe structures (Ramon et al., 2015). The latter included both face-preferential (red) and non-face-preferential (green) areas of the amygdala, hippocampus and perirhinal cortex (AMY, HC, PrC).

Collectively, these univariate findings are also in line with previous reports of personally meaningful stimuli eliciting increased temporal pole activation (Nakamura et al., 2000) and selective responses across larger proportions of neurons in the amygdala, entorhinal and perirhinal cortex, and hippocampus of pre-surgical patients (Viskontas, Quiroga, & Fried, 2009). MVPA performed within face-preferential regions revealed that that familiar faces elicited highly similar neural representations in bilateral amygdala and left FFA (Ramon et al., 2015), suggesting categorical signalling of familiarity within these regions.[2]

Familiarity-dependent modulation in areas beyond the core system has been reported in numerous earlier studies, which have highlighted regions thought to be involved in spontaneous activation of person knowledge (Arsalidou et al., 2010; Bartels & Zeki, 2000, 2004; Bobes et al., 2013; Gobbini et al., 2004; Krienen, Tu, & Buckner, 2010; Leibenluft et al., 2004; Taylor et al., 2009), as well as more recent studies (Ramon et al., 2015; Visconti di Oleggio Castello et al., 2017).

Gobbini et al. (2004) and Leibenluft et al. (2004) reported increased responses for personally familiar faces as compared to famous faces, and for close as compared to more distant personally familiar faces, across a distributed set of areas that are part of the extended system. These included regions associated with "Theory of Mind" (ToM) (the medial prefrontal cortex and temporoparietal junction; Frith & Frith, 2012; Saxe & Kanwisher, 2003), retrieval of information from long term memory (precuneus; Burgess, Maguire, Spiers, & O'Keefe, 2001; Fletcher et al., 1995; Gorno-Tempini et al., 1998; Ishai et al., 2000; Leveroni et al., 2000), and emotional response and processing of biological significance of affective visual stimuli (amygdala, insula, and ventral striatum; Adolphs, Tranel, & Damasio, 1998; Davis & Whalen, 2001; Olausson et al., 2002; White, 1989). Based on their results, Gobbini and colleagues (Gobbini, 2010; Gobbini et al., 2004; Gobbini & Haxby, 2006, 2007; Haxby & Gobbini, 2007; Leibenluft et al., 2004) hypothesized that successful recognition of personally familiar individuals involves not only recognition of the visual appearance of a face, but also retrieval of person knowledge, episodic memories, and the emotional response to known individuals. The term "person knowledge" refers to information such as personal traits, intentions, attitudes, transient mental states, social network, and biographical information that are associated with known individuals. According to their model, Gobbini and Haxby (2007) proposed that ToM areas encode those aspects of person knowledge that are related to personal traits, social relationships, transient mental states, and intentions, while the precuneus and the anterior temporal regions are involved in retrieval of episodic memory and biographical information (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Frith & Frith, 2006; Gorno-Tempini et al., 1998; Leveroni et al., 2000; Nakamura et al., 2000; Todorov et al., 2007). The role of person knowledge in facilitating recognition is supported by recent behavioural evidence where previously unfamiliar faces associated with fictitious semantic information were recognized more efficiently than faces devoid of such information (Schwartz & Yovel, 2016).

We also have person knowledge about famous faces acquired through news channels, tabloids, movie theatres, and the media in general. However, this person knowledge for famous faces evokes a weaker response in ToM areas. Gobbini et al. (2004) showed that the hemodynamic response to personally familiar faces was stronger than to famous faces and strangers' faces in ToM areas and the precuneus. Similar findings have also been reported by Taylor et al. (2009) and Sugiura et al. (2011).

The role of ToM areas in the representation of personally familiar faces has been replicated in subsequent fMRI experiments using personally familiar faces characterized by different types of social and emotional attachment (Arsalidou et al., 2010; Bartels & Zeki, 2004; Bobes et al., 2013; Taylor et al., 2009). The role of the ToM areas in retrieval of person knowledge has been corroborated in studies that used experimentally learned person knowledge associated with faces (Cloutier et al., 2011; Todorov et al., 2007) and verbal statements about the personal attributes of friends (Krienen et al., 2010) (see Figure 7). Interestingly, visual familiarity with faces alone appears insufficient to activate areas associated with person knowledge, such as the ToM areas (Cloutier et al., 2011; Gobbini & Haxby, 2006; Natu & O'Toole, 2015). Moreover, individuals with congenital (or developmental) prosopagnosia have been reported to show a lack of modulation of activity in these ToM areas when they perceive familiar faces, which they do not recognize (Avidan & Behrmann, 2009).

Variations in type of familiarity and the respective contributions of visual learning and semantic knowledge are critical issues for understanding how familiarity optimizes face processing. Attempts to manipulate person knowledge, by inducing visual familiarity with previously unfamiliar faces, while holding visual knowledge constant have been conducted in studies that show the important independent contribution of person knowledge on brain responses (e.g., fMRI: Cloutier et al., 2011; EEG: Abdel Rahman, 2011; Heisz & Shedden, 2009; Kaufmann et al., 2009; Paller et al., 2003; Taylor et al., 2016). However, experimentally controlled visual and semantic experience may not entail familiarization comparable to that acquired across long-term, social interactions with personally familiar individuals; in real life, independent manipulation of visual and semantic experience seems

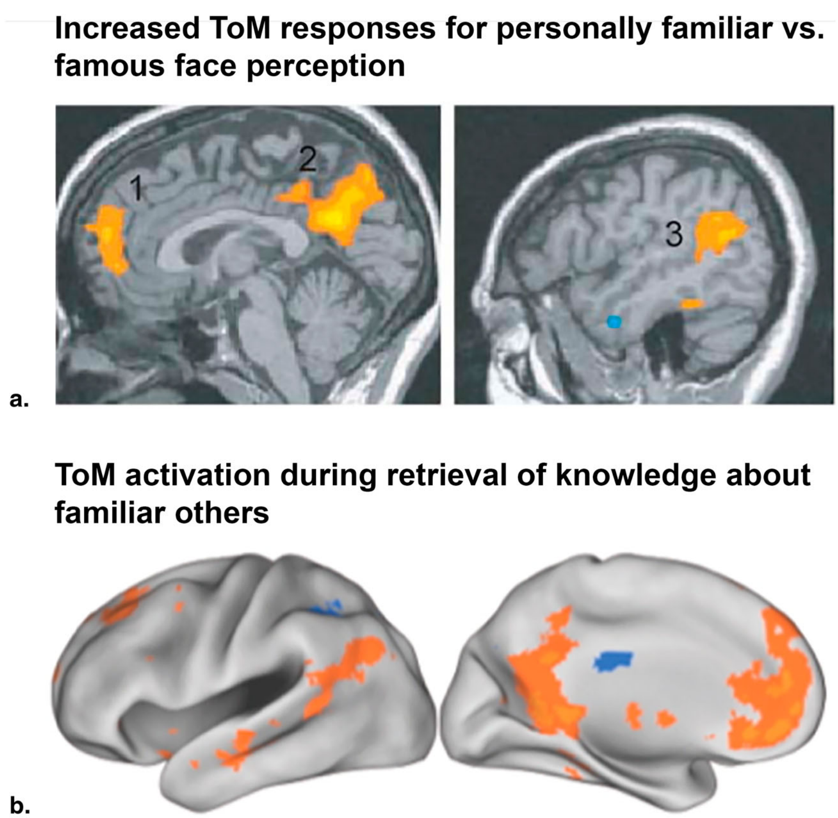

Figure 7. Personal familiarity increases activity within Theory of Mind regions. (a) Increased neural responses to personally familiar faces versus famous faces within Theory of Mind (ToM) areas (1: medial prefrontal cortex; 3: temporoparietal junction) and the posterior cingulate/precuneus (2) (Gobbini et al., 2004). (b) Increased responses in the ToM areas and the precuneus were also observed when participants answered regarding personal preferences of their friends (Krienen et al., 2010).

impossible to control. Future research is necessary to investigate the roles of these variables in the optimized processing of personally familiar faces. The fMRI studies reviewed above support the notion that processing of personally familiar individuals entails processing of visual appearance to achieve view-invariant representations, as well as emotional responses and spontaneous retrieval of person knowledge – all of which are essential for successful recognition and identification.

Conclusions

Considering the vast number of studies addressing face processing in general, most have not acknowledged the importance of distinguishing between familiar and unfamiliar faces. Some studies, however, have acknowledged the important difference between personally familiar, as well as other types of familiar and unfamiliar faces. The available empirical findings suggest that natural, repeated, and extensive social experience leads to representations that optimize processing of socially-relevant stimuli and enable efficient and appropriate social interactions with individuals who play the most important roles in our social lives. Personal familiarity optimizes face processing at multiple levels. Optimization of *early visual processes* is evident in the facilitation of detection and orientation to personally familiar faces, and detection of social cues in, as well as discrimination between personally familiar faces. Optimization of *later visual processes* is demonstrated through dramatically more robust and efficient representations of personally familiar faces that afford effortless identification over large variations in image quality. Facilitation of *non-visual processes* manifests as spontaneous activation of person knowledge and appropriate, individual-specific emotional responses to personally familiar faces. Future studies are required to systemically investigate and describe this optimization from a longitudinal perspective.

Notes

1. Several studies have used the term “recognition” to describe the process of determining the familiarity of a face (e.g., Besson et al., 2017; Busigny, Bled, Besson, & Barbeau, 2012; Caharel et al., 2014; Ramon, 2015b; Ramon et al., 2015; Ramon et al., 2011; Van Belle et al., 2010).
2. Recent studies that have employed MVPA have provided evidence for identity-specific representations of famous faces in the FFA (Axelrod & Yovel, 2015). Using a visual familiarization regime involving face learning with dynamic videos, Guntupalli et al. (2017) found identity-specific and view-invariant representations with MVPA in the FFA, the ATFA, and the right inferior frontal face area (rIFFA, see Figure 5c).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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