

## Personal familiarity of faces, animals, objects, and scenes: Distinct perceptual and overlapping conceptual representations

Holger Wiese<sup>a,\*</sup>, Maya Schipper<sup>a</sup>, Tsvetomila Popova<sup>a</sup>, A. Mike Burton<sup>b,c</sup>, Andrew W. Young<sup>b</sup>

<sup>a</sup> Durham University, UK

<sup>b</sup> University of York, UK

<sup>c</sup> Bond University, Australia

### ARTICLE INFO

#### Keywords:

Face recognition  
Object recognition  
Scene recognition  
Personal familiarity  
Event-related potentials

### ABSTRACT

While face, object, and scene recognition are often studied at a basic categorization level (e.g. “a face”, “a car”, “a kitchen”), we frequently recognise individual items of these categories as unique entities (e.g. “my mother”, “my car”, “my kitchen”). This recognition of individual identity is essential to appropriate behaviour in our world. However, relatively little is known about how we recognise individually familiar visual stimuli. Using event-related brain potentials, the present study examined whether and to what extent the underlying neural representations of personally familiar items are similar or different across different categories. In three experiments, we examined the recognition of personally highly familiar faces, animals, indoor scenes, and objects. We observed relatively distinct familiarity effects in an early time window (200-400 ms), with a clearly right-lateralized occipito-temporal scalp distribution for human faces and more bilateral and posterior distributions for other stimulus categories, presumably reflecting access to at least partly discrete visual long-term representations. In contrast, we found clearly overlapping familiarity effects in a later time window (starting 400 to 500 ms after stimulus onset), again with a mainly right occipito-temporal scalp distribution, for all stimulus categories. These later effects appear to reflect the sustained activation of conceptual properties relevant to any potential interaction. We conclude that familiarity for items from the various visual stimulus categories tested here is represented differently at the perceptual level, while relatively overlapping conceptual mechanisms allow for the preparation of impending potential interaction with the environment.

### 1. Introduction

Imagine getting up in the morning and walking into the kitchen. Typically, the situation in front of you will be very familiar. You recognise the arrangement of the room and the furniture within it as your kitchen, the person sitting at the table as your partner, the furry thing jumping up at your leg as your dog, and the coffee cup on the table as an old one from your student days but not your favourite. We constantly recognise individual people, as well as unique scenes, objects, and animals, and this has huge behavioural consequences. For instance, it would very likely influence your next actions if the animal in your kitchen was not your, but a completely unfamiliar dog. Accordingly, it is crucial that we recognise the visual stimuli around us not only as exemplars of visual categories (a face, a dog, a coffee cup), but as unique, individual entities. Here, we investigated the neural processes underlying the identification of visual stimuli that are individually familiar to

us.

Psychological research has investigated face, scene, and object recognition for decades (e.g., Biederman, 1972; Bruce & Young, 1986; Marr & Nishihara, 1978). However, relatively little is known about the representation of unique identity, and how similar the representations for different stimulus categories are. In all cases, the recognition of a unique entity requires the matching of a visually perceived stimulus with a long-term memory representation. Importantly, as we recognise known faces, objects, and scenes across a wide range of viewing conditions (e.g. with changing lighting, viewing angles etc.), such representations need to allow for identification from a wide range of highly variable images. Understanding how visual perceptual mechanisms cope with image variability has important theoretical implications. For instance, it is now well-established that familiar faces are processed fundamentally differently from unfamiliar faces (Young & Burton, 2017, 2018). The same face can look very different in different circumstances,

\* Corresponding author at: Department of Psychology, Durham University, South Road, Durham DH1 3LE, United Kingdom.

E-mail address: [holger.wiese@durham.ac.uk](mailto:holger.wiese@durham.ac.uk) (H. Wiese).

and while it is easy for us to recognise a familiar face across changing conditions, e.g. independent of changes in lighting, viewing angle, or emotional expression, this same task can be very difficult for unfamiliar faces (Bruce et al., 1999; Burton, Wilson, Cowan, & Bruce, 1999; Jenkins, White, Van Montfort, & Burton, 2011). The fundamental difference between familiar and unfamiliar faces therefore lies in the way they are represented in our cognitive system. While familiar faces have long-term representations that allow for recognition from a wide range of images, such representations can only emerge with sufficient exposure to a specific face in different conditions (Kramer, Young, & Burton, 2018). Accordingly, image-independent representations are not available for unfamiliar faces, and face learning may therefore reflect establishing what an individual face looks like across many different conditions (Burton, Kramer, Ritchie, & Jenkins, 2016).

Similarly, researchers have long discussed how objects can be recognized from different views and have suggested both object-centred (or structural) and view- or image-based solutions (e.g., Marr & Nishihara, 1978; Tarr & Bulthoff, 1998). Additionally, objects can be described at different levels of categorization, namely superordinate, basic, and subordinate levels (e.g., a mammal, a dog, a border collie; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Differentiation at the subordinate level depends on properties of the specific basic object class (Biederman, Subramaniam, Bar, Kalocsai, & Fiser, 1999), as, for instance, different lamps (e.g., a floor versus a desk lamp) may be easily distinguished by the shape of individual parts and their relation, whereas different cars (a Mazda versus a Skoda) may not.

Importantly, however, this classic view of object discrimination at different levels does not extend as far as unique, individual identity. In many cases, we are not only able to distinguish between different subordinate categories (a border collie versus a cocker spaniel), but also to recognise individual familiar entities (my border collie versus a different border collie). Accordingly, it appears plausible to assume the existence of robust long-term representations for individual objects, and a similar case can be made for scenes. However, relatively little is known about the cognitive and neural basis of such representations, and how they relate to those of familiar faces.

Face and object processing has been shown to take place in widely distributed and overlapping networks in the ventral visual stream (Haxby et al., 2001). At the same time, research has identified different maximally responsive brain regions for various stimulus categories. For instance, the Fusiform Face Area (FFA) has been interpreted as selectively responding to faces compared to other visual stimuli (Kanwisher, McDermott, & Chun, 1997), and this selectivity seems to extend to the faces of animals (Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000). While it is often assumed that the FFA is also involved in the recognition of individual facial identity (Gobbini & Haxby, 2007; Haxby, Hoffman, & Gobbini, 2000; Kovacs, 2020), studies taking within-person variability into account have not fully supported this idea (Davies-Thompson, Gouws, & Andrews, 2009). Instead, it appears that structures of the medial temporal lobe are more critically involved in image-invariant facial familiarity (Quiroga, Reddy, Kreiman, Koch, & Fried, 2005; Weibert et al., 2016).

Studies using event-related brain potentials (ERPs) have demonstrated a face-sensitive response in the N170, with a substantially increased negative peak over occipito-temporal channels at around 170 ms for faces relative to other visual stimuli (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2011). Like findings on the FFA, clear N170 responses have also been observed for animal faces (Balas & Koldewyn, 2013; Rousselet, Mace, & Fabre-Thorpe, 2004; Wiese, Stahl, & Schweinberger, 2009). However, effects depending on familiarity with an individual face are typically observed in the subsequent occipito-temporal N250, with more negative amplitudes for newly learnt (Andrews, Burton, Schweinberger, & Wiese, 2017; Kaufmann, Schweinberger, & Burton, 2009; Popova & Wiese, 2023; Tanaka, Curran, Porterfield, & Collins, 2006), famous (Bentin & Deouell, 2000; Gosling & Eimer, 2011; Saavedra, Iglesias, & Olivares, 2010), and

personally familiar (Popova & Wiese, 2022; Wiese et al., 2019; Wiese et al., 2022; Wiese et al., 2022) as compared to unfamiliar faces. Moreover, studies using repetition priming have found more negative amplitudes for repeated relative to non-repeated familiar faces from approximately 200 ms onwards (Begleiter, Porjesz, & Wang, 1995; Schweinberger, Pfutz, & Sommer, 1995; Schweinberger, Pickering, Jentsch, Burton, & Kaufmann, 2002), and this so-called N250r (r for repetition) is thought to reflect the pre-activation of visual face representations.

Of note, in the case of highly familiar faces, the ERP familiarity effect continues to build up after the N250 time range, peaking between 400 and 600 ms at occipito-temporal channels (e.g. Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019; see also Bentin & Deouell, 2000, Gosling & Eimer, 2011, and Tanaka et al., 2006, for potentially related findings). Due to its largely overlapping scalp distribution, this so-called Sustained Familiarity Effect (SFE) has been thought to have similar neural generators to the preceding N250 effect. However, their differential response to experimental manipulations (Wiese et al., 2019; Wiese, Tüttenberg, et al., 2019), as well as their different developmental trajectories during face learning (Popova & Wiese, 2022, 2023) suggest that the two effects are functionally not identical.

There is only limited evidence as to whether familiar animals and human faces are represented similarly in the brain. On the one hand, animals have faces, and many (cats, dogs, and most other mammals) have features and basic configurations (two eyes above a nose above a mouth) that are roughly similar to human faces. As discussed above, face-sensitive responses in the FFA and the N170 seem to show similarities between human and animal faces. Interestingly, a clear N250r has been reported for ape faces, with a similar scalp distribution to human faces (Schweinberger, Huddy, & Burton, 2004). This experiment, however, used unfamiliar animal faces, and accordingly the results cannot reflect the activation of image-independent long-term representations. However, as an N250r was not observed for the repetition of objects (i.e. car fronts), the results do suggest a degree of face selectivity across species in the N250 time range. On the other hand, we probably do not use the same information to differentiate individual animals and human faces. For recognising animals (such as cats and dogs – the animals that are arguably most likely individually familiar to us), we presumably rely heavily on specific albedo and coloration patterns in the fur (which may not be restricted to the face). In line with the idea of different representations for the recognition of familiar human faces and animals, a neuropsychological case study of prosopagnosia has demonstrated severely impaired recognition of individual human faces but accurate recognition of sheep faces (McNeil & Warrington, 1993).

Previous neuroscientific research has associated object recognition with the Lateral Occipital Complex (LOC; Grill-Spector, Kourtzi, & Kanwisher, 2001; Malach et al., 1995). While it was initially suggested that the LOC does not discriminate between familiar and unfamiliar objects (Malach et al., 1995), later work using Multivariate Pattern Analysis (MVPA) reported that this structure differentiates between familiar and unfamiliar basic-level objects (i.e., a lamp versus an exemplar from an unfamiliar object category; Margalit et al., 2016). Similarly, LOC has been shown to distinguish between different basic level objects (dogs, flowers, airplanes, shoes; Iordan, Greene, Beck, & Fei-Fei, 2015). However, an fMRI study comparing *individual* familiar with unfamiliar objects (the participant's bag versus somebody else's bag) revealed increased activation for the former category in the retrosplenial complex, the posterior cingulate and the precuneus, which was interpreted to reflect episodic memory retrieval (Sugiura, Shah, Zilles, & Fink, 2005).

In ERP studies, line drawings of common objects elicited more negative amplitudes in a repetition relative to a non-repetition condition at bilateral occipito-temporal electrode positions approximately 250 ms after target onset (Zhang, Begleiter, Porjesz, Wang, & Litke, 1995). While this effect appears similar to the N250r, no such repetition effect was observed for photos of car fronts (Schweinberger et al., 2004). A

further study (Miyakoshi, Nomura, & Ohira, 2007) compared objects owned by the participants (e.g. their cup, their bag) with familiar objects (a disposable cup, a paper bag) and unfamiliar objects (another participant's cup and bag). The authors reported more negative ERPs between 200 and 300 ms over the left occipito-temporal cortex for both personally familiar and familiar relative to unfamiliar objects, reflecting a left-lateralized N250 familiarity effect. Moreover, they observed more negative amplitudes for personally familiar relative to familiar objects in a later time window (300-700 ms) at frontal and right temporal sites. In a recent study, Munoz and colleagues compared single images of personally familiar and unfamiliar objects and found a reduced fronto-central N2 and a larger centro-parietal P3 for the former category (Munoz et al., 2020). While the timing of these effects was very similar to those reported by Miyakoshi and colleagues, the different scalp distribution might well be related to the different references used in the two studies (common average in the earlier, average mastoids in the later).

For scene perception, research has identified the Parahippocampal Place Area (PPA; Epstein & Kanwisher, 1998) but also the Retrosplenial Complex (RSC) and the Occipital Place Area (OPA) as particularly sensitive (Epstein & Baker, 2019). Like the work on object recognition discussed above, earlier research found that the PPA does not differentiate between familiar and unfamiliar scenes (Epstein, Harris, Stanley, & Kanwisher, 1999), while later MVPA work suggests that place-sensitive regions (and particularly the RSC) code information about individual known scenes (e.g. specific locations on a university campus; Epstein & Morgan, 2012). An additional study comparing personally familiar (e.g. the participant's office) with unfamiliar places (somebody else's office) yielded enhanced activation in the former condition in the posterior cingulate cortex, retrosplenial cortex, posterior precuneus, and left intraparietal sulcus (Sugiura et al., 2005).

ERP experiments on scene perception have described the posterior P2 as a key component, as it shows a stronger response for scenes as compared to objects and faces (Harel, Groen, Kravitz, Deouell, & Baker, 2016). The P2 further distinguishes between more specific scene properties, such as natural versus man-made scenes, independent of basic image properties such as foreground texture (Harel et al., 2020). Relatively little is known about electrophysiological markers of familiarity for scenes. In a repetition priming study, an N250r was evident for famous buildings, but this was reduced relative to the N250r for famous faces (Engst, Martin-Loeches, & Sommer, 2006). Interestingly, the scalp distribution of the two effects was similar, suggesting similar underlying neural generators. Moreover, priming effects were also observed in a later N400 time range, but with clearly different scalp distributions for the two stimulus categories. It should be noted, however, that the same images were used as primes and targets, which does not allow conclusions about image-independent recognition.

### 1.1. The present study

The present study examined the neural representation of familiarity at the level of unique identity with a variety of visual stimuli. Specifically, we focused on domain-specific as well as domain-general mechanisms of face, scene, and object recognition, and on the potential transition between the two types of mechanisms. In previous experiments, we have established robust familiarity effects for individual faces, both at the level of perceptual (i.e. visual; N250) representations and at conceptual processing stages, which seem to reflect the integration of visual with identity-specific semantic, episodic and affective information about a person (SFE; Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019). Here, we aimed to compare familiarity effects for faces with those for animals (i.e. our participants' cats or dogs; Experiment 1), indoor scenes (our participants' flats or houses; Experiment 2), and objects (our participants' shoes; Experiment 3).

The specific non-human-face categories were chosen based on the following reasoning: Similar to humans, cats and dogs have faces, which might trigger face-selective processes. However, we presumably largely

recognise individual animals on the basis of colouration/albedo patterns in the fur, which are not restricted to their face, rather than shape and surface reflectance information relevant for the recognition of individual human faces. This might suggest different mechanisms underlying the visual recognition of individual animals as compared to human faces. At the conceptual level, both well-known humans and animals likely trigger strong affective and mnemonic responses, which suggests similar processing.

Both well-known indoor scenes and objects are visually clearly distinct from human faces. Moreover, distinct neural correlates for the visual processing of scenes have been described. We therefore predicted clearly different neural responses related to the visual recognition of individual scenes and objects as compared to faces. Similarly, at a conceptual level, it appears that highly familiar faces elicit stronger emotional and mnemonic responses than indoor scenes (representing only temporarily occupied flats in the present study) or daily-life objects (such as shoes). We therefore also predicted different processing during the integration of perceptual and conceptual information.

We tested these assumptions by examining ERP familiarity effects for the above-described visual categories. Specifically, we investigated the N250 familiarity effect as a measure of visual recognition, as well as the SFE which is assumed to reflect the integration of perceptual with conceptual information. In addition to these analyses, we conducted mass univariate tests, examining all time points and electrodes separately, to investigate potential distinct and overlapping effects not captured by the analyses of a priori defined time windows.

## 2. General methods

### 2.1. Stimuli

Each participant in the three experiments provided 40 different pictures of one highly personally familiar face (relatives or close friends not known from university) and 40 different images of the same personally familiar animal (i.e. their pets [cats or dogs]; Experiment 1), 40 different images of personally familiar indoor scenes (i.e. different rooms in their houses or flats [portrait-format, not depicting any humans or animals]; Experiment 2), or 40 different images of the same personally familiar object (i.e. a specific pair of shoes; Experiment 3). Written consent of all the depicted people was obtained. In all experiments, eight pictures of butterflies were used as targets. Rectangles around the faces, animals, and objects were cropped from the original images, resized, copied into a frame of 190 × 285 pixels and converted to greyscale (see Fig. 1 for examples). Similarly, indoor scenes were resized to 190 × 285 pixels and converted to greyscale.

### 2.2. Procedure

Participants were seated in an electrically shielded chamber with their heads in a chin rest at 80 cm from a monitor. Participants were paired, such that familiar faces and pets/scenes/shoes for one participant were used as the unfamiliar stimuli for the other participant in the pair, resulting in identical stimuli in familiar and unfamiliar conditions across participants. The experiments consisted of a single block, in which all 160 pictures of familiar and unfamiliar faces as well as pets (Experiment 1)/scenes (Experiment 2)/shoes (Experiment 3) were presented once in random order, intermixed with 20 trials showing images of butterflies. Stimuli were presented for 1000 ms, followed by a fixation cross presented for between 1500 and 2500 ms (2000 ms on average). The task was to press a button with the right index finger whenever a butterfly was presented.

### 2.3. EEG recording and data analysis

During the experiments, 64-channel EEG was recorded using sintered Ag/Ag-Cl electrodes (EEGo, ANT Neuro, Enschede, The Netherlands;



Fig. 1. Example stimuli from Experiments 1–3. Face images are published with the explicit consent of the depicted person. Note the presence of high variability between different images of the same face, animal, scene, or object.

DC-120 Hz, 1024 Hz sampling frequency). AFz served as ground and CPz was used as the recording reference. Blink artefacts were corrected using Independent Component Analysis, as implemented in BESA 6.3 (Graefeling, Germany; [www.besa.de](http://www.besa.de)). EEG was filtered (0.1 to 40 Hz, zero phase shift), segmented from  $-200$  to  $1000$  ms relative to stimulus onset, and baseline-corrected, with the first 200 ms as the baseline. Artefact rejection was conducted using an amplitude threshold of  $100 \mu\text{V}$  and a gradient criterion of  $75 \mu\text{V}$ . Remaining trials were recalculated to the common average reference and then averaged according to experimental conditions. Mean number of trials was  $37.7$  ( $SD = 2.7$ ,  $\text{min} = 25$ ) in Experiment 1,  $36.5$  ( $SD = 4.2$ ,  $\text{min} = 24$ ) in Experiment 2, and  $37.3$  ( $SD = 3.3$ ,  $\text{min} = 24$ ) in Experiment 3.

For ERP analysis, mean amplitudes at left- and right-hemispheric lateral occipital and occipito-temporal electrodes (O9/O10, PO9/PO10, P9/P10, TP9/TP10) were calculated for the N250 (200-400 ms) and SFE (400-600 ms) time windows. Familiarity effects for faces have been observed with a maximum at occipito-temporal channels (Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019). However, to allow testing for varying generator locations for different stimulus categories, more posterior electrodes were added to the analysis. Repeated-measures Analyses of Variance (ANOVA) were run for each time window separately. Moreover, a priori hypotheses, examining the presence of familiarity effects for the different stimulus categories at each electrode site, were tested using repeated-measures *t*-tests and corrected for multiple comparisons using the Bonferroni procedure. Following an estimation approach (Cumming, 2012), measures of effect size and appropriately sized confidence intervals are reported throughout. CIs for partial eta squared were calculated using scripts provided by M.J. Smithson ([www.michaelsmithson.online/stats/CIstuff/CI.html](http://www.michaelsmithson.online/stats/CIstuff/CI.html)). Cohen's *d* was bias-corrected ( $d_{\text{unb}}$ ) and calculated using the mean standard deviation rather than the standard deviation of the difference as the denominator (Cumming, 2012).

As the main research question of the present studies was concerned with the extent to which personal familiarity for various stimulus categories is represented differently in the brain, we conducted exploratory mass univariate analyses for all three experiments, which are reported separately from the above-described ERP analyses. We assumed that such analyses would add complimentary information to answer our research question, as the technique is not restricted to a priori defined time windows and electrode positions. We calculated repeated-measures *t*-tests for familiar versus unfamiliar stimuli at each time point and electrode, and for faces and the respective other stimulus category separately. Resulting *p*-values were corrected for multiple comparisons using the False Discovery Rate procedure (Benjamini & Hochberg, 1995). To identify familiarity effects specific to either faces or pets/scenes/shoes on the one hand, as well as common to the two stimulus categories on the other hand, we then identified *p*-values in time/electrode-space significant for faces only or pets/scenes/shoes only (exclusive disjunction), as well as *p*-values significant for both faces and pets/scenes/shoes (conjunction).

#### 2.4. Transparency and openness

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. The conditions of our ethical approval do not permit the public archiving of the photos of the stimulus material used in this study (which includes facial photographs and other private material provided by the participants) and the images cannot be shared with anyone outside the author team. Images of selected stimuli for which we have explicit written consent are used as examples in Fig. 1. All data and analysis code can be accessed at [https://osf.io/rqndy/?view\\_only=f7dc13f1b4540fdbb2b0cd111507cb1](https://osf.io/rqndy/?view_only=f7dc13f1b4540fdbb2b0cd111507cb1) and will be made publicly available at the time of acceptance for publication. Study design and analyses were not pre-registered.

### 3. Experiment 1: personally familiar and unfamiliar faces versus animals

#### 3.1. Methods

##### 3.1.1. Participants

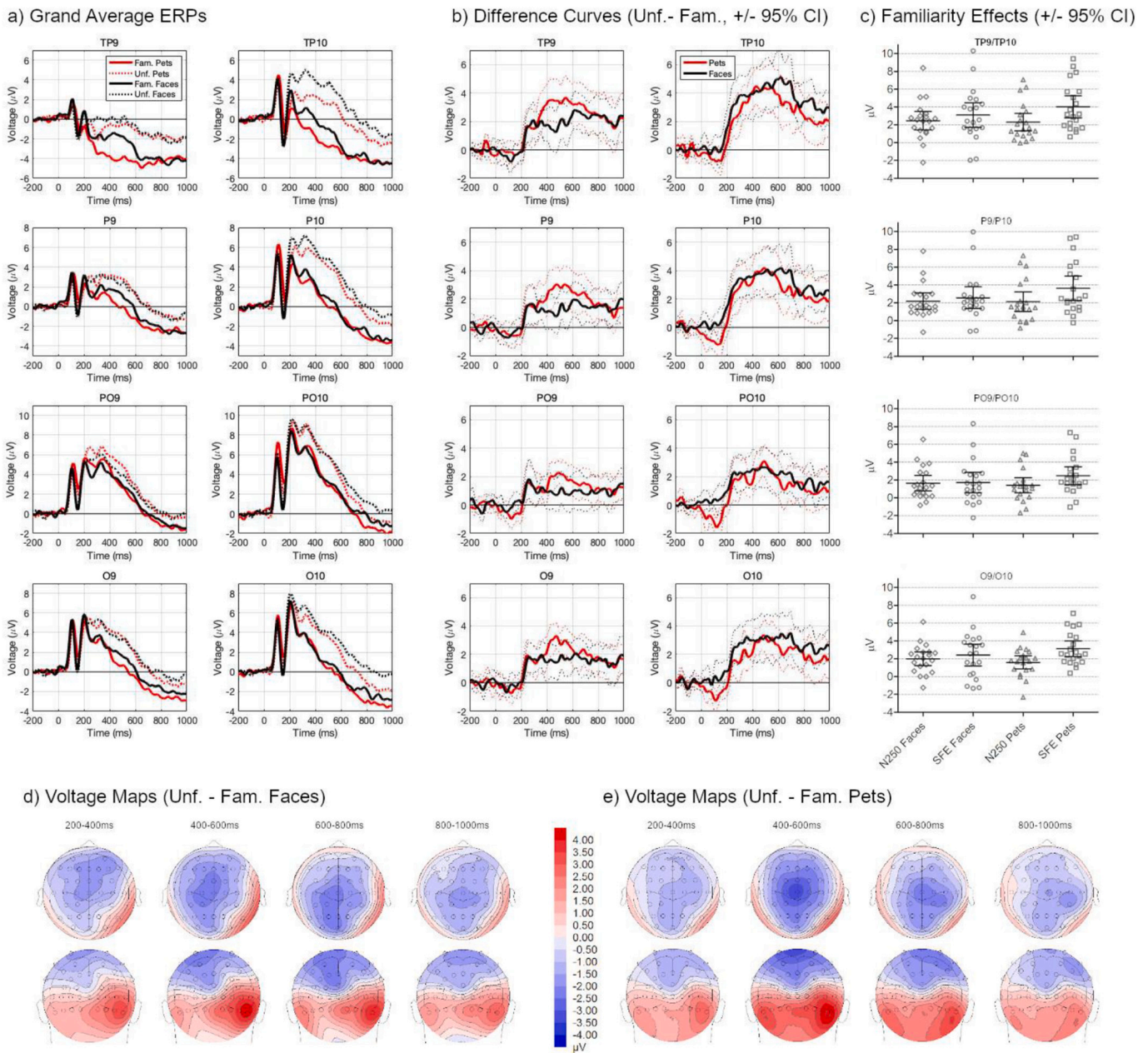
The necessary sample size was estimated using G\*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007). Assuming half of the SFE effect size for animals than for personally familiar faces in our initial study (Experiment 3 in Wiese, Tüttenberg, et al., 2019), power analysis suggested a total *N* of 15 to detect more negative amplitudes for personally familiar relative to unfamiliar pets (paired-sample *t*-test,  $d_z = 0.8$ ,  $1 - \beta = 0.8$ ). We tested 20 Durham University undergraduate students (18 female, 2 male; mean age =  $21.1$  years  $\pm 2.8$  SD), resulting in an achieved power of 0.91, 17 of whom were right-handed according to the Edinburgh Handedness Inventory. All participants received course credits or monetary compensation, reported normal or corrected-to-normal vision, and did not take central-acting medication. All gave written informed consent, and the experiment was approved by the ethics committee of Durham University's Psychology Department.

#### 3.2. Results

##### 3.2.1. ERP analysis

ERP results for Experiment 1 are depicted in Fig. 2. Visual inspection revealed clear familiarity effects for both human faces and pets, with a maximum at more anterior occipito-temporal channels and an onset at approximately 200 ms (see Fig. 2, b-e). However, while familiarity effects were generally right-lateralized, pets elicited stronger left-hemispheric effects than human faces, resulting in a more bilateral scalp distribution for the former stimulus category.

Statistical analyses confirmed these observations. A repeated-measures ANOVA in the N250 time range (200-400 ms) with the



**Fig. 2.** Results for Experiment 1. a) Grand average event-related potentials for familiar and unfamiliar faces and pets at left and right-hemispheric occipital to occipito-temporal electrodes. (b) Mean (+/- 95% CI) difference curves (unfamiliar – familiar) for faces and pets. (c) Mean ( $\pm$  95% CI) and individual familiarity effects in the N250 and SFE time ranges for faces and pets. (d) and (e) Scalp-topographical voltage maps (spherical spline interpolation, 110° equidistant projection) of familiarity effects for faces and pets.

**Table 1**

Planned pairwise comparisons for the N250 time range in Experiment 1. \* indicate significant results after Bonferroni correction (i.e. with  $p < 0.05/8 = 0.006$ ).

Stim. Category	Site	$M_{diff}$	95% CI	t(19)	p	$d_{umb}$	95% CI
Faces	TP9/TP10	2.467	[1.440, 3.495]	5.027	<0.001*	0.702	[0.358, 1.092]
	P9/P10	2.176	[1.264, 3.088]	4.992	<0.001*	0.500	[0.254, 0.779]
	PO9/PO10	1.650	[0.787, 2.513]	4.003	0.001*	0.365	[0.155, 0.598]
	O9/O10	1.993	[1.226, 2.759]	5.442	<0.001*	0.430	[0.230, 0.659]
Pets	TP9/TP10	2.308	[1.332, 3.285]	4.946	<0.001*	0.619	[0.313, 0.967]
	P9/P10	2.128	[1.019, 3.236]	4.016	0.001*	0.433	[0.185, 0.709]
	PO9/PO10	1.406	[0.555, 2.256]	3.460	0.003*	0.275	[0.098, 0.470]
	O9/O10	1.599	[0.863, 2.335]	4.548	<0.001*	0.306	[0.146, 0.467]

within-subjects factors site (TP, P, PO, O), hemisphere (left, right), stimulus category (faces, pets), and familiarity (familiar, unfamiliar) revealed a significant interaction of hemisphere by familiarity by

category,  $F(1, 19) = 4.642, p = 0.044, \eta_p^2 = 0.196, 90\% \text{ CI } [0.003, 0.416]$ , suggesting more clearly right-lateralized familiarity effects for faces and a more bilateral effect for pets (see Fig. 2 d/e). Planned

comparisons revealed significant familiarity effects for both categories at all sites (see Table 1).

Similarly, an ANOVA in the SFE time range (400-600 ms) yielded a significant interaction of hemisphere by familiarity by category,  $F(1, 19) = 12.340, p = 0.002, \eta_p^2 = 0.394, 90\% \text{ CI } [0.107, 0.578]$ , with more right-lateralized familiarity effects for faces relative to pets. Planned comparisons again revealed significant familiarity effects for both categories at all sites (see Table 2).

### 3.3. Discussion

Experiment 1 revealed clear N250 familiarity effects and SFEs for both human faces and animals. While similarly timed and generally lateralized to the right hemisphere, pets elicited stronger left-hemispheric familiarity effects than human faces. Accordingly, N250 familiarity effects for human faces and animals show clear similarities - but also differences, and it seems that the underlying generators are overlapping but not identical. Previous experiments have shown highly similar scalp distributions for N250 effects and SFEs elicited by personally familiar faces, well-known celebrities, as well as the participants' own faces (Wiese, Hobden, et al., 2022). Well-known animals, however, show at least partly different familiarity responses.

Interestingly, the pictures of animals used for this study nearly always depicted the pets' faces, even though participants had not been explicitly instructed to provide such images. Consequently, and in line with previous work (Balas & Koldewyn, 2013; Rousselet et al., 2004), a clear N170 was observed for both human faces and animals (see Fig. 2a). Despite all obvious differences with respect to head shape and surface reflectance properties (e.g. albedo patterns across the face and body, texture/"furriness"), it therefore appears that some early perceptual effects reflected in the N170, such as the detection of a face-like stimulus (Schweinberger & Neumann, 2016), are observed for both stimulus categories. More interestingly, given the differences in appearance between the two stimulus categories, familiarity effects over the right hemisphere were surprisingly similar. It appears as if the processes reflected in the right-hemispheric N250 and SFE are largely overlapping for the two stimulus categories, while additional left-hemispheric resources need to be recruited for the recognition of animals.

In sum, despite clear differences with respect to the involvement of left-hemispheric processes, animal faces do elicit clear familiarity effects, both in the N250 and SFE time range. Experiment 2 was designed to test whether similar results could be obtained with highly personally familiar but inanimate stimuli. For that purpose, we presented participants with images of indoor scenes, depicting rooms in either their own or somebody else's home.

## 4. Experiment 2: personally familiar and unfamiliar faces versus indoor scenes

### 4.1. Methods

#### 4.1.1. Participants

We tested 20 Durham university undergraduate students (11 female, 9 male; mean age = 20.7 years, SD = 0.8). Inclusion and exclusion

criteria, as well as handling of ethics and participant consent, were identical to Experiment 1.

### 4.2. Results

#### 4.2.1. ERP analysis

ERP results are depicted in Fig. 3. Again, both stimulus categories yielded clear familiarity effects. However, unlike Experiment 1, both the timing and the general scalp distribution of familiarity effects for faces as compared to indoor scenes appeared to be different. While the same pattern as in previous studies was observed for faces, with maximal familiarity effects at right occipito-temporal electrode sites starting at approximately 200 ms, effects for indoor scenes were delayed and showed a more posterior scalp distribution.

These observations were partly confirmed in the statistical analysis. A repeated-measures ANOVA in the N250 time range (200-400 ms) yielded a significant interaction of familiarity by stimulus category,  $F(1, 19) = 27.949, p < 0.001, \eta_p^2 = 0.595, 90\% \text{ CI } [0.310, 0.723]$ . For faces, planned comparisons revealed significant familiarity effects at all electrode sites, with strongest effect sizes at more anterior positions (see Table 3). By contrast, no significant familiarity effects were detected for indoor scenes.

A corresponding analysis in the SFE time window (400-600 ms) yielded a significant interaction of familiarity by stimulus category,  $F(1, 19) = 18.002, p < 0.001, \eta_p^2 = 0.487, 90\% \text{ CI } [0.188, 0.646]$ . Planned comparisons (see Table 4) revealed significant familiarity effects for both stimulus categories at all electrode sites, but effects were clearly larger for faces.

### 4.3. Discussion

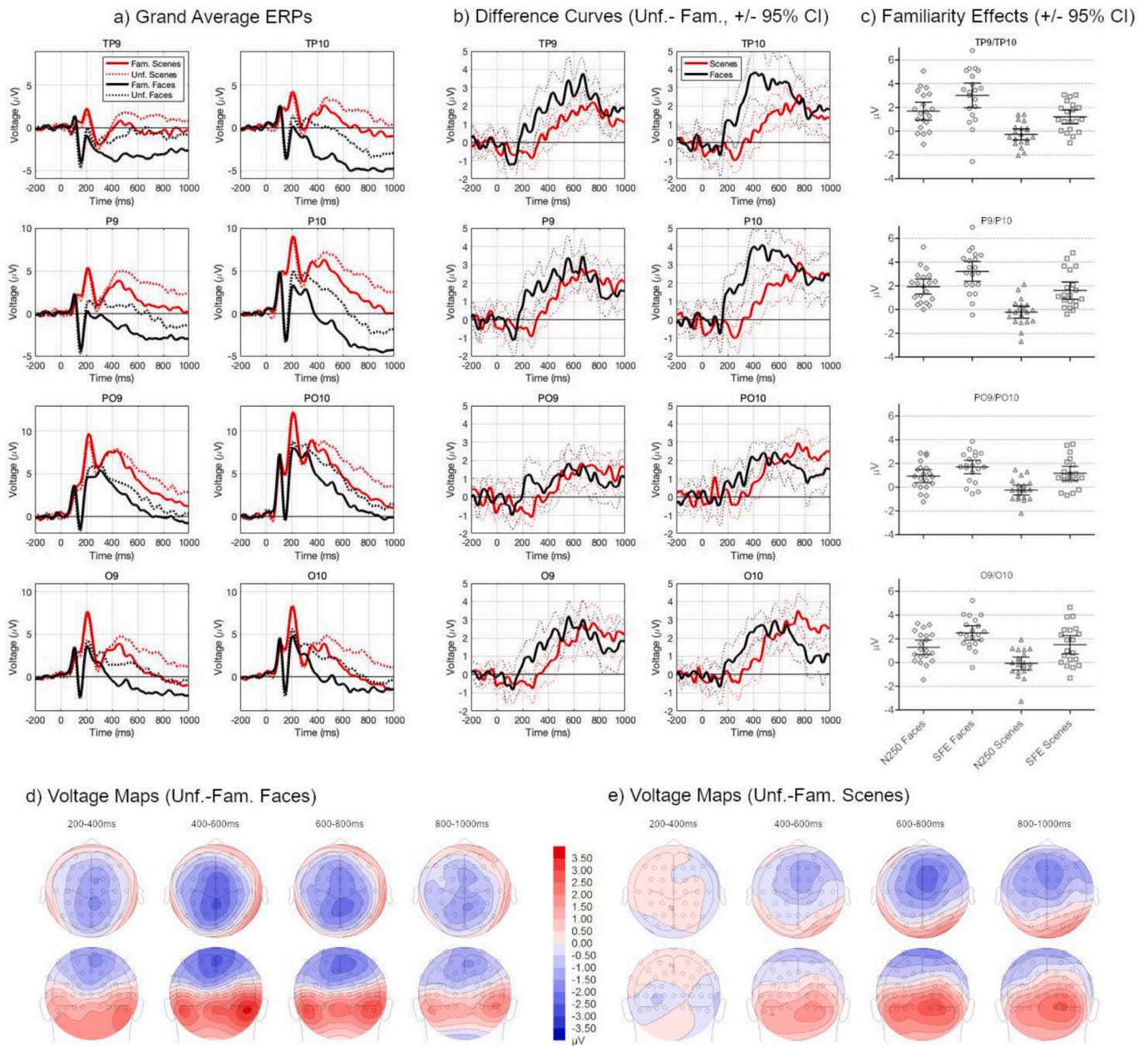
Like Experiment 1, we again observed clear familiarity effects for both stimulus categories. However, visual inspection of the ERP results suggested differences both with respect to timing and scalp distribution of these effects. While clear familiarity effects for faces were observed in the N250 time window, indoor scenes did not elicit statistically significant effects in this time range. Moreover, familiarity effects in the subsequent SFE time window were evident for both stimulus categories but larger for faces relative to scenes. Together, these findings seem to demonstrate a later onset of familiarity effects for the latter category.

As for previous studies, the presentation of scenes elicited a large P2. This component has been observed to differentiate between different types of scenes, and is more pronounced for man-made as compared to natural, and for closed than open scenes (Harel et al., 2016; Harel et al., 2020). However, different neural responses to familiar as compared to unfamiliar scenes were only observed in later time windows. Delayed familiarity effects for scenes relative to both faces and animals (in Experiment 1) may be related to the more heterogeneous nature of the stimuli. We presented multiple images of the same familiar person or animal, but a number of different rooms (e.g. the participant's versus somebody else's kitchen, living room, bedroom etc.). This potential confound arose from the necessity for large numbers of highly variable images (as one can take only a limited number of different pictures of the same room). Consequently, it seems that participants had to access

**Table 2**

Planned pairwise comparisons for the SFE time range in Experiment 1. \* indicate significant results after Bonferroni correction (i.e. with  $p < 0.05/8 = 0.006$ ).

Stim. Category	Site	$M_{diff}$	95% CI	t(19)	p	$d_{unb}$	95% CI
Faces	TP9/TP10	3.100	[1.718, 4.481]	4.696	<0.001*	0.918	[0.448, 1.449]
	P9/P10	2.570	[1.352, 3.788]	4.417	<0.001*	0.658	[0.306, 1.052]
	PO9/PO10	1.713	[0.571, 2.855]	3.139	0.005*	0.416	[0.126, 0.732]
	O9/O10	2.409	[1.192, 3.625]	4.144	0.001*	0.554	[0.244, 0.899]
Pets	TP9/TP10	4.028	[2.782, 5.274]	6.765	<0.001*	1.272	[0.750, 1.885]
	P9/P10	3.623	[2.256, 4.990]	5.548	<0.001*	0.834	[0.454, 1.282]
	PO9/PO10	2.479	[1.477, 3.481]	5.179	<0.001*	0.532	[0.277, 0.823]
	O9/O10	3.125	[2.245, 4.003]	7.454	<0.001*	0.690	[0.420, 1.011]



**Fig. 3.** Results for Experiment 2. a) Grand average event-related potentials for familiar and unfamiliar faces and scenes at left and right-hemispheric occipital to occipito-temporal electrodes. (b) Mean (+/- 95% CI) difference curves (unfamiliar - familiar) for faces and scenes. (c) Mean ( $\pm$  95% CI) and individual familiarity effects in the N250 and SFE time ranges for faces and scenes. (d) and (e) Scalp-topographical voltage maps (spherical spline interpolation, 110° equidistant projection) of familiarity effects for faces and scenes.

**Table 3**

Planned pairwise comparisons for the N250 time range in Experiment 2. \* indicate significant results after Bonferroni correction (i.e. with  $p < 0.05/8 = 0.006$ ).

Stim. Category	Site	$M_{diff}$	95% CI	t(19)	p	$d_{unb}$	95% CI
Faces	TP9/TP10	1.683	[0.930, 2.436]	4.677	<0.001*	0.426	[0.207, 0.673]
	P9/P10	1.928	[1.294, 2.562]	6.366	<0.001*	0.478	[0.275, 0.715]
	PO9/PO10	0.933	[0.384, 1.483]	3.557	0.002*	0.215	[0.079, 0.364]
	O9/O10	1.282	[0.673, 1.891]	4.404	<0.001*	0.340	[0.158, 0.545]
Scenes	TP9/TP10	-0.272	[-0.732, 0.188]	-1.238	0.231	-0.066	[-0.179, 0.043]
	P9/P10	-0.223	[-0.744, 0.300]	-0.890	0.385	-0.045	[-0.153, 0.059]
	PO9/PO10	-0.238	[-0.658, 0.183]	-1.184	0.251	-0.048	[-0.135, 0.036]
	O9/O10	-0.085	[-0.622, 0.453]	-0.329	0.746	-0.019	[-0.139, 0.099]

**Table 4**

Planned pairwise comparisons for the SFE time range in Experiment 2. \* indicate significant results after Bonferroni correction (i.e. with  $p < 0.05/8 = 0.006$ ).

Stim. Category	Site	$M_{diff}$	95% CI	t(19)	p	$d_{umb}$	95% CI
Faces	TP9/TP10	3.010	[1.984, 4.036]	6.139	<0.001*	0.816	[0.463, 1.226]
	P9/P10	3.201	[2.369, 4.033]	8.057	<0.001*	0.979	[0.608, 1.421]
	PO9/PO10	1.701	[1.128, 2.275]	6.212	<0.001*	0.448	[0.255, 0.671]
	O9/O10	2.491	[1.883, 3.099]	8.570	<0.001*	0.751	[0.474, 1.083]
Scenes	TP9/TP10	1.199	[0.624, 1.773]	4.369	<0.001*	0.280	[0.129, 0.449]
	P9/P10	1.602	[0.880, 2.323]	4.648	0.001*	0.362	[0.175, 0.573]
	PO9/PO10	1.173	[0.584, 1.762]	4.166	<0.001*	0.250	[0.111, 0.406]
	O9/O10	1.495	[0.717, 2.273]	4.024	0.001*	0.386	[0.165, 0.632]

various different representations to identify the stimuli as familiar or unfamiliar (“This is my kitchen”, “this is somebody else’s living room” etc.). It therefore appears plausible that scene recognition was more difficult relative to face or animal recognition, which might well explain the later onset of effects. At the same time, at least for faces, it does not seem to affect the timing or magnitude of ERP familiarity effects whether one or more representations are accessed (Wiese, Anderson, et al., 2022; Wiese, Tüttenberg, et al., 2019). We further note that it is somewhat unclear how to define individual versus basic level representations in the context of the present experiment. More specifically, are “my kitchen”, “my bedroom”, and “my living room” (only) represented separately, or (additionally) bound into a representation of “my home”? While this question needs to be addressed in future work, we suggest that these issues make the partly overlapping familiarity effects for scenes and faces even more interesting (see General Discussion below).

Somewhat surprisingly, statistical tests reported here did not confirm the difference in scalp distribution evident in the voltage maps (Fig. 3 d-e). As noted above, familiarity effects in the SFE time range were still relatively weak for indoor scenes and might have therefore not been sufficiently strong to elicit the corresponding interaction. In line with this interpretation, scene effects were strongest between 600 and 800 ms at occipital electrode sites. At the same time, this finding indicates that there may be some overlap in familiarity effects for scenes and faces, particularly in later time ranges. We will return to this point in the exploratory analysis section.

Experiment 3 tested recognition of personally familiar faces and objects. Here, we avoided the above-noted potential confound and compared recognition of highly variable images of a single well-known (versus an unfamiliar) object with a familiar (versus unfamiliar) face.

## 5. Experiment 3: personally familiar and unfamiliar faces versus objects

### 5.1. Methods

#### 5.1.1. Participants

We tested 20 Durham university undergraduate students (13 female, 7 male; mean age = 21.5 years, SD = 1.9). Inclusion and exclusion criteria, as well as handling of ethics and participant consent, were identical to Experiment 1.

### 5.2. Results

#### 5.2.1. Event-related potentials

Visual inspection of the ERP data (see Fig. 4) suggested similar familiarity effects for personally familiar objects (i.e. shoes) and faces, with only a slightly delayed onset and a similar time point of the maximum effect. Moreover, the scalp distribution for object familiarity effects appeared to be somewhat more posterior than for faces.

In line with these observations, a repeated-measures ANOVA in the N250 time range revealed a significant interaction of site by familiarity by stimulus category,  $F(3, 57) = 3.040$ ,  $p = 0.036$ ,  $\eta_p^2 = 0.138$ , 90% CI

[0.005, 0.245]. Planned comparisons (see Table 5) for faces yielded strongest familiarity effects at the most anterior site (TP9/TP10) and no significant effect (after correction for multiple comparisons) at the most posterior electrodes (O9/O10), while shoes elicited no significant effect at anterior electrodes (TP9/TP10) but clear effects at more posterior sites.

A corresponding ANOVA in the SFE time range again revealed a significant interaction of site by familiarity by stimulus category,  $F(3, 57) = 3.919$ ,  $p = 0.013$ ,  $\eta_p^2 = 0.171$ , 90% CI [0.022, 0.283]. Planned comparisons (see Table 6) showed that both stimulus categories yielded stronger effect sizes at more anterior relative to more posterior sites. This anterior/posterior gradient, however, was somewhat stronger for face relative to object stimuli.

### 5.3. Discussion

As in the previous experiments, we observed clear familiarity effects for both objects and faces in Experiment 3. Accordingly, all tested categories (human faces, animals, scenes, and objects) elicit such ERP effects. Again, we observed similarities, but also differences between the neural representations of familiar faces and the non-face category. A clear difference was reflected in the more posterior distribution of object familiarity effects. This was particularly evident in the earlier N250 time window, which, in the case of faces, has been interpreted as reflecting the activation of long-term visual representations of known identities. We therefore conclude that the visual representations of known non-face objects are stored differently from those for faces.

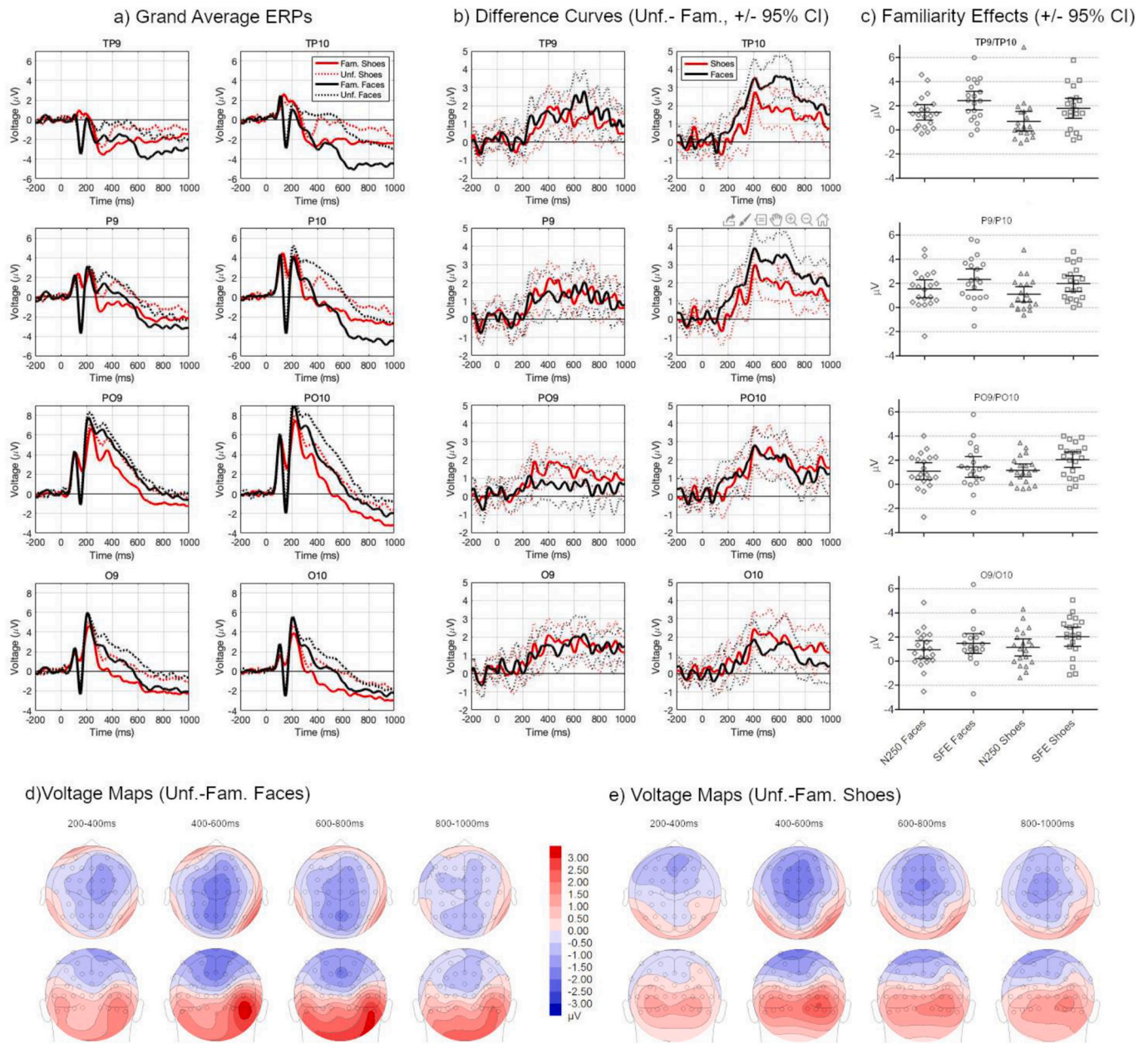
At the same time, more similar familiarity effects for the two stimulus categories were observed in the later time range (400-600 ms), in which both faces and objects showed largest effect sizes at more anterior electrode positions. It thus appears that later integrational and/or preparatory processes at a conceptual level are more similar for the two categories than the earlier process of visual perceptual recognition.

## 6. Exploratory Mass Univariate Analyses

Results of the mass-univariate analyses are depicted in Fig. 5. In line with the planned ERP analyses reported above, these tests revealed clear familiarity effects for faces at occipito-temporal and (with reversed polarity) at central and parietal sites in all three experiments. Note that the latter reversed effects necessarily result from the common average reference used in the present experiments and likely reflect the opposite ends of dipoles underlying occipito-temporal effects.

In all three experiments, familiarity effects for faces started consistently at approximately 200 ms at right occipito-temporal channels (see red boxes in the left column of Fig. 5). While similarly early effects were observed for animals in Experiment 1, familiarity for scenes and objects became detectable only at later time points (slightly before 400 ms in Experiment 3 and slightly after 400 ms in Experiment 2; see second from left column in Fig. 5). In addition to P10/TP10, in all experiments clear and long-lasting familiarity effects for faces were also observed at neighbouring right occipito-temporal channels (T8, TP8; see also Fig. 5d), while corresponding effects were absent or substantially





**Fig. 4.** Results of Experiment 3. a) Grand average event-related potentials for familiar and unfamiliar faces and objects at left and right-hemispheric occipital to occipito-temporal electrodes. (b) Mean (+/- 95% CI) difference curves (unfamiliar – familiar) for faces and objects. (c) Mean ( $\pm$  95% CI) and individual familiarity effects in the N250 and SFE time ranges for faces and objects. (d) and (e) Scalp-topographical voltage maps (spherical spline interpolation, 110° equidistant projection) of familiarity effects for faces and objects.

**Table 5**

Planned pairwise comparisons for the N250 time range in Experiment 3. \* indicate significant results after Bonferroni correction (i.e. with  $p < 0.05/8 = 0.006$ ).

Stim. Category	Site	$M_{diff}$	95% CI	t(19)	p	$d_{unb}$	95% CI
Faces	TP9/TP10	1.447	[0.813, 2.080]	4.780	<0.001*	0.455	[0.225, 0.715]
	P9/P10	1.536	[0.791, 2.282]	4.313	<0.001*	0.386	[0.176, 0.622]
	PO9/PO10	1.085	[0.388, 1.782]	3.259	0.004*	0.222	[0.072, 0.386]
	O9/O10	0.949	[0.216, 1.682]	2.711	0.014	0.241	[0.050, 0.446]
Shoes	TP9/TP10	0.706	[-0.109, 1.520]	1.814	0.085	0.293	[-0.042, 0.644]
	P9/P10	1.091	[0.456, 1.726]	3.595	0.002*	0.322	[0.121, 0.543]
	PO9/PO10	1.158	[0.627, 1.689]	4.565	<0.001*	0.233	[0.111, 0.369]
	O9/O10	1.126	[0.422, 1.830]	3.349	0.003*	0.278	[0.094, 0.479]

reduced for other stimulus categories. Importantly, however, all stimulus categories elicited right-hemispheric familiarity effects between 400 and 600 ms at P10/TP10, which continued until the end of the

analysis epoch.

In addition, all non-human-face categories elicited familiarity effects not detected for human faces (see green boxes in Fig. 5). These effects, in

**Table 6**

Planned pairwise comparisons for the SFE time range in Experiment 3. \* indicate significant results after Bonferroni correction (i.e. with  $p < 0.05/8 = 0.006$ ).

Stim. Category	Site	$M_{diff}$	95% CI	t(19)	p	$d_{umb}$	95% CI
Faces	TP9/TP10	2.411	[1.640, 3.181]	6.549	<0.001*	0.836	[0.486, 1.244]
	P9/P10	2.320	[1.452, 3.188]	5.595	<0.001*	0.678	[0.368, 1.034]
	PO9/PO10	1.430	[0.581, 2.280]	3.525	0.002*	0.359	[0.131, 0.610]
	O9/O10	1.457	[0.640, 2.276]	3.730	0.001*	0.453	[0.178, 0.756]
Shoes	TP9/TP10	1.782	[0.968, 2.597]	4.580	<0.001*	0.773	[0.370, 1.228]
	P9/P10	1.971	[1.322, 2.619]	6.358	<0.001*	0.650	[0.374, 0.972]
	PO9/PO10	2.028	[1.387, 2.670]	6.618	<0.001*	0.510	[0.298, 0.757]
	O9/O10	2.011	[1.225, 2.797]	5.356	<0.001*	0.568	[0.301, 0.873]

all cases, showed a more posterior and left-hemispheric distribution (including channels P9, PO9, P7, PO7, but also O1/O2 and O9/O10; see also Fig. 5d), but varied in time depending on the specific category. Specifically, while some earlier familiarity effects were detected for each category between 200 and 400 ms (outside the green boxes), the clearest effects were observed from approximately 400 ms on for both pets and shoes, and from approximately 600 ms on for scenes. We also observed very early familiarity effects for animals (at approximately 100 ms) that were not detected for any other stimulus category. These effects may reflect attention to low-level visual information (such as the characteristic spot of white fur on the dog's nose in Fig. 1) that can be used for identifying an individual animal.

## 7. General discussion

In a series of three experiments, we investigated the time course and distribution of cortical responses to highly varied images of individual familiar faces as compared to familiar items from other visual stimulus categories. In line with previous studies, we consistently detected familiarity effects for human faces starting at approximately 200 ms with a prominent right occipito-temporal scalp distribution, and no effects with similar distributions were observed for objects or scenes. However, early right occipito-temporal effects were observed for animals, which were complemented by left-hemispheric familiarity responses not observed for human faces in our planned analyses. Importantly, we further observed a substantial overlap of right occipito-temporal familiarity effects for all stimulus categories from approximately 400-500 ms onwards, suggesting that all examined categories rely on at least partly similar neural processing in later time windows. Moreover, additional left-hemispheric and posterior effects were observed for all non-human-face categories. While the majority of these effects were observed in relatively late time windows after 400 ms (see e.g. green boxes in Fig. 5), all non-human-face categories also elicited some exclusive effects during earlier stages. We conclude that early stages of recognition, presumably related to the activation of visual perceptual representations, are relatively selective for a particular stimulus category, while later responses at right occipito-temporal channels, presumably more strongly associated with conceptual, integrational processes and/or the preparation of an interaction, are relatively overlapping. In the following, we will first discuss relatively distinct familiarity responses for human faces and other object categories, before turning to common effects.

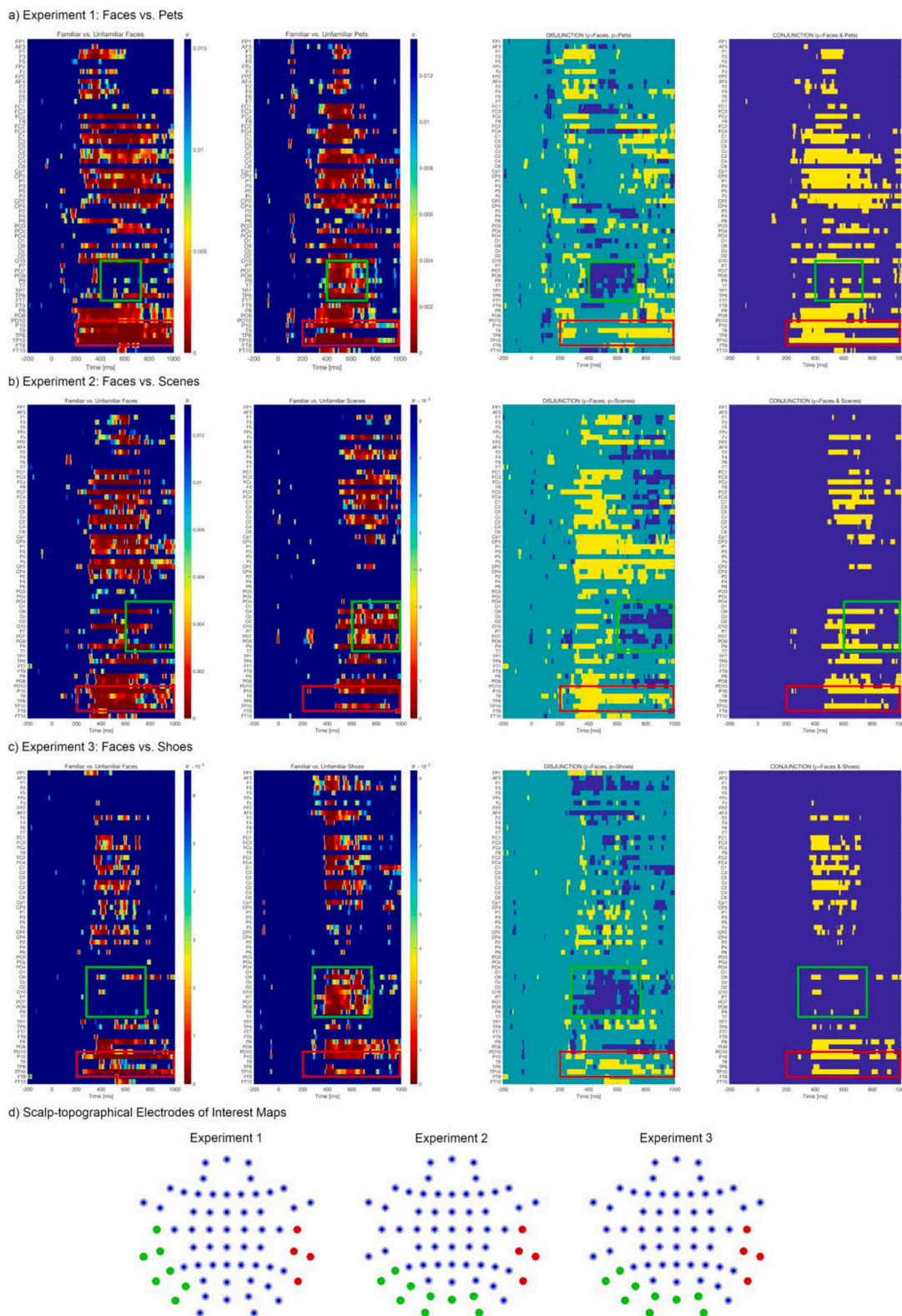
As noted above, ERP analyses designed to test a priori hypotheses revealed familiarity effects in the N250 time range that appeared to be selective to faces (see Schweinberger et al., 2004, for a similar conclusion on the N250r). In line with previous work (Wiese, Anderson, et al., 2022; Wiese, Hobden, et al., 2022; Wiese, Tüttenberg, et al., 2019), familiarity effects in the present study started approximately 200 ms after stimulus onset, were clearly right-lateralized, and were maximal at relatively more anterior occipito-temporal electrodes (TP10/P10). By contrast, none of the other examined stimulus categories yielded comparable effects in this time window. This difference between human faces and other stimulus categories was most evident in Experiment 2. Here, right occipito-temporal familiarity effects for indoor scenes were completely absent in the N250 time range. In Experiment 3, we observed

familiarity effects for objects in the N250 time range, but with weaker effect sizes (resulting in the absence of corresponding effects in the mass univariate analyses) and a more posterior scalp distribution relative to faces. Finally, in Experiment 1, personally familiar animals did elicit N250 effects similar to faces with respect to timing and the relatively more anterior scalp distribution. However, familiarity effects for animals were less clearly lateralized to the right hemisphere. In sum, the variation in spatio-temporal patterns suggests qualitative differences in the visual representation of personally familiar stimuli of different categories. This contrasts with the highly similar timing and scalp distribution observed for different "types" of familiar human faces (e.g., personal versus media-based familiarity; Wiese, Hobden, et al., 2022).

In line with selective, domain-specific effects for different stimuli, mass univariate analyses revealed that all non-human-face categories elicited additional familiarity responses at left-hemispheric and posterior electrode positions that were not observed for human faces. Interestingly, the standard ERP analysis of Experiment 2 did not detect topographical differences between familiarity effects for faces and scenes, while the mass univariate analysis did reveal such differences. We note that this latter finding does not contradict the standard analysis, as topographical differences particularly emerged at later time points than those covered by the N250 and SFE time windows, i.e. after 600 ms (see green boxes in the second row of Fig. 5). We therefore suggest this as an example of how planned ERP analyses and mass univariate approaches can complement each other. However, as the exploratory nature of the latter strategy makes the respective results relatively less reliable, future replication of the observed effect is clearly warranted.

Importantly, mass univariate tests further show that all tested stimulus categories yielded similar right occipito-temporal familiarity effects in the time range following the N250, i.e. starting between 400 and 500 ms after stimulus onset (see red boxes in Fig. 5). For human faces, we have previously interpreted this Sustained Familiarity Effect as reflecting the integration of visual perceptual recognition with activation of more conceptual identity-specific semantic, episodic, and affective information (Wiese, Anderson, et al., 2022; Wiese, Hobden, et al., 2022; Wiese, Ingram, et al., 2019; Wiese, Tüttenberg, et al., 2019). However, the finding of comparable effects for personally familiar versus unfamiliar animals, indoor scenes, and objects appears to qualify this interpretation. While personally familiar animals (i.e. our participants' pets) may well spontaneously elicit similarly rich semantic, episodic, and affective responses as personally familiar human faces, this appears unlikely for indoor pictures of houses and flats, which were temporary accommodations unlikely to be inhabited by our undergraduate participants for more than nine to twelve months. Similarly, everyday objects, such as a pair of shoes, should not spontaneously elicit comparable item-specific affective or semantic responses relative to highly familiar faces. It therefore appears unlikely that this type of information by itself underlies the SFE.

At the same time, common to all personally familiar stimuli is their relevance for preparing an upcoming action or interaction. Arguably, perception serves the purpose of providing the necessary information for potential upcoming interactions with the environment, and recognising a stimulus as "mine" ("my" shoes, "my" room, "my" dog, "my" friend etc.) increases the probability of such interactions. We are more likely to



**Fig. 5.** (a-c) FDR-corrected  $p$ -values of mass univariate repeated-measures  $t$ -tests for each time (horizontal axis) and electrode (vertical axis) in the three experiments. The leftmost column shows the comparison of familiar versus unfamiliar faces, and the respective comparison of familiar versus unfamiliar other stimuli is shown second from left. The third column from the left depicts exclusive disjunctions, i.e.  $p$ -values that are only significant for human faces (yellow) or the respective other stimulus category (purple). The right column shows conjunctions, i.e. those  $p$ -values significant for both human faces and the respective other object category. Red and green boxes show electrode/time points of interest as discussed in the text. (d) Scalp-topographical maps of electrode layouts used in Experiments 1–3. Red and green positions correspond to electrodes of interest as highlighted in red and green boxes in (a-c). Note the clear right-lateralization of the red cluster and the more left-sided and posterior (particularly Experiments 2 and 3) distribution of the green cluster.

interact with people and animals we know. Similarly, we more likely do something with our shoes (put them on, place them in a cupboard etc.) relative to somebody else's shoes. And we more likely initiate a behaviour in our room (sit down at the kitchen table, open the cupboard to get a coffee cup etc.) relative to somebody else's. This high behavioural relevance of a visual stimulus recognized as "mine" might be what is reflected in the SFE, and might also explain the "sustained" nature of the response, as activations need to be upheld until a potential interaction occurs or not. This interpretation of the SFE as reflecting the perpetuated activation of an individual item's conceptual representation for a potential upcoming interaction is in line with previous results. For instance, it explains why the SFE is substantially reduced by a distracting task (Wiese, Ingram, et al., 2019), as an interaction with the stimulus is less likely when it is clearly irrelevant for the task at hand.

An alternative interpretation of the SFE might more generally involve relevance to the self, rather than behavioural relevance. Previous studies have shown for instance that forming an association between abstract forms and the self enhances perceptual processing (Sui, He, & Humphreys, 2012). Moreover, as detailed in the Introduction, studies have found different ERP responses for items that were the participants' own (e.g. the participants' cup) as compared with familiar items not owned by the participant (a disposable cup; Miyakoshi et al., 2007; see also Sugiura et al., 2005), and these differential responses were observed in a time window overlapping with the SFE (300-700 ms). As a potential qualification, it seems unlikely that we process familiar objects such as a disposable cup or paper bag as individual items, as they are not perceived as unique and therefore more likely represented at the basic rather than individual level. Nevertheless, the SFE may be modulated by self-relevance in the sense of signalling personal "ownership", and the sustained nature of the effect might then reflect binding of separate processing stages (perception, memory, decision-making) which are all affected by self-relevance (Sui & Humphreys, 2015). However, we note that self-relevance can be trained in a single experimental session (Sui et al., 2012), while the SFE is not observed immediately after having learnt a new face but slowly builds up approximately over the first year of knowing a person (Popova & Wiese, 2022, 2023). Moreover, the magnitude of the SFE does not seem to be affected by whether face stimuli are task-relevant (e.g. in an explicit familiarity judgment) or not (e.g. in a butterfly detection task) (Wiese, Anderson, et al., 2022), which seems at odds with the idea of integrating decision-making processes.

We further note that the conception of self-relevance as personal ownership is interlinked with familiarity, as we are very likely to be more familiar with our own bag than with somebody else's bag. Interestingly, while personal ownership may be seen as bivalent (as a particular item is either mine or not), familiarity is graded, as faces (Kovacs, 2020; Kramer et al., 2018; Popova & Wiese, 2022) and arguably also animals, objects, and scenes can be more or less familiar. We note that at least the SFE to faces is substantially modulated by level of familiarity (Popova & Wiese, 2022; Wiese, Hobden, et al., 2022), which is somewhat difficult to integrate with the idea of a response signalling only bivalent personal ownership. As a qualification, ownership may be split between people for objects (a shared car), animals (the family dog), and scenes (a shared kitchen), and accordingly could be seen as graded. However, at least in Experiment 3 of the present study we tested participants with objects that were clearly bivalent in their ownership (i.e. shoes), and found very similar late right occipito-temporal effects relative to the other two experiments.

Finally, although a similar SFE was detected for all stimulus categories, and thus appears to be domain-general within the range of stimuli tested here, the present results indicate that, overall, our representations of personally familiar human faces and animals appear to be particularly similar. A potential explanation for this relatively larger overlap may be related to anthropomorphism, i.e., the tendency to attribute humanlike properties to nonhuman agents and objects (Epley, Waytz, & Cacioppo, 2007). Certainly in Western countries, people treat pets in many ways similarly to humans. Not only do we buy them

expensive food and toys (see for instance publications of the American pet products industry, [https://www.americanpetproducts.org/press\\_industrytrends.asp](https://www.americanpetproducts.org/press_industrytrends.asp)), but we also treat them as moral agents who are responsible for their actions and capable of complex emotions such as admiration, embarrassment, or guilt (Waytz, Cacioppo, & Epley, 2010). It has been suggested that we, on the one hand, try to use our knowledge of human behaviour to make sense of a non-human agent's actions, and, on the other hand, create humanlike out of non-human agents to satisfy a motivation for social connection (Epley et al., 2007). The present findings seem to support these ideas by demonstrating that personally familiar human and potentially anthropomorphic non-human agents appear to be similarly represented in our brains.

As a final point, we note that the present study focused on comparing the representations of individual human faces to various non-human-face categories, while the question of similarities and differences between the representations of different non-facial object categories is also clearly interesting. It seems likely to us that non-facial individual objects are visually represented in the brain in a category-specific way, while similar domain-general conceptual representations as those observed here also likely exist. Future research will be necessary to provide direct, within-experiment comparisons of different object categories, and we suggest the general experimental approach of the work presented here as a good starting point for this type of research.

In conclusion, the present study examined how personally familiar faces, animals, objects, and scenes are represented in the brain. While a right occipito-temporal early familiarity effect was detected exclusively for faces (both human and animal), a later sustained effect with a similar scalp distribution was observed for all stimulus categories. These findings therefore demonstrate both differences, presumably related to accessing visual perceptual long-term representations of individual known stimuli, and similarities, which most likely reflect the relevance at a conceptual level of personally familiar entities for potential interactions with the environment.

#### CRediT authorship contribution statement

**Holger Wiese:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Maya Schipper:** Investigation, Formal analysis, Data curation, Project administration, Writing – original draft. **Tsvetomila Popova:** Investigation, Data curation, Project administration, Writing – original draft. **A. Mike Burton:** Writing – original draft, Writing – review & editing. **Andrew W. Young:** Writing – original draft, Writing – review & editing.

#### Data availability

Data is fully available and a link to the corresponding OSF page is reported in the paper

#### References

- 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>
- Balas, B., & Koldewyn, K. (2013). Early visual ERP sensitivity to the species and animacy of faces. *Neuropsychologia*, 51(13), 2876–2881. <https://doi.org/10.1016/j.neuropsychologia.2013.09.014>
- 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\(94\)00240-1](https://doi.org/10.1016/0013-4694(94)00240-1)
- 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 (Statistical Methodology)*, 57(1), 289–300.
- 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), 35–55. <https://doi.org/10.1080/026432900380472>
- Biederman, I. (1972). Perceiving real-world scenes. *Science*, 177(4043), 77–80. <https://doi.org/10.1126/science.177.4043.77>
- Biederman, I., Subramaniam, S., Bar, M., Kalocsai, P., & Fiser, J. (1999). Subordinate-level object classification reexamined. *Psychological Research*, 62(2–3), 131–153. <https://doi.org/10.1007/s004260050047>
- 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(Pt 3), 305–327. <https://doi.org/10.1111/j.2044-8295.1986.tb02199.x>
- Burton, A. M., Kramer, R. S., Ritchie, K. L., & Jenkins, R. (2016). Identity from variation: Representations of faces derived from multiple instances. *Cognitive Science*, 40(1), 202–223. <https://doi.org/10.1111/cogs.12231>
- Burton, A. M., Wilson, S., Cowan, M., & Bruce, V. (1999). Face recognition in poor-quality video: Evidence from security surveillance. *Psychological Science*, 10(3), 243–248. <https://doi.org/10.1111/1467-9280.00144>
- Cumming, G. (2012). *Understanding the new statistics*. New York: Routledge.
- Davies-Thompson, J., Gouws, A., & Andrews, T. J. (2009). An image-dependent representation of familiar and unfamiliar faces in the human ventral stream. *Neuropsychologia*, 47(6), 1627–1635. <https://doi.org/10.1016/j.neuropsychologia.2009.01.017>
- 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*. Oxford: Oxford University Press.
- Engst, F. M., Martin-Loeches, M., & Sommer, W. (2006). Memory systems for structural and semantic knowledge of faces and buildings. *Brain Research*, 1124(1), 70–80. <https://doi.org/10.1016/j.brainres.2006.09.038>
- Epley, N., Waytz, A., & Cacioppo, J. T. (2007). On seeing human: A three-factor theory of anthropomorphism. *Psychological Review*, 114(4), 864–886. <https://doi.org/10.1037/0033-295X.114.4.864>
- Epstein, R., & Baker, C. I. (2019). Scene perception in the human brain. *Annual Review of Vision Science*, 5, 373–397. <https://doi.org/10.1146/annurev-vision-091718-014809>
- Epstein, R., Harris, A., Stanley, D., & Kanwisher, N. (1999). The parahippocampal place area: Recognition, navigation, or encoding? *Neuron*, 23(1), 115–125. [https://doi.org/10.1016/s0896-6273\(00\)80758-8](https://doi.org/10.1016/s0896-6273(00)80758-8)
- Epstein, R., & Kanwisher, N. (1998). A cortical representation of the local visual environment. *Nature*, 392(6676), 598–601. <https://doi.org/10.1038/33402>
- Epstein, R., & Morgan, L. K. (2012). Neural responses to visual scenes reveals inconsistencies between fMRI adaptation and multivoxel pattern analysis. *Neuropsychologia*, 50(4), 530–543. <https://doi.org/10.1016/j.neuropsychologia.2011.09.042>
- Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G\*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. <https://doi.org/10.3758/bf03193146>
- Gobbini, M. I., & Haxby, J. V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia*, 45(1), 32–41. <https://doi.org/10.1016/j.neuropsychologia.2006.04.015>
- Gosling, A., & Eimer, M. (2011). An event-related brain potential study of explicit face recognition. *Neuropsychologia*, 49(9), 2736–2745. <https://doi.org/10.1016/j.neuropsychologia.2011.05.025>
- Grill-Spector, K., Kourtzi, Z., & Kanwisher, N. (2001). The lateral occipital complex and its role in object recognition. *Vision Research*, 41(10–11), 1409–1422. [https://doi.org/10.1016/s0042-6989\(01\)00073-6](https://doi.org/10.1016/s0042-6989(01)00073-6)
- Harel, A., Groen, I. L., Kravitz, D. J., Deouell, L. Y., & Baker, C. I. (2016). The temporal dynamics of scene processing: A multifaceted EEG investigation. *eNeuro*, 3(5). <https://doi.org/10.1523/ENEURO.0139-16.2016>
- Harel, A., Mzozoyana, M. W., Al Zoubi, H., Nador, J. D., Noesen, B. T., Lowe, M. X., & Cant, J. S. (2020). Artificially-generated scenes demonstrate the importance of global scene properties for scene perception. *Neuropsychologia*, 141, 107434. <https://doi.org/10.1016/j.neuropsychologia.2020.107434>
- Haxby, J. V., Gobbini, M. I., Furey, M. L., Ishai, A., Schouten, J. L., & Pietrini, P. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science*, 293(5539), 2425–2430. <https://doi.org/10.1126/science.1063736>
- 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](https://doi.org/10.1016/s1364-6613(00)01482-0)
- Iordan, M. C., Greene, M. R., Beck, D. M., & Fei-Fei, L. (2015). Basic level category structure emerges gradually across human ventral visual cortex. *Journal of Cognitive Neuroscience*, 27(7), 1427–1446. <https://doi.org/10.1162/jocn.2015.00790>
- 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>
- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience*, 17(11), 4302–4311. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/9151747>
- 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>
- Kovacs, 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.2020.01627>
- 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>
- Malach, R., Reppas, J. B., Benson, R. R., Kwong, K. K., Jiang, H., Kennedy, W. A., ... Tootell, R. B. (1995). Object-related activity revealed by functional magnetic resonance imaging in human occipital cortex. *Proceedings of the National Academy of Sciences of the United States of America*, 92(18), 8135–8139. <https://doi.org/10.1073/pnas.92.18.8135>
- Margalit, E., Shah, M. P., Tjan, B. S., Biederman, I., Keller, B., & Brenner, R. (2016). The lateral occipital complex shows no net response to object familiarity. *Journal of Vision*, 16(11), 3. <https://doi.org/10.1167/16.11.3>
- Marr, D., & Nishihara, H. K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proceedings of the Royal Society of London - Series B: Biological Sciences*, 200(1140), 269–294. <https://doi.org/10.1098/rspb.1978.0020>
- McNeil, J. E., & Warrington, E. K. (1993). Prosopagnosia: a face-specific disorder. *Quarterly Journal of Experimental Psychology A*, 46(1), 1–10. <https://doi.org/10.1080/14640749308401064>
- Miyakoshi, M., Nomura, M., & Ohira, H. (2007). An ERP study on self-relevant object recognition. *Brain and Cognition*, 63(2), 182–189. <https://doi.org/10.1016/j.bandc.2006.12.001>
- Munoz, F., Casado, P., Hernandez-Gutierrez, D., Jimenez-Ortega, L., Fondevila, S., Espuny, J., ... Martin-Loeches, M. (2020). Neural dynamics in the processing of personal objects as an index of the brain representation of the self. *Brain Topography*, 33(1), 86–100. <https://doi.org/10.1007/s10548-019-00748-2>
- 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>
- Quiroga, R. Q., Reddy, L., Kreiman, G., Koch, C., & Fried, I. (2005). Invariant visual representation by single neurons in the human brain. *Nature*, 435(7045), 1102–1107. <https://doi.org/10.1038/nature03687>
- Rosch, E., Mervis, C. B., Gray, W. D., Johnson, D. M., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology*, 8, 382–439.
- Rousselet, G. A., Mace, M. J., & Fabre-Thorpe, M. (2004). Animal and human faces in natural scenes: How specific to human faces is the N170 ERP component? *Journal of Vision*, 4(1), 13–21. <https://doi.org/10.1167/4.1.2>
- 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., Huddy, V., & Burton, A. M. (2004). N250: 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 and associative priming of face recognition - evidence from event-related potentials. *Journal of Experimental Psychology-Learning Memory and Cognition*, 21(3), 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. *Brain Research. Cognitive Brain Research*, 14(3), 398–409. [https://doi.org/10.1016/s0926-6410\(02\)00142-8](https://doi.org/10.1016/s0926-6410(02)00142-8)
- Sugiura, M., Shah, N. J., Zilles, K., & Fink, G. R. (2005). Cortical representations of personally familiar objects and places: Functional organization of the human posterior cingulate cortex. *Journal of Cognitive Neuroscience*, 17(2), 183–198. <https://doi.org/10.1162/0898929053124956>
- Sui, J., He, X., & Humphreys, G. W. (2012). Perceptual effects of social salience: Evidence from self-prioritization effects on perceptual matching. *Journal of Experimental Psychology. Human Perception and Performance*, 38(5), 1105–1117. <https://doi.org/10.1037/a0029792>
- Sui, J., & Humphreys, G. W. (2015). The integrative self: How self-reference integrates perception and memory. *Trends in Cognitive Sciences*, 19(12), 719–728. <https://doi.org/10.1016/j.tics.2015.08.015>
- 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>
- Tarr, M. J., & Bulthoff, H. H. (1998). Image-based object recognition in man, monkey and machine. *Cognition*, 67(1–2), 1–20. [https://doi.org/10.1016/s0010-0277\(98\)00026-2](https://doi.org/10.1016/s0010-0277(98)00026-2)
- Tong, F., Nakayama, K., Moscovich, M., Weinrib, O., & Kanwisher, N. (2000). Response properties of the human fusiform face area. *Cognitive Neuropsychology*, 17(1), 257–280. <https://doi.org/10.1080/026432900380607>
- Waytz, A., Cacioppo, J. T., & Epley, N. (2010). Who sees human? The stability and importance of individual differences in anthropomorphism. *Perspectives on Psychological Science*, 5(3), 219–232. <https://doi.org/10.1177/1745691610369336>
- Weibert, K., Harris, R. J., Mitchell, A., Byrne, H., Young, A. W., & Andrews, T. J. (2016). An image-invariant neural response to familiar faces in the human medial temporal lobe. *Cortex*, 84, 34–42. <https://doi.org/10.1016/j.cortex.2016.08.014>

- Wiese, H., Anderson, D., Beierholm, U., Tüttenberg, S. C., Young, A. W., & Burton, A. M. (2022). Detecting a viewer's familiarity with a face: Evidence from event-related brain potentials and classifier analyses. *Psychophysiology*, *59*(1), Article e13950. <https://doi.org/10.1111/psyp.13950>
- Wiese, H., Hobden, G., Siilbek, E., Martignac, V., Flack, T. R., Ritchie, K. L., ... 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., Stahl, J., & Schweinberger, S. R. (2009). Configural processing of other-race faces is delayed but not decreased. *Biological Psychology*, *81*(2), 103–109. <https://doi.org/10.1016/j.biopsycho.2009.03.002>
- 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>
- 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>
- Zhang, X. L., Begleiter, H., Porjesz, B., Wang, W., & Litke, A. (1995). Event related potentials during object recognition tasks. *Brain Research Bulletin*, *38*(6), 531–538. [https://doi.org/10.1016/0361-9230\(95\)02023-5](https://doi.org/10.1016/0361-9230(95)02023-5)