Electrophysiological correlates of processes supporting memory for faces.

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Abstract: The retrieval processes supporting recognition memory for faces were investigated using event-related potentials (ERPs). The focus for analyses was ERP old/new effects, which are the differences between neural activities associated with correct judgments to old (studied) and new (unstudied) test stimuli. In two experiments it was possible to identify three old/new effects that behaved as neural indices of the process of recollection. In both experiments there was one old/new effect that behaved as an index of the process of familiarity. These outcomes are relevant to the ongoing debate about the functional significance of ERP old/new effects and the implications that scalp-recorded electrophysiological data have for theories of the processes supporting long-term memory judgments.

1. Introduction

It is widely accepted that recognition memory judgments can receive contributions from two functionally and neurally distinct retrieval processes, commonly termed recollection and familiarity (Mandler, 1980; Yonelinas, 1994). Recollection entails the recovery of qualitative information from a prior encounter, whereas familiarity is a graded strength signal that can be used as a signal of prior occurrence (Yonelinas, 1994, 2002).

The findings in several event-related potential (ERP) studies have been interpreted as providing support for dual-process models of memory retrieval because of the alignment of distinct old/new effects with the processes of recollection and familiarity, respectively. Old/new effects are differences between the neural activities elicited by old (studied) and new (unstudied) stimuli that attract correct old/new judgments. The left-parietal old/new effect comprises a greater relative positivity for old than for new stimuli, is evident primarily from 500-800ms post-stimulus, and as the label suggests is largest over left-parietal scalp. The weight of evidence suggests that this effect indexes the process of recollection (for reviews see Wilding, 2000; Rugg & Curran, 2007; Wilding & Ranganath, 2012). The mid-frontal old/new effect (in some quarters termed the FN400 (Curran, 1999, 2000; Woodruff et al., 2006)) also comprises a greater relative positivity for old than for new test stimuli. This effect is typically evident from 300-500ms post-stimulus and is largest at fronto-central scalp locations. The effect has been linked with the process of familiarity, although a competing account holds that this effect indexes conceptual priming (Voss et al., 2010a, 2010b). There are at least two strong challenges to a conceptual priming account for the mid-frontal ERP old/new effect. First, for words there is strong evidence that the neural correlate of conceptual priming has a different distribution to the old/new effect in the 300-500ms time window that has been linked to the process of familiarity (Rugg et al., 1998; Bridger et al., 2012). Second, changes in the magnitude of mid-frontal ERP old/new effects have been observed using manipulations (such as object or background colour) for which an appeal to changes in conceptual priming is challenging (e.g. Curran & Cleary, 2003; Ecker et al., 2007a). For ERPs acquired in tasks where faces have been the test stimuli, the picture is somewhat variable, however, as described below.

Yick & Wilding (2008) demonstrated that the ERP old/new effects elicited by faces are qualitatively different than those elicited by words. They showed that in a 500-800ms post-stimulus epoch the old/new effects shared a common left-parietal maximum, reminiscent of the left-parietal ERP old/new effect, and extended to a greater degree to anterior electrodes for faces than for words, suggesting that two distinct effects were present in this time window. These findings, however, were obtained in a task where only old/new judgments were required, thereby limiting the extent to which inferences could be made about the functional significance of the different modulations they observed, and in particular their link to the processes of recollection and familiarity. This constraint does not apply to three other studies in which faces were used as stimuli. In these studies the manipulations at the time of encoding permitted separations between ERP old/new effects for studied faces that either were or were not associated with memory for encoded details. In so far as recollection but not familiarity supports memory for these details, this separation permits a means of aligning old/new effects with one or other of these processes.

In the first experiment of this kind in which faces were the test stimuli, Yovel & Paller (2004) used a design that paired a target face with a fictional occupation (e.g. butcher, astronaut, spy). At test, participants were asked to make an initial old/new judgment, and then to indicate whether they (i) could remember the occupation information presented along with the face at study – *specific context*[1], ii) could remember details other than the occupation information – *other context*, or (iii) were unable to remember contextual information – *no context*. When participants made response (i) they were asked to provide the relevant occupation detail from the study phase. The logic for interpreting ERP old/new effects in this experiment was that recollection of task-relevant detail served as the basis for correct specific context judgments, other context judgments were based on non-criterial recollection, and the no-context option indicated that the initial old judgment was based upon familiarity. The assumptions for interpreting the ERPs acquired in the study by Yovel & Paller (2004) were that: (i) old/new effects that did not vary in size according to whether context information was recovered were likely correlates of familiarity, and (ii) old/new effects that were larger when accompanied by memory for context were likely correlates of recollection.

The analyses of old/new effects in this study were restricted to the 300-500ms and 500-700ms time windows. In the first of these, old/new effects were equivalent in size for the response categories associated with recovery of context (specific as well as other). There were, however, no reliable old/new effects for no-context judgments. In the 500-700ms time window, ERP old/new effects were reliable for all three options associated with a correct old response, and the effects were larger for the two options associated with the recovery of context. The differences between the effects in the two time windows were quantitative rather than qualitative, suggesting the same old/new effects were observed across epochs for correct context judgments.

These effects can most straightforwardly be linked to the process of recollection, with the small old/new effect for no-context judgments in the 500-700ms time window possibly reflecting sub-threshold recollection. In summary, the findings of Yovel & Paller (2004) allow one strong claim, which is that ERPs in this task index processes tied to recollection rather than to familiarity.

MacKenzie & Donaldson (2007) obtained somewhat different electrophysiological outcomes in a very similar design. In the 300-500ms epoch, MacKenzie and Donaldson identified an equivalent frontally distributed old/new effect for the specific- and other-context categories. At posterior sites in the same epoch, there was an old/new effect that was statistically equivalent for all three categories associated with correct old judgments. This posterior effect fulfills one criterion for a neural index of familiarity – insensitivity to the accuracy of the context judgments - hence these data suggest that there are two old/new effects in this time window. The behavior of the anterior effect links it to recollection, while the posterior effect is more readily linked to familiarity. The strength of these arguments is limited, however, because there were no reliable differences between the scalp distributions of the old/new effects for these three response categories in this epoch. In addition, in the absence of data associated with misses (incorrectly rejected old items), another interpretation of the posterior modulation is that it is a repetition effect. This possibility gains support from the finding that, in studies where verbal and facial stimuli have been employed, a repetition effect is often observed at central posterior sites in this epoch (for words: Azimian-Faridani & Wilding, 2006; Rugg et al., 1998; faces: Henson et al., 2003; Schweinberger & Burton, 2003; pictures: Yu & Rugg, 2010). It has been proposed that this posterior effect is an index of implicit memory (Rugg et al., 1998). A stronger link between this posterior modulation and the process of familiarity in MacKenzie and Donaldson's study would have stemmed from a demonstration that the effect was attenuated for misses, thereby linking changes in the effect to the decisions made on the task and not simply to the study history of test faces.

For the 500-700ms epoch, MacKenzie and Donaldson reported graded old/new effects that decreased in magnitude from the specific-context, to other-context, to no-context response categories. This graded pattern links all of the old/new effects in this epoch to recollection, but a novel finding was that MacKenzie and Donaldson demonstrated there were two separable indices of recollection: the scalp distribution of the no-context old/new effect differed reliably from the effect for the two context categories. The main reason for this distribution difference is an old/new effect that extends to a greater degree to frontal sites for responses associated with correct specific-context and other-context judgments. In summary, the findings of MacKenzie & Donaldson (2007) converge in part with those of Yovel & Paller (2004), in that the findings in both studies can readily be interpreted as support for the claim that ERPs elicited by faces in source retrieval tasks index processes tied closely to recollection. While Yovel and Paller demonstrated only one ERP modulation linked to recollection, however, MacKenzie and Donaldson's data argue strongly that distinct ERP modulations elicited by faces are tied to recollection (see also comments in Yick & Wilding, 2008). It remains the case that in neither study is there strong evidence for an ERP index of familiarity, particularly at mid-frontal electrode locations in the 300-500ms epoch, which is where in studies using verbal stimuli and other kinds of non-verbal stimuli (Curran & Cleary, 2003; Groh-Bordin et al., 2006; Ecker et al., 2007b) a putative index of this process has been reported (for review see Wilding & Ranganath, 2012).

A similar study conducted by Curran & Hancock (2007) revealed different outcomes again. For the 300-500ms epoch, Curran and Hancock reported analyses that mirrored those completed by Yovel & Paller (2004). They also focused analyses on mid-frontal electrodes, guided by the findings in studies in which verbal stimuli had been employed (Curran, 2000; Mecklinger, 2006). The key finding was that there were statistically equivalent old/new effects at frontal sites for old items associated with recovery of context information as well as those associated with the no-context category. Furthermore, ERPs associated with misses did not diverge from those elicited by correct rejections and were reliably more negative-going than those associated with correct context responses. On the basis of these findings, Curran and Hancock suggested that they had obtained for faces a mid-frontal old/new effect, thereby suggesting that the effect is a material-general index of familiarity. In the 500-700ms epoch, Curran and Hancock restricted their analyses to posterior sites, where only the correct context judgment categories were reliably different from correct rejections, with this outcome linking this effect to the process of recollection, mirroring one aspect of the findings reported by MacKenzie & Donaldson (2007).

To summarise, despite similar manipulations in these three studies, the questions of whether ERPs index familiarity in tasks where faces are employed, and what forms ERP indices of recollection for faces take, remain unclear. The present study is motivated by the need to understand the disparate findings, and this is important because establishing functional significance is a precursor to deploying ERP indices to test predictions of cognitive models, and because the identification of material-specific indices of memory processes has implications for memory models as well as offering a tool to explore phenomena such as incidental retrieval and retrieval control (e.g. Wilding & Herron, 2006).

Towards this end, two ERP experiments were conducted to assess the sensitivity of ERPs to processes supporting memory judgments when faces are employed. In a methodological departure from the experiments described above, here the information to be retrieved was not about nominal occupations. This change was motivated by a concern that the face/name occupation pairings in these studies meant that at least some of the old/new effects obtained were a reflection of recovery of across-domain associations (Mayes et al., 2007). In an attempt to restrict mnemonic content to face processing somewhat more directly, in these experiments internal facial features (eyes, nose or mouth) were obscured at study and test judgments included identification of the feature that had been obscured.

To elaborate, in each study phase a white bar was inserted to obscure either one eye or the mouth in Experiment 1, and an additional location - the nose - in Experiment 2. At test studied and unstudied faces were shown. For faces judged to be old participants made a subsequent facial feature response (eye/mouth in Experiment 1, eye/nose/mouth in Experiment 2). This response manipulation allows the separation of ERPs into three categories: correctly rejected new test faces, and correctly identified old faces for which the facial feature judgment was either correct or incorrect. If recollection is the basis for accurate feature judgments and if old/new effects associated with faces attracting correct feature judgments are larger than those attracting incorrect judgments in the 300-500ms epoch at anterior electrodes, this outcome would be consistent with the findings of MacKenzie & Donaldson (2007), and challenge the view that this scalp location and time window offers a general index of familiarity. Moreover, if differences of this kind are restricted to anterior locations in this epoch it would support the view that two distinct memory-related processes, with anterior and posterior maxima respectively, are active in this time period. Accordingly, if the early posterior old/new effect is insensitive to the accuracy of feature judgments it would support the claim that it indexes familiarity (MacKenzie & Donaldson, 2007). Finally, if the old/new effects in the 500-700ms epoch in these studies extend to anterior electrode locations, and if this anterior projection is larger for test stimuli attracting correct feature judgments, it will support claims made previously (MacKenzie & Donaldson, 2007; Yick & Wilding, 2008) that a material-specific index of recollection can be observed at these anterior locations. At issue overall is the sensitivity of ERP old/new effects to processes supporting memory for faces and face features.

2. Experiment 1:

2.1. Methods

2.1.1. Participants

These were 30 Caucasian right-handed English speakers with normal or corrected-to-normal vision. The experiment was approved by the Cardiff University Psychology Ethics Committee. Data from 14 participants were discarded; 5 had insufficient trials (<16) in at least one of the three critical response categories following artifact rejection (for criteria see below), and for the remaining 9 the conditional probability of a correct feature judgment fell below 0.60[2]. The mean age of the remaining participants was 21 (age range 18-28, 5 males).

2.1.2. Stimuli

The stimulus set comprised 360 front-view faces of young to middle age Caucasian males and females. All were standardized black-and white images (400 x 500 pixels) containing head-and-shoulder information with minimal background. The faces were taken from the Stirling Database and a small set of faces was obtained from the Internet using Google Image ™ [stimuli are available from Y.Y.Y. on request: belleyick@gmail.com]. Each image was used in two forms, comprising complete and incomplete images. To form the incomplete images, all images were randomly allocated into 1 of 2 facial feature groups (eye or mouth). Stimuli in the eye group were further divided into two to form the left eye and the right eye group. Each incomplete stimulus was formed by inserting a white block to obscure the relevant facial part. An example of the faces is shown in Figure 1.

There were 8 study-test blocks and 1 practice block. Each block contained 20 study and 40 test trials, the test trials comprising the studied faces and an equal number of unstudied faces. Each study and test phase contained an equal number of male and female faces. In each study phase, half of the faces had the mouth obscured; the remainder had one eye obscured. Block order was balanced, with one block containing faces with the left eye and the mouth obscured, followed by a block containing faces with the right eye and the mouth obscured. Within each study phase, the two possible occlusions had an equal likelihood of occurrence for male and for female faces. The old/new status of the faces was counterbalanced across participants, as was the order of study-test block presentation: half of the participants completed the first half of the study-test blocks first. Manipulating the old/new status of the faces and the sequence of the study-test block presentations produced 4 study-test lists. The order of stimulus presentation within each study and test block was randomly determined for each participant by the stimulus presentation software. During each study and test phase, all faces were presented visually against a white background on a computer monitor located 1 meter from participants. They subtended maximum visual angles of 5.6° (vertical) and 4.2° (horizontal).

2.1.3. Procedure

A full instruction and practice block was administered after participants were fitted with an electrode cap. In the study phases, each trial began with an asterisk (*) that was displayed in the centre of the screen for 1000ms. A 100ms blank screen then intervened, after which a complete face was displayed in the centre of the screen for 2000ms. The face remained on the screen for a further 100ms, during which one feature was occluded. This was followed by a blank screen lasting the length of time the participant took to respond plus 1500ms before presentation of the asterisk signaling the onset of the next trial. A binary feature location response was required; half of the participants responded with the left index finger to faces with an eye obscured and with the right index finger for the mouth. This correspondence was reversed for the remaining participants.

A test phase immediately followed each study phase. Each test trial began with an asterisk which was presented for 1000ms and followed by a blank screen for 100ms. Test faces were presented for 300ms and followed by a black screen lasting the length of time the participant took to respond plus 1500ms. Participants were asked to indicate the old/new status of each face using a binary response. For half of the participants, the left thumb was designated for old responses, the right thumb for new responses. This mapping was reversed for the remaining participants. Once the old/new response was given and the 1500ms blank period had ended, a question mark (?) was presented lasting the length of time the participant took to make the second judgment. This was a location judgment, which required participants to indicate the location of the white bar (eye/mouth) that had obscured a facial feature at study. The keys used for eye/mouth responses were the same as those used for those responses in the study phase. When a new response was made, a second key press when the question marks came up initiated the next trial. The hands used for the eye/mouth response at study, as well as the old/new response at test, were counterbalanced across participants to create a total of 4 study-test response combinations.

2.1.4. EEG recordings

EEG data were recorded continuously from 32 silver/silver-chloride electrodes. All electrodes were embedded in an elastic cap and located at midline sites (Fz, Cz, Pz, Oz) and left/right hemisphere locations (FP1/FP2, F7/F8, F5/F6, F3/F4, F1/F2, T7/F8, C5/C6, C3/C4, C1/C2, P7/P8, P5/P6, P3/P4, P1/P2, O1/O2) based on the International 10-20 system (Jasper, 1958). Electrodes were also placed on the left and right mastoids. Electro-oculogram (EOG) was recorded from electrode pairs placed above and below the left eye and on the outer canthi. EEG (range DC-419 Hz; sampling rate 2048 Hz) was acquired referenced to linked electrodes located midway between POZ and PO3/PO4. EEG was re-referenced computationally off-line to the average of the signal at the two mastoids into baseline corrected epochs of 1280ms, each including a 100ms pre-stimulus baseline, relative to which all post-stimulus amplitudes were measured. Data were high-pass filtered off-line (0.03 – 60 Hz) and down-sampled to 200 Hz. Trials containing large EOG artifacts were rejected, as were trials containing A/D saturation or baseline drift exceeding ±80μV. Other EOG blink artifacts were corrected using a linear regression estimate (Semlitsch, Anderer, Schuster, & Presslich, 1986). Participants were excluded from all analyses if, after artifact rejection, they contributed fewer than 16 trials to any of the critical response categories. The averaged ERPs underwent a 7-point (22Hz) binomially weighted smoothing filter prior to analysis. All ANOVAs reported below used the

Greenhouse-Geisser correction where appropriate (Greenhouse & Geisser, 1959). Epsilon values are reported along with uncorrected degrees of freedom.

2.2. Results

2.2.1. Behavioral Data

Accuracy: Mean probabilities of correct judgments for old and new faces are shown in the left half of Table 1. Old/new discrimination [Pr = p(hit) – p(false alarm); (Snodgrass & Corwin, 1988)] irrespective of the accuracy of feature judgments was reliably above chance (Pr = 0.63, t(15) = 20.72, $p < .01$), as was the conditional probability of a correct feature judgment [mean = 0.66, t(15) = 30.52, $p < .01$]. There was no reliable difference between the likelihood of a correct eye or mouth judgment.

Reaction Times: Mean reaction times (RTs) for correct and incorrect judgments to new and old faces are also shown in Table 1. A 2*2 ANOVA with factors of accuracy and old/new status revealed a reliable main effect of status (F (1,15) = 10.42, $p < .01$), and an interaction (F (1,15) =12.85, $p < .01$), reflecting the fact that responses to old words did not differ according to accuracy, while false alarms were reliably slower than correct rejections (t(15) = 5.01, $p < .01$). The RTs for correct old judgments subsequently attracting correct feature judgments were reliably quicker than for those attracting incorrect feature judgments (t(15) = 3.03, $p < .01$).

2.2.2. Electrophysiological Data

The principal analyses focused on correct new responses (CRs) and correct old responses separated according to feature accuracy (correct = hit/hit; incorrect = hit/miss). For all 16 participants, the mean numbers of trials after artifact rejection for the hit/hit, hit/miss and CR response categories were 33 (range = 17 to 47), 21 (16 to 27), and 48 (28 to 68). For the main analysis, 16 electrode sites from an equal number of left and right frontal and parietal locations were selected (left anterior: FP1, F7, F5, F3; right anterior: FP2, F8, F6, F4; left posterior; O1, T5, P5, P3; right posterior: O2, T6, P6, P4). Grand averaged ERPs for all of these locations are shown in Figure 2. The old/new effects for the hit/hit and the hit/miss response categories start from approximately 300ms post-stimulus and these effects are largest over superior sites up to approximately 700ms. The waveforms for the hit/hit and hit/miss response category differ to some extent in the 300-500ms time window. The waveform for the hit/hit category becomes markedly more positive-going than the hit/miss category from 500ms onwards, after which both waveforms are more positive-going than those associated with CRs.

The ERP analyses were divided into 3 sections, comprising main, focused and topographical analyses. These terms will be used consistently throughout to signal when we are referring to these separate outcomes. These analyses were conducted for the 300-500 and 500-700ms epochs, selected *a priori* on the basis of approaches and findings in previous ERP studies (Curran & Hancock, 2007; Yovel & Paller, 2004). The initial main analyses included factors of response category (3 levels), anterior/posterior dimension (2), hemisphere (2), and site (4). Subsequent analyses following any reliable main effects of category and/or interactions involving category comprised all possible paired contrasts. Reliable main effects are reported only when they are not moderated by interaction terms, and only the highest order un-moderated interaction terms are reported.

Focused analyses were also conducted in time windows and at electrode sites where it has been proposed that ERPs index the processes of familiarity and recollection (Curran & Hancock, 2007; MacKenzie & Donaldson, 2007). For familiarity, the focused analyses were conducted at three mid-frontal electrodes (F3, Fz, F4) and at three parietal electrodes (P3, Pz, P4) in the

300-500ms epoch, based on the suggestion that early frontal and/or parietal effects might index familiarity for faces (Curren & Hancock, 2007; MacKenzie & Donaldson, 2007). For recollection, the analyses were conducted over data taken from left-parietal (P3, P5, P7) electrodes (Curran, 1999, 2000; Rugg et al., 1998), as well as at the three mid-frontal electrodes because a frontal modulation has been observed when faces were the test stimuli in the 500-700ms epochs (MacKenzie & Donaldson, 2007; 2009; Yick & Wilding, 2008).

Topographic analyses were conducted to investigate differences between the scalp distributions of the ERP old/new effects associated with the hit/hit and hit/miss response categories for the 300-500 and 500-700ms epochs (see Figure 3). Reliable differences between scalp distributions can indicate that not entirely the same set of processes is engaged in different experiment conditions, or that the extent to which members of the same set of processes are engaged is not equivalent. Interactions involving condition and scalp locations in ANOVAs can signal differences between scalp distributions, but only when the interactions involving location remain when differences between the magnitudes across conditions have been controlled for. For this reason, the topographic analyses were conducted on difference scores obtained by subtracting mean amplitudes associated with correct rejections from those associated with correct and incorrect feature judgments to old faces. These scores were then re-scaled using the max-min method (McCarthy & Wood, 1985; Wilding, 2006). Concerns have been raised over approaches to re-scaling (Urbach & Kutas, 2006), but some of these do not apply to the max-min approach when it is employed on difference scores (Wilding, 2006). Analyses of scalp distributions were conducted only when interactions involving scalp locations were revealed in the initial analyses of the hit/hit and hit/miss ERP old/new effects, and because of the intention of removing the interpretation ambiguities that remain with interactions obtained when analysing unrescaled data, the analyses included the same location factors employed in the main ANOVAs already described. In addition, the initial topographic analyses described below included the factors of response category (hit/hit vs hit/miss) as well as epoch (300-500 vs 500-700ms).

2.3.1. Main analyses

Initial analyses including all 3 response categories revealed an interaction between category, anterior/posterior and site in the 300-500ms epoch [F (2,30) = 2.88, $p < .05$; ε = .53)] and an interaction between category and site in the 500-700ms epoch [F (6,90) = 14.14, $p < .01$; ε = .57)]. All possible paired contrasts were then conducted separately within the two time windows.

300-500ms (Table 2): The significant interaction between category, anterior/posterior and site for the hit/hit vs CR contrast reflects, as Figure 2 shows, a positive-going difference which is most pronounced at right–frontal and prefrontal locations. For the contrast between hit/miss and CR, the reliable category by hemisphere interaction reflects a somewhat greater relative positivity for hit/miss that is largest over the left hemisphere. The two interaction terms revealed in the hit/hit versus hit/miss contrast (category x hemisphere, category x anterior/posterior x site) reflect the fact that the greater relative positivity for hit/hit is broadly right lateralized, and the difference between the two response categories is largest at right-frontal and prefrontal electrode locations.

500-700ms (Table 2): The contrasts involving CRs revealed category x site and category x hemisphere interactions that were either significant or approached significance. These outcomes reflect the facts that the old/new effects are larger over the left hemisphere than the right and largest at sites closest to the midline. The category x hemisphere interaction obtained in the contrast between hit/hit and hit/miss mean amplitudes reflects an overall greater relative positivity for the hit/hit category at right hemisphere locations.

2.3.2. Focused analyses

The analyses for the 300-500ms epoch revealed reliable and statistically equivalent positive-going old/new effects for the hit/hit and hit/miss response categories (see Table 3). This was also the case in the 500-700ms epoch. At posterior sites in the later epoch the category x site interaction reflects the fact that the hit/hit old/new effect is larger at P3 than at P5 and P7. The marginally significant effects in the hit/hit versus hit/miss contrasts between 500 and 700ms reflect a tendency for the hit/hit old/new effects to be larger.

2.3.3. Topographic analyses

The initial contrast including both hit/hit and hit/miss response categories did not yield any significant interactions involving the factors epoch and category, however, a reliable three-way interaction between epoch, anterior/posterior, and site was obtained for the hit/hit contrast only ($F\ (3,45) = 4.42$, $p < .02$, $\varepsilon = .73$). This interaction reflects that fact that the old/new effects in the later epoch have a broader distribution that extends further to both prefrontal sites and to posterior mid-lateral sites than is the case in the earlier time window. Within each epoch, interactions between category, anterior/posterior, and site were obtained (300-500ms: $F\ (3,45) = 8.19$, $p < .01$, $\varepsilon = .63$; 500-700ms: $F\ (3,45) = 5.20$, $p < .02$, $\varepsilon = .62$). In both cases, the interactions reflect the fact that the old/new effects project to anterior sites markedly more for the hit/hit than for the hit/miss response category.

2.4. Discussion

The experiment was designed to identify the ERP correlates of processes contributing to memory for faces and for face features. This was operationalized by asking participants to distinguish between studied and unstudied faces, and to report – for studied faces – on which of two features (mouth or eye) had been occluded in the study presentation. Turning first to the behavioral data, old/new discrimination and the accuracy of feature judgments were reliably above chance. RTs were in general faster for correct than for incorrect judgments. Overall, the behavioral data indicate that the participants included in these analyses were able to recover feature information in this task on a reasonable proportion of trials, and the RTs are consistent with findings in other studies with comparable response and mnemonic demands (Wilding & Rugg, 1996).

For the ERP data, in the 300-500ms epoch the global analyses revealed a greater relative positivity for the hit/hit in comparison to the hit/miss ERPs. This was somewhat right lateralized and largest at prefrontal electrodes. The focused analyses at mid-frontal electrode locations, however, did not reveal reliable differences between the hit/hit and hit/miss ERP old/new effects, and this was also the case for the analyses at posterior sites. Consistent with these outcomes, and the fact that there were reliable old/new effects for both the hit/hit and hit/miss response categories, the topographic analysis revealed reliable differences between the scalp distributions of the two effects. The principal driver for this, as Figure 3 shows, is the anterior extension of the old/new effect for the hit/hit response category. These outcomes suggest strongly that the ERPs in this epoch index two functionally and neurally distinct processes, one of which has a more anterior focus and is more sensitive to the hit/hit vs hit/miss contrast than is the other.

In the 500-700ms epoch the pattern of statistical outcomes is broadly similar. In keeping with the findings in the earlier epoch, and confirmed by the analyses of scalp distributions, the principal differences between the old/new effects were at right hemisphere and frontal locations. The outcomes of the separate focused analyses at anterior and at posterior sites revealed reliable positive-going old/new effects for both the hit/hit and the hit/miss response categories, but although there were trends, the old/new effects were not reliably larger for the hit/hit category. This outcome is a little surprising, as larger effects for stimuli attracting correct rather than incorrect context judgments in this epoch have commonly been reported for faces as well as when other stimulus types have been employed in retrieval tasks (MacKenzie & Donaldson, 2007; Curran & Hancock, 2007; Wilding & Rugg, 1996; Ecker et al., 2007a).

One possible explanation for these outcomes stems from the forced choice requirements at test. The paradigm employed in Experiment 1 was structurally very similar to that employed in the first of two experiments by Wilding & Rugg (1996). In their second experiment, they included a 'don't know' option for both the initial old/new and the forced choice context judgment in order to obtain a cleaner separation between hit/hit and hit/miss old/new effects. They reasoned that because of the forced choice nature of the context decision in their first experiment, a proportion of trials contributing to the hit/hit waveforms were 'lucky guesses'. The presence of these trials (the exact proportion of which would depend upon the level of source accuracy and the number of source options available) would presumably reduce the likelihood of observing reliable differences between the hit/hit and the hit/miss ERP old/new effects. They reasoned that employing the 'don't know' option was a way of removing these trials from the hit/hit waveforms.

These considerations are relevant here, because they raise the possibility that the reason for statistically equivalent old/new effects for the hit/hit and hit/miss old/new effects (in whatever epoch they are observed) is not because the effect of interest indexes processes engaged to the same degree. Rather, it may be a consequence of the contribution of correct "guess" trials to the hit/hit response category for which little or no context information was available. This possibility was assessed in the present experiment, but rather than using 'don't know' options (Wilding & Rugg, 1996), an additional context response was included. When the number of context options is increased, and if participants use all context responses available to them when uncertain, the proportion of trials in the hit/hit response category that are 'lucky guesses' will be lower than when only a binary context judgment is required. This was accomplished here by extending the number of facial features that might be occluded to 3, adding the nose to the eyes and mouth that were employed in Experiment 1. This was the principal methodological divergence between the experiment described above and the one that is described below.

3. Experiment 2:

3.1. Methods

3.1.1. Participants

Twenty-eight took part in the study. Data from 4 were discarded prior to analysis because of insufficient trials in at least one of the critical categories following artifact rejection (here and elsewhere in this section the same criteria and procedures as in Experiment 1 were followed unless noted otherwise). Participants were excluded if the conditional probability of a correct feature judgment was below 0.43[2]. Of the 24 participants remaining, the average age was 21 (age range 18-29, 2 males).

3.1.2. Stimuli

The stimulus set comprised 384 faces, taken from the same source as in Experiment 1. All stimuli were randomly allocated into 1 of 3 facial feature groups (eye, nose or mouth) prior to the insertion of a white block to obscure the relevant facial part. The experiment consisted of 12 study-test blocks. Each block contained 16 study and 32 test trials. In each study phase, the 3 possible occlusions had a roughly equal number of occurrences (16 trials: 5: 5: 6). The counterbalancing strategy was identical to that in Experiment 1.

3.1.3. Procedure

The procedure and the events occurring in each block were identical to those in Experiment 1, except for the feature response requirements. A three-way feature location response was required; response with the left index finger to stimuli with an eye obscured, a response with the right index finger for nose, and a response with the right middle finger for mouth. The fingers used for feature responses were fixed for all participants. Only the hands used for the old/new responses at test were counterbalanced across participants.

3.1.4. EEG recordings

EEG was recorded from 25 silver/silver chloride scalp electrodes located at midline sites (Fz, Cz, Pz) and left/right hemisphere locations (FP1/FP2, F7/F8, F5/F6, F3/F4, T7/F8, C5/C6, C3/C4, P7/P8, P5/P6, P3/P4, O1/O2). EEG and EOG were recorded at 200Hz with a bandwidth of 0.03-40Hz (-3dB). EEG was recorded referenced to Fz and the data from Fz were reclaimed when the ERPs were re-referenced off-line to the average of the signals taken from the electrodes located over the mastoid processes.

3.2. Results

3.2.1. Behavioral Data

Accuracy: Old/new discrimination [Pr = p(hit) – p(false alarm)] was above chance when correct old responses were collapsed across context judgments (Pr = 0.64, t(23) = 20.88, $p < .01$,

Table 1). The conditional probability of a correct context judgment was reliably above chance (mean = 0.62, t(23) = 4.74, $p < .01$). The likelihoods of correct context judgments for eye, nose and mouth occlusions did not differ reliably. They were .61, .61 and .63, respectively.

Reaction Times: As shown in Table 1, a repeated measures ANOVA (factors of accuracy and old/new status) revealed a reliable main effect of accuracy (F (1,23) = 28.11, $p < .01$), and an interaction between accuracy and status (F (1,23) = 16.56, $p < .01$). This is because only RTs for new faces differed reliably with accuracy (t(15) = 4.92, $p < .01$). When correct responses to old faces were separated according to context accuracy the RTs were reliably faster for correct context responses (t(23) = 3.13, $p < .01$). The behavioral data on the far right of Table 1 are for a subset of 16 participants who had sufficient trials to allow analysis of ERPs elicited by misses. The outcomes of the behavioral analyses on this subset resemble closely those for all 24 participants reported here.

3.2.2. Electrophysiological Data

The same analysis strategy was employed as in Experiment 1. For all 24 participants, the mean numbers of artifact-free trials for hit/hit, hit/miss and correct rejection ERPs were 42 (range = 18 to 78), 24 (16 to 45), and 68 (17 to 109). For the sub-set of 16 participants for whom there were enough artifact-free trials for analyses involving misses, the mean numbers of trials were 24 (16 to 38) for misses, 46 (23 to 78) for hit/hit, 25 (16 to 46) for hit/miss and 79 (30 to 109) for correct rejections. Figures 4 and 5 show the grand averages and scalp maps elicited by the hit/hit, hit/miss, and CR response categories for all participants. Figure 4 shows that the ERPs associated with correct feature judgments start to diverge from approximately 300ms at anterior electrodes from those associated with correct rejections, and somewhat later at posterior locations. The differences are broadly distributed along the anterior-posterior dimension in the 500-700ms time window, and are somewhat left lateralized at posterior electrodes. The ERPs for correct rejections and incorrect feature judgments differ minimally in the first 500ms at anterior scalp locations. The differences become more prominent in the 500-700ms time window where the magnitude of the differences decreases along the superior-inferior dimension.

3.3.1. Main analyses

The initial analyses for each of the 3 categories revealed an interaction between category, hemisphere and site in each epoch [300-500ms: $F(6,138) = 3.30$, $p < .05$; $\varepsilon = .61$); 500-700ms: $F(6,138) = 3.33$, $p < .05$; $\varepsilon = .63$]. An interaction between category, anterior/posterior and hemisphere was also reliable in the later epoch [$F(2,46) = 4.01$, $p < .05$; $\varepsilon = .90$].

300-500ms (Table 2): The reliable interactions between category and site reflect the fact that both the hit/hit and hit/miss old/new effects are largest at sites closest to the midline. The interactions between category and anterior/posterior for the hit/hit old/new effect and the hit/hit vs hit/miss contrast reflect the fact that only the hit/hit old/new effect is markedly larger at anterior than at posterior sites. For the hit/hit vs hit/miss contrast the three-way interaction between category, hemisphere and site reflects the fact that the more positive-going effect for the hit/hit category is largest at left superior electrodes.

500-700ms (Table 2): For the hit/hit old/new effect the interaction between category, anterior/posterior and site arises because the effects are largest at anterior superior sites. For the hit/miss effect the interaction between category, anterior/posterior and hemisphere arises because the right greater than left pattern at frontal locations is not matched at posterior locations. Finally, for the hit/hit vs hit/miss contrast the interaction between category, hemisphere and site arises for the same reason as in the 300-500ms epoch.

3.3.2. Focused analyses

The initial focused analyses over the three mid-frontal electrodes (F3, Fz, F4) for the three response categories revealed reliable main effects of category for both epochs (see Table 3). Reliable main effects were obtained for all comparisons except for the hit/hit and hit/miss contrast at posterior electrode locations from 300-500ms, indicating positive-going old/new effects that are larger for the hit/hit than the hit/miss response categories at anterior electrode locations. At posterior sites in this epoch, there were reliable old/new effects for both the hit/hit and hit/miss response categories, and while there is a trend for the hit/hit old/new effects to be larger, this is not reliable (p = .07). Finally, the focused analyses at three left- parietal electrodes (P7, P5, P3) from 500-700ms revealed category x site interactions because the old/new effects are largest at P3 and larger for the hit/hit than for the hit/miss response category.

3.3.3. Topographic analyses

A reliable interaction was obtained between epoch, category and site (F (3,69) = 5.44, $p < .01$; ε = .62). An analysis including the factor of epoch for hit/hit responses revealed a reliable interaction between epoch, anterior/posterior and hemisphere (F (1,23) = 14.44, $p < .01$), and the same analysis for hit/miss responses revealed an interaction between epoch, anterior/posterior and site (F (3,69) = 4.53, $p < .02$; ε = .72). The first interaction reflects the fact that the old/new effects for the hit/hit category project further to left anterior sites in the earlier epoch and further to left posterior sites in the later epoch (see Figure 5). The second interaction reflects a shift from a posterior/occipital to a prefrontal distribution across time. Analyses within each epoch also revealed interactions between category, hemisphere and site (300-500ms: F (3,69) = 4.40, $p < .05$, ε = .68; 500-700ms: F (3,69) = 5.30, $p < .01$, ε = .86). These outcomes reflect the fact that the similarities between the hit/hit and hit/miss old/new effects at posterior sites are not matched anteriorly, where the hit/hit effects are larger, and more so at left than at right hemisphere locations.

3.3.4. *Analyses of Misses*

Figure 6 shows the ERP waveforms for misses, CRs and the hit/hit response category for the 16 participants who contributed sufficient incorrect initial responses to studied faces. Consistent with the impression given in Figure 6, there were no reliable effects obtained in any analyses between 300 and 700ms when misses and CRs were contrasted. By contrast, analyses using the montages employed in the main analyses described above revealed that the hit/hit and hit/miss ERPs were reliably more positive-going than misses in both epochs (Hit/hit: 300-500ms: $F(1,15) = 16.11$, $p < .01$; 500-700ms: $F(1,15) = 23.85$, $p < .01$; Hit/miss: 300-500ms: $F(1,15) = 7.96$, $p < .05$; 500-700ms: $F(1,15) = 12.22$, $p < .01$).

3.4. Discussion

3.4.1. Behavioral data

Response accuracy was comparable to that reported in Experiment 1: old/new discrimination as well as the conditional probability of a correct context judgment was reliably above chance. Although the context judgment might have been considered to be more difficult in comparison to that in Experiment 1 because of an increase in the number of options available, accuracy and RTs did not differ markedly across the two experiments, possibly because of the shorter study-test blocks in Experiment 2. Critically, because of the use of three rather than two context response options, the present experiment is likely to have reduced the proportion of correct context judgments that were based on “lucky guesses”. The RT data also converges with previous studies in that correct context judgments were associated with faster RTs than incorrect context judgments (Wilding & Rugg, 1996). Comparable results have been reported using the R/K paradigm, where R responses have been faster than K responses (Vilberg et al., 2006).

3.4.2. ERP data

300-500ms

For both the hit/hit and hit/miss response categories, the global analyses revealed reliable old/new effects. There was also a greater positivity for the hit/hit relative to the hit/miss response category, particularly at anterior and left hemisphere sites, and in keeping with these outcomes, the topographic analysis also revealed that the distributions of the hit/hit and hit/miss old/new effects were different. The major inconsistency between the findings in Experiments 1 and 2 in this early epoch is the outcomes of the focused analyses at frontal sites. The analyses in Experiment 2 revealed more positive-going old/new effects for the hit/hit than for the hit/miss response category. This was not the case in Experiment 1, and nor was it the case at posterior sites, where (although approaching significance), hit/hit and hit/miss ERP old/new effects did not differ.

500-700ms

In this epoch the old/new effects were larger when associated with correct context judgments. The scalp distributions of the old/new effects were also reliably different, reflecting the fact that the differences between the old/new effects tend to be largest at left frontal locations. Critically, the absence of reliable repetition effects for misses also suggests (as is the case for the earlier epoch) that the processes indexed here can be linked to explicit memory.

Perhaps the most surprising outcome in Experiment 1 was the absence of reliably larger old/new effects (at least as revealed in the focused analyses) for the hit/hit than for the hit/miss response category in this epoch. A large part of the rationale for the change in task demands in Experiment 2 stemmed from the disparities between the findings in Experiment 1 and in several prior studies (MacKenzie & Donaldson, 2007; Curran & Hancock, 2007; Wilding & Rugg, 1996), and an important divergence between the findings across the experiments reported here is the fact that the focused analyses in Experiment 2 revealed reliably larger old/new effects associated with correct context judgments between 500 and 700ms, as well as at anterior sites between 300 and 500ms.

The similarities between response accuracies in Experiments 1 and 2 suggest the disparities in the ERP data are not explained by this factor. Rather, the most likely reason is that the disparities stem from differences between the proportions of trials associated with recollection in the correct and incorrect context judgment response categories. The practice of averaging ERP signals associated with the same combinations of stimulus-type and response in forced-choice retrieval tasks means that some accurate judgments will be "correct guesses" (Wilding & Rugg, 1996). By using three context response options in Experiment 2, it was anticipated that a clearer separation of neural activities with or without recollection of task-relevant material would occur (in comparison to Experiment 1), because relatively fewer correct guesses would contribute to the ERPs associated with correct context judgments. The consequence of this should be a greater likelihood of observing differences between neural activities associated with correct and incorrect context judgments in Experiment 2 in comparison to Experiment 1. By this account, therefore, the statistically equivalent old/new effects from 300-500ms in Experiment 1 for correct and incorrect context judgments (with the exception of posterior modulations between 300 and 500ms) stem from a lack of sensitivity, because in Experiment 2 these effects were larger when context judgments were accurate.

In summary, common to both experiments and both epochs in which analyses were conducted is evidence for differences between the scalp distributions of the old/new effects linked with successful old/new judgments and either successful or unsuccessful context judgments. These outcomes argue strongly for the existence of at least two separable processes in each epoch. The data from Experiment 2 indicate that three of these effects are larger when associated with correct context judgments, thereby providing additional insights into their likely functional significance, which is a question we return to below in the General Discussion, alongside a discussion of how these data points relate to those reported in previous similar studies.

4. General discussion

In two experiments event-related potentials (ERPs) were acquired while people made judgments about the prior occurrence of faces and about occluded face features. The two experiments differed primarily in the number of context elements (face features) that were occluded at encoding.

How do the findings describe above compare with those obtained in previous studies? In the Introduction, three studies were described in detail. Yovel & Paller (2004) identified only an old/new effect for response categories associated with retrieval of context from 300-500ms, and an effect that was larger when context was retrieved in the 500-700ms epoch. If recollection is the basis for accurate context judgments then these outcomes permit the claim that ERPs index recollection when faces are the test stimuli. The fact that modulations with similar sensitivities were identified via the focused analyses in Experiment 2 licenses a similar claim, but goes beyond it because of the fact that the differences between scalp distributions for hit/hit and hit/miss old/new effects in both epochs point to the involvement of separable processes in each epoch, a claim which was not possible on the basis of the analysis outcomes reported by Yovel & Paller (2004).

The outcomes at anterior sites from 300-500ms in Experiment 2 mean that the findings here are at odds with those reported by Curran & Hancock (2007), in whose hands an anteriorly distributed effect in this epoch predicted only the accuracy of old/new judgments. Where the findings do correspond with those of Curran and Hancock is in the 500-700ms epoch, where, at posterior sites, a positive-going old/new effect was larger when associated with accurate context judgments. It is not possible to pursue further the correspondences between outcomes in these experiments and the experiment conducted by Curran & Hancock (2007), because they analyzed only data from a selection of frontal scalp locations from 300-500ms, and parietal locations from 500-700ms.

Overall, the present findings are most clearly comparable with those reported by MacKenzie & Donaldson (2007). Their findings are consistent with the view that two distinct processes were engaged in the 300-500ms epoch, as well as two in the subsequent (500-700ms) epoch. In the earlier epoch, they reported that an anteriorly distributed modulation was larger when accompanied by memory for context, whereas a posteriorly distributed modulation was of equal size for all response categories for stimuli judged correctly to be old. The claim that two separate memory–related processes are indexed in this epoch can also be made here on the basis of the amplitude divergences and topographic outcomes that are reported. MacKenzie & Donaldson (2007) did not observe a reliable topographic separation between the distributions of old/new effects separated according to recovery of context, and in this regard the findings here add considerable weight to their claim that two distinct processes operate in this time period in tasks of this kind. Moreover, new information provided by the findings in Experiment 2 also stems from the analysis of misses: these did not differ from correct rejections and were reliably more negative-going that ERPs elicited by words judged correctly to be old. This outcome extends the findings reported by MacKenzie & Donaldson (2007), indicating that the posterior modulation in this epoch is not simply sensitive to stimulus repetition and should thus be linked with explicit memory processes.

The similarities between the claims that these findings and those of MacKenzie and Donaldson permit extend to the 500-700ms epoch. They linked two effects with the process of recollection. They suggested that a posteriorly distributed modulation (often described as the left-parietal old/new effect) was a material-independent index of recollection, while an old/new effect that extends more anteriorly was associated with recollection of detail specific to their task demands. The scalp distributions of the hit/hit old/new effect in experiments 1 and 2 (see left-hand side of Figures 3 and 5) have a comparable anterior projection that is not commonly observed when verbal stimuli are employed (for an example where the two effects were compared directly, and for a very similar distribution for face information, see Yick & Wilding, 2008), and the differences between scalp distributions reported here also license claims about the involvement of two processes. What the findings reported here provide for the first time is evidence for the anterior projection of the old/new effect in a task where the requirement is restricted to information about faces and face features. This permits a stronger claim about the likely functional correlates of this effect than can be made in tasks where the information linked with faces comprised a verbal descriptor (see Introduction as well as Yick & Wilding, 2008 and MacKenzie & Donaldson, 2007). It would, however, be premature to align this effect only with faces. The anterior projection could equally index recovery of configural or spatial information, and if this was in fact the case then similar effects should be observed in tasks where, for example, pictures are employed (see also MacKenzie & Donaldson, 2009), or more speculatively, under conditions where configural or spatial information is imagined rather than perceived (see also Yick & Wilding, 2008).

Common to the three face memory studies described in the Introduction is the assumption that the basis for veridical old responses attracting correct context judgments was recollection, and ERP indices of this process would comprise old/new effects that were larger when associated with correct rather than incorrect context judgments. A second assumption is that old/new effects associated with familiarity would be of comparable size, irrespective of a separation according to the accuracy of context judgments. Applying this logic to the effects observed in Experiment 1 and 2 here (and assuming greater sensitivity in Experiment 2) licenses the claim that three old/new effects can be linked to recollection. The somewhat weaker claim is that a posterior modulation from 300-500ms indexes familiarity. This claim is 'weaker' in so far as there is a trend towards a reliably greater positivity for the hit/hit response category in the focused analysis in Experiment 2, and more importantly because of the experiment manipulations employed here. The context memory task design is assumed to provide a basis for comparisons where recollection varies across conditions (correct versus incorrect context judgments) while familiarity is held constant. Arguably stronger evidence linking an effect to familiarity would stem from direct manipulations of familiarity and a subsequent correspondence between ERP and behavioural measures. This has not, to our knowledge, been implemented for tasks in which faces have been employed as the test stimuli (for an elaboration of this argument and an attempt to manipulate familiarity via a bias manipulation, see Azimian-Faridani & Wilding, 2006).

It is also worth re-visiting assumptions about changes in familiarity according to the accuracy of context judgments, as well as whether or when familiarity can support context judgments. One possibility is that there is an enhanced level of recognition confidence in the initial old judgment for stimuli that go on to attract correct rather than incorrect context judgments (Wixted, 2007). It has been shown that old responses attracting correct context judgments are associated with a higher level of confidence than those attracting incorrect context judgments in a combined ROC and context memory paradigm (Slotnick & Dodson, 2005). If higher levels of confidence are a proxy for higher levels of familiarity, and familiarity is commonly higher when recollection occurs, then there is no means of allocating the effects observed in this experiment to one process or the other. One way to address this challenge empirically is to require separate confidence judgments for the old/new and context judgments, and partial out the data accordingly (Woroch & Gonsalves, 2010; Kirwan, Wixted, & Squire, 2008). In the absence of this manipulation in this task, it is certainly worth noting that Yonelinas and colleagues have recently argued persuasively for a relationship of independence between the processes of recollection and familiarity (Ozubkoa & Yonelinas, 2014; Addante et al., 2012; Yonelinas & Jacoby, 2012), and that this independence assumption gains support from both event-related field (ERF) and functional magnetic resonance imaging (fMRI) data (Evans & Wilding, 2012; Johnson et al., 2013). These theoretical considerations and empirical findings suggest that there is no systematic correspondence between levels of familiarity and the occurrence of recollection.

A second consideration of relevance here stems from the observation that, while it has generally been considered that correct context judgments are based primarily on recollection (Allan et al., 1998; Wilding & Rugg, 1996; Viberg & Rugg, 2007), some attention has also been paid to the possibility that accurate context judgments can be based on familiarity under some circumstances (Diana et al., 2008; Mayes et al., 2007). One articulation of this is that familiarity can contribute to context judgments for item-context combinations that are unitized (Diana et al., 2008; Ranganath et al., 2003). Unitization occurs when target (item) and context information are bound together to form a single entity, and as a result accurate context judgments can be supported by familiarity. This view holds that old items attracting correct context judgments are associated with a higher level of familiarity strength than those attracting incorrect context judgments: it is the level of strength that guides the context judgment.

If unitization occurred for studied stimuli here, is it reasonable to assume that the greater relative positivity for the hit/hit response category relative to the hit/miss category in Experiment 2 is a reflection of a greater level of familiarity in the case of the former? There is no means of ruling this out definitively, but it is certainly notable that the evidence for the use of familiarity in this way has emerged in studies where the study phase manipulations have encouraged item-context binding (e.g Staresina & Davachi, 2010), which was not done explicitly here. Where experiment manipulations have been employed to compare the basis for responding in 'unitised' and 'non-unitised' experiment conditions, in the latter condition estimates of the contribution of recollection have tended to outweigh estimates for familiarity (Diana et al., 2008).

These considerations promote the view that the ERP old/new effects observed in Experiment 2 which are largest for the hit/hit response category index processes linked with recollection. For the two modulations identified in the 500-700ms epoch, these outcomes substantiate prior observations, and the likely functional significance of the effects has been discussed above, as has the posterior effect in the 300-500ms epoch, which is a possible index of familiarity in tasks of this kind.

The remaining modulation for discussion here is the anteriorly distributed effect in the 300-500ms epoch. Positive-going neural activity in this epoch for old relative to new test stimuli has been interpreted as an index of familiarity by some researchers (Rugg et al., 1998; Woodruff et al., 2006; Curran & Hancock, 2007) and an index of conceptual priming by others (Yovel & Paller, 2004; Paller et al., 2007; Voss et al., 2010a, 2010b). The fact that in Experiment 2 activity at mid-frontal scalp locations was reliably larger for faces attracting correct rather than incorrect feature judgments makes it difficult to align the effect with familiarity in this task. Given the foregoing considerations about the relationship between the processes of recollection and familiarity, this mid-frontal modulation ties more closely to recollection here (MacKenzie & Donaldson, 2007).

One possibility is that the absence of evidence for ERP indices of familiarity arises because the nature of the stimuli that were encountered precluded the use of familiarity for task decisions. Curran & Hancock (2007) have argued that the absence of neural indices of familiarity in two published studies (Yovel & Paller, 2004; MacKenzie & Donaldson, 2007) arose because the faces employed were relatively similar, thereby making familiarity unhelpful for task judgments. Evidence consistent with this account is the presence of a frontally distributed old/new effect from 300-500ms in their study in which the faces employed might be considered to be more distinctive than those employed in studies where comparable effects were not observed (Curran & Hancock, 2007). Critically, this modulation indexed the accuracy of old/new judgments but not context judgments.

In so far as the stimuli employed here are very similar to those used by MacKenzie & Donaldson (2007), this explanation might also hold for the findings in Experiment 2, but the outcomes of the analysis in Experiment 2 revealed reliable old/new effects for hit/miss as well as hit/hit ERPs, suggesting that, if this account is in fact correct, then another modulation with a similar time-course and scalp distribution is evident here in Experiment 2. Yick & Wilding (2008) speculated that early on-setting anteriorly distributed activity associated with accurate memory for faces might reflect the online representation of material-specific information. That is one possibility for the effect obtained in Experiment 2, and would explain the amplitude increase for the hit/hit relative to the hit/miss condition.

In this context, it is also worth considering the fact that the outcomes in these experiments are consistent with the view that for face stimuli the 300-500ms epoch contains indices of the processes of recollection as well as familiarity. Broad support for this account comes from an intracranial EEG study (Staresina et al., 2012) in which recordings were obtained from electrodes located in the hippocampus and the perirhinal cortex of patients with epilepsy. A source memory task was administered to patients, and activity associated with hit/hit and hit/miss responses was compared. Between 200 and 400ms post-stimulus, hit/hit responses were more positive-going than hit/miss responses in the hippocampus, whereas both responses were of the same size in the perirhinal cortex. These findings indicate that different neural generators can contribute to the processes of recollection and familiarity over similar time periods, with the data in Experiment 2 licensing the same claim.

In conclusion, the data reported here build on claims about the nature and number of separable memory processes that are indexed by ERPs in tasks where faces are the test stimuli, and where, for the first time, the context judgments required are about face features. A degree of consensus over the functional significance of ERP old/new effects elicited by verbal stimuli has enabled ERPs to be deployed to adjudicate between competing accounts of memory phenomena and to assess predictions of functional models (e.g. Azimian-Faridani & Wilding, 2006; Rugg et al., 1998; Woodruff et al., 2006). The same level of consensus is not in place yet for non-verbal stimuli, and it would be premature to claim that for indices of memory processes in the 300-500ms time window the outcomes in the experiments reported here contribute very strongly to a consensual account. Perhaps the strongest statement that the current data allow concerns the ERPs elicited at posterior scalp locations in this early epoch. While strong claims that this posterior modulation indexes familiarity await the outcomes of experiments in which face familiarity is manipulated explicitly, the fact that both hit/hit and hit/miss effects were reliably more positive-going than misses argues strongly for the link between this modulation and processes supporting explicit memory judgments.

A more forceful argument can be made on the basis of the findings in the 500-700ms epoch. These findings, in combination with those in previous studies (in particular MacKenzie & Donaldson, 2007; Yick & Wilding, 2008), support the view that two distinct processes linked to recollection are associated with successful recovery of information about faces and face features. This outcome is important for at least two reasons. First, because it licenses the use of ERPs to contribute to dynamic characterisations of how memory for a critical class of socially relevant stimuli is supported. Second, because the identification of robust content-specific retrieval indices widens considerably the scope for ERPs in the investigation of memory phenomena, with two opportunities of note being the ability to address questions about the circumstances under which task irrelevant information comes to mind, and when it can be suppressed (see Elward et al., 2013).

Footnotes:

1. It has often been acknowledged that identifying what constitutes an item and what constitutes an item context is not straightforward. Moreover, separations between intrinsic and extrinsic context have also been considered, along with a similar acknowledgment that this separation is not wholly straightforward either (for a consideration of both points sees Ecker et al., 2007a). Here we use the term context to cover what have commonly been view as intrinsic features (such as the colour or shape of an item), as well as extrinsic features (typically considered to include background perceptual elements, such as the colour or shape of a background on which items are placed, additional contextual information such as the autobiographical content used by Yovel & Paller (2004), and/or the cognitive operations that are completed at the time of exposure to an item).
2. In both experiments this criterion was set at 0.1 above a performance level that would indicate little no ability to discriminate between the relevant features (0.5 in Experiment 1, 0.33 in Experiment 2). This approach was implemented, in a similar way to that adopted previously (Evans et al., 2010), to exclude a small number of participants for whom the behavioral data provide little reason to believe that ERPs would distinguish between processes of interest.

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Table1

Table 1. Top: Mean probabilities for correct identification of old (p(Hit)) and new (p(CR)) faces, and the conditional probabilities for correct (Hit/hit) and incorrect (Hit/miss) source judgments for faces attracting correct old judgments. Bottom: Mean reaction times for correct and incorrect (miss and FA: false alarm) old/new judgments and for initial correct old judgments separated by source accuracy (Hit/hit and Hit/miss). Experiment 1 and Experiment 2 (misses): n = 16; Experiment 2 (other than misses): n = 24. Standard deviations are in parentheses.

	Experiment 1	**Experiment 2**	**Experiment 2:Misses**
p(Hit)	0.79 (0.07)	0.77 (0.07)	0.75 (0.07)
p(CR)	0.84 (0.09)	0.87 (0.11)	0.88 (0.12)
p(Hit/hit)	0.66 (0.09)	0.62 (0.13)	0.63 (0.13)
p(Hit/miss)	0.34 (0.09)	0.38 (0.13)	0.37 (0.13)
Hit	1196 (255)	1134 (365)	1122 (366)
CR:	1084 (293)	1063 (306)	1082 (250)
Miss:	1180 (370)	1211 (352)	1163 (291)
FA	1443 (486)	1491 (592)	1462 (645)
Hit/hit:	1166 (243)	1182 (330)	1182 (350)
Hit/miss:	1227 (273)	1286 (413)	1161 (394)

Table2

Table 2. F- and p-values for three paired comparisons: Hit/hit versus Correct Rejection (CR), Hit/miss vs CR, Hit/hit vs Hit/miss, over the 300-500 and 500-700ms epochs. Only effects involving response category that were reliable in at least one epoch are shown. n.s. (non-significant) denotes p > 0.10. Full dfs are shown, along with epsilon values in brackets alongside each relevant F-value.

Hit/hit vs. CR

	Experiment 1			**Experiment 2**		
Effect	**df**	**300-500ms**	**500-700ms**	**df**	**300-500ms**	**500-700ms**
RC	1,15	19.99, p<0.01	44.63, p<0.01	1,23	37.02, p<0.01	83.80, p<0.01
RC x AP	1,15	n.s.	n.s.	1,23	9.62, p<0.01	n.s.
RC x HM	1,15	n.s.	3.12, p<0.10, n.s.	1,23	n.s.	n.s.
RC x ST	3,45	2.91, p=0.05 (0.91)	11.02, p<0.01 (0.79)	3,69	19.33, p<0.01 (0.66)	30.46, p<0.01 (0.75)
RC x AP x ST	3,45	3.76, p<0.05 (0.76)	n.s.	3,69	n.s.	3.13, p<0.05 (0.80)

Hit/miss vs. CR

Effect	**df**	**300-500ms**	**500-700ms**	**df**	**300-500ms**	**500-700ms**
RC	1,15	3.79, p=0.07, n.s.	9.28, p<0.01	1,23	10.70, p<0.01	22.11, p<0.01
RC x HM	1,15	7.96, p<0.05	22.32, p<0.01	1,23	n.s.	n.s.
RC x ST	3,45	n.s.	3.11, p<0.05 (0.82)	3,69	5.18, p<0.01 (0.56)	2.72, p=0.09 (0.53) n.s.
RC x AP x HM	1,15	n.s.	n.s.	1,23	n.s.	6.92, p<0.05
RC x AP x ST	3,45	n.s.	n.s.	3,69	n.s.	3.08, p=0.06 (0.66) n.s.
RC x HM x ST	3,45	n.s.	n.s.	3,69	n.s.	3.06, p=0.06 (0.67) n.s.

Hit/hit vs. Hit/miss

Effect	**df**	**300-500ms**	**500-700ms**	**df**	**300-500ms**	**500-700ms**
RC	1,15	n.s.	9.50, p<0.01	1,23	11.54, p<0.01	16.12, p<0.01
RC x AP	1,15	n.s.	n.s.	1,23	4.83, p<0.05	n.s.
RC x HM	1,15	9.70, p<0.01	10.35, p<0.01	1,23	n.s.	n.s.
RC x ST	3,45	n.s.	n.s.	3,69	n.s.	14.88, p<0.01 (0.70)
RC x AP x ST	3,45	5.42, p<0.05 (0.60)	n.s.	3,69	n.s.	n.s.
RC x HM x ST	3,45	n.s.	n.s.	3,69	5.08, p<0.01 (0.63)	5.63, p<0.01 (0.75)

RC = Response category, AP = anterior/posterior dimension, HM = hemisphere, ST = site.

Table3

Table 3. F- and p- values for focused analyses for the 300-500 and 500-700ms epochs. All terminology and other information as for Table 2. Note that the electrodes employed in the analyses at posterior electrodes are not the same in the 300-500 and 500-700ms epochs.

Anterior Electrodes: F3, Fz, F4

Contrast	Effect	Experiment 1 df	Experiment 1 300-500ms	Experiment 1 500-700ms	Experiment 2 df	Experiment 2 300-500ms	Experiment 2 500-700ms
Initial	RC	2,30	5.83, p<0.01 (0.81)	32.01, p<0.01 (0.85)	1,23	22.69, p<0.01 (0.94)	32.01, p<0.01 (0.85)
HH vs. CR	RC	1,15	13.38, p<0.01	30.82, p<0.01	1,23	38.23, p<0.01	55.62, p<0.01
	RC x ST	2,30	n.s.	n.s.	2,46	n.s.	n.s.
HM vs. CR	RC	1,15	4.97, p<0.05	8.95, p<0.05	1,23	5.85, p<0.05	3.51, p=0.05 (0.78)
	RC x ST	2,30	n.s.	n.s.	2,46	n.s	n.s
HH vs. HM	RC	1,15	n.s.	4.24, p=0.06, n.s.	1,23	22.82, p<0.01	21.30, p<0.01
	RC x ST	2,30	n.s.	n.s.	2,46	n.s	n.s

Posterior Electrodes 300-500ms: P3, Pz, P4; 500-700ms: P3, P5, P7

Contrast	Effect	Experiment 1 df	Experiment 1 300-500ms	Experiment 1 500-700ms	Experiment 2 df	Experiment 2 300-500ms	Experiment 2 500-700ms
Initial	RC	2,30	5.13, p<0.05 (0.84)	22.28, p<0.01 (0.81)	2,46	12.78, p<0.01 (0.93)	18.90, p<0.01 (0.96)
	RC x ST	4,60	n.s	63.03, p<0.05 (0.71)	4,92	n.s	6.91, p<0.01 (0.77)
HH vs. CR	RC	1,15	15.23, p<0.01	81.00, p<0.01	1,23	24.19, p<0.01	31.72, p<0.01
	RC x ST	2,30	n.s	5.29, p<0.05 (0.89)	2,46	3.89, p<0.05 (0.93)	12.92, p<0.01 (0.80)
HM vs. CR	RC	1,15	4.59, p<0.05	16.03, p<0.01	1,23	11.99, p<0.01	10.47, p<0.01
	RC x ST	2,30	3.92, p<0.05 (0.97)	n.s	2,46	n.s	3.66, p<0.05 (0.84)
HH vs. HM	RC	1,15	n.s	4.24, p=0.06, n.s.	1,23	3.44, p=0.07, n.s.	10.44, p<0.01
	RC x ST	2,30	n.s	3.41, p=0.06 (0.88), n.s.	2,46	n.s	3.85, p<0.05 (0.91)

Figure1

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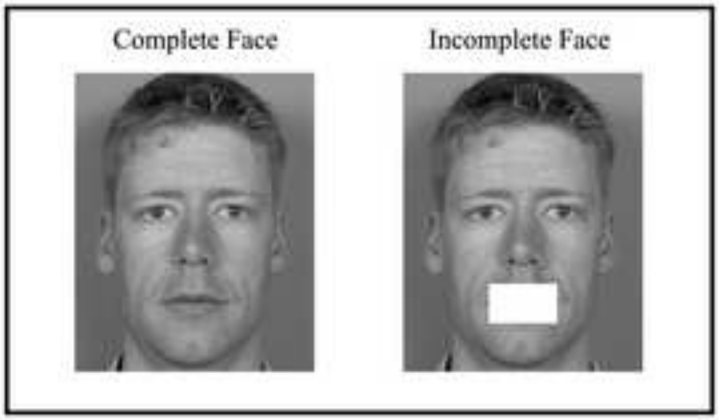

Figure 1. An example of the facial stimulus used: complete and incomplete faces with the mouth occlusion.

Figure2

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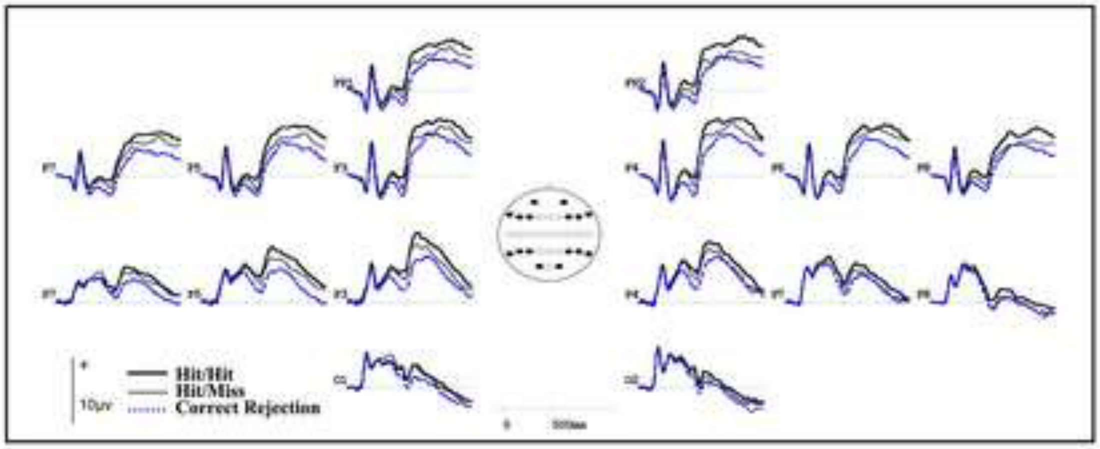

Figure 2. Grand averaged ERP waveforms from Experiment 1 elicited by faces attracting correct new responses (correct rejections), and correct old judgments followed either by correct or incorrect context judgments (hit/hit and hit/miss). See graphical insert at centre of figure for electrode locations.

Figure3
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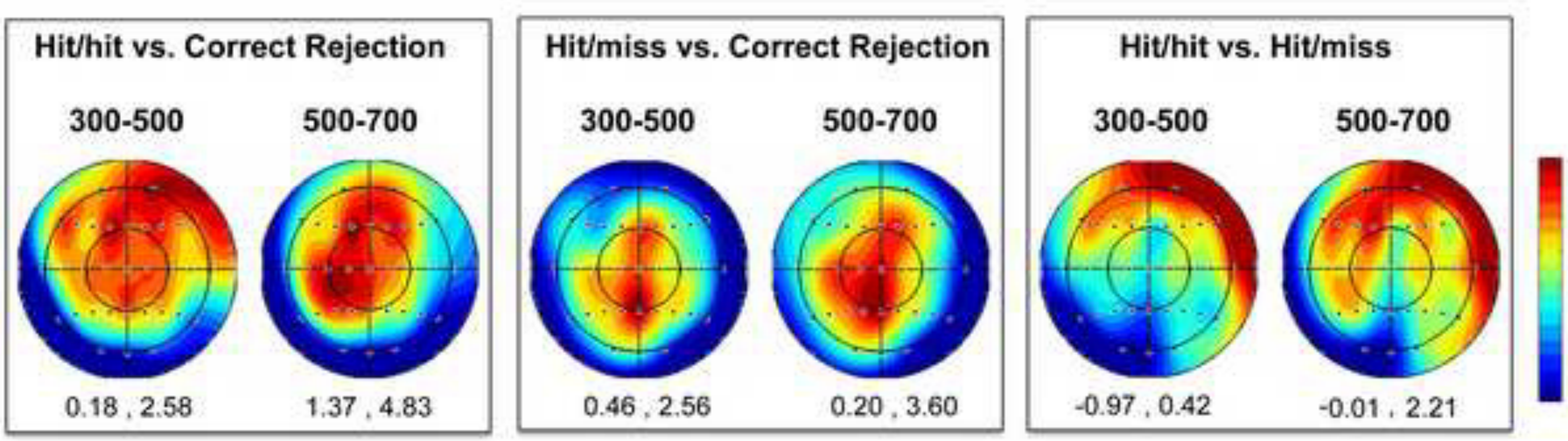

Figure 3. Topographic maps for Experiment 1 showing the scalp distributions of the differences between 3 different contrasts of interest for the 300-500 and 500-700ms time windows. The maps are scaled according to the maxima (red) and minima (blue) of each contrast with the range displayed below each map (in microvolts). In each case the maps were computed from difference scores obtained by subtracting mean amplitudes from one condition from those from another, as indicated by the headers above each pair of maps.

Figure4
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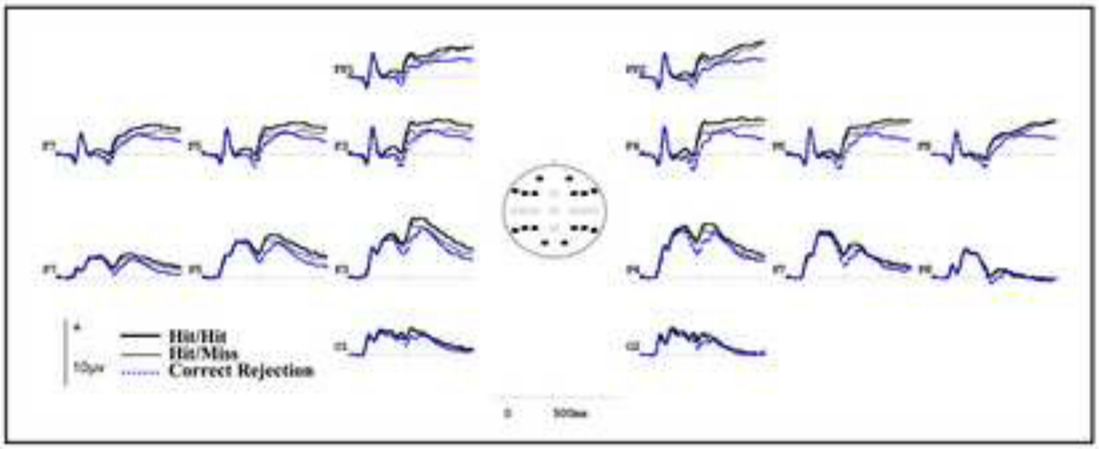

Figure 4. Grand averaged ERP waveforms from Experiment 2 elicited by faces attracting correct new responses (correct rejections), and correct old judgments followed either by correct or incorrect context judgments (hit/hit and hit/miss). See graphical insert at centre of figure for electrode locations.

Figure5
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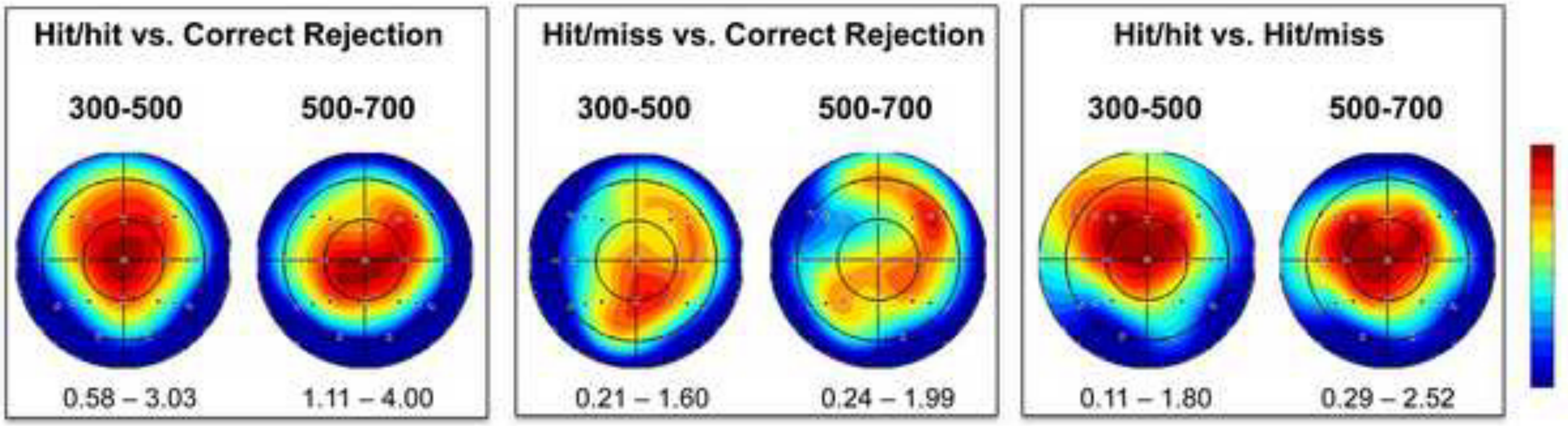

Figure 5. Topographic maps for Experiment 2 showing the scalp distributions of the differences between 3 different contrasts of interest for the 300-500 and 500-700ms time windows. All other information is as for Figure 3.

Figure6

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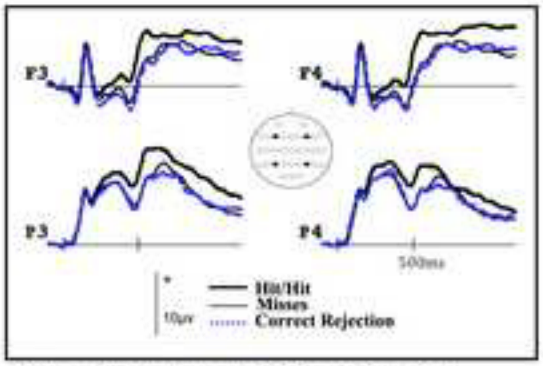

Figure 6. Grand averaged ERP waveforms from Experiment 2 elicited by old faces attracting correct context judgments (hit/hit), old items attracting incorrect new judgments (misses) and correct rejections (n=16). Data are shown for 4 mid-superior locations over frontal and posterior scalp.