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On the sensitivity of event-related fields to recollection and familiarity

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Short Title: ERFs, Recollection and Familiarity

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Declarations of Interest: None

17 **Abstract**

18

19 The sensitivity of event-related potentials (ERPs) to the processes of recollection and
20 familiarity has been explored extensively, and ERPs have been used subsequently to infer the
21 contributions these processes make to memory judgments under a range of different
22 circumstances. It has also been shown that event-related fields (ERFs, the magnetic counter-
23 parts of ERPs) are sensitive to memory retrieval processes. The links between ERFs,
24 recollection and familiarity are, however, established only weakly. In this experiment, the
25 sensitivity of ERFs to these processes was investigated in a paradigm used previously with
26 ERPs. An early frontally distributed modulation varied with memory confidence in a way that
27 aligns it with the process of familiarity, while a later parietally distributed modulation tracked
28 subjective claims of recollection in a way that aligns it with this process. These data points
29 strengthen the argument for employing ERFs to assess the contributions these processes can
30 make to memory judgments, as well as for investigating the nature of the processes
31 themselves.

32

33 **Keywords:** Recollection, Familiarity, MEG, Confidence, Remember-Know, ERPs.

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37 1. **Introduction**

38

39 Memories for experiences are widely considered to receive contributions from two processes
40 (Mandler, 1980, 1991; Wixted & Mickes, 2010; A.P. Yonelinas, 2002). Recollection is
41 recovery of qualitative information about an event. Familiarity is a scalar strength signal that
42 can support certain kinds of memory judgments. The evidence for the distinction between
43 these processes spans behavioural, neuropsychological, and functional brain imaging research
44 in humans, alongside studies in other animals (Aggleton & Brown, 1999; Aggleton et al.,
45 2005; Rugg & Curran, 2007; Vargha-Khadem et al., 1997; Yonelinas, Otten, Shaw, & Rugg,
46 2005).

47 Event-related potentials (ERPs) have been employed widely in studies designed to test claims
48 about the validity of the separation between the processes of recollection and familiarity
49 (Allan, Wilding, & Rugg, 1998; Friedman & Johnson, 2000; Wilding & Ranganath, 2012). In
50 other studies, ERPs have been employed alongside behavioural data to adjudicate between
51 accounts of how one or both of these processes support memory characteristics such as
52 source (context) judgments (Diana, Van den Boom, Yonelinas, & Ranganath, 2011),
53 judgments of recency (Grove & Wilding, 2009), testing effects (Bai, Bridger, Zimmer, &
54 Mecklinger, 2015), and the revelation effect (Azimian-Faridani & Wilding, 2004).

55 The use of ERPs in these ways was preceded by studies in which the sensitivity of ERP
56 old/new effects to the processes of recollection and familiarity was investigated (for review,
57 see Wilding & Ranganath, 2012). Old/new effects are differences between neural activities
58 for old (studied) and new (unstudied) test items attracting correct old/new judgments. The
59 left-parietal old/new effect is prominent between 500 and 800 ms post-stimulus over left-
60 posterior-parietal scalp, and has been linked with the process of recollection (Allan et al.,
61 1998). The mid-frontal old/new effect has a fronto-central scalp maximum between 300 and
62 500 ms post-stimulus and has been linked with the process of familiarity (for key data and
63 discussion of alternative accounts, see Bridger, 2012; Paller, Voss, & Boehm, 2007; Rugg &
64 Curran, 2007).

65 Somewhat less attention has been paid to event-related fields (ERFs), and far fewer studies
66 have been designed to test the sensitivity of ERFs to recollection and familiarity. That is the
67 intention of the research described here. This builds on indications of the general sensitivity

68 of MEG measures to memory processes, which has been accomplished via assessment of
69 ERFs (Tendolkar et al., 2000; Walla et al., 1999; Walla, Hufnagl, Lindinger, Deecke, Imhof,
70 et al., 2001; Walla, Hufnagl, Lindinger, Deecke, & Lang, 2001), time-frequency plots (Düzel,
71 Habib, Guderian, & Heinze, 2004; Düzel et al., 2003; Guderian & Düzel, 2005; Neufang,
72 Heinze, & Düzel, 2006), and/or data transformed into source space (Dhond, Witzel, Dale, &
73 Halgren, 2005; Gonsalves, Kahn, Curran, Norman, & Wagner, 2005; Lee, Simos, Sawrie,
74 Martin, & Knowlton, 2005; Seibert, Hagler, & Brewer, 2011).

75 For ERFs, Düzel and colleagues (Düzel, Neufang, & Heinze, 2005) identified three
76 temporally and spatially separable ERF modulations comprising changes in signal strength
77 for items that attracted correct 'old' rather than correct 'new' judgments. One of these
78 old/new effects was most prominent over left-posterior scalp from 500 to 800ms post-
79 stimulus (see also Tendolkar et al., 2000), while another was prominent over left-frontal scalp
80 between 300 and 500ms. The third was largest over occipito-temporal scalp locations
81 between 250 and 350ms. What are likely to be the same three modulations were identified in
82 a later study (Bridson, Muthukumaraswamy, Singh, & Wilding, 2009) and in their
83 experiment the three were shown to be functionally dissociable.

84 In each of these studies, however, the task manipulations did not permit a strong basis for
85 separating responses associated with familiarity or recollection. This limitation does not
86 apply to the study reported by Staresina and colleagues (2005), however, who asked
87 participants to make old/new judgments and then, for old judgments, a binary (high/low)
88 confidence judgment. They reasoned that highly confident judgments are based upon a
89 relatively greater contribution from recollection than from familiarity. They did not, however,
90 observe any ERF modulations that varied with response confidence.

91 Bergstrom and colleagues (Bergström, Henson, Taylor, & Simons, 2013) also examined the
92 sensitivity of ERFs to recollection, although the baseline condition in their study (a semantic
93 retrieval requirement) makes comparison of their data to others difficult. Horner and
94 colleagues (2012) acquired MEG data in a task where participants made old/new judgments
95 and then context judgments. Confidence in the context judgment was also assessed. They
96 reported old/new effects over occipito-temporal and left-frontal scalp with the same temporal
97 characteristics as those described by Düzel et al. and by Bridson and colleagues (Bridson et
98 al., 2009; Düzel et al., 2005). While these modulations were not sensitive to the accuracy of
99 context judgments, there was some evidence that a later modulation (500 to 600ms), also with

100 a left-frontal maximum, was sensitive to the accuracy of context judgments. This outcome
101 would align this activity with the process of recollection, rather than familiarity.

102 In the study that is most relevant to the one described here, Evans and Wilding (2012)
103 measured neural activity while people were exposed to new and old words. They employed
104 the Remember/Know paradigm, in which, upon encountering an item they believe they have
105 studied previously, participants must make either a Remember or a Know response. The
106 former is to be given when specific details about the previous encounter can be recovered,
107 and the latter when only a feeling a familiarity drives the view that an item was encountered
108 previously (Rajaram, 1993; Tulving, 1985).

109 In keeping with the logic detailed in many places, Evans and Wilding (2012) noted that, if
110 there is neural activity signalling the process of recollection, then it should be evident to a
111 greater degree when people make a Remember rather than a Know response, assuming that a
112 Remember response is based primarily on recollection (Rajaram, 1993; Smith, 1993; Tulving,
113 1985). A modulation with a left-parietal maximum peaking between 500 and 800 ms post-
114 stimulus behaved in this way, mirroring previous findings with ERPs (Paller & Kutas, 1992).

115 Evans and Wilding also observed a modulation in the 300-500 ms post-stimulus window at
116 frontal sites that was larger for Know than for Remember responses. They linked this
117 modulation with the process of familiarity, because under certain circumstances a neural
118 index of familiarity should behave in this way (for similar arguments, see Berry et al, 2012;
119 Yu et al, 2010). While the spatial distribution and time-course of the modulation they
120 reported is consistent with that of the mid-frontal ERP old/new effect, for ERPs there has
121 been little evidence for larger early memory effects for Know rather than Remember
122 judgments (Smith, 1993). This is also true for memoranda attracting correct or incorrect
123 source judgments, which in some ways parallels the Remember/Know separation (Senkfor &
124 Van Petten, 1998; Trott, Friedman, Ritter, & Fabiani, 1997; Wilding & Rugg, 1996). We
125 return to the issue of differential sensitivity of ERPs and ERFs to the same process in the
126 Discussion.

127 In summary, there is some evidence for the sensitivity of ERFs to the processes of
128 recollection and familiarity, and arguably a stronger case for the former than the latter. The
129 experiment reported here was designed to test further the functional significance of the ERFs
130 that have been linked to recollection and familiarity. The behavioural process separation was
131 accomplished by employing a variant of the Remember/Know paradigm that has been used

132 previously in functional imaging studies (Woodruff, Hayama, & Rugg, 2006; Yonelinas et
133 al., 2005; Yu et al., 2010).

134 In an initial study phase participants were exposed to a list of words. In a subsequent test
135 phase participants saw studied and unstudied words that were shown one at a time.
136 Participants were asked to give a Remember response for words where they could recover
137 details of the study encounter. For all other test words they were asked to make old/new
138 judgments on a four-point confidence scale (confident/unconfident Know;
139 confident/unconfident New).

140 Following the logic of earlier studies (Woodruff et al., 2006; Yonelinas et al., 2005), if the
141 early anterior modulation described above indexes familiarity, then it will vary with response
142 confidence, differentiating in a graded manner the confidence categories in the following
143 order: confident Know, unconfident Know, unconfident New, confident New. If the later
144 modulation indexes recollection, then it will be reliable only for words attracting Remember
145 responses.

146

147 2. Method

148

149 2.1. *Participants*

150 These were 35 right-handed, healthy native English speakers. All gave informed consent and
151 the experiment was approved by the Cardiff University School of Psychology Ethics
152 Committee. The analyses reported here are from 20 participants (17 females; age range: 18-
153 26). Fifteen participants were excluded; 8 because they failed to contribute sufficient trials
154 (>14) to one or more of the critical experimental conditions after artefact rejection; 6
155 participants because of artefacts in the MEG signal (of these 2 were due to metal interference,
156 2 for excessive alpha activity and 2 due to large ocular artefacts); and 1 participant because of
157 poor discrimination (a hit minus false alarm score < 0.2: the values for hits and false alarms
158 were calculated by summing the probabilities of Remember, Confident and Unconfident old
159 responses to old and new words, respectively). The averaged behavioural outcomes for all 35
160 participants are shown in Appendix 1.

161

162 2.2. *Stimuli*

163 A pool of 450 words (all concrete nouns) was used. Words were 3-13 letters long (mean =
164 6.3) and had a mean written frequency of 18.8 counts/million and range of 10-30 (Kucera &
165 Francis, 1967). Five lists of 75 words were constructed by selecting words randomly from the
166 pool. Each participant received three of these lists at study. The remaining two lists were
167 designated as new words and were intermixed randomly with the study items to form the test
168 list. Five complete experiment lists were created such that each word was encountered at
169 study and at test in three versions, and at test only in two versions. An additional 75 words
170 were employed for practice phases (50 of these for the practice study list, all 75 for the test
171 list).

172

173 2.3. *Procedure*

174

175 Once participants had given informed consent and were situated below the MEG dewar, they
176 completed a practice session. They were seated 2m from a monitor on which all stimuli were
177 presented in white on a black background at fixation (subtending maximum visual angles of
178 0.2° vertically and 2.3° horizontally). For the test phase of the practice session participants
179 were asked to justify their responses on each trial verbally.

180 There was one study block with 225 trials. Participants had a short break after every 75 trials.
181 Each trial started with presentation of a fixation cross for 1000ms, the study word (300ms)
182 and then a blank screen. Participants were asked to judge whether each word referred to an
183 animate or inanimate object, responding via keypress with their left and right index fingers,
184 respectively. 1000ms after a response was made a screen displaying the instruction “BLINK
185 NOW” was shown for 1000ms. Trials where no response was registered within 5000ms of
186 stimulus offset were treated as errors and the next trial started automatically.

187 There was a 10min break between study and test phases. Participants were able to get up and
188 walk around before being seated back beneath the dewar. The instructions for the test phase
189 were reiterated before the test phase began. There was a single test block (375 trials) and
190 participants were given a break every 75 trials. The structure and timing of study and test
191 trials was identical: all that differed were the response requirements. Participants were asked
192 for a five-way judgement to each test word. They were asked to give a Remember response if

193 they believed the word had been shown at study and in addition if any detail from study could
194 be recalled (Rajaram, 1993; Rajaram & Roediger, 1997). This response was made via a
195 button press with the thumb. Participants were instructed that, if no contextual information
196 could be retrieved the test words were to be judged on a 4-point confidence scale with button
197 presses using the other hand: confident Know (thumb), unconfident Know (index finger),
198 unconfident New (middle finger) and confident New (ring finger). Participants were
199 instructed that a Know response should reflect their view that the test word had been shown
200 at study, albeit in the absence of memory for specific contextual information. A New
201 response reflected the view that the test word had not been shown at study.

202 The hands participants responded with at study and at test were counterbalanced, but the
203 mapping of responses to digits was retained. In both phases participants were asked to be as
204 accurate and as quick as possible. They were also asked to keep their head as still as possible
205 throughout the experiment and to keep their eyes focussed on the centre of the screen. They
206 were asked to try to blink only when the “BLINK NOW” message was visible on-screen.

207

208 2.4. *MEG recording, processing and analysis*

209

210 MEG was recorded during study and test phases. Test data only are presented here. Whole-
211 head recordings were taken using a 275-channel CTF radial gradiometer system. The
212 sampling rate was 300Hz. An additional 29 reference channels were recorded for noise
213 cancellation purposes, and the primary sensors were analysed as synthetic third-order
214 gradiometers (Vrba & Robinson, 2001). Four of the 275 channels were turned off due to
215 excessive sensor noise. Participants were seated upright in a dimmed magnetically shielded
216 room. Data were acquired continuously, then epoched offline into 2100ms segments
217 including a 100ms baseline relative to which all mean signal strengths were measured. Trials
218 containing large signal and/or EOG artefacts were excluded prior to averaging, based on
219 visual inspection of data for each participant, blind to condition at the time of pre-processing.
220 Average ERFs were formed for each participant for Remember, confident Know and
221 unconfident Know responses to old words and also to unconfident New and confident New
222 responses to new words. The mean numbers of trials in each response category were as
223 follows: Remember = 70 (range 16-142), confident Know = 56 (16-120), unconfident Know
224 = 30 (14-72), unconfident new = 40 (16-78), confident new = 52 (16-102).

225 To test the proposal that ERFs index familiarity (Bridson et al., 2009; Evans, 2012), signal
226 strengths associated with the critical response categories were analysed for data for the 300-
227 500ms post-stimulus time period taken from a cluster of sensors over anterior scalp locations.
228 Further analyses were conducted on data taken from the 500-800ms period from a cluster of
229 sensors over posterior-parietal scalp, where activity linked with the process of recollection
230 has been identified previously (Bridson et al., 2009; Evans & Wilding, 2012).

231 To identify the specific sensors at which activities linked to these processes were largest in
232 these time windows a full-width half maximum (FWHM) approach was adopted, recognising
233 that variation in head-shape and orientation in the dewar will result in small differences
234 between the maxima of effects of interest across ostensibly similar studies. In this procedure
235 the sensor with the maximum value was found in each time window (300-500 and 500-
236 800ms). Those sensors that exceeded half the value of the peak sensor were included in the
237 cluster.

238 The FWHM computation was completed over difference scores that were calculated to reflect
239 activity differentiating between correct responses to old and new items in a way that is not
240 biased towards responses that might be based on recollection or familiarity. This was
241 accomplished by subtracting signal strength estimates for correct rejections from those for
242 hits. Correct rejection estimates were obtained for each participant via an average of signal
243 strengths for confident and unconfident New responses given to new test words. The hit
244 strength estimates for each participant was derived in two stages. First, by calculating the
245 average of confident and unconfident Know responses to old test words. Second, by
246 computing an unweighted average of this estimate and that obtained from Remember
247 responses to old words.

248

249 3. Results

250

251 3.1. Behaviour

252

253 The proportions of old and new words attracting each of the five response options are shown
254 in Table 1. For old words, Remember responses dominate, with the proportions dropping
255 from correct through to incorrect old judgments. The opposite pattern can be seen for the

256 distribution of responses to new words, and this cross-over is reflected in a reliable
257 interaction obtained in a 2*5 ANOVA with factors of word status and response option
258 ($F(2.76,52.46) = 76.70, p<.001$). In this and in all subsequent ANOVAs the Geisser-
259 Greenhouse correction (Winer, 1971) was employed as appropriate and epsilon-corrected
260 degrees of freedom are shown in the text.

261 Also displayed in Table 1 are the reaction times (RTs) for each response category. These are
262 collapsed across study status. A one-way ANOVA with five levels revealed a main effect of
263 response category ($F(2.37, 45.06) = 29.41, p<.001$), because responses are quickest for high
264 confidence New and for Remember responses.

265

266 *3.2.Event-Related Fields (ERFs)*

267

268 Figure 1 shows the scalp distributions of the neural activities averaged over the 300-500 and
269 500-800ms time periods that differentiate correct responses to old and new test words. The
270 maps were computed from difference scores obtained by subtracting mean signal strengths
271 associated with correct rejections from the unweighted average of Remember and Know
272 responses to old items (see section 2.4.). The FWHM procedure based on these data resulted
273 in the identification of a cluster of 11 sensors over left-frontal scalp in the 300-500ms epoch¹
274 The largest difference (27 fT) was at sensor LT22. For the 500-800ms epoch the largest
275 difference was at sensor LT27 (28 fT) and the FWHM procedure resulted in a cluster
276 comprising 17 sensors over left occipito-temporal scalp². Both of these cluster locations
277 resemble closely those identified in previous MEG studies by Evans, Wilding and colleagues
278 (Bridson et al., 2009; Evans & Wilding, 2012).

279

280 *3.2.1.300-500ms*

281

282 Figure 2 (a) shows representative ERFs for the critical response categories from sensors
283 located over left-frontal scalp. The panel below the ERFs displays the mean signal strengths
284 for the five key response categories. An initial analysis established that, when collapsed

285 across response confidence, mean signal strength for Know responses was reliably greater
286 than that for Correct Rejections ($t(19) = 2.44, p = .025$).

287

288 The critical question is how the signal strengths vary for the four categories associated with
289 explicit confidence judgments: a graded change as described in the Introduction would favour
290 a familiarity account for this modulation (Woodruff et al., 2006; Yonelinas et al., 2005; Yu et
291 al., 2010). To assess this possibility an analysis strategy was adopted that has been employed
292 previously in similar fMRI (Yonelinas et al., 2005) and ERP studies (Woodruff et al., 2006;
293 Yu et al., 2010). For each participant a regression coefficient was calculated using the mean
294 signal from the cluster in the 300-500ms window along with a dummy variable reflecting the
295 four confidence levels. If the null hypothesis (no relationship between ERF magnitudes and
296 confidence) is correct then across participants the mean of the beta coefficients will
297 approximate zero. Contrary to the null hypothesis, the coefficients differed significantly from
298 zero ($t(19) = 2.90, p < .01$).

299 As noted in the Introduction, Evans and Wilding (2012) reported that signal strength at
300 similar scalp locations was greater for old words attracting Know rather than Remember
301 responses. This difference (-75vs -76 fT), did not reach significance here ($t(19) < 1$), while the
302 old/new effect for Remember responses was reliable ($t(19) = 2.90, p < .01$)

303

304 *3.2.2.500-800ms*

305

306 Evans and Wilding (2012) also reported that at posterior-parietal sites old words attracting
307 Remember responses were associated with reliably greater signal strength than old words
308 attracting Know responses, as well as correctly rejected new words. The relevant data and
309 ERFs for all five key response categories are shown in Figure 2(b). Three planned paired
310 analyses based on their outcomes were conducted and revealed the same two reliable
311 outcomes they reported (2012): While Know responses were not reliably different from
312 Correct Rejections, Remember responses were associated with greater signal strength than
313 both of these response categories (collapsed across confidence: R vs CR: $t(19) = 3.72, p <$
314 $.01$; R vs K: $t(19) = 2.41, p < .05$).

315 While these outcomes replicate those in our earlier study, the pattern of data in Figure 2
316 suggests a graded response to old items. Post-hoc t-tests (adjusted alpha = .0125) did not,
317 however, reveal reliable old/new effects for correct confident or unconfident Know
318 judgments (relative to the confident New baseline), reliable differences between Remember
319 and confident Know judgments to old words, nor between new words attracting confident or
320 unconfident judgments.

321

322 4. Discussion

323

324 This experiment was designed to assess the functional significance of ERF modulations that
325 might index the processes of familiarity and recollection. A link between an early anteriorly
326 distributed modulation and familiarity was first suggested by Bridson and colleagues (2009).
327 This suggestion was based primarily on the temporal and spatial similarities between this
328 modulation and the mid-frontal ERP old/new effect, for which several authors have suggested
329 a link with the process of familiarity (for a review, see Rugg & Curran, 2007).

330 This functional account was adopted by Evans and Wilding (2012). They used ERFs to argue
331 for a model of independence between the processes of familiarity and recollection, based
332 around how this early ERF modulation behaved in a Remember/Know task. The experiment
333 reported here was designed to test this assumption, as well as to assess the (arguably more
334 established) link between a parietally distributed ERF old/new effect and the process of
335 recollection (Allan et al., 1998).

336 Temporally and spatially similar modulations to those observed by Evans and Wilding (2012)
337 were obtained here. Turning first to putative indices of familiarity, activity at a cluster of
338 electrodes over left-frontal scalp from 300-500ms tracked familiarity strength, in so far as
339 confidence in old/new status is a proxy for strength. Figure 2 shows a linear relationship
340 between confidence and mean signal strengths, and this was corroborated in the analyses
341 reported above.

342 Comparable data patterns have been reported previously for studies in which ERPs were
343 employed, albeit with slightly different contrasts (Woodruff et al., 2006; Yu et al., 2010). In
344 both of these experiments a contrast between ERPs for the four levels of confidence used

345 here was reported. The contrasts were conducted over data collapsed across the old/new
346 status of the test words. While the same graded pattern reported here was observed, in both
347 cases additional analyses were reported. These were introduced in order to address the
348 concern that the pattern arose simply because ERP amplitudes varied for old and new items,
349 and the proportion of old items in each response category increased moving from ‘confident
350 New’ through to ‘confident Old’.

351 Woodruff and colleagues (Woodruff et al., 2006) conducted an analysis where they selected
352 trials to enable a contrast between categories associated with the same number of old and new
353 items, and the same average confidence reported data. They argued that their null result in
354 this analysis suggested that the graded pattern indicated that it was not the old/new status of
355 items that drove the graded effect they observed in their primary analysis. Rather than relying
356 on a null outcome, Yu et al. (2010) showed that a comparable graded pattern was found when
357 averaged ERPs were restricted to old items and separated for three response categories:
358 ‘confident Old’, ‘unconfident Old’ and ‘unconfident New’.

359 This analysis could not be conducted in this experiment because of the proportion of
360 ‘unconfident New’ responses given to old words, and so we adopted a different approach.
361 The confidence contrast was restricted to items attracting correct responses. The evidence
362 that this modulation is not simply a reflection of greater signal strength for old than for new
363 words is the graded function we have documented. If the modulation of interest simply
364 reflected signal strength in this way than a step function would have been observed: greater
365 signal strength for old words alongside no changes in signal according to confidence
366 (separately) for old and for new words.

367 These data can therefore be interpreted as favouring a familiarity account of this ERF
368 modulation. Other accounts of the functional significance of this modulation remain viable,
369 however, and these are motivated by different accounts of the functional significance of the
370 mid-frontal event-related potential (ERP) old/new effect. Paller and colleagues (Paller et al.,
371 2007). have argued that many data points that have formed the basis for the familiarity
372 account of this ERP old/new effect can equally well be accounted by an account in terms of
373 processes supporting a facilitation in response times as a function of repetition of
374 semantically related material.

375 For ERPs, the data that can adjudicate between these accounts have been discussed in several
376 places (Bridger, 2012; Paller et al., 2007; Voss, Lucas, & Paller, 2012; Wilding & Evans,

377 2012). For ERFs, however, the limited data available can be accommodated equally well by a
378 familiarity account and by a conceptual priming account, if it is assumed that the level of
379 conceptual priming will co-vary with familiarity strength. What this means is that while it is
380 possible to deploy this anterior ERF modulation to make functional claims about familiarity
381 when the stimuli have conceptual content, it would be premature to extend the use of this
382 modulation to stimulus sets where this semantic relationship does not hold.

383 Also of note is that the index linked to familiarity here did not behave in exactly the same
384 way as in our earlier study (Evans & Wilding, 2012). In this experiment the modulation
385 associated with Remember and with Know responses was indistinguishable. In our previous
386 study it was larger for the latter, with that finding being critical for the argument that the
387 processes of recollection and familiarity are independent (Evans & Wilding, 2012).

388 In keeping with the logic already outlined, Evans & Wilding (2012) noted that, if there is
389 neural activity signalling the process of recollection, then it should be evident to a greater
390 degree when people make a Remember rather than a Know response. They also observed
391 that, if familiarity and recollection are independent, and if familiarity is a continuous strength
392 signal, then all items given a Remember response will have a level of familiarity associated
393 with them. For only a subset of these items, however, will the level of familiarity exceed the
394 threshold sufficient to license a Know response. This contrasts with the levels of familiarity
395 associated with Know responses, which by definition must exceed criterion in each instance.
396 Over the course of a task in which many Remember and Know responses are given,
397 therefore, the mean level of familiarity will be greater for items attracting Know rather than
398 Remember responses.

399 It also follows from this argument that the size of the difference between a neural index of
400 familiarity for items attracting Remember and Know responses will diminish as the overall
401 likelihood of familiarity contributing to judgments goes up. Based on the recommendations
402 for computing familiarity from Remember/Know data under an independence assumption
403 (Yonelinas & Jacoby, 1995) estimates of familiarity were calculated. For this study the mean
404 value is 0.74, whereas it was 0.50 in our previous study³. These outcomes therefore offer an
405 explanation for the lack of correspondence across studies in the R/K data taken from anterior
406 sensors in the 300—500ms time window.

407 Also of note is that the ERF modulation has, in two cases, showed what may be a greater
408 sensitivity to changes in familiarity than its likely ERP counterpart. First, and as noted in the

409 Introduction, the ERF but not the ERP modulation separated studied words presented twice
410 from those presented only once at test (Bridson et al., 2009). Second, indications of larger
411 mid-frontal ERP old/new effects for Know than for Remember responses have not been
412 obtained (Smith, 1993). These outcomes raise the possibility that the ERF index presents
413 some advantages if the question of interest depends upon changes in a neural index of
414 familiarity.

415 Turning to the 500-800ms epoch, there are some correspondences between the outcomes and
416 those reported previously by Evans & Wilding (2012). In keeping with the earlier findings, an
417 old/new effect was reliable only for Remember responses, and was reliably larger than the
418 effect for Know responses. In terms of statistical outcomes, therefore, the data in the two
419 studies correspond closely. Figure 2, however, shows that ERF signal strengths for confident
420 and unconfident Know responses lie between those for Remember responses and for correct
421 rejections, and are numerically greater for high than for low confidence Know responses.
422 Post-hoc tests for ERFs separated by confidence did not reveal reliable differences between
423 old items attracting correct responses, but the same was also true for new items.

424 How should these trends be considered? The absence of differences (both statistically and
425 numerically) between new items attracting confident or unconfident new judgments, and
426 indeed the absence of a larger modulation for confident new than unconfident old responses,
427 argues against an interpretation solely in terms of response confidence, as well as any
428 interpretation of the data in terms of familiarity strength. The apparently graded pattern for
429 old words (Remember > confident Know > unconfident Know) remains a challenge,
430 however.

431 The temporal and spatial correspondence between this modulation and that observed in
432 comparable ERP studies suggests a link between this modulation and the process of
433 recollection. In light of this, the trends in Figure 2 (albeit not supported by statistical
434 outcomes) can be accommodated by assuming that a Remember response is given only when
435 a certain level or quality of content is recovered. In this sense the data are consistent with the
436 view that recollection is graded (Elfman, Aly, & Yonelinas, 2014). This explanation does not
437 sit as well, however, with the absence of a comparable modulation associated with Know
438 responses in our earlier study (2012).

439 Two differences between the designs of the two experiments merit consideration. The first is
440 the use of confidence ratings in this experiment only: It is possible that the confidence

441 manipulation influenced the way in which participants decided whether items should attract a
442 Remember or a Know response. The second difference is the encoding tasks for the critical
443 retrieval contrasts: shallow encoding in the earlier study (Evans & Wilding, 2012), deep
444 encoding in this study. It is possible that the criteria for producing a Know response vary with
445 encoding context, and resolving the apparent differences across the findings in these studies
446 is important for delineating in detail the functional properties of recollection.

447 *4.1. Summary.* This experiment was conducted to assess the sensitivity of ERFs to the
448 processes of familiarity and recollection. The design was a close variant of one employed
449 previously to identify neural activity linked with familiarity in fMRI (Yonelinas et al., 2005)
450 and ERP (Woodruff et al., 2006; Yu et al., 2010) studies of memory retrieval. The graded
451 manner in which ERPs at anterior locations from 300 to 500ms tracked response confidence
452 and item status is consistent with the view that this MEG signal can act as an index of
453 familiarity, at least for stimuli with conceptual content. While the statistical outcomes for the
454 data from 500-800ms at posterior occipital sensors match those obtained previously (Evans &
455 Wilding, 2012), and are consistent with the view that this effect is a neural index of
456 recollection, the trends in the data for Know responses were unexpected. They indicate that
457 further examination of ERFs, and possibly ERPs, has the potential to contribute to the debate
458 over the properties of this fundamental retrieval process.

459

460 **Footnotes:**

461

462 1. The sensors in the early time window at left frontal scalp were: LF46, LF56, LT11,
463 LT12, LT13, LT21, LT22, LT23, LT33, LT41, LT42.

464 2. The sensors in the later time window at left parietal scalp were: LT16, LT26, LT27,
465 LT37, LO12, LO13, LO14, LO22, LO23, LO24, LO31, LO32, LO33, LO34, LO42,
466 LO43, LO44.

467 3. These calculations are based on the behavioural data taken from the shallow encoding
468 condition reported by Evans & Wilding (2012). The data from this condition
469 contributed the critical ERP data upon which claims regarding a relationship of
470 independence between the processes of recollection and familiarity were made.

471

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603

604

605 **Acknowledgments:**

606

607 The authors would like to thank Suresh Muthukumaraswamy for technical support, and Amie
608 Doidge, Jane Herron and Angharad Williams for comments on the manuscript. This research
609 was funded by BBSRC grant number BB/I001247/1 awarded to both authors.

610

611

612 **Figure Legends:**

613

614 **Figure 1.** Scalp maps showing distributions of ERF activity for a) the 300-500ms, and b) the
615 500-800ms epochs. The maps were computed based upon a subtraction of correct rejections
616 from the unweighted average of Remember and Know responses to old items, described in
617 detail in the methods. The circles on each of the maps indicate the approximate location of
618 the sensors selected via the FWHM procedure in each time window.

619

620 **Figure 2.** Averaged across participant event-related fields (ERFs) for the 5 critical response
621 categories and averaged for the sensor clusters to which data from the 300-500ms (a: left-
622 frontal) and 500-800ms (b: left posterior) epochs were analysed. The accompanying graphs
623 for each location and epoch show mean signal strengths for the 5 key response categories for
624 the same sensor clusters. R = Remember, CK = confident Know, UK = unconfident Know,
625 UN = unconfident New, CN = confident New. Error bars = + 1 S.E.

626

627

628

629 **Table 1.** Proportions of old and new words assigned to each response category, with
630 associated reaction times (collapsed across study status).

631

	Remember	Confident Know	Unconfident Know	Unconfident New	Confident New
634 Old	0.37	0.30	0.17	0.10	0.06
635 New	0.03	0.05	0.16	0.33	0.42
636 RT (ms)	1262	1591	1936	1799	1467

637

638

639 **Appendix 1.** Behavioural data for 35 participants.

640

641 Proportions of old and new words assigned to each response category, with associated
642 reaction times (collapsed across study status).

643

	Remember	Confident Know	Unconfident Know	Unconfident New	Confident New
646 Old	0.39	0.26	0.17	0.11	0.06
647 New	0.04	0.06	0.18	0.34	0.38
648 RT (ms)	1230	1567	1813	1698	1433

649

650 Mirroring the statistical outcomes for the analyses for the 20 participants contributing
651 sufficient trials to all 5 key response categories of interest, a 2*5 ANOVA of the accuracy
652 data (factors of Old/New and Response) revealed a reliable interaction term: $F(3.09, 105.13)$
653 $= 100.68, p < .001$). The data pattern is very similar overall to that shown for the 20
654 participants included in the main analyses (Table 1). As reported in Methods, 8 of the 15
655 participants excluded did not contribute sufficient trials to one of more of the key response
656 categories to be included in the analyses. The correspondence between the numerical values
657 in Table 1 and Appendix 1 reflects in part the fact that the specific categories for which there
658 were insufficient trials varied across the excluded participants.

659

660 For the reaction time data, a one-way ANOVA with 5 levels revealed a main effect of
661 response category ($F(2.46, 83.51) = 33.45, p < .001$), with this outcome reflecting the fact that
662 the slowest responses are for low confidence responses (cf Table 1).

663

Figure 1

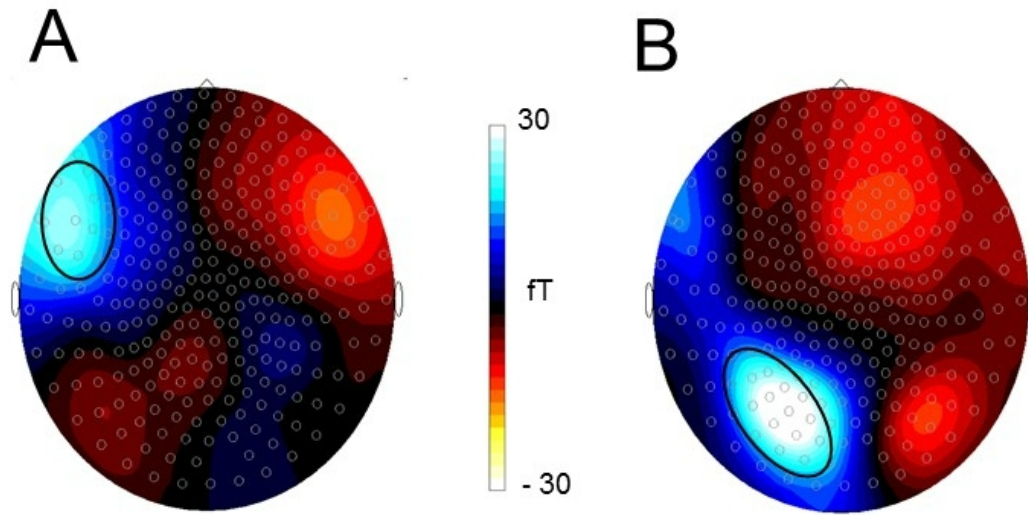


Figure 2

