Effects of attention and confidence on the hypothesized ERP correlates of recollection and familiarity

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Abstract

Dual-process theories suggest that recognition memory is determined by two separate processes: familiarity and recollection. Experiment 1 behaviorally replicated past studies using the *remember/know* procedure to indicate that the amount of attention devoted to study influences both recollection and familiarity, but recollection more strongly. Experiments 1 and 2 assessed the effects of attention on two ERP components that have been hypothesized to be related to familiarity (FN400 old/new effect, 300–500 ms, anterior) and recollection (parietal old/new effect, 400–800 ms, posterior). Parietal old/new effects were reduced by divided attention, but FN400 old/new effects were not. Parietal ERPs (400–800 ms) in experiment 2 increased with confidence in recognizing old items, but not new items. These results support the hypothesis that the parietal old/new effect is related to recollection.
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Dual-process theories suggest that recognition memory performance is determined by separate processes of familiarity and recollection (Brainerd, Reyna, & Kneer, 1995; Hintzman & Curran, 1994; Jacoby, 1991; Mandler, 1980; Norman & O'Reilly, 2003; Reder et al., 2000; Yonelinas, 1994). The dual-process perspective is theoretically attractive because it potentially explains various phenomena that have been challenging to single-process, familiarity-based models (Clark & Gronlund, 1996; Hintzman & Curran, 1994; Norman & O'Reilly, 2003; Reder et al., 2000; Yonelinas, 1997). However, the measurement methods used to behaviorally dissociate familiarity and recollection effects have been controversial (reviewed by Humphreys, Dennis, Chalmers, & Finnigan, 2000; Yonelinas, 2002). An alternative measurement approach is to neurophysiologically dissociate recollection and familiarity (Rugg & Yonelinas, 2003) with methods such as functional magnetic resonance imaging (fMRI) (Dobbins, Rice, Wagner, & Schacter, 2003; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Henson, Cansino, Herron, Robb, & Rugg, 2003) or event-related brain potentials (ERP) (Curran, 1999, 2000; Curran & Cleary, 2003; Curran & Dien, 2003; Curran, Tanaka, & Weiskopf, 2002; Düzel, Vargha-Khadem, Heinze, & Mishkin, 2001; Guillem, Bicu, & Debruille, 2001;

Mecklinger, 2000; Nessler, Mecklinger, & Penney, 2001; Rugg, Mark et al., 1998; Tsivilis, Otten, & Rugg, 2001). The present experiments further examine the utility of ERPs for measuring activity related to recollection and familiarity.

The work of several groups (reviewed in Friedman & Johnson, 2000; Mecklinger, 2000) has promoted the idea that an early (300–500 ms), mid-frontal, negative ERP effect is related to familiarity (here called the "FN400 old/new effect"; Curran, 1999, 2000; Curran & Cleary, 2003; Curran & Dien, 2003; Curran et al., 2002)[1], and a later (400–800 ms), parietal, positive ERP effect is related to recollection (here called the "parietal old/new effect" ; Allan, Wilding, & Rugg, 1998; Curran, 1999, 2000; Curran & Cleary, 2003; Curran & Dien, 2003; Curran, Schacter, Johnson, & Spinks,

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[1] The relationship between the FN400 and the N400 is unclear. We use the FN400 label because our 300–500 ms old/new differences are more frontally distributed than the centro-parietal N400 recorded to semantic incongruity (reviewed by Kutas & Van Petten, 1988, 1994). Many studies have found 300–500 ms old/new effects associated with the centro-parietal N400 (e.g., Bentin & McCarthy, 1994; Besson, Fischler, Boaz, & Raney, 1992; Finnigan, Humphreys, Dennis, & Geffen, 2002; Olichney et al., 2000; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991) whereas others have found it to be more frontal (Mecklinger, 2000; Nessler et al., 2001; Rugg, Mark et al., 1998; Tsivilis et al., 2001). Its frontal manifestation elsewhere has been called the mid-frontal (Tsivilis et al., 2001) or medial frontal (Friedman & Johnson, 2000) old/new effect. We consider previous studies describing 300–500 ms old/new effects, however labeled or spatially distributed, to be potentially relevant to the FN400.

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2001; Curran et al., 2002)[2]. Our own work has started with the theoretical perspective that familiarity is the product of a global matching process that represents the similarity between a test item and all studied information (e.g., Clark & Gronlund, 1996; Gillund & Shiffrin, 1984; Hintzman, 1988; Shiffrin & Steyvers, 1997). According to this perspective, the FN400 seems related to familiarity because it responds similarly to studied items and similar lures. Examples include studied words and plurality-reversed lures (Curran, 2000), studied pictures and orientation-reversed lures (Curran & Cleary, 2003), studied geometric figures and visually similar lures (Curran et al., 2002), and studied words and semantically similar lures (Nessler et al., 2001). We have further assumed that recollection involves the retrieval of qualitatively specific information about individual items (e.g., Hintzman & Curran, 1994; Norman & O'Reilly, 2003; Yonelinas, 1994). The observation that parietal old/new differences can be observed between studied and similar lures in the aforementioned experiments is consistent with a relationship to recollection (Curran, 2000; Curran & Cleary, 2003; Curran et al., 2002; Nessler et al., 2001).

Other research has challenged the hypothesis that the FN400 is related to familiarity. For example, Olichney and colleagues (Olichney et al., 2000) found that the magnitude of 500–800 ms parietal old/new effects (labeled "LPC old/new effects") was correlated with memory ability in amnesic patients and control subjects, and the parietal old/new differences were not significant when the amnesic group was considered as a whole. However, the N400 old/new effect was uncorrelated with memory performance (including recognition memory) and was normal in the amnesic patients. Thus, the authors conclude that the N400 old/new difference is unlikely to be related to the episodic memory processes such as familiarity. Second, Tsivilis et al. (2001) studied memory for objects under conditions in which the background context was incidentally varied. If both parts (object and context) of the display were present at study and test, the FN400 (labeled "mid-frontal 300–500 ms effect") differed from conditions in which both the object and context were new. However, changing one part of the display from study to test (either the object or the context, but not both) abolished the FN400 old/new effect. In other words, the FN400 was insensitive when only part of the display was familiar. Thus, Tsivilis et al. suggest that the FN400 old/new differences may be related to a novelty-detection process that is correlated with, but downstream to, familiarity assessment.

The hypothesis that the parietal effect is related to recollection has been more widely accepted, but it has also been questioned. Finnigan et al. (2002) found that a 300–500 ms N400 effect recorded over the parietal scalp varied with presentation frequency whereas a later 500–800 ms parietal effect varied with the accuracy of recognition judgments. They suggested these two effects may respectively be related to strength and decision processes underlying a single-process, signal-detection-like recognition memory mechanism, rather than being related to separate familiarity and recollection processes. Finnigan et al.'s meaning of "strength" and the present meaning of "familiarity" are both inspired by the global matching models of memory, so we are in agreement on the nature of the N400 old/new effect (although their N400 was parietal rather than frontal). According to Finnigan et al.'s perspective, however, parietal old/new effects could simply reflect decision-related processes such as confidence or criterion setting rather than indexing a secondary recollection process.

These differing perspectives on the functional interpretation of the FN400 and parietal old/new effects suggest that further research is needed. Another potentially fruitful approach for linking the FN400 effect to familiarity and the parietal effect to recollection is to establish a correspondence between these ERP effects and results from behavioral measurement methods. For example, several studies have measured ERPs during the *remember/know* paradigm (for methodological review of the *remember/know* procedure see, Gardiner & Richardson-Klavehn, 2000). The parietal old/new effect is larger when recognition is based upon a subjective experience of "remembering" than "knowing" (Düzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Rugg, Schloerscheidt, & Mark, 1998; Smith, 1993; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999), though these amplitude differences might be attributable to greater latency jitter in "knowing" trials (Spencer et al., 2000). ERP correlates of "knowing" possibly related to familiarity were less clear in these experiments, although an early knowing-related frontotemporal effect has been observed that may be related to the FN400 familiarity effect (Düzel et al., 1997).

Other experiments have taken an indirect approach by showing that variables affecting familiarity and recollection estimates in previous studies have corresponding effects on ERPs. For example, the parietal old/new effect has been observed to be larger for words than pseudowords, but the FN400 old/new effect was similar for words and pseudowords (Curran, 1999). The parietal effects are consistent with findings that "remembering" is greater for words than pseudowords (Curran, Schacter, Norman, & Galluccio, 1997; Gardiner & Java, 1990; Whittlesea & Williams, 2000). However, estimates of familiarity derived from "knowing" from these same experiments with words and pseudowords have been less consistent, so the correspondence between the FN400 effects and familiarity is less certain. Some of these differences may be attributable to characteristics of the pseudowords (Whittlesea & Williams, 2000).

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[2] The parietal old/new effect co-occurs with the P300 component (Bentin & McCarthy, 1994; Spencer, Vila Abad, & Donchin, 2000), and has been variously labeled the "P300 old/new difference"(Johnson, 1995), the "late ERP old/new effect"(Rugg, 1995), and the "P600 old/new effect" (Curran, 1999; Rugg & Doyle, 1992).

Comparisons between behavioral and electrophysiological indices of recollection and familiarity would be stronger in cases where existing behavioral work is more clear-cut. Yonelinas (2001) has recently shown that familiarity and recollection estimates can be similar across the process-dissociation, remember/know, and receiver operating characteristics (ROCs) procedures. For example, all three procedures showed that both recollection and familiarity are greater following semantic processing at encoding rather than perceptual processing (i.e., levels of processing, LOP, see also Gardiner, 1988; Jacoby, 1991; Rajaram, 1993; Toth, 1996; Wagner, Gabrieli, & Verfaellie, 1997). Several ERP studies have shown that the parietal old/new effect increases with LOP (Paller & Kutas, 1992; Paller, Kutas, & McIsaac, 1995; Rugg, Allan, & Birch, 2000; Rugg, Mark et al. 1998). Among those studies that considered LOP effects on the FN400, the FN400 was unaffected by LOP when conditions were randomized within each block (Rugg, Mark et al., 1998), but the FN400 old/new effect was observed after deep (but not shallow) study when conditions were manipulated between blocks (Rugg et al., 2000). Yonelinas (2001) behavioral studies used an intermediate design in which study conditions were blocked, but followed by a mixed test list. Thus, although some behavioral consistency has been demonstrated, the FN400 results have been less reliable.

Yonelinas (2001) also manipulated divided attention at study. Both ROC and *remember/know* experiments indicated that divided attention affected recollection and familiarity, but recollection more strongly (see also, Gardiner & Parkin, 1990; Jacoby & Kelley, 1991; Parkin, Gardiner, & Rosser, 1995; Reinitz, Morrissey, & Demb, 1994). One study has investigated effects of divided attention at study on ERPs recorded during study (Mangels, Picton, & Craik, 2001), but none have investigated how divided attention at study affects the putative ERP correlates of familiarity and recollection during retrieval. The present experiments manipulated attention during study and measured ERPs during recognition tests to determine if the FN400 and parietal old/new effects conformed to behavioral indications that both familiarity and recollection are reduced by dividing attention.

1. Experiment 1[3]

1.1. Method

1.1.1. Subjects

Fifty-one students from Case Western Reserve University participated in one session (approximately 2 h) in partial fulfillment of a course requirement. Data from 12 subjects were discarded because of excessively high sensor impedances (five), excessive eye blinking (four), excessive

movement (one), computer malfunction, or mis-instruction (one). Twenty-eight of the 39 subjects retained for analyses were male. The behavioral results of the included and excluded subjects were qualitatively similar.

1.1.2. Stimuli

Stimuli consisted of 300 common English words. Words were centrally presented in white against a black background. Visual display was a 15 in. Apple multiscan color monitor. The words were divided into four sets of 75 that were roughly equated for word frequency (MN = 15.39, S.D. = 18.86, range = 0 : 99, (Kucera & Francis, 1967)) and number of letters (MN = 5.42, S.D. = 1.04, range = 4 : 7). These sets were counterbalanced through the attention and old/new conditions across subjects. Additional words with similar characteristics were used as practice and buffer items. Stimuli for the divided attention task were digital recordings of a single male voice speaking the digits from 0 to 9.

1.1.3. Design

Attention during study (full, divided) and memory status (old, new) of the words were manipulated within subjects. Each of four experimental blocks included two study lists (25 words per list) followed by a single test list (75 words). Each pair of study lists included one full-attention list and one divided-attention list. The order of full/divided lists was alternated across blocks and counterbalanced across subjects. Test lists included randomly intermixed words from the full, divided, and new conditions (25 per condition per block).

1.1.4. Procedure

Subjects were instructed before completing a short practice block that consisted of two 25-word study lists followed by a single 12-word test list. A Geodesic Sensor Net was applied between the practice and experimental blocks.

Subjects studied two word lists (one full and one divided) before each recognition test. Each study list contained 25 words surrounded by one-word primacy and recency buffers. Each study trial included a 600 ms fixation sign (+) preceding a 1000 ms word. Subjects were instructed to study each word for an upcoming recognition test. Because subjects were not given an explicit encoding task, it is likely that the two conditions differ in level of processing in addition to attention. During divided-attention lists, subjects additionally heard a random digit presented at the beginning of each trial. Subjects were instructed to press a key each time three odd digits occurred consecutively (following Craik, 1982; Jacoby & Kelley, 1991). No digits were presented during full attention lists. A rest period of at least 2 min intervened between each study and test list.

Each test block contained 75 test words (25 per condition) that were divided into five sub-blocks, so that subjects could periodically rest their eyes. Each sub-block began with a non-studied word that was not included in analyses

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to minimize post-break movement artifacts. All test-trial event onsets were synchronized to the refresh cycle of the monitor. Trials began with a variable duration plus sign (500–1000 ms), followed by a 2000 ms test-word presentation, followed by a question mark. Subjects were instructed to withhold their responses until the question mark appeared, and to minimize blinking and other movements. Test trials were concluded upon the subject's response. Subjects responded by pressing "remember", "know" or "new" keys. Assignment of response categories to keys/hands was counterbalanced across subjects. "Remember" and "know" keys were always assigned to the first two fingers of one hand and the "new" key was always assigned to the first finger of the other hand. Subjects responded "remember" when they could recollect specific details about the word from the study episode, but "know" when they judged the word to be studied without the recollection of details.[4]

1.1.5. EEG/ERP methods

Scalp voltages were collected with a 128-channel Geodesic Sensor Net[TM] (Tucker, 1993) connected to an ac-coupled, 128-channel, high-input impedance amplifier (200 MΩ, Net Amps[TM], Electrical Geodesics Inc., Eugene, OR). Amplified analog voltages (0.1–100 Hz bandpass, −3 dB) were digitized at 250 Hz. Individual sensors were adjusted until impedances were less than 50 kΩ. The EEG was collected continuously during test blocks, digitally low-pass filtered at 40 Hz, and then segmented into epochs starting 100 ms before test-word onset and lasting 1500 ms after. Trials were discarded from analyses if they contained incorrect responses, eye movements (EOG over 70 μV), or more than 20% of channels were bad (average amplitude over 200 μV or transit amplitude over 100 ms). Individual bad channels were replaced on a trial-by-trial basis with a spherical spline algorithm (Srinivasan, Nunez, Silberstein, Tucker, & Cadusch, 1996). Consistently bad channels for a given subject were replaced throughout that subject's entire dataset (bad channels per subject: median = mode = 1, range = 0–3). EEG was measured with respect to a vertex reference (Cz), but an average-reference transformation was used to minimize the effects of reference-site activity and accurately estimate the scalp topography of the measured electrical fields (Bertrand, Perin, & Pernier, 1985; Curran, Tucker, Kutas, & Posner, 1993; Dien, 1998; Lehman & Skrandies, 1985; Picton, Lins, & Scherg, 1995; Tucker, Liotti, Potts, Russell, & Posner, 1994). Average-reference ERPs are computed for each channel as the voltage difference between that channel and the average of all channels. The average reference was corrected for the polar average

reference effect (Junghöfer, Elbert, Tucker, & Braun, 1999). ERPs were baseline-corrected with respect to a 100 ms prestimulus recording interval.

2. Results

2.1. Analysis strategy

Only 14 subjects had a sufficient number (>15) of correct, artifact-free "remember" and "know" trials in both the full and divided conditions. More subjects could be retained by comparing remember and know trials collapsed across full/divided attention (n = 35), or by comparing full and divided trials collapsed across *remember/know* (n = 39). ERP analyses from the *remember/know* and divided/full attention comparisons are presented separately below. Results from the 14 subjects with sufficient trials in all remember/know × full/divided attention categories are not presented because they were not consistent with the results of the analyses from the larger samples.[5] Behavioral results are presented for the larger of the two samples (n = 39).

2.2. Behavioral results

Table 1 shows the mean proportion of "remember", "know", and "new" responses given in each condition. As detailed by Yonelinas (2002), recollection processes (R) can be directly estimated from the proportion of "remember" responses, but familiarity processes (F) cannot be directly estimated from the proportion of "know" responses because the latter judgment is contingent on recollection failure. Familiarity can be estimated by assuming that familiarity and recollection are independent, and dividing the know proportion by 1 minus the recollect proportion ($F = K/[1 − R]$). Because we are particularly interested in estimating recollection (R) and familiarity (F) in the present experiment, analyses focused on these estimates.[6]

An estimate type (R, F) by condition (full, divided, new) repeated measures ANOVA resulted in both main effects and the interaction being highly significant (all F > 19, all P < 0.001). Within each estimate type, contrasts indicated that each condition significantly differed from each other condition (all P < 0.001), so divided attention reliably affected both recollection and familiarity. The interaction suggests that divided attention reduced recollection more than

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[4] Remember/know instructions were standard except that "recollect" and "familiar" labels were used rather than "remember" and "know" because the former terms tend to cause less confusion (Norman, 2002). The judgments are described herein as "remember" and "know" to clearly differentiate between subjects' responses (remember, know) and the underlying processes of interest (recollection, familiarity). I thank Ken Norman for providing instructions from his experiments.

[5] Remember/know × full/divided ANOVAs on the FN400 and parietal effects (as described later) from these 14 subjects revealed only a significant effect of full/divided on the FN400. This is an effect that was not significant when full and divided conditions were compared across 39 subjects. Furthermore, these analyses failed to replicate the remember/know and full/divided effects that were significant in the subsequent analyses.

[6] The observation that "remember" responses were given to 9% of new items may indicate that some subjects misunderstood instructions, assuming that false recollection rarely occurs with unrelated lures. However, the pattern of results did not qualitatively differ when subjects with high false remember rates (>10%) were omitted.
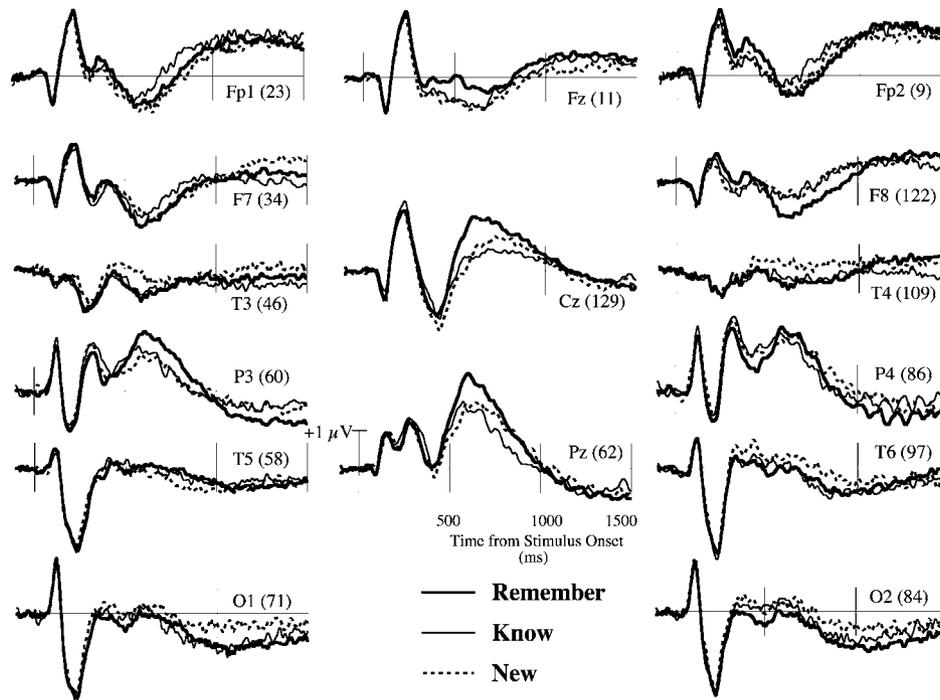
Fig. 1. Grand average ERPs from experiment 1. Shown channels are representative of the international 10–20 system (Jasper, 1958). Channels are labeled according to Geodesic Electrode Net numbers (see Fig. 2) along with their nearest 10–20 equivalent location.

Table 1
Behavioral results from experiment 1

	Full	Divided	New
Remember (R) (recollection)	0.62	0.33	0.09
Know (K)	0.23	0.33	0.29
New (N)	0.15	0.33	0.63
Familiarity (F) ($=K/[1 - R]$)	0.61	0.50	0.32

Notes: Top three rows are the proportions of R, K, and N responses within each condition.

familiarity. Overall, these results agree with others reviewed in the introduction.[7]

2.3. Remember/know ERP results

Correct trials given remember or know responses were collapsed across the full and divided attention conditions, and compared with correctly rejected new trials. Thirty-five subjects had at least 19 acceptable trials in each condition (mean trials/condition: remember = 81, know = 50, new = 54). ERPs recorded near selected locations from the international 10–20 system are shown in Fig. 1 (Jasper, 1958). FN400 and parietal old/new effects were analyzed within temporal windows (FN400: 300–500 ms; parietal:

400–800 ms) and spatial regions (described below) identified in previous studies (following, Curran, 2000; Curran & Cleary, 2003; Curran & Dien, 2003; Curran et al., 2001, 2002). Condition (remember, know, new) × hemisphere repeated-measures ANOVAs were computed within each window separately. These were followed by planned condition × hemisphere ANOVAs to specifically assess old/new effects associated with remember judgments (remember versus new), old/new effects associated with know judgments (know versus new), and differences between remembering and knowing. All condition main effects are reported, regardless of significance. Hemisphere × condition interactions are reported only when significant. ANOVA results are summarized in Tables 2 and 3, adjusted according to the conservative Geisser-Greenhouse procedure for sphericity violations (Winer, 1971).

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[7] Recollection results were very similar between the subjects who were included ($n = 39$) versus excluded from the primary analyses. Familiarity estimates were qualitatively similar, but lower for excluded subjects: full = 0.47 divided = 0.34, new = 0.20 (compare to values from included subjects in Table 1).

Table 2
Experiment 1: FN400 ANOVA results (300–500 ms, LAS and RAS regions)

Effect	d.f.	F	M.S.E.	P
Remember, know, new	2, 34	5.36	0.88	<0.01
Remember vs. new	1, 34	10.64	0.86	<0.01
Know vs. new	1, 34	4.52	0.87	<0.05
Remember vs. know	1, 34	1.18	0.90	n.s.
Full, divided, new	2, 38	9.48	1.62	<0.001
Full vs. new	1, 38	18.18	1.40	<0.001
Div vs. new	1, 38	10.70	2.08	<0.01
Full vs. div	1, 38	0.08	1.38	n.s.

Notes: d.f. = degree of freedom; div = divided; and n.s. = not significant.

Table 3
Experiment 1: parietal ANOVA results (400–800 ms, LPS and RPS regions)

Effect	d.f.	F	M.S.E.	P
Remember, know, new	2, 34	12.58	0.68	<0.001
×Hem	2, 34	11.28	0.15	<0.001
Remember vs. new	1, 34	21.43	0.57	<0.001
×Hem	1, 34	17.86	0.19	<0.001
Know vs. new	1, 34	0.04	0.86	n.s.
×Hem	1, 34	9.23	0.14	<0.01
Remember vs. know	1, 34	21.88	0.62	<0.001
×Hem	1, 34	3.77	0.13	0.06
Full, div, new	2, 38	19.47	1.38	<0.001
×Hem	2, 38	10.74	0.22	<0.001
Full vs. new	1, 38	44.28	1.21	<0.001
×Hem	1, 38	15.24	0.31	<0.001
Div vs. new	1, 38	7.02	1.50	<0.05
×Hem	1, 38	14.61	0.13	<0.001
Full vs. div	1, 38	11.56	1.44	<0.01

Notes: d.f. = degree of freedom; div = divided; hem = hemisphere; and n.s. = not significant.

2.4. Remember/know: FN400 results (300–500 ms)

The FN400 was analyzed over two anterior, superior channels groups centered near the standard F3 and F4 locations. The regions are labeled left and right anterior/superior (LAS and RAS, see Fig. 2) and ERPs averaged within these regions are plotted in Fig. 3. Mean LAS and RAS amplitude

Fig. 2. Approximate sensor locations and selected locations from the 10–20 system. Channels within regions of interest used in ANOVAs are shown in black. L = left, R = right, A = anterior, P = posterior, S = superior, and I = inferior.
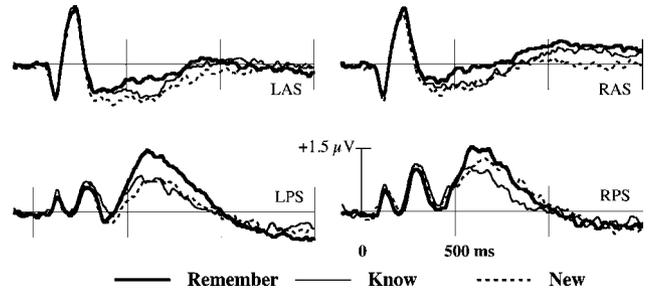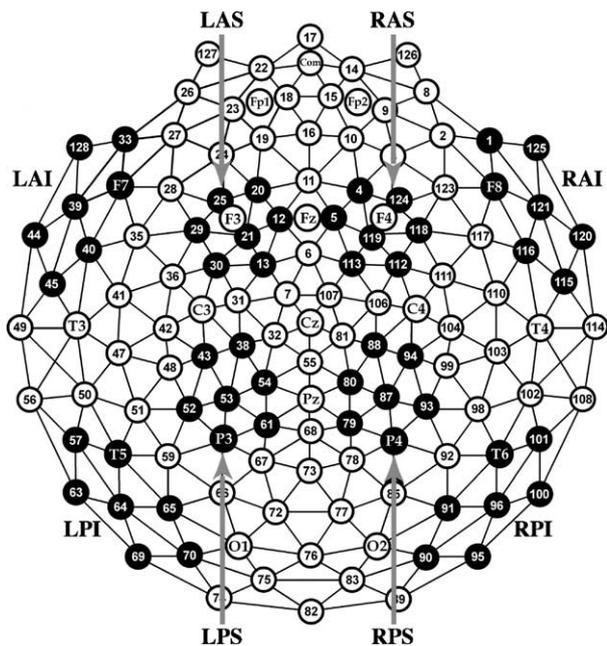

Fig. 3. Grand average ERPs from experiment 1. ERPs are averaged across channels within the LAS, RAS, LPS, and RPS regions of interest shown in Fig. 2.

between 300 and 500 ms was the dependent measure (Fig. 4). As shown in Table 2, significant old/new differences were observed for old items associated with both remember and know responses, and the remember and know categories did not differ. Thus, the FN400 old/new effect was found to be similar for both remembering and knowing.

2.5. Remember/know parietal results (400–800 ms)

Mean LPS and RPS (left and right posterior/superior) amplitude within each channel group, between 400 and 800 ms, was the dependent measure (see Fig. 2 for locations, Fig. 3 for ERP plots, Fig. 4 for mean amplitudes, and Table 3 for ANOVA results). A greater parietal positivity was observed for remembered words than known words, especially over the left hemisphere. Furthermore, the parietal effect was larger for remembering than knowing. The significant know/new × hemisphere interaction suggested knowing was more positive than new over the left hemisphere ($P = 0.08$), but new was more positive than knowing over the right hemisphere ($P < 0.05$). It should be acknowledged that condition differences in the amount of latency jitter across trials may contribute to the observed amplitude differences (Spencer et al., 2000). However, ERP conditions differing in latency
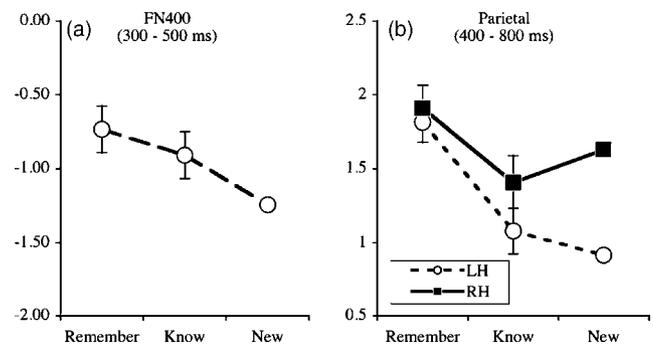

Fig. 4. Mean amplitudes (μV) corresponding to the FN400 (a) and parietal (b) old/new effects in experiment 1. Error bars represent the standard error of the old/new difference (hence, the absence of error bars for the new conditions). (a) Mean amplitudes across the LAS and RAS regions from 300 to 500 ms. (b) Mean amplitudes within the LPS and RPS regions from 400 to 800 ms.
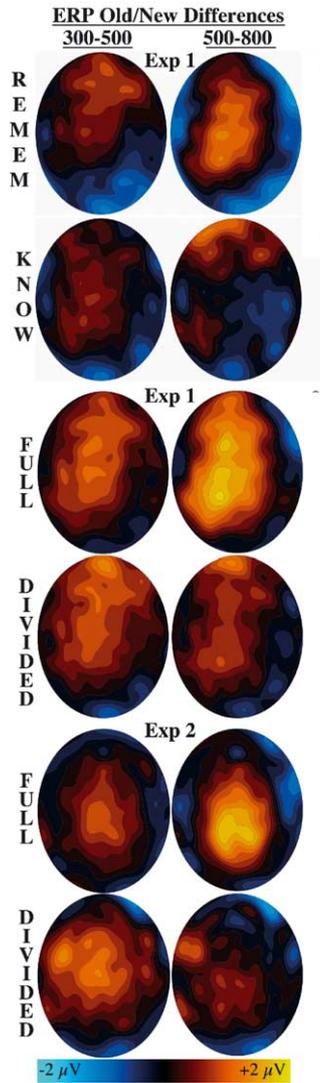
ERP Old/New Differences

Fig. 5. Topography of the old/new differences estimated by spherical-spline interpolations (Srinivasan et al., 1996). The front of the head is depicted at the top of each oval.

jitter often differ in the peakedness of the waveforms, such that low jitter leads to peaked waveforms and high jitter leads to a flatter, shallower waveform. The present ERP conditions do not clearly differ in peakedness (see Fig. 3).

2.6. Remember/know: topographic comparisons

Further analyses investigated topographic differences between the FN400 and parietal old/new effects (see Fig. 5). Because the temporal overlap between these effects would obscure topographic differentiation, the 400–800 ms parietal window was limited to 500–800 ms to maintain separation from the 300–500 ms FN400 window. Old/new differences within each temporal window were computed separately from the full and divided attention conditions, and the mean of these differences was taken within each of the eight spatial regions shown in Fig. 2 (Curran, 1999, 2000; Curran &

Cleary, 2003; Curran et al., 2002). Amplitude differences between the conditions and temporal windows were removed by vector-length normalization (McCarthy & Wood, 1985). The normalized differences were the dependent measures in a condition (remember, know) × time (300–500, 500–800) × hemisphere × anterior/posterior × superior/inferior repeated measures ANOVA. Interactions between time and the topographic factors would indicate that the FN400 and parietal old/new effects are topographically different.

As seen in Fig. 5, both the FN400 (300–500) and parietal (500–800) old/new differences are positive-going over superior regions and negative-going over inferior regions (Curran, 1999, 2000; Curran & Cleary, 2003; Curran et al., 2002). The time × hemisphere × anterior/posterior × inferior/superior interaction indicated that, relative to the FN400 old/new effect, the parietal effect had larger left posterior/superior (i.e., left parietal) differences and opposite-going right anterior/inferior differences, $F(1, 34) = 4.85$, M.S.E. $= 0.01$, $P < 0.05$. This overall topographic difference between the FN400 and parietal old/new effects was qualified by several interactions between *remember/know*, time, and topography. One generally consistent interpretation of the following interactions is that remembering and knowing were associated with similar 300–500 ms old/new effects, but 500–800 ms old/new effects were larger and topographically different for remembering than knowing. The time × remember/know × anterior/posterior interaction suggested that anterior differences were more positive than posterior differences for all time × remember/know combinations except the 500–800 ms differences related to remembering; in this case, posterior differences were more positive than anterior, $F(1, 34) = 10.52$, M.S.E. $= 0.05$, $P < 0.01$. The time × remember/know × inferior/superior interaction suggested that 300–500 ms FN400 effects showed similar superior > inferior differences for knowing and remembering, but the 500–800 ms parietal effects showed much larger superior > inferior differences related to remembering than knowing. The time × remember/know × inferior/superior × hemisphere interaction can be interpreted similarly to the previous interaction, with the additional hemispheric interaction capturing the fact that the large superior > inferior difference associated with remembering from 500–800 ms especially involved left, superior and right, inferior regions.

In summary, the time × region interactions suggest that the FN400 and parietal old/new effects are topographically different. Further interactions suggest that remembering and knowing primarily differ at the parietal old/new effect.

2.7. Remember/know: late frontal (100–1500 ms)

Although the experiment was not designed with late frontal effects in mind, they were examined for completeness because old > new differences are commonly observed
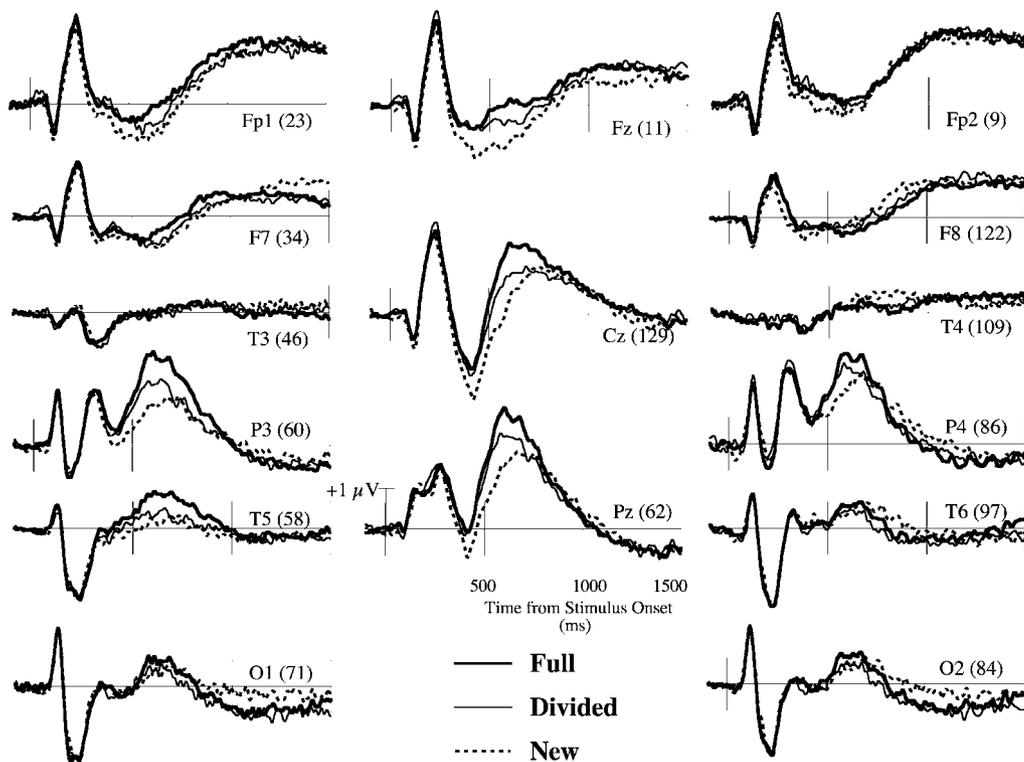
Fig. 6. Grand average ERPs from experiment 1. Shown channels are representative of the international 10–20 system (Jasper, 1958). Channels are labeled according to Geodesic Electrode Net numbers (see Fig. 2) along with their nearest 10–20 equivalent location.

(Allan et al., 1998; Curran & Friedman, 2003; Curran et al., 2001; Johnson, Kounios, & Nolde, 1996; Ranganath & Paller, 2000; Wilding, 1999; Wilding & Rugg, 1997a,b). Six channel groups (seven channels/group) were defined near the Fp1/Fp2, F7/F8, and F3/F4 locations (following Curran & Friedman, 2003).[8] Mean amplitude from 1000 to 1500 ms was entered into a condition (remember, know, new) × hemisphere × frontal region (Fp1/2+, F7/8+, F3/4+) ANOVA. The only significant condition effect was a condition by hemisphere interaction, suggesting that condition differences were only observed over the right hemisphere, $F(1, 34) = 4.50$, M.S.E. $= 1.09$, $P < 0.05$. Comparing conditions within the right hemisphere suggested that both old/new differences were significant (remember > new, $P < 0.001$; know > new, $P < 0.05$), but the remember and know conditions did not significantly differ (see RAS region of Fig. 3). These results are consistent with previous ERP remember/know experiments that have examined late frontal effects (Düzel et al., 1997; Rugg, Schloerscheidt et al., 1998; Smith, 1993; Trott et al., 1999).

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[8] The channels falling within each region were: Fp1+ (18, 19, 22, 23, 24, 26, 27), Fp2+ (2, 3, 8, 9, 10, 14, 15), F7+ (F7, 33, 39, 40, 44, 45, 128), F8+ (F8, 1, 115, 116, 120, 121, 125), F3+(12, 13, 20, 21, 25, 29, 30), F4+(4, 5, 112, 113, 118, 119, 124), see Fig. 2 for channel locations. Note that the F3+ and F4+ regions are identical to those previously labeled LAS and RAS.

2.8. Full/divided attention ERP results

Correct trials within the full and divided conditions were collapsed across remember and know responses and compared with correctly rejected new trials. Thirty-nine subjects had at least 19 acceptable trials in each condition (mean trials/condition: full = 71, divided = 56, new = 52). ERPs recorded near selected locations from the international 10–20 system are shown in Fig. 6 (Jasper, 1958). Analyses were analogous to those previously comparing remember, know, and new conditions. ERP waveforms from regions of interest are show in Fig. 7, mean amplitudes in Fig. 8, and ANOVA results in Table 1 (FN400) and Table 2 (parietal).
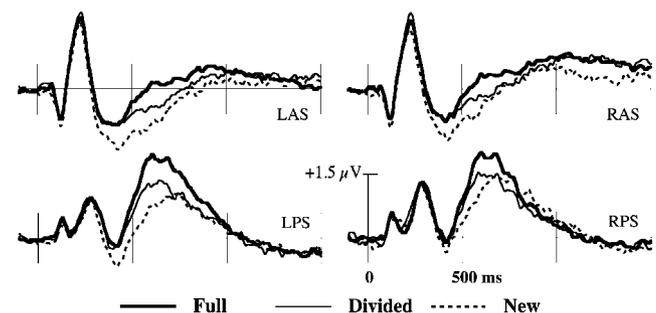

Fig. 7. Grand average ERPs from experiment 1. ERPs are averaged across channels within the LAS, RAS, LPS, and RPS regions of interest shown in Fig. 2.
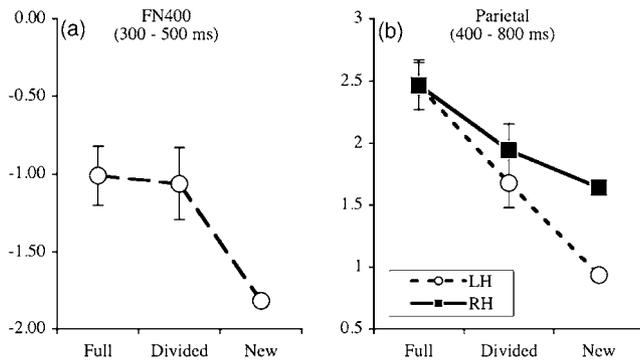
Fig. 8. Mean amplitudes (μV) corresponding to the FN400 (a) and Parietal (b) old/new effects in experiment 1. Error bars represent the standard error of the old/new difference (hence, the absence of error bars for the new conditions). (a) Mean amplitudes across the LAS and RAS regions from 300 to 500 ms. (b) Mean amplitudes within the LPS and RPS regions from 400 to 800 ms.

2.9. Full/divided attention: FN400 results (300–500 ms)

Mean LAS and RAS amplitude between 300 and 500 ms was the dependent measure. As shown in Table 2, significant old/new differences were observed in both the full and divided conditions, and the full and divided conditions did not differ. Thus, the FN400 old/new effect was found to be of similar magnitudes following either full or divided attention at study.

2.10. Full/divided attention: parietal results (400–800 ms)

Mean LPS and RPS amplitude between 400 and 800 ms was the dependent measure. As shown in Table 3, significant old/new differences were observed in both the full and divided conditions, but the effect was greater following full than divided attention. Each of the old/new differences was greater over the left than right hemisphere, as is often observed (Allan et al., 1998). Thus, the parietal old/new difference was greater for words studied with full attention than for words studied with divided attention.

2.11. Full/divided attention: topographic comparisons

Normalized old/new differences (Fig. 5) were the dependent measures in a condition (full, divided) × time (300–500, 500–800 ms) × hemisphere × anterior/posterior × superior/inferior repeated measures ANOVA. The time × anterior/posterior interaction indicated that 300–500 ms FN400 differences were larger anteriorly whereas the 500–800 ms parietal differences were larger posteriorly, $F(1, 38) = 4.54$, M.S.E. $= 0.14$, $P < 0.05$. This interaction upholds the a priori choice of anterior regions for FN400 analyses and posterior regions for the parietal analyses reported earlier. Several other lower-order topographic interactions were observed, but interpretation hinges on two

higher-order interactions, so only these are reported. The time × hemisphere × anterior/posterior × superior/inferior was significant, $F(1, 38) = 4.43$, M.S.E. $= 0.01$, $P < 0.05$. The four-way interaction stems from the fact that, relative to the FN400 old/new effect, the parietal effect is associated with larger left posterior/superior (i.e., left parietal) differences and opposite-going right anterior/inferior differences. A similar observation is captured by the significant condition × time × hemisphere × superior/inferior interaction, $F(1, 38) = 8.76$, M.S.E. $= 0.01$, $P < 0.01$. This interaction indicates that the early and late old/new differences had similar topographic patterns for the divided-attention condition, but for the full-attention condition the opposite going left/superior and right/inferior differences were larger in the later window.

In summary, the time × region interactions suggest that the FN400 and parietal old/new effects are topographically different. The last interaction with condition reiterates the results of the prior analyses—indicating that dividing attention affected the later parietal old/new effect but not the earlier FN400 old/new effect.

2.12. Full/divided attention: late frontal effects (1000–1500)

A condition (full, divided, new) × 2 hemisphere × 3 frontal regions (Fp1/2+, F7/8+, F3/4+) ANOVA revealed a significant condition × hemisphere interaction, $F(2, 76) = 3.81$, M.S.E. $= 1.10$, $P < 0.05$. Right hemisphere voltages were more positive for old than new items, as is typically observed (see RAS region of Fig. 7). Contrasts (M.S.E. $= 1.10$) focused on right, frontal regions revealed that full (MN $= 1.74$ μV, $F(1, 76) = 7.48$, $P = 0.01$) and divided (MN $= 1.93$ μV, $F(1, 76) = 17.37$, $P < 0.001$) conditions were more positive than new (MN $= 1.38$ μV), but full and divided did not significantly differ ($F(1, 76) = 1.87$).

3. Experiment 2

Experiment 1 used both behavioral and ERP methods to examine the effects of divided attention on recollection and familiarity. Familiarity and recollection were estimated from behavioral remember/know judgments by assuming the two processes are independent (Yonelinas, 2002). FN400 ERP old/new effects were hypothesized to be related to familiarity whereas parietal ERP old/new effects were hypothesized to be related to recollection (Curran, 1999, 2000; Curran & Cleary, 2003; Curran & Dien, 2003; Curran et al., 2002; Mecklinger, 2000; Nessler et al., 2001; Rugg, Mark et al., 1998). This hypothesis was upheld by the finding that parietal old/new effects were larger when associated with remembering than knowing, but remembering and knowing produced similar FN400 old/new effects. Both the behavioral estimates and ERP indices suggested that divided attention during study impairs recollection more than

familiarity. At a more detailed level, however, the behavioral *remember/know* estimates and ERP analyses suggest different effects of divided attention on familiarity. In accord with previous behavioral studies, the *remember/know* results suggest that familiarity is hurt by divided attention, whereas ERP analyses suggest that the hypothesized FN400 old/new effect was unaffected by dividing attention. The goals of experiment 2 were to replicate experiment 1 and to investigate the effects of confidence.

Understanding how confidence influences the parietal old/new effect is important for assessing its functional significance. Words studied with full attention are recognized with greater confidence than those studied with divided attention (Yonelinas, 2001). Some dual-process models conceptualize recollection as a high-threshold process that leads to high-confidence responses (Norman & O'Reilly, 2003; Yonelinas, 1994, 2001). From this perspective, conditions associated with higher recollection rates (e.g., full attention) would naturally be associated with higher confidence. From a single-process perspective that denies the existence of separate familiarity and recollection processes, confidence differences may be considered to reflect processes related more to decision making than to memory retrieval per se (Finnigan et al., 2002).

Confidence ratings were collected in experiment 2. Both the single-process and dual-process perspectives predict that the parietal old/new effect should be affected by confidence in recognizing old items, but they differ with respect to predicted effects of confidence on new items. If the parietal old/new effect is related to a high-threshold recollection process, it should be affected by confidence in recognizing old items, but not by confidence in rejecting new items. This follows from the high-threshold assumption that new items are very rarely recollected. If the parietal old/new effect is related to decision making or criterion setting, it should be affected by confidence in both old and new items because confidence differences in either case reflect distance from the response criterion.

4. Method

The method was identical to experiment 1, except that recognition responses were made on a four-point confidence scale: 1 = sure new, 2 = maybe new, 3 = maybe old, and 4 = sureold (order reversed for half the subjects). Subjects were 58 students from Case Western Reserve University who participated in partial fulfillment of a course requirement. Data from 21 subjects were discarded because of excessive eye blinking (eight), excessively high sensor impedances (four), computer malfunction (four), amplifier malfunction (two), incorrect sampling rate (two), or itching from saline solution (one). Thirty of the 37 subjects retained for analyses were male. The behavioral results of the included and excluded subjects were qualitatively similar.

5. Results

5.1. Behavioral results

Table 4 shows recognition performance for subgroups of subjects used in particular ERP analyses described below. Only subjects with at least 20 artifact-free trials in each condition were included in each analysis. "All good" subjects were those with sufficient trials/condition, regardless of confidence. "HC old" includes all subjects with sufficient high-confidence hits in both the full and divided conditions. "HC/LC divided" subjects had sufficient high confidence and low confidence response in the divided attention condition. "HC/LC new" subjects had sufficient high confidence and low confidence response in the new condition.

Focusing on all good subjects, as in experiment 1, hit rates were higher following full than divided attention, $t(36) = 12.53$, S.E. $= 0.02$, $P < 0.0001$ (first row of Table 4). When compared with the false alarm rate to new items (29%), each condition showed above chance discrimination between old and new: full, $t(36) = 19.43$, S.E. $= 0.03$, $P < 0.0001$; divided, $t(36) = 16.31$, S.E. $= 0.02$, $P < 0.0001$. Table 4 also shows the proportion of accurate trials on which subjects gave the most confident ("sure") response. All pairwise differences were significant such that confidence in correct responses was ranked full > divided > new (all $P < 0.01$). Notably, with only one exception, the pattern of statistical effects reported for all good subjects was replicated in each of the subgroups. The one exception was the HC/LC new group which did not show a significant confidence difference between divided and new conditions.

5.2. ERP results

Analyses ideally would include separate ERPs from high- and low-confidence responses in each condition (correct full, divided, and new trials). However, only three subjects yielded at least 20 good trials in each of the six categories (two confidence × three condition). Confidence-related effects were assessed in the following analyses by examining subsets of subjects with sufficient trials in particular conditions. All subjects retained in each analysis had at least 21 acceptable trials in each condition.

Table 4
Behavioral results from experiment 2

Group	n	Accuracy			Confidence		
		Full	Divided	New	Full	Divided	New
All good	37	0.79	0.59	0.71	0.75	0.54	0.45
HC old	30	0.81	0.61	0.72	0.78	0.58	0.48
HC/LC divided	18	0.81	0.63	0.70	0.76	0.53	0.44
HC/LC new	20	0.76	0.55	0.74	0.75	0.55	0.51

Notes: Confidence refers to the proportion of accurate trials given high-confidence responses. HC = high confidence; and LC = low confidence.
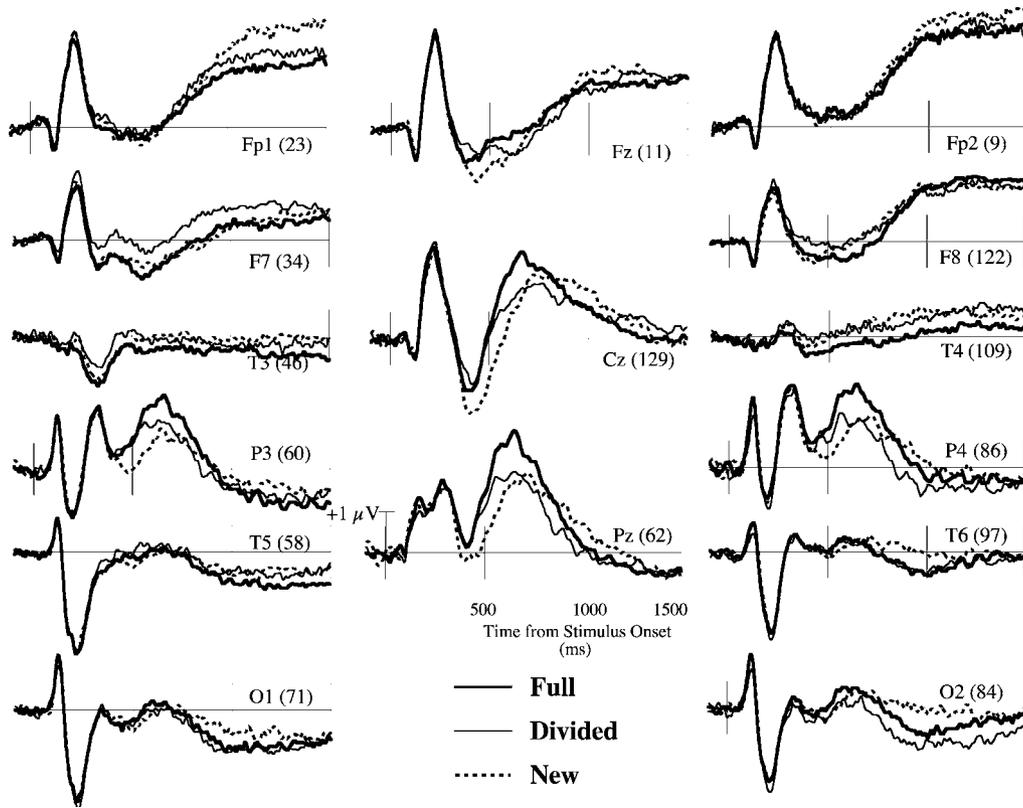
Fig. 9. Grand average ERPs from all good subjects from experiment 2. Shown channels are representative of the international 10–20 system (Jasper, 1958). Channels are labeled according to Geodesic Electrode Net numbers (see Fig. 2) along with their nearest 10–20 equivalent location.

5.3. All good subjects (across confidence)

Initial analyses included all subjects with sufficient accurate trials in the full, divided, and new conditions—regardless of confidence (trials/condition: full = 69, divided = 51, new = 60). These analyses were meant to replicate those in experiment 1. Corresponding ERP plots are shown in Fig. 9 (10–20 locations) and Fig. 10 (regions of interest). Mean amplitudes are shown in Fig. 11. The FN400 (300–500 ms, LAS and RAS regions) was significantly more negative for new than divided condition (Table 5, Fig. 11). Full/new
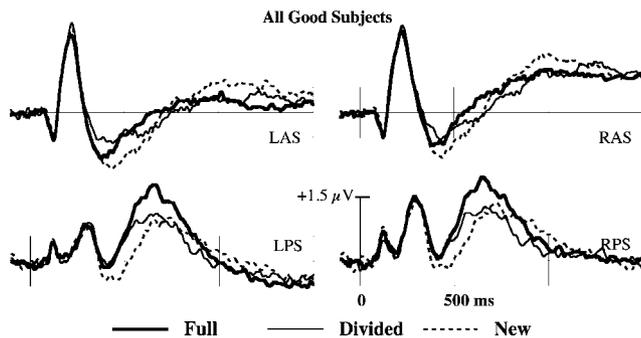

Fig. 10. Grand average ERPs from all good subjects from experiment 2. ERPs are averaged across channels within the LAS, RAS, LPS, and RPS regions of interest shown in Fig. 2.

Table 5
Experiment 2: FN400 ANOVA results (300–500 ms, LAS and RAS regions)

Effect	d.f.	F	M.S.E.	P
All good				
Full, div, new	2, 36	6.41	1.85	<0.01
Full vs. new	1, 36	3.66	1.53	0.06
Div vs. new	1, 36	12.90	1.84	<0.001
Full vs. div	1, 36	2.86	2.19	0.09
HC old				
Full (HC), div (HC), new	2, 29	7.36	1.96	<0.01
Full (HC) vs. new	1, 29	5.10	1.15	<0.05
div (HC) vs. new	1, 29	14.62	1.96	<0.001
Full (HC) vs. div (HC)	1, 29	3.12	2.75	0.09
HC/LC div				
Div (HC), div (LC), new	2, 17	2.98	2.01	0.07
Div (HC) vs. new	1, 17	5.19	2.30	<0.05
Div (LC) vs. new	1, 17	3.12	1.25	0.10
Div (HC) vs. div (LC)	1, 17	0.92	2.49	n.s.
HC/LC new				
Full, div, new (HC), new (LC)	3, 19	4.57	2.07	<0.01
Full vs. new (HC)	1, 19	10.30	1.59	<0.01
Div vs. new (HC)	1, 19	10.81	2.33	<0.01
Full vs. new (LC)	1, 19	0.61	2.46	n.s.
Div vs. new (LC)	1, 19	2.36	2.04	n.s.
New (HC) vs. new (LC)	1, 19	3.90	2.03	0.06

Notes: Exp = experiment; d.f. = degree of freedom; div = divided; LC = low confidence; HC = high confidence; and n.s. = not significant.
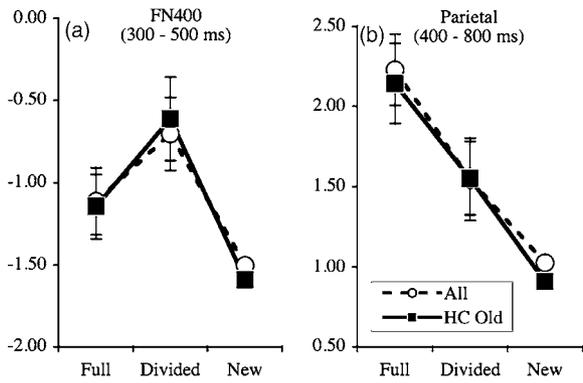
Fig. 11. Mean amplitudes (μV) corresponding to the FN400 (a) and Parietal (b) old/new effects in experiment 2. Error bars represent the standard error of the old/new difference (hence, the absence of error bars for the new conditions). The dashed line (- - -) shows all good subjects, and the solid line (—) shows the HC Old group. (a) Mean amplitudes across the LAS and RAS regions from 300 to 500 ms. (b) Mean amplitudes across the LPS and RPS regions from 400 to 800 ms.
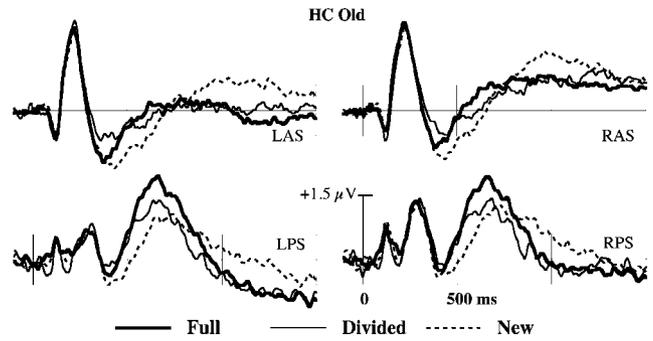

Fig. 12. Grand average ERPs from the HC old group of experiment 2. ERPs are averaged across channels within the LAS, RAS, LPS, and RPS regions of interest shown in Fig. 2.

and full/divided differences were marginally significant. The parietal old/new effect (400–800 ms, LPS and RPS regions) was significant following both study conditions, but was larger following full than divided attention (Table 6). Although statistical details varied, the overall pattern of results was qualitatively similar to experiment 1. Dividing attention reduced the parietal old/new effect, but not the FN400 old/new effect. Notably, the marginal trend toward full/divided FN400 differences was in the opposite direc-

Table 6
Experiment 2: parietal ANOVA results (400–800 ms, LPS and RPS regions)

Effect	d.f.	F	M.S.E.	P
All good				
Full, divided, new	2, 36	12.89	2.10	<0.001
Full vs. new	1, 36	29.27	1.84	<0.001
Div vs. new	1, 36	4.06	2.46	0.05
Full vs. div	1, 36	8.71	2.00	<0.01
HC old				
Full (HC), divided (HC), new	2, 29	11.48	1.99	<0.001
Full (HC) vs. new	1, 29	24.28	1.88	<0.001
Div (HC) vs. new	1, 29	7.87	1.58	<0.01
Full (HC) vs. div (HC)	1, 29	4.16	2.52	0.05
HC/LC divided				
Div (HC), div (LC), new	2, 17	4.76	2.30	<0.05
Div (HC) vs. new	1, 17	5.28	1.48	<0.05
Div (LC) vs. new	1, 17	1.86	1.84	n.s.
Div (HC) vs. div (LC)	1, 17	6.05	3.57	<0.05
HC/LC new				
Full, div, new (HC), new (LC)	3, 19	8.44	2.57	<0.001
Full vs. new (HC)	1, 19	23.93	1.64	<0.001
Div vs. new (HC)	1, 19	1.20	3.96	n.s.
Full vs. new (LC)	1, 19	29.82	1.89	<0.001
Div vs. new (LC)	1, 19	3.50	3.35	0.08
New (HC) vs. new (LC)	1, 19	0.48	3.25	n.s.

Notes: Exp = experiment; d.f. = degree of freedom; div = divided; LC = low confidence; HC = high confidence; and n.s. = not significant.

tion such that the FN400 old/new difference was larger following divided than full attention.

5.4. High confidence old (HC old)

The next analysis focused on subjects with sufficient high confidence hits in both the full and divided attention conditions. These analyses were intended to assess the effects of divided attention on ERP old/new effects when confidence differences between conditions are minimized (e.g., Rugg & Doyle, 1992; Wilding & Rugg, 1996). Each of these conditions was compared with ERPs to all correct rejections (regardless of confidence) to examine old/new differences. The mean number of acceptable trials per condition was full = 58, divided = 32, new = 63. Corresponding waveforms are shown in Fig. 12. The FN400 old/new effect was significant following either divided or full attention, and the full/divided difference was marginal (Table 5). The parietal old/new also was significant following either divided or full attention—with full being more positive than divided (Table 6). The overall patterns were quite similar, whether or not low-confidence trials were included (Fig. 11).

5.5. High versus low confidence—divided attention (HC/LC divided)

The HC/LC divided group included only subjects with sufficient high- and low-confidence hits in the divided attention condition, so the effects of confidence could be directly assessed within a single condition. ERPs associated with hits also were compared with ERPs to all correct rejections (regardless of confidence). The mean number of acceptable trials per condition was high = 31, low = 27, new = 64. Corresponding ERP waveforms are shown in Fig. 13, and mean amplitudes in the high and low categories are shown with the dashed lines (- - -) in Fig. 14. The FN400 old/new effects was significant for high confidence hits, but not for low confidence hits (Table 5). The parietal old/new effect similarly was significant for only high-confidence hits, and a significant difference emerged when high- and low-confidence hits were directly compared (Table 6).
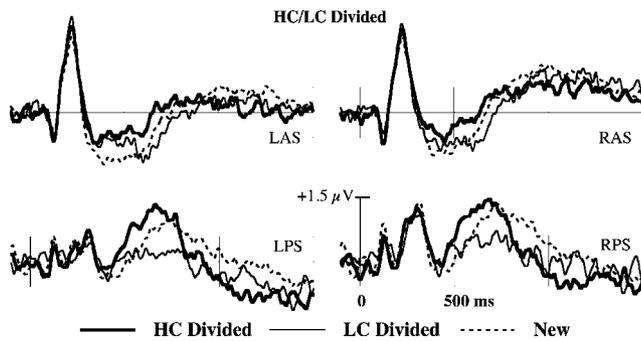
Fig. 13. Grand average ERPs from the HC/LC divided group of experiment 2. ERPs are averaged across channels within the LAS, RAS, LPS, and RPS regions of interest shown in Fig. 2.

Fig. 15. Grand average ERPs from the HC/LC new group of experiment 2. ERPs are averaged across channels within the LAS, RAS, LPS, and RPS regions of interest shown in Fig. 2.

5.6. High versus low confidence new (HC/LC new)

The previous analyses suggested that the parietal old/new effect increased with confidence in hits. The HC/LC new group included only subjects with sufficient high- and low-confidence correct rejections. These analyses examine whether the confidence effects observed with hits extend to correct rejections. Old/new effects were assessed by comparing ERPs to high- and low-confidence correct rejections to ERPs from hits (regardless of confidence). The mean number of acceptable trials per condition was full = 69, divided = 50, new/high = 35, new/low = 32. Corresponding ERP waveforms are shown in Fig. 15, and mean amplitudes in the new/high and new/low categories are shown with the solid lines (—) in Fig. 14. The FN400 old/new effects were significant when ERPs associated with hits were compared with high-confidence correct rejections, but not when compared with low-confidence correct rejections (Table 5). A direct comparison of FN400 amplitude from high- and low-confidence correct rejections was marginally significant. Following full attention at study, the parietal old/new effect was significant regardless of confidence in

correct rejections (Table 6). Following divided attention at study, the parietal old/new effect was marginally significant with respect to low-confidence correct rejections, but not with respect to high-confidence correct rejections. A direct comparison of parietal amplitudes from high- and low-confidence correct rejections was not significant.

5.7. Topographic comparisons

Topographic analyses on normalized old/new differences were analogous to those reported for experiment 1 (see Fig. 5). Because the main goal is confirming topographic differences between the FN400 and parietal effects rather than further analyzing confidence effects, the topographic analyses include all good subjects regardless of confidence. Again, only the more meaningful higher-order interactions are explicitly addressed.

The time × anterior/posterior × inferior/superior interaction indicates that 300–500 ms FN400 differences were larger than the 500–800 ms parietal differences over anterior/superior regions but the opposite was true over posterior/superior regions, $F(1, 36) = 8.38$, M.S.E. = 0.02, $P < 0.01$. The time × condition × superior/inferior interaction was also significant, $F(1, 36) = 34.49$, M.S.E. = 0.03, $P < 0.001$. Keeping in mind that both old/new effects are characterized by opposite-going superior and inferior differences, this interaction captures greater 300–500 ms FN400 superior/inferior differentiation for the divided condition and greater 500–800 ms parietal superior/inferior differentiation for the full condition.

In summary, the first interaction suggests that the FN400 and parietal old/new effects are topographically different. The second interaction reiterates the results of the prior analyses indicating that F400 differences were somewhat larger for the divided attention condition, but parietal differences were larger for the full attention condition.
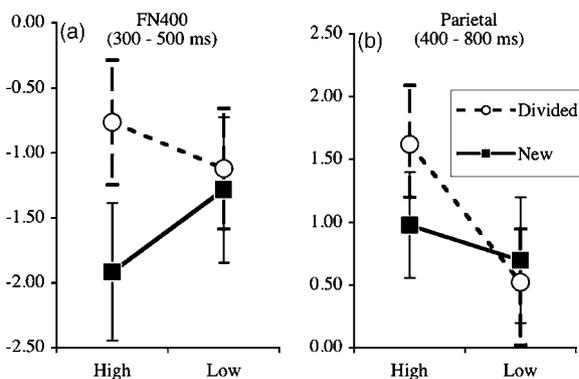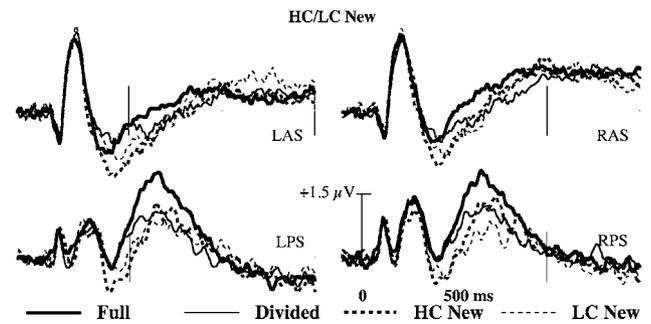

Fig. 14. Confidence effects on mean amplitudes corresponding to the FN400 (a) and parietal (b) effects in experiment 2. Error bars represent the standard error of mean. The dashed line (- - -) shows the HC/LC divided group, and the solid line (—) shows the HC/LC new group. (a) Mean amplitudes across the LAS and RAS regions from 300 to 500 ms. (b) Mean amplitudes within the LPS and RPS regions from 400 to 800 ms.

5.8. Late frontal effects (1000–1500)

As described for experiment 1, late frontal effects were examined with a condition (full, divided, new) × two

hemisphere × three region (Fp1/ Fp2, F3/F4, F7/F8) ANOVA. The condition × region interaction was significant, $F(2, 36) = 9.33$, M.S.E. $= 1.48$, $P < 0.001$. Fp amplitudes (see Fp1 and Fp2 channels in Fig. 9) were more positive in the new condition (MN $= 4.41 \mu V$), than the other conditions (full $= 3.43 \mu V$, divided $= 3.40 \mu V$), but condition differences were not significant in the other regions. This new > old pattern conflicts with the old > new pattern typically reported for late frontal effects (Allan et al., 1998; Curran & Friedman, 2003; Curran et al., 2001; Johnson et al., 1996; Ranganath & Paller, 2000; Wilding, 1999; Wilding & Rugg, 1997a,b). No confidence effects approached significance when divided conditions with high versus low confidence and new conditions with high versus low confidence were compared.

The explanation of the unusual new > old effects is unclear. It may reflect that fact that the confidence judgments required subjects to ruminate about new responses more than normally. Previous ERP experiments requiring confidence judgments did not examine late frontal effects (Rubin, Van Petten, Glisky, & Newberg, 1999; Rugg & Doyle, 1992). Other work has suggested that assigning confidence to correct rejections may engage inferential strategies not required when judging the confidence of remembered items (Strack & Bless, 1994).

6. General discussion

6.1. Summary of results

Estimates of familiarity and recollection derived from the *remember/know* procedure in experiment 1 suggest that both processes are impaired by dividing attention during study, but this impairment was stronger for recollection than familiarity. These results are consistent with previous behavioral estimates (Yonelinas, 2001, 2002). Two ERP components have been hypothesized to be related to familiarity (FN400 old/new effect, 300–500 ms, anterior) and recollection (parietal old/new effect, 400–800 ms, posterior). This hypothesis is consistent with the finding that the parietal old/new effect, but not the FN400 old/new effect, was larger when recognition involved remembering than knowing. As expected from the behavioral estimates, both experiments demonstrated that divided attention reduced the parietal old/new effect more than the FN400 old/new effect. However, in contrast to the behavioral estimates of familiarity, we failed to observe a significant effect of attention on the FN400. Thus, the hypothesized ERP correlate of familiarity (FN400) did not conform to behavioral estimates of familiarity derived from the *remember/know* procedure. Experiment 2 further examined how the ERP old/new effects were influenced by confidence. Most importantly, the confidence in recognizing old items increased the 400–800 ms parietal amplitudes, but confidence in new items did not. This is more consis-

tent with the idea that the parietal old/new effect is related to a high-threshold recollection process that is primarily engaged by studied items than with a generic decision processes that should be influenced by confidence to both old and new items.

6.2. Recollection and the parietal old/new effect

Several lines of evidence have supported the hypothesis that the parietal old/new effect is related to the recollection component of dual-process theories. The parietal old/new effect has been associated with the ability to recollect details such as word plurality (Curran, 2000), picture orientation (Curran & Cleary, 2003), study modality (Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1997a), speaker's voice (Rugg, Schloerscheidt et al., 1998; Wilding & Rugg, 1996, 1997a), or temporal source (Trott, Friedman, Ritter, & Fabiani, 1997). The parietal old/new effect is larger when recognition is based upon "remembering" than "knowing" (Düzel et al., 1997; Rugg, Schloerscheidt et al., 1998; Smith, 1993; Trott et al., 1999). The parietal old/new effect is sensitive to variables thought to affect recollection such as word frequency (Rugg, 1990; Rugg, Cox, Doyle, & Wells, 1995; Rugg & Doyle, 1992), level-of-processing (Paller & Kutas, 1992; Paller et al., 1995; Rugg et al., 2000; Rugg, Mark et al., 1998), and words versus pseudowords (Curran, 1999). The present research adds to this evidence by replicating previous remember/know ERP results in experiment 1 (Düzel et al., 1997; Rugg, Schloerscheidt et al., 1998; Smith, 1993; Trott et al., 1999) and by demonstrating that the parietal old/new effect is larger following full than divided attention at study—a pattern consistently reported for behavioral estimates of recollection (Gardiner & Parkin, 1990; Jacoby & Kelley, 1991; Parkin et al., 1995; Reinitz et al., 1994; Yonelinas, 2001).

An alternative to the recollection hypothesis holds that the parietal old/new effect represents a decision process (e.g., criterion setting) that is sensitive to confidence differences between conditions (Finnigan et al., 2002). Recognition confidence is higher for words studied with full than divided attention (Yonelinas, 2001), and it is conceivable that each of the effects listed in the previous paragraph are similarly confounded by confidence. Behavioral *remember/know* differences also have been dismissed as merely reflecting confidence differences arising from applying different decision criterion to a unitary familiarity signal (Donaldson, 1996; Hirshman & Master, 1997). Results from the present experiment 2 indicated that 400–800 ms parietal amplitudes were significantly affected by confidence for old words (only the divided attention condition yielded enough low confidence responses for this analysis), but not for new words. This is more consistent with the hypothesis that parietal old/new differences reflect the operation of a high-threshold recollection process that is rarely engaged by new items (e.g., Norman & O'Reilly, 2003; Yonelinas, 1994, 2001) than that they reflect confidence differences arising from a generic decision

process that should apply equally to old and new items. A similar conclusion was reached from a previous ERP study of recognition memory that found 600–900 ms amplitudes associated with a prominent parietal positivity were more positive for high than low confidence response to old items but not to new items (Rubin et al., 1999). Furthermore, the parietal old/new effect is not influenced by response bias differences between subjects (Windmann, Urbach, & Kutas, 2002).

Confidence results from recognition memory experiments (experiment 2; Rubin et al., 1999) do not support the idea that the parietal old/new effect is well explained by confidence differences arising from generic decision processes. However, the fact remains that the P300 is a prominent component of the parietal old/new effect (Johnson, 1995; Spencer et al., 2000) and that P300 amplitude increases with confidence in non-memory tasks (Paul & Sutton, 1972; Squires, Squires, & Hillyard, 1975). Thus, non-recollective aspects of confidence would be expected to exert some influence on the parietal old/new effects even if such confidence effects do not exhaustively explain the data. Visual inspection of Fig. 15 suggests that right parietal amplitudes (RPS) may differ with confidence more than left (LPS), but confidence effects on new items were non-significant even when the RPS region was considered alone, $F(1, 19) = 1.38$, M.S.E. $= 2.30$, $P > 0.10$. Relevant hemispheric differences were also observed in the *remember*/*know* ERP analysis of experiment 1 in which parietal *remember*/*know* differences were marginally greater over the left than right hemisphere, but right-hemisphere amplitudes were more positive for new than know conditions. The latter effect may be related to greater confidence associated with correctly rejecting new items than with correctly responding "know" to old items. These hemispheric differences are reminiscent of two other recent studies investigating how the parietal old/new effect is influenced by other non-recollective factors known to affect the P300: probability (Herron, Quayle & Rugg, 2003) and sequential structure (Düzel & Heinze, 2002). Both of these experiments, like the present experiment 2, showed that parietal old/new effects recorded over the left hemisphere are particularly resistant to such non-recollective factors.

It should be acknowledged that detecting significant confidence effects on 400–800 ms parietal ERPs to old words but not to new words may be an artifact of the high and low confidence criteria being closer for new than old items. That is, if the psychological distance between high and low confidence old words is greater than the difference between high and low confidence new words, than ERPs would be more sensitive to confidence differences between old than new items. Such an influence cannot be ruled out, but concern over this possibility is lessened by the fact that the FN400 was marginally affected by confidence in new items ($P = 006$) but not by confidence in old items ($F < 1.0$).

6.3. Familiarity and the FN400 old/new effect

The 300–500 ms FN400 old/new effect has been hypothesized to be related to familiarity because it discriminates between old and new items, yet is unable to differentiate between studied items and similar lures (Curran, 2000; Curran & Cleary, 2003; Curran et al., 2002; Nessler et al., 2001). The latter type of discrimination presumably requires the recollection of details. The present experiments were intended to examine whether or not dividing attention at study influenced the FN400 old/new effect analogously to its influence on behavioral estimates of familiarity. Under the same conditions in which *remember*/*know* estimates suggest that attention does influence familiarity, we failed to observe significant attention influences on the FN400 old/new effect. Thus, the FN400 did not behave in accord with the behavioral familiarity estimate.

One complication of testing the hypothesized relationship between the FN400 and familiarity is the lack of a clear benchmark. Theory provides one such benchmark that, for example, predicts the aforementioned effects of study/test similarity (e.g., Clark & Gronlund, 1996; Gillund & Shiffrin, 1984; Hintzman, 1988; Shiffrin & Steyvers, 1997). An empirical benchmark currently does not exist because all of the behavioral estimates of familiarity have been subject to criticism: *remember*/*know* judgments, process dissociation, ROC analyses (reviewed by Humphreys et al., 2000; Yonelinas, 2002). One of the advantages of examining divided attention effects is that previous ROC and remember/know experiments have both suggested that dividing attention at study has a small but significant effect on familiarity (Yonelinas, 2001, 2002). However, both of these estimation methods rely on the assumption that familiarity and recollection are statistically independent. If familiarity and recollection are positively correlated, artifactual cross-over interactions can occur (Curran & Hintzman, 1995). This concern is lessened in the present situation because divided attention is having consistent effects on recollection and familiarity (both are reduced by divided attention) rather than exhibiting opposite effects (i.e., a cross-over interaction). Thus, in the present situation, it appears that available behavioral estimates are probably providing an appropriate benchmark.

It is possible that the behavioral estimates of familiarity (F) are more sensitive than the ERPs (FN400), so a consideration of statistical power is relevant. Starting with standard old/new differences (averaged across full/divided), the effect size was over four times larger for $F(\gamma = 1.89)$ than for the FN400 ($\gamma = 0.47$)[9]. For F, the effect size of the full/divided difference ($\gamma = 0.73$, power $(1 - \beta) = 0.99$) was only 39% of the old/new effect size. If we assume that

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[9] Effect sizes and power calculations assumed paired t-tests between the conditions of interest. Behavioral familiarity estimates were based on $F = K/(1 - R)$. FN400 measures were based on the mean amplitude across the LAS and RAS regions. Power was calculated with the G• Power program (Erdfelder, Faul, & Buchner, 1996).

the FN400 full/divided effect size also should be 39% of its old/new effect size, then the expected FN400 full/divided effect size would be $\gamma = 0.18$. Given the sample size used in experiment 1, the power of this experiment to detect such an ERP difference is only 0.29. Thus, there is reason to believe that the statistical power to detect divided attention effects in the present experiment was substantially greater for behavioral estimates of familiarity (F) than for the FN400.

Although effects of confidence were primarily relevant to the interpretation of the parietal old/new effects, the marginally significant ($P = 0.06$) difference between FN400 amplitudes to high and low confidence new items is worth mentioning (see Fig. 15, left). Familiarity should be lower for new items that are correctly rejected with high confidence than for new items that are correctly rejected with low confidence. Given that the FN400 is more negative in novel than familiar conditions, the observation that the FN400 was more negative for high than low confidence correct rejections is consistent with the hypothesis that the FN400 varies with familiarity.

Differential confidence may also contribute to the failure to detect FN400 differences between the full and divided conditions. Confidence is greater in the full than divided attention conditions, so it may be most appropriate to compare full-attention hits with high-confidence correct rejections and compare divided-attention hits with low-confidence correct rejections. These comparisons yielded significant FN400 differences between full and high-confidence correct rejections, but not between divided and low-confidence correct rejections (Table 5). From this perspective, when confidence differences between conditions are taken into account, the FN400 old/new effect was larger following full than divided attention.

Olichney et al. (2000) have suggested an alternative to the FN400 familiarity hypothesis—that the 300–500 ms N400 old/new effect may reflect a short-term memory process that contributes to semantic language comprehension. This perspective is influenced by the assumption that FN400 old/new effects and N400 semantic incongruity effects (reviewed in Kutas & Van Petten, 1988, 1994) reflect the activity of a common underlying mechanism. There seem to be at least three complications for this perspective. First, the present results contrast with previous semantic priming research showing that attention to the prime influences the N400 ERP to a subsequent target word (Holcomb, 1988). Thus, attention to the first presentation of a word may influence the N400 semantic incongruity effect although the present research suggest that attention during study does not influence the FN400 old/new effect. Second, the observation of FN400 old/new differences with novel visual shapes challenges the specificity of the effect to language comprehension (Curran et al., 2002). Third, recent evidence that the FN400 old/new effect to pictures is maintained across a 1-day retention interval challenges any short-term account (Curran & Friedman, 2004).

6.4. Neuroanatomical mechanisms of familiarity and recollection

The FN400 and parietal ERP old/new effects have been dissociated by demonstrations that they occur at different times, are associated with different scalp topographies, and are differentially affected by experimental manipulations (as reviewed previously). Such evidence inspires the view that these ERP effects reflect the activity of different memory-related brain processes possibly underlying recollection and familiarity. ERPs cannot precisely localize the brain mechanisms underlying these effects, but other methods have yielded some relevant evidence (as recently reviewed in Rugg & Yonelinas, 2003).

Evidence relating the 400–800 ms parietal ERP old/new effect to the hippocampus (Düzel et al., 2001) converges with other evidence suggesting that hippocampal activity is central to recollection (Rugg & Yonelinas, 2003). An amnesic patient with seemingly isolated bilateral hippocampal damage sustained in childhood demonstrated a typical FN400 old/new effect, but the parietal old/new effect was absent (Düzel et al., 2001). Another amnesic patient with selective hippocampal damage has shown recollection deficits (Holdstock et al., 2002), although debate continues over whether or not the hippocampus also contributes to familiarity (Manns, Hopkins, Reed, Kitchener, & Squire, 2003; Yonelinas et al., 2002). Functional imaging studies have shown that hippocampal activity is specifically associated with "remembering" rather than "knowing" (Eldridge et al., 2000) and with source recollection (Dobbins et al., 2003). A recently proposed neural network model of recognition demonstrates a biologically plausible implementation of how the hippocampus may contribute to recollection (Norman & O'Reilly, 2003).

Familiarity has been hypothesized to depend upon the perirhinal cortex that is adjacent to the hippocampus (Aggleton & Brown, 1999; Norman & O'Reilly, 2003; Rugg & Yonelinas, 2003), although others have argued that the familiarity is more widely dependent on other nearby structures including the hippocampus (Manns et al., 2003; Stark & Squire, 2003). Recent fMRI research has documented perirhinal old/new differences thought to be related to familiarity because they were sensitive to neither intentional/incidental task differences nor to the amount of contextual information retrieved (Henson et al., 2003). Intracranial recordings and magnetoencephalography (MEG) have suggested that activity possibly related to the FN400 originates from anterior, inferior temporal regions (e.g., perirhinal cortex). Intracranial ERP old/new effects from epileptic patients show a similar 400 ms peak in anterior temporal regions ("AMTL-N400", (Elger et al., 1997; Grunwald, Lehnertz, Heinze, Helmstaedter, & Elger, 1998; Smith, Stapleton, & Halgren, 1986)). MEG old/new effects (350–450 ms) have been estimated to arise within the left, anterior, inferior temporal regions during recognition memory tests with words (Düzel et al., 2003). Further research

is needed to better understand the relationship between the FN400 old/new effect recorded at the scalp and these seemingly similar intracranial and MEG patterns.

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