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The relationship between the right frontal old/new ERP effect and post-retrieval monitoring: specific or non-specific?

Hiroki R. Hayama, Jeffrey D. Johnson, and Michael D. Rugg

Center for the Neurobiology of Learning and Memory, and Department of Neurobiology and Behavior, University of California, Irvine, Irvine, CA 92697-3800

Abstract

Post-retrieval processes are thought to be engaged when the outcome of an attempt to retrieve information from long-term memory must be monitored or evaluated. Previous research employing event-related potentials (ERPs) has implicated a specific ERP modulation - the 'right frontal old/new effect' - as a correlate of post-retrieval processing. In two experiments we examined whether the right frontal effect is specifically associated with processing of the products of an episodic retrieval attempt. During study, subjects in both experiments made one of two semantic judgments on serially presented pictures. In experiment 1, one study phase was followed by a source memory task, in which subjects responded 'new' to unstudied pictures, and signaled the semantic judgment made on each studied picture. A separate study phase was followed by a task in which the studied items required a judgment about their semantic attributes. Robust right frontal effects were elicited by old items in both tasks, indicating that the effects are not selective for the monitoring of the content of information retrieved from episodic memory. In experiment 2, separate study phases were followed by test phases where semantic judgments were made either on old items (as in experiment 1), or on new items. Right frontal effects were elicited by whichever class of items, old or new, required the semantic judgment. Together, these findings indicate that the right frontal old/new effect reflects generic monitoring or decisional processes, rather than processing dedicated to the evaluation of the products of an episodic retrieval attempt.

Keywords

Source memory; monitoring; episodic memory; ERPs; evaluation

It has long been proposed that an important component of memory retrieval is the monitoring of the products of retrieval in light of current behavioral goals (e.g. Norman & Bobrow, 1979). Among the processes contributing to this monitoring function are evaluation of the content of the retrieved information in relation to the goals of the retrieval attempt (Burgess & Shallice, 1996). These and related processes have been generically referred to as 'post-retrieval' processes (Wilding and Rugg, 1997a; Allan et al., 1998). This construct has proven useful in accounting both for deficits in memory performance following brain lesions, and patterns of retrieval-related neural activity in studies of memory retrieval using event-related potential (ERPs) or functional neuroimaging methods. Several neuropsychological studies

Correspondence: Hiroki R. Hayama, Center for the Neurobiology of Learning and Memory, University of California Irvine, Irvine, CA 92697-3800. Email: hhayama@uci.edu. Telephone: 949-824-8861. Fax: 949-824-4807.

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have implicated the prefrontal cortex (PFC) in post-retrieval processing (Parkin et al., 1996; Curran et al., 1997; Swick and Knight, 1999; for review see, Blumenfeld & Ranganath, 2007).

In the case of event-related potentials (ERPs), numerous studies have demonstrated that correctly identified old (studied) items elicit waveforms that are more positive-going than the ERPs elicited by correctly rejected new (unstudied) items. These 'old/new effects' have been fractionated on a combination of functional, temporal and topographic criteria (see for reviews: Friedman & Johnson, 2000; Rugg et al., 2002; Rugg 2005). One ERP effect in particular, the 'right frontal old/new effect', has been suggested as a neural signature of post-retrieval processing. This effect was first described in detail by Wilding and Rugg (1996), when it was found to be larger for correct relative to incorrect judgments in a source memory test. Because the effect appeared to be linked to the retrieval of contextual information from the study episode (recollection), the authors proposed that it reflects processes necessary for the formation of a coherent representation of a prior episode.

Subsequent ERP studies have shown, however, that the right frontal effect can be of equivalent magnitude for incorrect and correct source judgments (Senkfor and Van Petten 1998; Van Petten et al., 2000), and can even be larger for incorrect judgments (Trott et al., 1997). Although these findings do not necessarily invalidate Wilding and Rugg's (1996) original proposal (an incorrect source judgment does not necessarily imply there was a failure to recollect *any* episodic information), they unquestionably serve to weaken the idea that the right frontal effect reflects processes tied to successful recollection. This idea is further undermined by findings (Duzel et al., 1997; Trott et al., 1999) that the effect can be elicited by recognition memory test items attracting 'Know' judgments (which are held to reflect recognition based on familiarity in the absence of recollection; Tulving 1985). Furthermore, in two studies employing simple yes/no recognition tests, the right frontal effect was elicited by items that, because they were subjected to only 'shallow' encoding, were likely judged old solely on the basis of familiarity (Rugg et al., 2000; Ullsperger et al., 2000). Together, the foregoing findings indicate that the right frontal effect is not exclusively a correlate of successful episodic retrieval.

Although the generators of the right prefrontal effect have not been definitively localized, its scalp distribution strongly suggests a major role for the right prefrontal cortex (Wilding and Rugg, 1996; Friedman and Johnson, 2000; Rugg and Allan, 2000; Rugg et al., 2002). This proposal is bolstered by the functional parallels that have been reported between the right frontal ERP effect and retrieval-related right dorsolateral prefrontal activity identified in studies employing event-related functional magnetic resonance imaging (fMRI; see Rugg et al, 2002 for review). Notably, the ERP and fMRI effects both tend to be more prominent in source memory tasks than in simple recognition memory tests, but are elicited by recognition test items when there is uncertainty about their study status (see below).

On the assumption that the right frontal ERP effect reflects retrieval-related activity in the right prefrontal cortex, findings from functional neuroimaging studies offer insights into the possible functional significance of the effect. Using event-related fMRI in conjunction with the Remember/Know procedure, Henson and colleagues (1999a) reported greater right dorsolateral prefrontal cortex (DLPFC) activity for items attracting 'Know' than 'Remember' responses. Although at first consideration this result does not seem to implicate a role for this region in post-retrieval processing, the authors suggested that monitoring demands would be greater when the information available for a memory judgment was relatively impoverished, in this case due to the absence of recollection. In support of this hypothesis, Henson et al. (2000) demonstrated that DLPFC activity was greater for recognition test items endorsed with low compared to high confidence judgments. Thus, according to this perspective, right prefrontal activity correlates not with retrieval success, but with demands placed by the

outcome of a retrieval attempt on post-retrieval monitoring. Consistent with this view, Rugg, Henson and Robb (2003) reported that correctly detected old items elicited greater right DLPFC activity when the retrieval task required a source judgment (and hence evaluation of retrieved content) than a simple yes/no recognition decision.

In combination with the ERP findings, these fMRI results suggest that prefrontally-mediated post-retrieval monitoring is engaged in two primary situations. The first situation is when the outcome of a retrieval attempt must be evaluated in order to select an appropriate response, as in tests of source memory (Wilding 1996, Wilding 1997a, 1999; Henson et al., 1999b; Rugg et al., 2003). The second situation occurs when the information derived from a retrieval attempt is impoverished, leading to uncertainty whether retrieval has been successful (Henson et al., 1999a; 2000; Rugg et al., 2000; 2002; Ullsperger et al., 2000).

Recent fMRI studies of recognition memory, however, have challenged the view that the right DLPFC is engaged in response to the demand for post-retrieval processing. Dobbins and Han (2006) investigated whether recruitment of DLPFC during episodic retrieval depended on the amount of evidence supporting a retrieval decision, or on the decision rule applied to the evidence. These investigators found that test items in 'same-different' tests elicited greater DLPFC activity than equivalent items presented in the context of a 'forced-choice' test, prompting the conclusion that right DLPFC was sensitive not to monitoring demands, but to the number of internal decisions required by the task. Dobbins and Han (2006) went on to demonstrate very similar effects when performance was based on on-line perceptual information rather than the products of memory retrieval. In a similar vein, Fleck et al. (2006) demonstrated that a DLPFC region where activity was sensitive to recognition memory confidence (greater activity for low than high confidence responding, cf. Henson et al., 2000) showed a similar confidence effect for a perceptual judgment task. Together, the findings from these studies suggest first, that the role of the right DLPFC in post-retrieval processing may have more to do with decision-making than the monitoring or evaluation of retrieved information, and second, that the cognitive operations supported by this brain region are not engaged solely by the requirement to process information recovered from long-term memory.

The present study was motivated by the findings of Dobbins and Han, 2006 and Fleck et al., 2006 described above. To the extent that the proposal that the right frontal ERP effect reflects differential activity in the DLPFC is valid (see above), it should be possible to demonstrate that, like the engagement of the right DLPFC, the right frontal ERP effect can be elicited in circumstances where there is no requirement to monitor the products of an episodic retrieval attempt.

We tested this prediction in two experiments designed to permit the magnitudes and scalp distributions of ERP 'old/new' effects to be contrasted according to experimental manipulations that varied the extent to which judgments made on recognition memory test items required access to the products of retrieval. Experiment 1 investigated whether the right frontal effect was selectively elicited by the need to monitor the episodic content of a retrieval attempt. This was achieved by contrasting the ERPs elicited in tests that differed with respect to the nature of the judgment (source vs. semantic) required on test items identified as belonging to the study phase. In Experiment 2, we manipulated the class of test item (studied vs. unstudied) for which a second, semantic, judgment was required.

Experiment 1

Materials and Methods

Subjects—Twenty-four volunteers from the UCI community participated in return for payment of \$15/hour. All subjects were right-handed, native English speakers, with normal or

corrected-to-normal vision. Informed consent was obtained in accordance with guidelines of the UCI Institutional Review Board. The data from 8 subjects were excluded from all analyses: 1 for inadequate memory performance and 7 for having fewer than 16 artifact-free trials in one or more of the critical experimental conditions. Data are reported from the remaining 16 subjects (9 males) ranging in age from 18 to 21 (mean = 20).

Stimuli—A pool of 200 nameable color pictures of individual objects served as the experimental stimuli. One hundred and sixty of the pictures were used as the critical study and test items, twenty were used in a practice phase preceding the experiment proper, and the remaining twenty were used as study buffers (2 at the beginning and end of each study list), a practice list before test (the 4 buffers from study along with 4 new items), and test buffers (2 at beginning of test). The critical stimuli were selected such that equal numbers could be categorized according to each of three semantic judgments: animacy (living or not-living), size (bigger or smaller than a shoebox), and location (more likely to be found indoors or outdoors). For each of the 8 possible combinations of these categories (i.e. living, small, indoor; non-living, small, indoor; and so forth), there were 20 items. For each subject, the 160 critical pictures were randomly assigned to 4 groups of 40 items, with the restriction that each group contained 5 items from each of the 8 categorical combinations. The items from two of these groups were presented in separate 40-item study phases and subsequently served as old pictures during the corresponding test phases. The items from the remaining groups served as new items in the two 80-item test phases.

During each study and test phase, a solid gray frame was continuously displayed in the center of the black background of a computer monitor. Words were presented in black uppercase 30-point Helvetica font. All pictures and words were presented centrally inside the gray frame. The gray frame subtended horizontal and vertical visual angles of 2.9° at the 1-m viewing distance.

Procedure—Each study trial consisted of the presentation of a red fixation character (+) presented at the center of the gray frame for 1200 ms, a semantic judgment word cue for 1200 ms, a picture for 1000 ms, and a centrally-presented black fixation character (+) for 2400 ms. Each test trial consisted of a red fixation for 500 ms, a test picture for 1000 ms, and a centrally-presented black fixation character for 3000 ms.

Instructions and practice were administered before subjects were fitted with an electrode cap. For the study phases, subjects were informed that they would see one of two words and then a picture immediately afterwards (Figure 1). The word signified the type of judgment to be made on the picture that followed (BIG?, LIVING?, or INDOOR?). For each subject, two of the semantic judgments (size, animacy, or indoor/outdoor) were used during the study phases, and the remaining judgment was used for the semantic test phase. For one of the study judgments, subjects were instructed to use the index and middle finger on the designated hand to signify a yes or no response, respectively, to the judgment (e.g. index - yes it is bigger than a shoebox, middle - no it is not). For the other judgment, the respective fingers on the other hand were used (e.g. index - yes indoors, middle - no outdoors).

One of two types of memory task (source or semantic) followed each study phase (Figure 1). Each test phase began with a short practice list of eight items to familiarize subjects with the test tasks. Half of the practice items were the buffer items from the preceding study phase and the remaining items were new. A short break (approximately 30 seconds) followed the practice list, allowing for clarification of the instructions before the test phase continued. In both memory tasks, a series of pictures were presented, and subjects were instructed to respond 'new' with the index finger of the designated hand to unstudied pictures. In the source task, if a test item was old, subjects were instructed to signify the type of semantic judgment made for

the picture at study, using the index or middle finger of the hand not employed for new responses. In the semantic task, if a test item was 'old', the requirement was to make a semantic judgment on the item, again using the index or middle finger of the hand not employed for new responses. Crucially, the semantic dimension on which the item was judged differed from either of those employed during the study phase (see Fig 1). The three semantic dimensions (i.e., size, animacy, indoor/outdoor) were rotated across subjects so that they were employed equally often in the study and the semantic test phases. Mapping of responses to hands and the order of administration of the different test tasks, were counterbalanced across subjects. For both study and test tasks, speed and accuracy of responding received equal emphasis in the instructions.

ERP Recording and Analysis—Electroencephalographic activity (EEG) was recorded continuously during the test phases from 31 silver/silver-chloride electrodes. Twenty-nine of these electrodes were embedded in an elastic cap and 2 were placed on the left and right mastoid processes. The locations of the cap electrodes were based on the International 10–20 system (American Electroencephalographic Society, 1994) and corresponded to midline sites (Fz, Cz, Pz) as well as homotopic (left/right) pairs of sites (Fp1/Fp2, AF7/AF8, F3/F4, F5/F6, F7/F8, C3/C4, C5/C6, T7/T8, P3/P4, P5/P6, P7/P8, PO7/PO8, O1/O2). Vertical and horizontal electrooculograms (EOG) were recorded from electrode pairs situated above and below the left eye and on each outer canthus. Data were acquired with respect to a common Cz reference using a Contact Precision Instruments [London, UK] system at a 256-Hz sampling rate and an amplifier bandwidth of 0.01–40 Hz (–3dB). Electrode impedances were maintained below 5 k Ω . Offline, the continuous EEG data were epoched to 2048 ms duration with 102 ms pre-stimulus baseline. The resulting epoched data were downsampled to a 125-Hz sampling rate and algebraically re-referenced to linked mastoids. Trials containing movement artifact, EOG artifact other than blinks, or excessive baseline drift were rejected. The averaged ERPs were smoothed with a 5-point moving-window filter at a cutoff of 19.4 Hz (–3dB). A previously described linear regression method (e.g., Henson et al., 2004) was used to correct blink artifacts for all subjects.

Results

In this section, any reference to 'old' items refers to studied items to which subjects made correct responses (i.e. old items that were endorsed with the correct source judgment in the source task or the correct semantic judgment in the semantic task). All analyses (behavioral and ERP) utilized data associated with these responses, unless otherwise specified. The term 'new items' applies only to items correctly endorsed as new (correct rejections).

For all ANOVAs described below, the degrees of freedom associated with effects involving factors with more than two levels were corrected for non-sphericity by the Greenhouse-Geisser procedure (Greenhouse & Geisser, 1959).

Behavioral Performance—Mean proportions and response times (RTs) corresponding to correct old, incorrect old, and new items in the test phases are listed in Table 1. To test whether item memory differed according to task, response categories were collapsed over correct old and incorrect old items to form 'collapsed old' categories for the source and semantic tasks (proportions identified as old are 0.89 and 0.94 respectively). ANOVA [with factors of task (source vs. semantic) and item type (collapsed old vs. new)] gave rise to a main effect of item type [$F(1,15) = 19.36, p < 0.005$], reflecting more accurate performance for new items. There was, however, no significant difference in performance as a function of task.

ANOVA restricted to correct old responses [factors of task and item type (old vs. new)] gave rise to a main effect of item type [$F(1,15) = 161.13, p < 0.001$] and a task $\times$ item type interaction

[$F(1,15) = 46.06, p < 0.001$]. Subsidiary ANOVAs conducted separately on the data for each item type indicated that old items were more likely to be classified correctly in the semantic task than the source task [$F(1,15) = 43.04, p < 0.001$], whereas accuracy for new items did not differ across the tests.

ANOVA of RTs for correct responses gave rise to main effects of task [$F(1,15) = 12.19, p < 0.005$] and item type [$F(1,15) = 90.25, p < 0.001$], and a task $\times$ item type interaction [$F(1,15) = 16.10, p < 0.005$]. Subsidiary ANOVA of each item type revealed that the format of the test did not affect RTs for new items, whereas RTs for old responses were longer in the source compared to the semantic task. [$F(1,15) = 19.49, p < 0.005$].

ERPs—Grand average ERPs ($N=16$) from representative electrode sites are illustrated for each test according to item type in Figure 2. In the source task, the across subject mean numbers of trials (and range) forming the ERPs were 19 (16–28) and 26 (18–34) for old and new conditions, respectively. In the semantic task, the trial numbers for the analogous conditions were 23 (16 – 30) and 27 (16–37). Due to insufficient artifact-free trials, ERPs elicited by studied items associated with incorrect source or semantic judgments were not analyzed. As is evident from Figure 2, from approximately 200 ms post-stimulus, the waveforms for old items are more positive-going than those to new items in both tests. These old/new effects continue over time, and demonstrate a left parietal maximum between approximately 400 and 800 ms post-stimulus. From approximately 800 ms post-stimulus waveforms from posterior sites elicited by old items are more negative-going than new items in the source task, whereas the converse effect is apparent for the semantic task. At more anterior sites, waveforms for old items are more positive-going than new items in both tests. This anterior old/new difference is maximal over the right frontal scalp.

The ERP analyses were conducted in three parts. The primary analysis focused on two ERP old/new effects – the left parietal and right frontal effects – that have been the objects of numerous prior studies (for reviews see: Mecklinger 1999; Friedman & Johnson, 2000; Rugg et al., 2002; Rugg 2005). In the case of the latter of these effects, we predicted that it would be unaffected by the task manipulation (see Introduction). The left parietal effect, which is typically maximal between 500–800 ms post-stimulus, is widely held to be an ERP correlate of successful episodic retrieval (recollection) (see reviews above). By contrasting the left parietal effect according to type of retrieval test, we were therefore able to assess whether recollection was affected by the test manipulation.

The second part of the ERP analysis was guided by the data, and focused on a late onset, centrally maximum, negativity that appears greater for waveforms elicited by ‘old’ items in the source task relative to the semantic task (Figure 3). In a final set of analyses the scalp topographies of the old/new effects characterized by the foregoing analyses were contrasted.

Left parietal and right frontal effects—Initial analyses were conducted on the mean ERP amplitudes (with respect to the pre-stimulus baseline) for correct old and new items over three latency regions: 500–800 ms, 1100–1400 ms, and 1400–1900ms post-stimulus onset. These regions were selected *a priori* on the basis of prior studies of left parietal and right frontal old/new effects (Wilding & Rugg, 1996; Wilding, 1999). The analyses utilized the sixteen electrode sites identified in Figure 2, which were factored by hemisphere, anterior/posterior location, and electrode site. Initial ANOVAs, incorporating the additional factors of task (source vs. semantic), and item type (old vs. new) were performed on the data from each latency range. Subsidiary ANOVAs were used as necessary to elucidate interactions between task, item type and electrode location factors. Effects not involving the factor of item type are of no interest in the present context and are not reported.

Results of the initial ANOVAs described above are summarized in Table 2 for each latency region. ANOVA of the 500 – 800 ms region gave rise to a main effect of item type, an item type $\times$ hemisphere $\times$ anterior/posterior interaction, and a task $\times$ item type $\times$ anterior/posterior $\times$ electrode site interaction. The three-way interaction reflects the tendency for old/new effects to be largest over the left posterior scalp regardless of task. The four-way interaction is difficult to interpret, but seems to reflect the differential distribution across sites of the frontally-distributed old/new effects in each task. Importantly, separate task-wise ANOVAs revealed significant old/new $\times$ hemisphere $\times$ anterior/posterior interactions [$F(1,15) = 5.96$, $p < 0.05$ and $F(1,15) = 5.72$, $p < 0.05$, for the source and semantic tasks respectively], in both cases indicative of a cross-over between left-lateralized parietal and right-lateralized frontal effects.

For the 1100 – 1400 ms latency region, the initial ANOVA revealed six significant interactions, as detailed in table 2. Of these interactions, only one involved the factor of task (task $\times$ item type $\times$ electrode site). This interaction arose because of the greater tendency for the old/new effects in the source than the semantic task to attenuate or reverse at medial electrode sites (Figure 2). The remaining interactions, including the four-way interaction between item type $\times$ hemisphere $\times$ anterior/posterior $\times$ electrode site, reflect the emergence in this latency region of a robust right frontal old/new effect, and the tendency for the magnitude of this effect to be maximal over the right lateral/anterior scalp.

ANOVA of the 1400 – 1900 ms latency region gave rise to five significant interactions, none of which involved the factor of task (See Table 2). These interactions reflect the continued presence of a right frontal old/new effect, and the tendency for the old/new effects to reverse polarity over the left hemisphere.

The foregoing analyses confirm the robustness of the left parietal and right frontal effects evident in figure 2. The analyses revealed subtle differences in the timing and scalp distribution of the right frontal effect in each task, but no evidence to suggest that these effects differed between the tasks in overall magnitude.

To directly assess whether left parietal and right frontal effects differed as a function of task, ANOVAs were conducted separately for the 500 – 800 latency data from the left parietal quadrant and for the 1100 – 1400 and 1400 – 1900 latencies on the data from the right frontal quadrant. In the case of the left parietal effect, ANOVA revealed a main effect of item type [$F(1,15) = 14.97$, $p < 0.005$] and a task $\times$ item $\times$ electrode site interaction [$F(2.4,36.6) = 3.77$, $p < 0.05$]. Subsidiary ANOVA revealed a task $\times$ item interaction only for the posterior most electrode site in the quadrant [$F(1,15) = 5.54$, $p < 0.05$]. ANOVA excluding this site revealed a main effect of item type [$F(1,15) = 15.46$, $p < 0.005$] which was unmodified by the factor of task ($p > 0.21$). In the case of the right frontal effect, ANOVA for both latency regions revealed a main effect of item type [$F(1,15) = 49.4$, $p < 0.001$ and $F(1,15) = 14.83$, $p < 0.005$, respectively] and an item type $\times$ electrode site interaction [$F(1.3,19.6) = 7.48$, $p < 0.01$ and $F(1.5,22.9) = 9.75$, $p < 0.005$, respectively]; neither of these effects interacted with test ($F < 1$). Thus, in accordance with the conclusions drawn from the results of the ANOVAs conducted on the data from all four electrode quadrants, these more focused analyses indicate that the magnitudes of the left parietal and right frontal old/new effects in the two tasks were statistically equivalent.

Late Posterior Effect—As noted above, the ERPs elicited in the source task condition appear to demonstrate a late-onsetting, negative-going old/new ERP effect. This was quantified by measuring the mean amplitude of the 1200 – 1900 ms latency region. In light of its apparent midline maximum, the electrode sites employed to characterize the effect differed from those used in the preceding analyses (see Figure 3). The sites were factored according to anterior/posterior location (frontal, central, parietal) and chain (left, middle, right). ANOVA revealed

item type $\times$ anterior/posterior [$F(1.2,18.6) = 4.26, p < 0.05$] and item type $\times$ anterior/posterior $\times$ chain [$F(2.9,43.1) = 4.58, p < 0.01$] interactions. In addition, there were two interactions involving the factor of task: task $\times$ item type, and task $\times$ item type $\times$ anterior/posterior location [$F(1,15) = 7.43, p < 0.025$ and $F(1.9,28.6) = 7.50, p < 0.005$, respectively]. Separate task-wise ANOVAs revealed that the factor of item type modulated the waveforms from the source task only (in the form of a main effect, and an item type $\times$ anterior/posterior interaction; respectively, $F(1,15) = 5.80, p < 0.05$ and $F(1.5,22.8) = 8.67, p < 0.005$). These results reflect the posterior maximum of the ‘reversed’ old/new effects evident in this task. ANOVA of the data from the posterior sites only revealed a significant main effect of item type [$F(1,15) = 15.77, p < 0.005$]. The analogous ANOVA for the semantic task gave rise to no effects involving the item type factor ($F_s < 1$).

Topographic Analyses—The scalp topographies of the left parietal effect in the 500 – 800 ms latency region, and the right frontal effect in the 1100 – 1400 and 1400 – 1900 ms latency region are illustrated in Figure 4. The analyses were based on data from the same electrode groupings and site factors as were used in the initial analyses (see Figure 2). Prior to analysis, the data were range normalized to eliminate the potentially confounding effects of global amplitude differences (McCarthy and Wood, 1985). ANOVAs contrasting topographies as a function of test were conducted separately for each latency region (500 – 800, 1100 – 1400, and 1400 – 1900 ms). Effects that do not involve the factor of task are not of primary interest in the present context and are not reported. ANOVA of the 500 – 800 ms interval revealed a task $\times$ anterior/posterior $\times$ electrode site [$F(2.4,35.3) = 9.54, p < 0.01$] interaction. Separate follow-up ANOVAs on the frontal and posterior sites did not reveal any significant effects, however. These analyses indicate that task did not affect the scalp distribution of the left parietal effect.

ANOVA contrasting the topographies of the right frontal effect in the 1100 – 1400 ms latency region revealed a task $\times$ electrode site interaction [$F(2,30.3) = 3.42, p < 0.05$]. As is evident from figure 4, this interaction reflects the emergence of the late posterior negative old/new effect in the source task only, rather than differences in scalp topography related to the right frontal effect. In support of this interpretation, ANOVA restricted to the frontal quadrants did not reveal any effects involving the task factor (all $p_s > 0.09$), whereas ANOVA of the posterior quadrants revealed a task $\times$ site interaction [$F(1.6,23.7) = 6.85, p < 0.01$]. In the later 1400 – 1900 ms latency region, ANOVA revealed no significant effects involving the factor of task (all $p_s > 0.18$).

Discussion

Behavioral performance—Whereas the RT and accuracy measures differed for items correctly judged old in the two retrieval tasks, these performance indices did not differ across the tasks for correctly classified new items. The equivalent performance for the new items suggests that subjects adopted a serial strategy in the performance of both tasks, first determining whether an item was old or new, and only then initiating the second judgment of study or semantic status. The adoption of this strategy has been reported in prior studies that contrasted tests requiring simple recognition versus source memory judgments (Van Petten et al., 2000; Rugg et al., 2003; Kahn et al., 2004), where it has been referred to as ‘familiarity-gated recollection’ (Kahn et al., 2004).

The differences in performance for the two classes of old item raise caveats in the interpretation of differences in the ERP old/new effects elicited in the two conditions. Such differences may reflect the confounding effects of performance or task difficulty rather than differences in the neural correlates of the underlying cognitive operations. These performance differences do not,

of course, compromise the interpretation of effects that are common to the two memory conditions, and which are the focus of the discussion below.

ERP findings—The principal aim of the present experiment was to investigate whether the right frontal ERP old/new effect is selectively associated with the requirement to monitor the products of episodic retrieval. The present findings suggest that this is not the case. Prominent right frontal effects, statistically equivalent in both their magnitudes and scalp topographies, were evident from around 800 ms post-stimulus onset in each retrieval task. Thus, the effect is elicited regardless of whether old items are evaluated in respect of information retrieved from episodic or semantic memory.

In addition to the aforementioned right frontal old/new effects, robust left parietal effects were also elicited in both retrieval tasks. Like the right frontal effects, neither the magnitudes nor the scalp distributions of these earlier-occurring effects differed between the two tests. There is extensive evidence to suggest that the left parietal effect is a neural correlate of successful episodic retrieval (recollection). There is also evidence to indicate that the magnitude of the effect co-varies with the amount of information recollected (Vilberg et al., 2006; Wilding, 2000). Thus, the present findings suggest that subjects recollected equivalent amounts of information in response to old items in the two tasks, despite the fact that this information was task-relevant in the source task only. An interesting question, that cannot be resolved on the basis of the present data, is why recollection was seemingly as extensive when episodic information was largely superfluous (beyond that required to make an ‘old/new’ determination) as when the information was highly task-relevant. Irrespective of the answer to this question the findings for the left parietal effect bear significantly on the functional interpretation of the right frontal effects. To the extent that the frontal effects are automatically elicited whenever a test item elicits relatively extensive recollection (cf. Maratos et al., 2002), the present findings can be reconciled with the proposal that the right frontal effect is associated selectively with successful episodic retrieval. Resolution of this issue is the motivation for experiment 2, and further comment is deferred to the discussion of that experiment.

In addition to the left parietal and right frontal effects, a late-onsetting (ca. 800 ms) posteriorly distributed ‘reversed’ old/new effect that was evident in the source task only. This effect, sometimes referred to as the late posterior negativity (LPN), has been the subject of a variety of different interpretations (for review, see Johannsen & Mecklinger, 2003). For example, it has been proposed that the effect is a reflection of response processing (Wilding & Rugg 1997b, Kuo & Van Petten 2006), memory search for sensory details (Cycowitz et al., 2001; 2003), or successful recovery of source information (Senkfor & Van Petten, 1998; Van Petten et al., 2000). It has also been proposed that the effect is functionally heterogeneous, with contributions from all of the above classes of processing (Herron, 2007). The present findings are clearly compatible with proposals identifying the effect with processes selectively engaged during tests of source memory. However, the fact that response times to old items were some 300 ms longer in the source than the semantic task means that a response-based account cannot be ruled out.

Experiment 2

Introduction

The results from Experiment 1 suggest that the right frontal old/new effect is not elicited specifically in response to the requirement to monitor episodic content. As was noted in the discussion of Experiment 1, the findings, can, however, be reconciled with the proposal that the right frontal effect is associated selectively with successful episodic retrieval. By this argument, the effect is elicited whenever more than a certain amount of information is recollected, and the presence of sizeable left parietal old/new effects suggests that recollection

was extensive in both the source and the semantic task. Alternatively, it is possible that the effect observed in experiment 1 reflects more general processing differences between old and new items, such as the number of internal decisions that are required before a response can be selected (See Introduction). If the right frontal effect does indeed reflect something like the number of internal decisions required in response to a test item, it should be elicited by whichever class of item elicits more decisions, regardless of study status. By contrast, if the right frontal effect is linked to successful episodic retrieval, it should only be evident for old items.

Experiment 2 investigated this issue by contrasting two recognition memory tests that varied with respect to the class of test item that required an additional semantic judgment. These additional judgments were performed for old items in one task (replicating the semantic task of experiment 1), and for new items in the alternate task. If the hypothesis linking the right frontal effect to the number of internal decisions is correct, the effect should be elicited by old items in the first of these tasks, but by new items in the second task. If, however, the effect reflects cognitive processes engaged by successful episodic retrieval, it should be elicited by old items in both tasks.

Materials and Methods

Subjects—Twenty-two volunteers from the UCI community participated in return for payment of \$15/hour. All subjects were right-handed, native English speakers, with normal or corrected-to-normal vision. Informed consent was obtained in accordance with guidelines of the UCI Institutional Review Board. The data from 6 subjects were excluded from all analyses: 1 because of technical difficulties and 5 for having fewer than 16 artifact-free trials in one or more of the critical experimental conditions. Data are reported from the remaining 16 subjects (8 males) ranging in age from 18 to 24 (mean = 20).

Stimuli, Procedure, and EEG Recording and Analyses—The experimental materials were the same as those employed in experiment 1, as was one of the two experimental tasks. Thus, one of the present experimental conditions took the form of the semantic task first used in experiment 1 (here termed the ‘evaluate old’ task). The second task employed in the present experiment was identical in every respect except for the requirement to perform a semantic judgment on items judged to be new, rather than on those judged old (‘evaluate new task’). All other aspects of the experimental procedures, along with EEG recording analysis procedures, were identical to those adopted in experiment 1.

Results

Reference to ‘old’ or ‘new’ items refers to items for which subjects made a correct old or new judgment and, when appropriate, a correct semantic judgment. All analyses (behavioral and ERP) utilized data associated with correct responses, unless otherwise specified.

Behavioral Performance—Behavioral performance is summarized in Table 3. To test whether recognition accuracy differed according to test, hit and correct rejection rates were collapsed over semantic judgment accuracy. ANOVA [factors of task and item type (old vs. new)] gave rise to no significant effects.

ANOVA restricted to correct responses gave rise to a task $\times$ item type interaction [$F(1,15) = 10.97$, $p < 0.01$]. Subsidiary ANOVAs conducted separately on the data for each task indicated that, in each case, accuracy was lower for the class of item requiring the semantic judgment [$F(1,15) = 8.82$, $p < 0.025$ and $F(1,15) = 6.45$, $p < 0.05$ for evaluate old and evaluate new tasks respectively].

ANOVA of RTs also gave rise to a task by item type interaction [$F(1,15) = 61.79, p < 0.001$]. Subsidiary ANOVAs revealed that RTs were longer for old responses in the evaluate old task [$F(1,15) = 16.22, p < 0.005$], whereas RTs were longer for new responses in the evaluate new task [$F(1,15) = 70.27, p < 0.001$].

The foregoing analyses support the impression given in Table 3 that accuracy was lower and RTs were longer for the class of item requiring the semantic judgment. Additional pairwise tests revealed that neither accuracy nor RT differed between the items in each task that required the additional semantic judgment (i.e. old items in the evaluate old condition vs. new items in the evaluate new condition). Likewise, accuracy and RT did not differ for the items that did not require the additional judgment.

ERPs—Grand average ERPs (16 subjects) from representative electrode sites are illustrated for each test according to item type in Figure 5. In the evaluate new task, the across subject mean number of trials (and range) forming the ERPs were 24 (16–34) and 21 (16–31) for old and new items respectively. In the evaluate old task, the trials numbers for the analogous conditions were 20 (16 – 32) and 22 (16–30). Due to insufficient artifact-free trials, ERPs elicited by items associated with incorrect semantic judgments were not analyzed. As is evident from Figure 5, from approximately 200ms post-stimulus, waveforms for old items appear to be more positive-going than waveforms for new items regardless of task. These old/new effects continue over time and demonstrate a left parietal maximum between approximately 400 and 700 ms. From approximately 700 ms post-stimulus, waveforms over the frontal scalp in the evaluate old test demonstrate a large right frontal effect similar to that observed in experiment 1. In striking contrast, this effect appears to be reversed in the evaluate new task, such that a sustained right anterior positivity is elicited by the new rather than the old items.

Initial analyses were conducted on the mean ERP amplitudes for correct old and new response categories over two latency regions: 500 – 800 ms, and 1100 – 1900 ms post-stimulus onset. These latency regions were selected on the basis of the results of Experiment 1. In the present case, the 1100 – 1400 ms and 1400 – 1900 ms latency regions that had been separately analyses in experiment 1 are collapsed into a single region since preliminary analyses revealed identical patterns of results with respect to the right frontal effect. Initial analyses utilized the same sixteen electrodes and experimental factors as were employed in the first experiment. Results of the global ANOVAs over the two latency regions are summarized in Table 4.

For the 500 – 800 ms latency region, ANOVA revealed a main effect of item type, which was accompanied by an item type $\times$ hemisphere $\times$ electrode site interaction. There were no significant interactions involving the factor of task. Despite the failure to find evidence for a reliable interaction involving the factors of item type, hemisphere and anterior/posterior location (for the three-way interaction, $p < .1$), the foregoing three-way interaction was largely driven by the presence of robust left parietal old/new effects in the two tasks (frontal old new effects, collapsed across task and site, averaged $1.29\mu\text{V}$ and $1.25\mu\text{V}$ for left and right hemispheres respectively. Corresponding parietal effects averaged $1.60\mu\text{V}$ and $0.72\mu\text{V}$. Scalp topographies of old/new differences for the 500 – 800 ms latency region are illustrated in Figure 6).

For the 1100 – 1900 ms latency region, ANOVA revealed six significant interactions, five of which interacted with the factor of task (Table 4). These interactions with the task factor reflect the reversed right frontal old/new effects in the evaluate new task.

The foregoing analysis supports the impression given by Figure 5 that robust right frontal effects were elicited in both tasks, but were associated with old items in the evaluate old task and new items in the evaluate new task. In order to directly contrast the magnitudes of the

effects in the two tasks, the 1100–1900ms data from the frontal electrode quadrants were re-factored according to whether the test item required a semantic judgment (factors of judgment/no judgment, task, hemisphere and electrode site). The ANOVA gave rise to significant effects for judgment type and its interaction with hemisphere [$F(1,15) = 22.32$, $p < 0.001$ and $F(1,15) = 9.99$, $p < 0.01$, respectively). No effect involving the task factor approached significance. A subsidiary ANOVA restricted to the right frontal quadrant gave rise to solely to a main effect of judgment type [$F(1,15) = 34.63$, $p < 0.001$]. Thus, the right frontal effects elicited in the tasks are both highly robust and statistically equivalent in magnitude.

The scalp topographies of the ‘judgment effects’ described above are illustrated in Figure 6. ANOVA of the data from all four electrode quadrants revealed a judgment type $\times$ electrode site interaction [$F(1.5,23.0) = 6.33$, $p < 0.025$]. A subsidiary ANOVA confined to the data from the frontal quadrants revealed no effects involving the factor of judgment type ($ps > .15$), whereas ANOVA of the posterior quadrants gave rise to a significant judgment type $\times$ electrode site interaction [$F(1.9,27.9) = 9.43$, $p < 0.01$]. These findings indicate that the topographies of the judgment effects in the two tasks over the frontal scalp were statistically equivalent, but that they differed over the posterior scalp, most likely reflecting the fact that the posterior old/new effects in each task are of opposite polarities when the right frontal effects are brought into register, as in Figure 6.

Discussion

Behavioral Performance—In each test, RTs were longer and accuracy was lower for the class of item that required the additional semantic judgment. These performance differences demonstrated a symmetrical cross-over between the two tests, such that performance was equivalent both for the items requiring the additional judgment (old items in the evaluate old condition and new items in the evaluate new condition) and for the items where no further judgment was required. The equivalent performance across the two conditions for the items that did not require semantic classification suggests that, as in Experiment 1, subjects first determined the study status of each item and only then initiated a semantic classification.

ERP findings—The aim of experiment 2 was to determine whether the right frontal effect is selectively associated with recollection, or alternatively, whether it is elicited in response to more general processing demands. The finding that the effect was elicited by the class of item for which the additional semantic judgment was required supports the latter alternative. More specifically, the results from the evaluate old task replicated those obtained from the equivalent task in experiment 1; relative to the ERPs elicited by items judged new, ERPs elicited by old items demonstrated a robust right frontal effect. In striking contrast, the effect was reversed in the evaluate new condition, such that it was elicited by items judged new relative to those endorsed as old. The magnitudes and scalp topographies of the two frontal ERP effects were statistically indistinguishable (see Figure 5). Thus, the possibility that the right frontal effect found in the semantic task of experiment 1 reflects incidental source recollection can be ruled out. Instead, it would appear that the requirement to perform a semantic judgment on a recognition memory test item is sufficient to elicit the effect regardless of whether the item is old or new (for a prior example of the modulation of new item right frontal effects by task demands see Curran and Friedman, 2003). We return to the implications of this finding for ideas about the functional significance of the right frontal effect in the General Discussion below.

In contrast to the right frontal effect, the left parietal effect was elicited by old items in both tasks. The magnitudes and scalp distributions of these effects were equivalent across the two conditions, suggesting that, as in Experiment 1, subjects recollected equivalent amounts of information in response to old test items. The finding in the evaluate new task that old items

elicited the left parietal effect but that the right frontal effect was elicited by new items indicates that the two effects can be doubly dissociated, and constitutes compelling evidence that they reflect functionally distinct cognitive operations.

General Discussion

In Experiment 1, we employed two retrieval tasks that differed with respect to the type of information requiring evaluation before a response could be selected. The source task required evaluation of the products of an episodic retrieval attempt, whereas the semantic task required evaluation of a semantic property of each item judged old. Large right frontal effects, similar in both their magnitudes and topographies, were elicited by old items in the two tasks. In Experiment 2, the nature of the information requiring evaluation was held constant, but the study status of the item requiring an additional semantic judgment was varied. Robust right frontal effects were elicited by the class of items that required the additional judgment. Together, these findings (summarized in Figure 7) provide compelling evidence that the right frontal ERP effect is not associated solely with the requirement to monitor the outcome of an episodic retrieval attempt. Thus, to the extent that right frontal effects do indeed reflect activity generated in right DLPFC (Rugg et al., 2002), the findings add to prior evidence suggesting that 'post-retrieval' processes supported by this region are not selective for episodic memory (Dobbins and Han, 2006; Fleck et al., 2006).

The results of these two experiments are well accommodated by the framework proposed by Dobbins and Han (2006) to account for their findings with respect to DLPFC (see Introduction). In brief, these authors reported that right prefrontal activity co-varied not with the demands made by a retrieval task on post-retrieval monitoring, but rather on the number of internal decisions that were required prior to a behavioral response. The present findings, in which right frontal effects were elicited by whichever test item required two as opposed to a single judgment, clearly lend themselves to a similar explanation. On the other hand, the present findings are also compatible with the alternate proposal that the right frontal effect reflects the engagement of processes supporting post-retrieval monitoring (Wilding, 1999; Rugg et al., 2002; Rugg, 2005), so long as this construct is extended to encompass the monitoring of information retrieved from semantic as well as episodic memory.

By themselves, the present findings cannot arbitrate between these alternate interpretations. A clear prediction of Dobbins and Han's (2006) 'decisional' account however is that neither the content of retrieved information nor the accuracy of the associated judgment should influence the magnitude of the right frontal effect. An obvious way to test this prediction is to contrast the effects elicited by items associated with correct vs. incorrect judgments. Unfortunately, the very small numbers of error trials preclude such an analysis in the present study. Several prior studies of source memory have, however, reported such contrasts, with conflicting results. Thus, whereas right frontal effects were reported to be larger for accurate than inaccurate source judgments in two studies (Wilding and Rugg, 1996; Wilding 1999), equivalent effects for these two response categories were reported in two other studies (Senkfor and Van Petten 1998; Van Petten et al., 2000; in one further study, larger effects were reported when the source judgment was incorrect, Trott et al., 1999). Whereas it might be claimed that the monitoring hypothesis can do a better job of accounting for these diverse data sets than the decisional account, this is far from a compelling argument.

A recent study by Woodruff et al. (2006) reported findings that seem difficult to reconcile with the monitoring account of the right frontal effect. Recognition memory was tested with a modified 'Remember/Know' procedure in which subjects were required to signal whether they recollected a test item. Importantly, when recollection failed, they were required to rate their confidence about the item's study status on a four point scale (confident new to confident old).

Relative to items receiving either confident new judgments, unconfident new judgments, or unconfident old judgments, items that were confidently judged old elicited a robust right frontal effect. This finding conflicts with the monitoring account, according to which the largest effects should have been elicited by the items for which familiarity was nearest to the old/new criterion, that is, items attracting unconfident judgments (Henson et al., 1999, 2000; Rugg et al., 2002; see also Fleck et al., 2006). The findings can however be reconciled with a decisional account if it is assumed that when an item is recognized with high confidence, a further decision is required as to whether it should be endorsed as recollected.

An often neglected aspect of the right frontal old/new effect is its time-course. As in the present experiments, it is not uncommon for the effect to persist for several hundreds of milliseconds, and to still be evident a long as two seconds after stimulus onset. Functional accounts of the effect, including those discussed above, have focused on processes supporting the behavioral response mandated by the experiment task, and have neglected the fact the effect extends well beyond the time when response selection must have occurred. In the experiments reported here, for example, mean response times in the conditions requiring a semantic judgment were on the order of 1300–1400 ms. Given that response selection would have occurred some 100–150 ms earlier, this means that the generators of the effect (putatively, right DLPFC) remained active for more than a half second after the response had been selected. Although these considerations do not necessarily mean that the processes reflected by the right frontal effect play no role in online behavior, they do suggest that the role of these processes extends beyond the selection of stimulus-locked responses. Identification of these ‘post-selection’ processes would seem likely to shed new light both on the functional significance of the right frontal ERP effect and the functions of the prefrontal cortex.

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Figure 1.

Experiment 1: during study, subjects were cued to make one of two semantic judgments on serially presented pictures (top). Each test task was preceded by a separate study phase. In the semantic task (bottom left) subjects made a third semantic judgment on each picture judged old, or signaled that an item was new. In the source task (bottom right) subjects made source judgments on pictures judged old or signaled an item was new.

Figure 2.

Grand-average ERPs from left and right frontal and parietal electrode sites elicited by items accorded correct old and new judgments, for the semantic (top) and source (bottom) tasks of experiment 1.

Figure 3.
 Grand-average ERPs from the Pz electrode site at which the late posterior negativity was maximal for items in the source task of experiment 1.

Figure 4.

Scalp topographies of the differences in mean amplitude of the 500 – 800, 1100 – 1400, and 1400 – 1900 ms latency regions between ERPs elicited by correctly judged old and new items in the semantic (top) and source (bottom) tasks of experiment 1. The topographic maps are scaled to the maxima (red) and minima (blue) of each effect with the range displayed below each map in microvolts.

Figure 5. Grand-average ERPs from left and right frontal and parietal electrode sites elicited by items accorded correct old and new judgments for the evaluate old (top) and evaluate new (bottom) tasks of experiment 2

Figure 6.

Scalp topographies of the between condition differences in mean amplitude of the 500–800 and 1100 – 1900 ms latency regions in each task of experiment 2. Note that for the 500–800 ms region, old – new subtractions are plotted for both task. For the 1100–1900 ms region, however, the plots are of the old – new subtraction for the evaluate old task, and are of the new – old subtraction for the evaluate new task, allowing a direct comparison of the topographies of the right frontal effects associated with the two tasks. Maps are scaled to the maxima (red) and minima (blue) of each effect with the range displayed below each map in microvolts.

Figure 7.

Grand-average ERPs from the lateral frontal electrode site (AF8) at which right frontal effects were most prominent across experiments.

Table 1
Mean (SD) proportions and RTs (in ms) for each response type in the two test phases of experiment 1

		Proportions(SD)	RT (SD)
Semantic	Correct	0.84(0.08)	1294(295)
	Incorrect	0.07(0.05)	1613(574) ^a
	New	0.97(0.03)	928(179)
Source	Correct	0.69(0.08)	1621(441)
	Incorrect	0.20(0.08)	1741(593)
	New	0.98(0.02)	957(275)

Note: a denotes that RT data are based on 13 subjects. The excluded subjects made no incorrect responses.

Table 2
Outcomes of ANOVAs contrasting old/new effects according to task (experiment 1)

Latency Region	Effect	F-value	Significance
500 – 800	ON	$F(1,15) = 17.11$	$p < 0.005$
	ON HM AP	$F(1,15) = 6.87$	$p < 0.025$
	TA ON AP ST	$F(2,3,34) = 8.38$	$p < 0.005$
1100 – 1400	ON HM	$F(1,15) = 7.74$	$p < 0.025$
	ON AP	$F(1,15) = 17.61$	$p < 0.005$
	TA ON ST	$F(1,9,28.8) = 4.91$	$p < 0.01$
	ON AP ST	$F(2,1,31.6) = 14.50$	$p < 0.001$
	ON HM AP	$F(1,15) = 29.14$	$p < 0.001$
	ON HM AP ST	$F(2,30.3) = 5.14$	$p < 0.025$
1400 – 1900	ON HM	$F(1,15) = 8.57$	$p < 0.025$
	ON ST	$F(1,3,19.2) = 9.25$	$p < 0.005$
	ON AP ST	$F(2,3,34.3) = 8.83$	$p < 0.005$
	ON HM AP	$F(1,15) = 25.26$	$p < 0.001$
	ON HM AP ST	$F(2,30.2) = 4.05$	$p < 0.05$

Note: Task (TA), item type (ON), hemisphere(HM), anterior/posterior (AP), and electrode site (ST).

Table 3
Mean (SD) proportions and RTs (in ms) for each response type in the two test phases of experiment 2

		Proportions(SD)	RT(SD)
Evaluate Old	Correct old	0.85(0.09)	1349(354)
	Incorrect old	0.06(0.06)	1691(644) ^a
	New	0.93(0.08)	931(179)
Evaluate New	Correct new	0.83(0.08)	1476(386)
	Incorrect new	0.10(0.07)	1678(524) ^b
	New	0.89(0.08)	1059(229)

Note: a and b denote the RT means and SDs based on 15, and 12 subjects, respectively. The excluded subjects made no such responses.

Table 4
Outcomes of ANOVAs contrasting old/new effects according to task (experiment 2)

Latency Region	Effect	F-value	Significance
500 – 800	ON	$F(1,15) = 6.82$	$p < 0.05$
	ON HM ST	$F(1.8,27.2) = 6.12$	$p < 0.01$
1100 – 1900	TA ON	$F(1,15) = 19.926$	$p < 0.001$
	ON ST	$F(1.6,23.8) = 6.31$	$p < 0.025$
	TA ON HM	$F(1,15) = 6.22$	$p < 0.05$
	TA ON AP	$F(1,15) = 8.902$	$p < 0.01$
	TA ON HM AP	$F(1,15) = 6.33$	$p < 0.025$
	TA ON AP ST	$F(2,30.6) = 9.90$	$p < 0.001$

Note: Task (TA), item type (ON), hemisphere(HM), anterior/posterior (AP), and electrode site (ST).