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The electrophysiology of incidental and intentional retrieval: ERP old/new effects in lexical decision and recognition memory

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Abstract

Event-related brain potentials (ERPs), recorded from a 128-sensor array were used to differentiate brain processes associated with intentional vs incidental memory retrieval. Two experiments examined ERP differences between old (studied) and new (non-studied) words and pseudowords while subjects performed either a recognition memory task or lexical decision task. Previous research has related a P600 old/new effect to the recollection of details, and the present experiments show that this effect was not amplified by intentional retrieval. The P600 effect was larger for words than pseudowords. An earlier (300 to 500 ms), frontally maximal, N400-like old/new effect ('FN400') was similar for words and pseudowords. A third, previously unidentified, mid-frontal, old/new effect was associated with only pseudoword recognition from 300 to 500 ms. Results are discussed with respect to dual-process theories of recognition memory.

1. Introduction

Studies of memory retrieval measuring event-related brain potentials (ERPs) have reliably shown differences in brain electrical activity between old (i.e., previously studied) and new (non-studied) stimuli. ERPs are more positive (relative to a mastoid reference) to old than new stimuli from about 300 to 800 ms after stimulus onset. Research has begun to specify the relationship of ERP old/new effects to putative memory retrieval processes [26, 41]. Many ERP studies of recognition memory have been interpreted within dual-process frameworks that differentiate between familiarity and recollection [8, 19, 23, 31]. Though details differ between theories, familiarity is generally thought to reflect an assessment of the global similarity between studied and tested items [16, 17], whereas recollection enables the retrieval of detailed information. Within the context of such theories, recent studies indicate that an ERP old/new effect occurring between 400 and 800 ms (subsequently denoted the 'P600 old/new effect' (following [44]) is related to recollection [2, 35, 36, 43, 49, 51, 58, 59, 61].

Some dual-process perspectives have held that recollection processes primarily depend on intentional retrieval [23], but others have argued that recollection can have both voluntary and involuntary manifestations [38, 39, 47, 48]. In other words, people may recollect information when they are trying to remember (intentional or voluntary recollection), or people may automatically recollect information even when they are not trying to remember (incidental or involuntary recollection). Some theorists have doubted the existence of involuntary recollection [37], so ERPs might provide evidence for such a process. In addition, the theoretical significance of purported ERP recollection effects would be clarified by knowing if they are modulated by retrieval intention.

Experiments by Paller and colleagues have suggested that recollection-related ERP effects do not require retrieval intention. Paller and Kutas [35] studied ERP old/new effects in a tachistoscopic word identification task that did not require subjects to intentionally retrieve previously studied words from memory. The magnitude of the P600 old/new effect was greater for old words studied with an image generation task than with a letter-counting task. Paller and Kutas inferred that these effects were related to recollection because the study task affected subsequent recognition and recall, but did not affect identification. A later study [36] examined both incidental retrieval conditions (lexical decision, Experiment 1) and intentional retrieval conditions (lexical decision followed by recognition, Experiment 2). In both experiments, the ERP old/new effect was greater for study conditions that improved recognition without improving lexical decision times (image

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generation vs syllable counting), so a relationship to recollection was again inferred.

Paller et al.'s [35, 36] experiments demonstrate that recollection-related, P600 old/new effects can be observed when intentional retrieval is unnecessary, but more would be learned by directly comparing conditions that differ in retrieval intention. First, even though intentional retrieval is unnecessary in certain tasks, subjects still might engage in intentional retrieval. ERP old/new effects in incidental tasks only support a relationship to incidental retrieval processes insofar as it can be assumed that intentional retrieval is completely absent. By directly comparing intentional and incidental tasks, the effects of retrieval intention can be assessed under the less restrictive assumption that retrieval intention varies between conditions. Second, it is conceivable that the P600 old/new effect does not require retrieval intention, but is nonetheless amplified by it. Direct comparisons of incidental and intentional retrieval tasks are needed to address these possibilities. Paller et al. [36] found that the difference between the image generation and syllable counting conditions was significant in an experiment that fostered intentional retrieval, but not in a separate incidental retrieval experiment. Thus, it appears that the ERP old/new effect may benefit from intentional retrieval, but the intentional and incidental conditions were not directly compared across experiments. Furthermore, requiring subjects to make two judgments in the direct task (lexical decision followed by recognition) but only one judgment in the indirect task (lexical decision) may have introduced differences beyond those attributable to retrieval intention.

Bentin and colleagues [4, 5] compared ERP old/new effects between intentional recognition and lexical decision (a task in which memory retrieval is primarily incidental). One study compared a continuous lexical decision task with study-test recognition [5]. In another study, the lexical decision task always followed the recognition task [4]. Across these studies, both similarities and differences between tasks were observed, but none of these experiments directly compared tasks under identical conditions.

Retrieval intention has been shown to influence ERP old/new effects in continuous repetition experiments. In continuous repetition procedures, stimuli are repeated within a single list rather across separate study and test lists. Swick and Knight [52] compared ERP old/new effects between lexical decision and recognition tasks with young and elderly subjects. Words and pseudowords were repeated after 0–19 items intervening items (3–60 s). P600 old/new effects were greater for recognition than lexical decision in young subjects, but the reverse was true for elderly subjects. Paller and Gross [34] found that P600 old/new effects were larger during intentional recognition than during incidental retrieval in a continuous word repetition paradigm (averaging 22 s between repetitions). These experiments [34, 52] show that the P600 old/new effect can fluctuate with retrieval intention, but the results from these continuous repetition paradigms might not apply to the study-test paradigms with longer retention intervals.

Retrieval intention also can modulate ERP old/new effects when memory is tested with a stem completion task. Badgaiyan and Posner [3] compared ERP old/new effects in a stem completion task with either intentional ('complete the stem with a studied word') or incidental ('complete the stem with the first word that comes to mind') instructions. Frontal memory-related ERP effects were only observed with intentional retrieval, but these effects are difficult to compare with those from standard recognition conditions. Memory-related ERP effects differ between stem completion and recognition [1], and Badgaiyan and Posner's blocking of old and new stems (intended to replicate similar PET experiments) could influence the results [25].

In summary, a number of studies have found that ERP old/new effects can vary with retrieval intention, but the applicability of these findings to standard study-test recognition conditions is uncertain. The present research compared ERP old/new effects in lexical decision and recognition tasks (following, [21]). If the P600 old/new effect is larger in recognition than lexical decision, it would suggest that the effect indexes a recollection process that benefits from retrieval intention. If the P600 old/new effect does not differ between tasks, it would suggest that the effect is related to incidental aspects of memory retrieval. Two separate experiments were completed to ascertain the replicability of the results. Subjects completed six study-test blocks with words and pronounceable pseudowords. Half the blocks tested lexical decision and half tested recognition. EEG was recorded from 128 scalp locations during presentation of the test stimuli.

2. Methods

The methods for Experiments 1 and 2 are described together. The only methodological differences between experiments were (a) test-trial timing (detailed below) and (b) inclusion of a single, non-studied filler item at the beginning of each test block in Experiment 2.

2.1. Subjects

Subjects were undergraduates participating to satisfy a research requirement in introductory psychology at Case Western Reserve University. All subjects were right-handed and native English speakers. A total of 54 subjects participated in Experiment 1 and 42 subjects in Experiment 2. After rejecting the data of subjects with less than 16 acceptable trials in any condition (criteria detailed later), 32 subjects were included in the analysis of Experiment 1 and 28 subjects in Experiment 2.

2.2. Stimuli

Stimuli were 384 low frequency words (1 or 2 occurrences per million [28]) ranging from 4–8 letters long. Low frequency words were selected to maximize recognition accuracy [18], repetition priming effects [21], and old/new effects [43, 44]. A matching set of 384 pseudowords was created by randomly replacing the vowels in each word. Vowel replacement was modified by hand to insure that all pseudowords were pronounceable, orthographically legal, and not overly reminiscent of real words. Items were counterbalanced across subjects so that each item appeared approximately equally in each condition. If a pseudoword was used for a given subject, the word from which it was derived was not used (and vice versa). Another 24 words and 24 pseudowords served as practice and filler stimuli. Stimuli were presented centrally on a 14″ Apple Multiscan Color Monitor. Stimuli (12 point Geneva font) subtended approximate visual angles of 1.3° to 2.6° (horizontally) and 0.6° (vertically) from a viewing distance of 45 cm.

2.3. Design

Task (lexical decision [LD], recognition [RG]), lexicality (word [W], pseudoword [P]), and old/new (old [O], new [N]) were manipulated within subjects. Each subject received 48 trials per condition across six study-test blocks. All study blocks were procedurally identical. Half the test blocks were LD, and half the test blocks were RG. Task order was counterbalanced so that odd number blocks were LD for half the subjects, and even number blocks were LD for the other half. Lexicality and old/new were manipulated within each block. Response fingers (index and middle fingers of the right hand) were counterbalanced so that all finger/condition combinations occurred approximately equally across all subjects.

2.4. Procedure

Subjects started with a brief practice block including an 8-item study list, an 8-item LD test, and an 8-item RG test. Application of the Geodesic Electrode Net followed completion of the practice.

Each study list included 34 randomly intermixed items (half words and half pseudowords). The first and last items were non-tested buffers. Each item was displayed centrally for 1995 ms with a 1005 ms fixation (a plus sign) between trials. Subjects were asked to make lexical decisions as quickly as possible on each study trial and to memorize each item. The subjects were told that the identity of each test block was randomly determined, so they were encouraged to carefully study each list in case a recognition test followed. The type of the test block was revealed to the subject after the study list by presenting ‘Studied or Not Studied ?’ or ‘Word or Nonword ?’ on the screen prior to each test list.

Each test list included 64 items (16 PO, 16 PN, 16 WO, 16 WN). The entire list was divided into four, 16-item sublists containing four items from each condition (randomly intermixed). Subjects were allowed to rest as long as needed between each sublist. Because of excessive movement artifact following rest breaks in Experiment 1, a new filler item was added to the beginning of each sublist in Experiment 2. For LD blocks, subjects were instructed to press one key for words and the other for pseudowords. For RG blocks, subjects were instructed to press one key for old (studied) stimuli and the other for new (not studied) stimuli.

The timing of each trial event slightly differed between Experiments 1 and 2 because of a programming error in Experiment 1. Experiment 2 event timing was precisely synchronized with the refresh cycle of the display monitor (15 ms per cycle), but they were not synchronized in Experiment 1. Therefore, the actual timing of Experiment 1 events randomly varied from the desired timing (± 15 ms). Each trial began with a central fixation sign for a variable duration (Experiment 1: 455–871 ms; Experiment 2: 525–1005 ms). The fixation was replaced by the test stimulus for 1729 ms (Experiment 1) or 1995 ms (Experiment 2), which in turn was replaced by a central question mark. The question mark remained on the screen until the subject pressed a response key. An asterisk appeared when the subject responded and remained visible throughout the 2 s interstimulus interval. EEG recording began either 429 ms (Experiment 1) or 495 ms (Experiment 2) prior to stimulus onset and lasted for 2048 ms (512 samples @ 250 Hz). Subjects were instructed to wait for a question mark before responding, to remain as motionless as possible, and to minimize eye blinks.

2.5. EEG recording

Scalp voltages were collected with a 128-channel Geodesic Sensor Net™ [55] connected to a custom-built, AC-coupled, 128-channel, high input impedance amplifier (200 kΩ, Net Amps™, Electrical Geodesics Inc., Eugene, OR, U.S.A.). Amplified analog voltages (0.1–100 Hz bandpass) were digitized at 250 Hz. Individual sensors were adjusted until each reached an impedance of less than 50 kΩ. Though these impedances were somewhat higher than those obtained with other recording methods, high input impedance amplifiers enable low noise EEG recording with sensor impedances in the range of 50 kΩ [55].

2.6. EEG data reduction

Trials were dropped from analyses if they contained eye movements (vertical EOG channel difference greater than 70 μV) or more than five bad channels. Channels were considered bad for an individual trial if they changed more than 100 μV between adjacent samples, or reached amplitudes over 200 μV. Individual channels that were consistently bad for a given subject were excluded from all analyses for that subject. Most subjects had no excluded channels (26 of 32 in Experiment 1; 17 of 28 in Experiment 2), and the highest number of excluded channels was three (one subject in each experiment). All analyses were performed on across-channel means, so each subject's bad channels were excluded from the computation of these means. ERPs were baseline-corrected with respect to a 428 ms pre-stimulus interval and digitally low-pass filtered at 55 Hz.

Subjects with less than 16 good trials in any condition were removed from the final analyses. The final number of subjects retained was 32 in Experiment 1 and 28 in Experiment 2.[1] Rather than only including correct trials in the ERPs, as is often done, all artifact-free trials were used. Considering only correct trials would have biased the comparison of LD and RG tasks because accuracy is based on different discriminations in each task. For example, using only accurate trials could produce differences between RG and LD old/new effects merely because the RG old/new effect is based on accurately recognized words but the LD old/new effect would include potentially unrecognized words. Subjects rarely responded prior to stimulus offset, so these infrequent trials were not excluded from analyses.

ERPs are conventionally represented as voltage differences between each recording site and a reference site (e.g., the mastoid reference). Such voltage differences are spatially ambiguous insofar as each ERP represents a mixture of activity recorded at both the recording site and the reference site [33]. An average-reference transformation can be used to minimize the effects of reference site activity [6, 10, 11, 30, 56]. The average reference is computed for each channel as the voltage difference between that channel and the average of all channels. In principle, all head potentials will average to zero, so referencing each channel to the average would provide a reference-independent measure of the voltage at each site. In practice, the underside of the head cannot be sampled, so the measured average will deviate from zero [54]. The accuracy of the average-reference derivation (i.e., its approximation to a true zero reference) increases with the dense, extensive sampling provided by the 128-channel Net [11, 56], so it is the primary data representation considered here. However, to facilitate comparison with results from similar experiments in the literature, Appendix A (Fig. A1) shows grand-average ERPs computed with an average-mastoid reference for 15 standard locations from the international 10–20 system [24].

3. Results

3.1. Behavioral results

Behavioral results were combined from Experiments 1 and 2 for conciseness and statistical power. Table 1 shows the accuracy, reaction time (RT), and abbreviated labels for each condition. Accuracy was relatively high in all conditions, but more so in lexical decision than in recognition. Differences in recognition discrimination between words and pseudowords were assessed with a t-test on A'. A' is a measure of discrimination derived from signal-detection theory that corrects for response bias and ranges from 0 (chance) to 1 (perfect discrimination between old and new items) [12].[2] Discrimination was significantly higher for words ($A' = 0.92$) than pseudowords ($A' = 0.89$), $t(59) = 5.70$, $SE = 0.01$, $P < 0.001$.

Subjects were instructed to withhold responses until stimulus offset, so RTs (correct trials only) are measured from stimulus offset. RTs were entered into a task (recognition, lexical decision) by lexicality (words, pseudowords) by old/new ANOVA. RTs were faster for lexical decision than recognition, $F(1,59) = 8.09$, $MSE =$ 43,836, $P < 0.01$, and faster for old than new stimuli, $F(1,59) = 14.75$, $MSE = 19{,}758$, $P < 0.001$. The only other significant effect was a task by old/new interaction, $F(1,59) = 4.23$, $MSE = 18{,}462$, $P < 0.05$, suggesting that old/new effects were larger in recognition than in lexical decision. Old/new effects were analysed in each condition separately with t-tests and were significant in all conditions (all t's > 2.6, P's < 0.02) except for pseudowords in the lexical decision task, $t(59) = 1.39$, $SE = 10.95$.

3.2. ERP results

Analyses were intended to characterize the manner in which the ERP old/new effect interacted with task and lexicality, and to broadly characterize the temporal and spatial pattern of these interactions. The global spatial topography was assessed by dividing the electrodes into 8 spatial regions—2 lateral (left, right) $\times$ 2 caudal (anterior, posterior) $\times$ 2 vertical (inferior, superior)—and averaging the mean voltage amplitude of all channels within each region [10]. The channels falling into each region are indicated in Fig. 1, along with the abbreviations used to

[1] Data from 36 subjects were excluded (Exp. 1: $N = 22$; Exp. 2: $N = 14$). Many subjects had less than 16 good trails per condition because of excessive body movements ($N = 11$), eye movements ($N = 7$), recording equipment problems ($N = 7$), or a combination of these three factors ($N = 6$). Other subjects were removed because the computer malfunctioned ($N = 2$), the subject did the wrong task in 1 or more blocks ($N = 2$), or the subject left early because of 'claustrophobia' ($N = 1$).

[2] $A' = 1/2 + [(\mathrm{HIT} - \mathrm{FA})(1 + \mathrm{HIT} - \mathrm{FA})]/[4*\mathrm{HIT}(1 - \mathrm{FA})]$. FA = proportion of false alarms ('studied' responses to new items). HIT = proportion of hits ('studied' responses to old items).

Table 1
Mean accuracy and reaction time (RT) in each experimental condition

Task	Lexicality	Old/new	Abbreviation	% Correct	RT
Lexical decision	Pseudoword	Old	LPO	96	491
		New	LPN	97	506
	Word	Old	LWO	98	450
		New	LWN	97	482
Recognition	Pseudoword	Old	RPO	80	505
		New	RPN	85	572
	Word	Old	RWO	87	493
		New	RWN	87	577

Note: Results are combined across Experiments 1 and 2. RT is reaction time from stimulus offset.

denote each region. Cross-channel averaging retains two advantages of high-density sampling. First, the accuracy of the average-reference derivation increases with dense, extensive sampling [11, 56]. Second, an average of multiple measurements provides a more reliable sample of the activity within any region than a single discrete measurement taken within the same region. By analogy with the temporal sampling domain, most ERP studies use a fine-grained sampling rate (e.g., 4 ms/sample), but average across broader time windows (e.g., 100+ ms) for analyses. However, cross channel averaging only provides a more reliable sample of within-region activity if it does not obscure any high spatial frequency changes [15], so follow-up analyses focused on smaller spatial regions when warranted.

Separate repeated measures ANOVAs were computed for each consecutive 100 ms window from 100–1500 ms after stimulus onset. Each ANOVA included the following factors: task (LD, RG) $\times$ lexicality (P, W) $\times$ old/new (O, N) $\times$ laterality (L, R) $\times$ caudality (A, P) $\times$ verticality (I, S). The dependent measure was the mean amplitude of the average-reference voltage within each 100 ms window. Because unequal correlations among the different anatomical regions can violate the sphericity assumption of repeated-measures ANOVAs, ANOVAs were adjusted according to the conservative Geisser–Greenhouse procedure for sphericity violations [62]. Data from Experiments 1 and 2 were analysed separately, but only effects significant in each experiment separately ($P < 0.05$) were considered reliable. All Figures show the

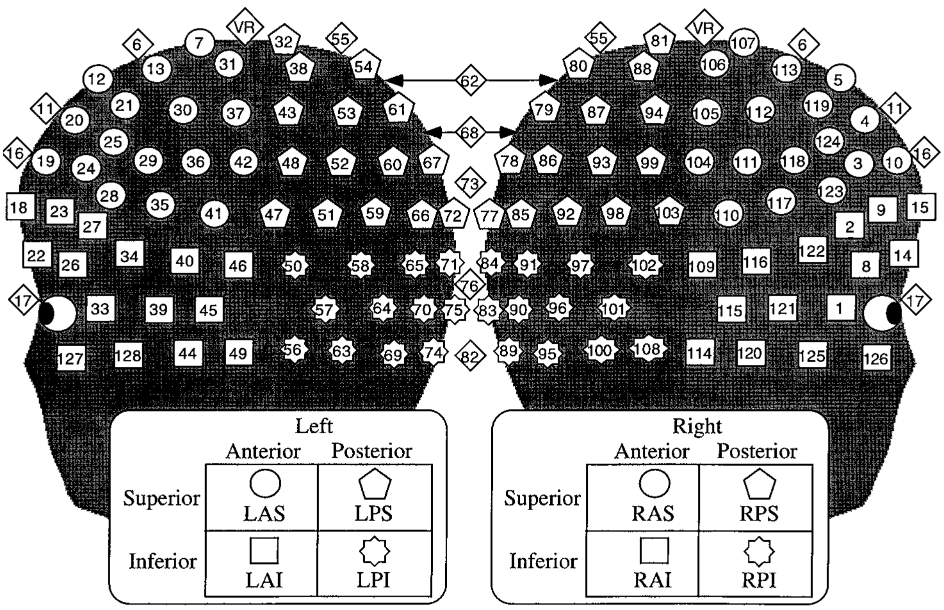

Fig. 1. Sensor locations on the 128-channel Geodesic Sensor Net. The approximate sensor locations were projected onto a 3-dimensional head model from which these 2-dimensional images were taken. Sensors appear more closely spaced at the edges because depth is lost in the 2-dimensional images, but actual electrode spacing is approximately equidistant throughout. Different symbols are used to denote channels within each of the 8 spatial regions used in ANOVAs. The tables define each symbol along with the abbreviations used for each region. Midline electrodes are denoted with diamond-shaped symbols. VR = vertex reference.

data collapsed across both experiments for brevity. The results of the initial ANOVAs will be summarized qualitatively before detailing the statistics.

Grand-average ERPs (average-reference, across both experiments) within each of the 8 regions are plotted in Fig. 2 (words) and Fig. 3 (pseudowords). The initial, 100 ms ANOVAs indicated that ERP differences between old and new items first reached significance between 300 and 400 ms. Follow-up ANOVAs showed that differences between words and pseudowords became significant between 250 and 300 ms (Exp. 1: $F(1,31) = 5.42$, $MSE = 0.02$, $P < 0.05$; Exp. 2: $F(1,27) = 11.37$, $MSE = 0.02$, $P < 0.01$), but old/new differences were marginally reliable during this period (Exp. 1: $F(1,31) = 2.97$, $MSE = 0.02$, $P = 0.09$; Exp. 2: $F(1,27) = 5.62$, $MSE = 0.03$, $P < 0.05$). Earlier lexicality than old/new effects are consistent with behavioral evidence that lexical decisions can be made faster than recognition judgments [21]. Within the 300–400 ms window, the old/new effect interacted across the vertical dimension. Lexicality and old/new interacted between 400 and 700 ms. Old/new effects waned between 700 and 1000 ms then restrengthened between 1000 and 1500 ms, but no longer interacted with lexicality. Most importantly, there were no reliable old/new × task interactions.

As previously summarized, old/new effects began simi-

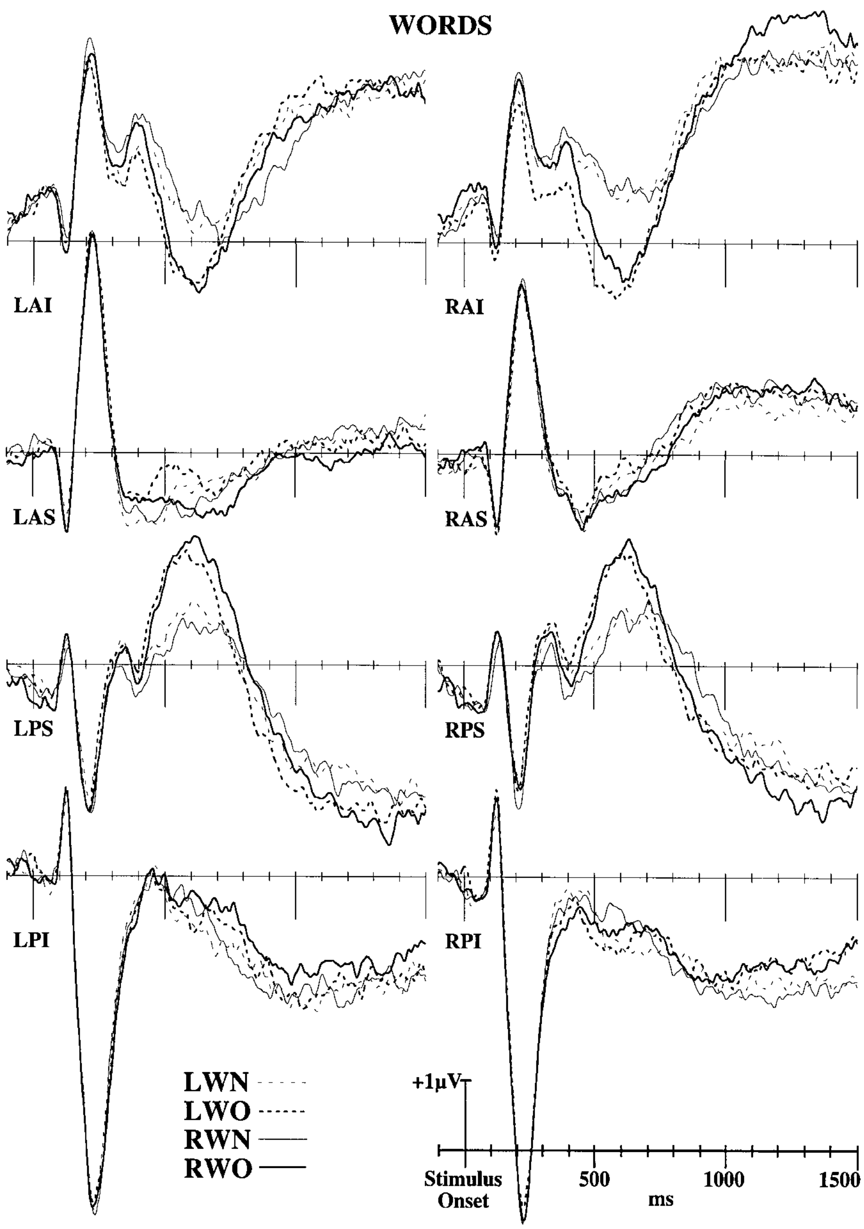

Fig. 2. Grand-average, average-referenced ERPs from words in Experiments 1 and 2. Plotted ERPs are channel means within each of the 8 spatial regions used for ANOVAs. See Fig. 1 for region abbreviations and corresponding electrode sites. LWO = Lexical Decision, Words, Old; LWN = Lexical Decision, Words, New; RWO = Recognition, Words, Old; RWN = Recognition, Words, New.

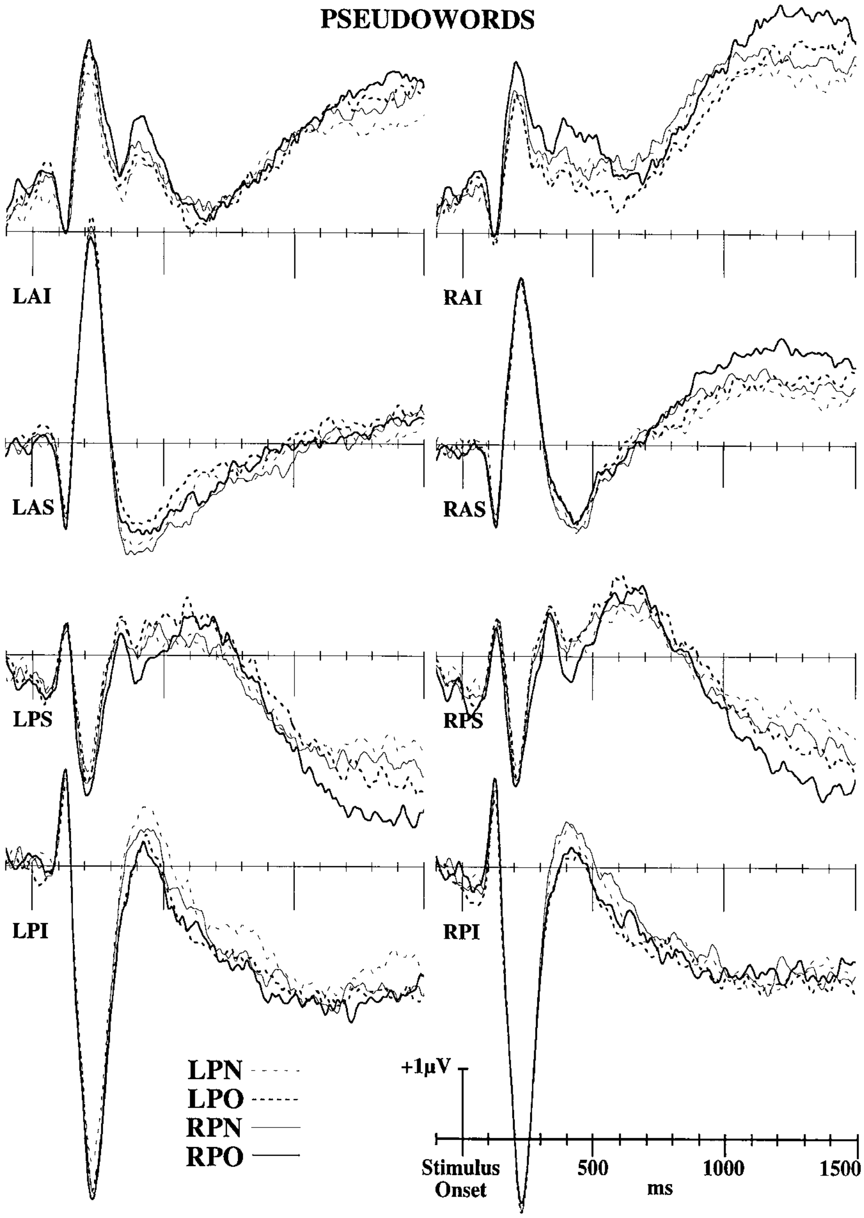

Fig. 3. Grand-average, average-referenced ERPs from pseudowords in Experiments 1 and 2. Plotted ERPs are channel means within each of the 8 spatial regions used for ANOVAs. See Fig. 1 for region abbreviations and corresponding electrode sites. LPO = Lexical Decision, Pseudowords, Old; LPN = Lexical Decision, Pseudowords, New; RPO = Recognition, Pseudowords, Old; RPN = Recognition, Pseudowords, New.

larly for words and pseudowords from 300 to 400 ms, but grew larger for words from 400 to 700 ms. Inspection of Fig. 4 (which plots both words and pseudoword ERPs collapsed across the two tasks) reveals two temporally overlapping, but topographically distinct, old/new effects. The first effect is maximal from 300 to 500 ms over the left, anterior, superior (LAS) region. The polarity and latency of the 300–500 ms effect is similar to the N400 described in language studies (reviewed by, [29]) and previous studies of recognition memory and word repetition [7, 46, 51, 57]. Because the present 300–500 ms effect is more frontally distributed than the centro-parietal N400, it will be denoted the 'FN400 old/new effect'.[3] The mirror image of the FN400 effect can be seen over posterior, inferior regions (LPI & RPI). The second effect is maximal over the left, posterior, superior (LPS) region from 400 to 700 ms, and corresponds to the P600 old/new effect. The mirror image of the P600 can be seen over anterior, inferior regions (LAI & RAI). Separate analyses were conducted to examine the FN400 and P600 old/new effects.

[3] I thank M. D. Rugg for pointing out topographic differences between N400 and FN400 (pers. comm., 8 October 1998).

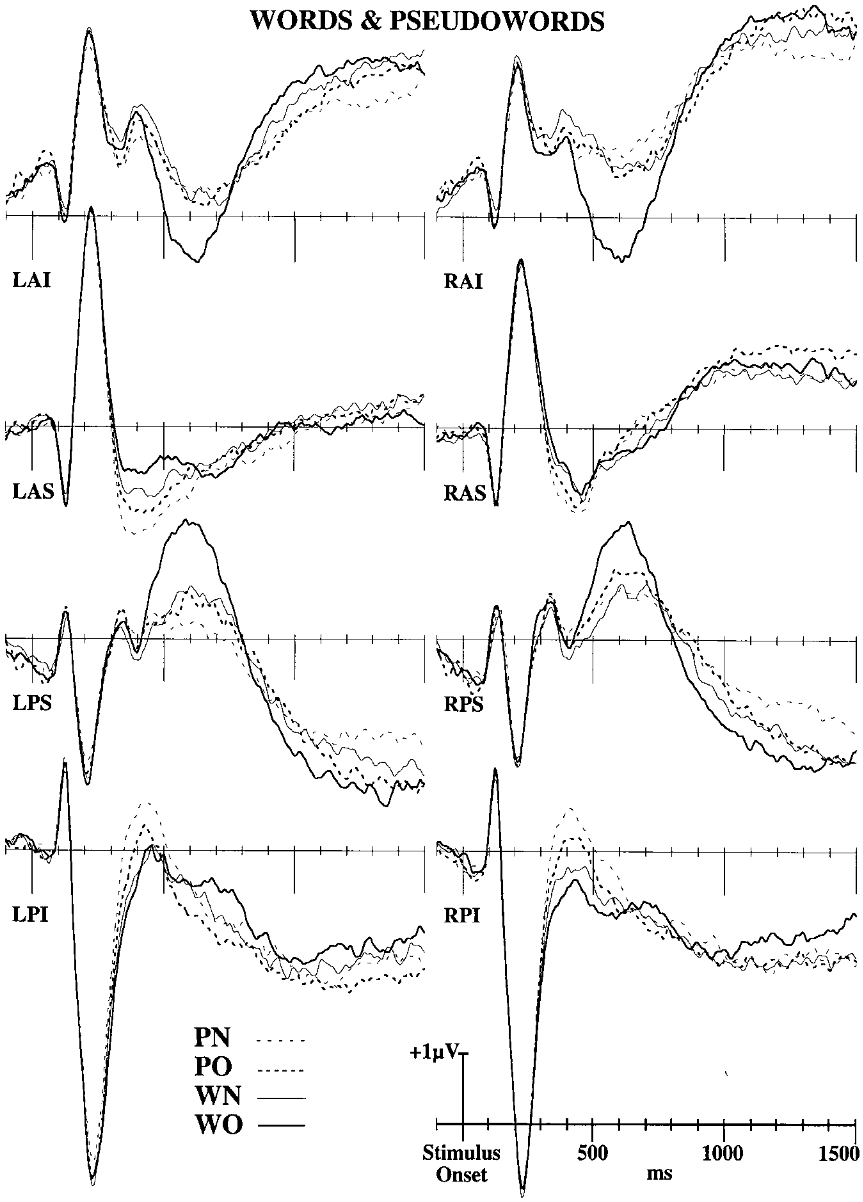

Fig. 4. Grand-average, average-referenced ERPs from words and pseudowords in Experiments 1 and 2. ERPs are collapsed across the recognition and lexical decision tasks. Plotted ERPs are channel means within each of the 8 spatial regions used for ANOVAs. See Fig. 1 for region abbreviations and corresponding electrode sites. PO = Pseudowords, Old; PN = Pseudowords, New; WO = Words, Old; WN = Words, New.

The FN400 effect was examined with an ANOVA including the anterior, superior (AS) and posterior, inferior (PI) regions: old/new × task (LD, RG) × lexicality (P, W) × laterality (L, R) × region (AS, PI). The dependent measure was mean amplitude between 300 and 500 ms. The main effect of lexicality was significant (Exp. 1: $F(1,31) = 17.77$, $MSE = 0.06$, $P < 0.001$; Exp. 2: $F(1,27) = 22.02$, $MSE = 0.06$, $P < 0.001$). Both lexicality (Exp. 1: $F(1,31) = 30.41$, $MSE = 0.68$, $P < 0.001$; Exp. 2: $F(1,27) = 40.57$, $MSE = 0.58$, $P < 0.001$) and old/new (Exp. 1: $F(1,31) = 9.24$, $MSE = 0.60$, $P < 0.01$; Exp. 2: $F(1,27) = 13.01$, $MSE = 0.46$, $P < 0.01$) interacted across the regions. Over anterior, superior regions (LAS & RAS), pseudowords were more negative than words, and new items were more negative than old items. The opposite was true over posterior, inferior regions (LPI & RPI). The polarity-reversing pattern is consistent with the presence of an electrical dipole (or dipoles) between these regions that is contributing to the old/new effect. The FN00 old/new effect did not interact with task or lexicality. The complete spatial topography of the old/new effect in each condition can be seen in Fig. 5. Figure 5 was constructed from the grand-average ERPs by taking the amplitude difference between old and new conditions at 388 ms (peak latency of the FN400), interpolating the differences across a spherical model of the head, and projecting the interpolated images onto a 3D head model. The topographies of the FN00 (Fig. 5) and

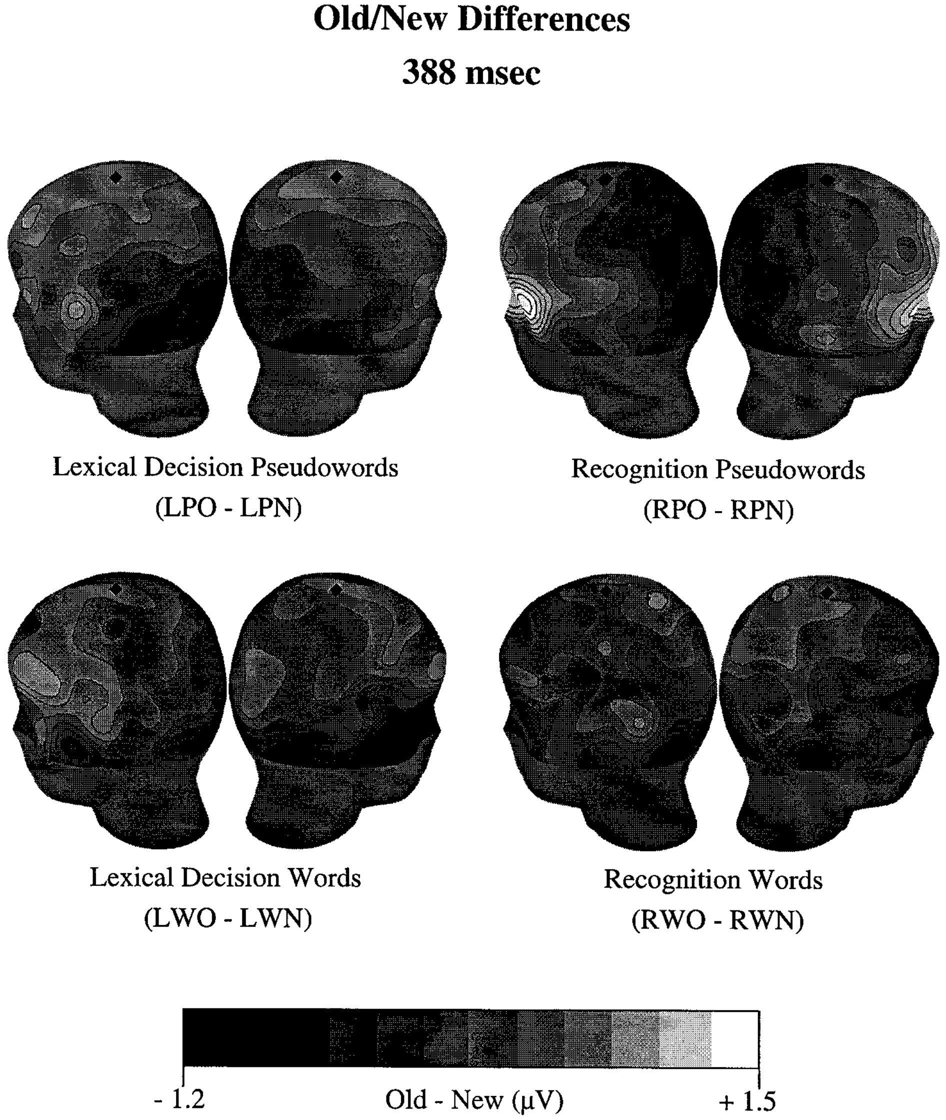

Fig. 5. Topographic distributions of old/new differences at 388 ms (FN400 peak latency). Contours lines are plotted every 0.21 μV. LPO–LPN = old/new differences for lexical decision, pseudowords. RPO–RPN = old/new differences for recognition, pseudowords. LWO–LWN- = old/new differences for lexical decision, words. RWO–RWN = old/new differences for recognition, words. The vertex is denoted with a black diamond.

P600 (Fig. 6) are shown at peak latency, rather than using mean amplitudes across the temporal windows used for ANOVAs, to highlight topographic differences between these temporally overlapping effects.

The P600 old/new effect was examined with ANOVAs including the anterior, inferior (AI) and posterior, superior (PS) regions: old/new (O, N) $\times$ task $\times$ lexicality $\times$ laterality $\times$ region (AI, PS). The dependent measure was mean amplitude between 400 and 700 ms. As in the previous window, both lexicality (Exp. 1: $F(1,31) = 11.75$, $MSE = 1.26$, $P < 0.01$; Exp. 2: $F(1,27) = 4.45$, $MSE = 1.18$, $P < 0.05$) and old/new (Exp. 1: $F(1,31) = 11.28$, $MSE = 0.96$, $P < 0.01$; Exp. 2: $F(1,27) = 31.22$, $MSE = 0.97$, $P < 0.001$) interacted across the regions. These two-way interactions were qualified by a three-way interaction between old/new, lexicality, and region (Exp. 1: $F(1,31) = 18.35$, $MSE = 0.74$, $P < 0.001$; Exp. 2: $F(1,27) = 11.98$, $MSE = 0.85$, $P < 0.01$). Contrasts comparing old and new conditions within each region (across tasks) indicated that old/new effects were significant within each region for words (all $P < 0.001$), but no regions showed reliable old/new effects for pseudowords. Old words were more positive than new words over posterior, superior regions (LPS & RPS), but the opposite pattern was observed over anterior, inferior regions (LAI & RAI). The P600 old/new effect did not interact with task. The complete topography of these old/new effects can be seen in Fig. 6 (584 ms is the peak latency of the P600).

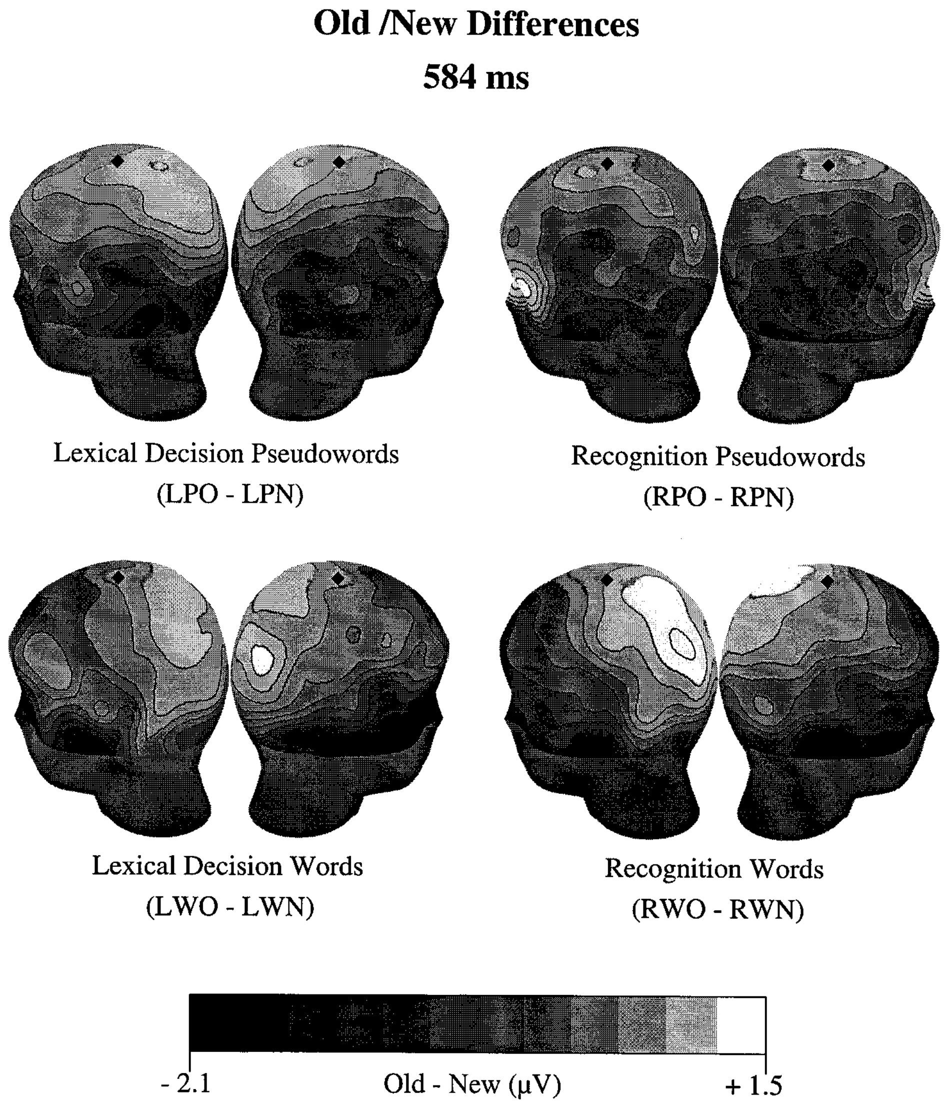

Fig. 6. Topographic distributions of old/new differences at 584 ms (P600 peak latency). Contours lines are plotted every 0.28 μV. LPO–LPN = old/new differences for lexical decision, pseudowords. RPO–RPN = old/new differences for recognition, pseudowords. LWO–LWN = old/new differences for lexical decision, words. RWO–RWN = old/new differences for recognition, words. The vertex is denoted with a black diamond.

The previously presented analyses focused on separate regions in which the FN400 and P600 effects were maximal. Topographic analyses were conducted to determine if the FN400 and P600 old/new effects were associated with globally distinct topographic patterns. Normalized old/new differences were entered into latency window (FN400 [300–500 ms], P600 [400–700 ms]) by lexicality by lateral by caudal by vertical ANOVAs (collapsed across tasks). Normalized (z-scores across regions within each window $\times$ lexicality condition) were analysed to focus on qualitative rather quantitative differences in topography [32]. Normalized differences in the two windows interacted across the caudal (Exp. 1: $F(1,31) = 11.37$, $MSE = 0.50$, $P < 0.01$; Exp. 2: $F(1,27) = 7.32$, $MSE = 0.80$, $P < 0.05$) and vertical dimensions (Exp. 1: $F(1, 31) = 6.74$, $MSE = 0.43$, $P < 0.05$; Exp. 2: $F(1,27) = 5.75$, $MSE = 0.39$, $P < 0.05$). P600 old/new differences were strongly positive over posterior regions and strongly negative over anterior regions. FN400 old/new differences were similar over posterior and anterior regions. Old/new differences were positive over superior regions and negative over inferior regions for both the FN400 and P600 windows, but this polarity reversal was more pronounced for the P600 than the FN400. Overall, these spatial interactions indicate topographic differences between the FN400 and P600 old/new (Figs 5 and 6).

Later old/new effects between 1000 and 1500 ms had the opposite topography (superior: new > old; inferior: old > new) than earlier effects. Similar late, superior old/new effects have been observed previously [60, 61]. Wilding and Rugg [60] concluded that these effects were response-related because of correlations between RT and amplitude (Pz, 1100–1400 ms). Such correlations are less meaningful in the present experiments because of the delayed-response procedure, but the effects could be related to response preparation. Most importantly, these very late effects did not interact with task or lexicality.

The previous analyses failed to reveal any instance in which the old/new effects differed between the recognition and lexical decision tasks—suggesting no effects of retrieval intention. Post hoc analyses focused on visually suggestive task differences to guard against Type II errors. First, Fig. 5 shows that the topography of the 300–500 ms old/new effects is similar for the LPO–LPN, LWO–LWN, and RWO–RWN comparisons, but the RPO–RPN comparison noticeably differs from the others. Although not captured in the initial ANOVAs, old pseudowords appear to elicit more positive voltages than new pseudowords over mid-frontal sites directly above the eyes. Post-hoc t-tests compared old and new conditions over the mean of this mid-frontal region (channels 2, 8, 9, 14, 15, 17, 18, 22, 23, 26, 27, see Fig. 1 for channel locations) for each task by lexicality condition separately. In the recognition task, ERPs were significantly more positive for old than new pseudowords in both experiments (Exp. 1: $t(31) = 2.78$, $SE = 0.24$, $P < 0.01$; Exp. 2: $t(27) = 3.26$, $SE = 0.16$, $P < 0.01$). Among the other conditions, the only comparison to reach significance in a single experiment was in the opposite direction (Exp. 2: RWO < RWN, $t(27) = -2.14$, $SE = 0.22$, $P < 0.05$). Thus, a unique mid-frontal old/new effect was observed only for pseudoword recognition between 300 and 500 ms. This pseudoword recognition effect appears to persist from 500 to 700 ms (Fig. 6), but the later effect was not reliable (Exp. 1: $t(31) = 1.89$, $SE = 0.29$, $P = 0.07$; Exp. 2: $t(27) = 1.16$, $SE = 0.14$, $P > 0.10$).

Inspection of Fig. 6 suggests that the late ERP old/new effect for words may be different between tasks. The effect appears larger for lexical decision than recognition over anterior, inferior regions, but larger for recognition than lexical decision over posterior, superior regions. To examine these possible task differences, mean amplitudes were computed across the anterior, inferior and posterior, superior regions (averaged across hemispheres). Midline channels (anterior: channel 17; posterior: channels 55, 62, 66, 73; all excluded from the original analyses) were included because apparent task differences included midline channels. Old/new differences were computed within each of these two regions. T-tests failed to identify significant effects when the LWO–LWN differences were compared with the RWO–RWN differences: (a) anterior (Exp. 1: $t(31) = 0.29$, $SE = 0.18$; Exp. 2: $t(27) = -0.13$, $SE = 0.20$), (b) posterior (Exp. 1: $t(31) = 1.27$, $SE = 0.16$, $P > 0.20$; Exp. 2: $t(27) = 1.14$, $SE = 0.19$, $P > 0.20$).

Finally, it appears that old/new differences for words may be larger for recognition than lexical decision from 1000 to 1500 ms within the RAI region (Fig. 2). Task × old/new ANOVAs (1000–1500 ms, RAI region only) showed a significant task by old/new interaction for Experiment 1 ($F(1,31) = 4.29$, $MSE = 0.42$, $P < 0.05$) that was not replicated in Experiment 2 ($F < 1$).

4. General discussion

The present experiments identified three distinct ERP old/new effects that were separable on the basis of timing, topography, and sensitivity to experimental variables. First, an FN400 old/new effect was maximal over anterior, superior and posterior, inferior regions between 300 and 500 ms. The FN400 old/new effect did not vary with task or lexicality. Second, a mid-frontal old/new effect between 300 and 500 ms was only observed for pseudoword recognition. Third, a P600 old/new effect was maximal over posterior, superior and anterior, inferior regions. The P600 effect was larger for words than pseudowords, but did not vary between tasks.

These experiments were primarily intended to examine the effect of retrieval intention on the P600 old/new effect. The P600 effect did not differ between an intentional recognition task and an incidental lexical decision task, so it was not amplified by retrieval intention. Theoretically, the results support prior claims that retrieval processes associated with recollection are not necessarily related to intentional retrieval, so recollected information may come to mind incidentally or involuntarily [38, 39, 47, 48].[4] The absence of retrieval intention effects could be specific to the present conditions. Retrieval intention can influence ERP old/new effects in continuous recognition [34, 52] and word-stem completion paradigms [3]. Retrieval intention could also influence the P600 old/new effect under different study-test recognition conditions. First, retrieval intention may increase the P600 old/new effect under conditions that are more demanding (present accuracy rates were high) or more likely to foster intentional retrieval strategies (e.g., memory search [16]). Second, deeper encoding conditions may enhance the subsequent efficacy of intentional retrieval. Third, the present results may be peculiar to the very low frequency words (1 to 2 occurrences per million) that were used. ERP old/new effects interact with word frequency in both direct and indirect tasks [40, 43, 44], and word frequency could mediate any effects of retrieval intention. Though the P600 old/new effect may benefit from retrieval intention under other conditions, the present results show that the effect can be independent of retrieval

[4] The finding that ERP old-new effects do not differ between recognition and lexical decision also reaffirms previous demonstrations that ERP old-new effects are not solely caused by differential responding to old and new items [27, 35, 42, 50].

intention, so there is no necessary link between retrieval intention and recollection.

The conclusion that the present P600 effect is associated with recollection depends on assuming equivalence to the late old/new effect related to recollection in previous research [35, 36, 43, 49, 51, 58, 59, 61]. This assumption is supported by the replication of the usual spatiotemporal pattern (reviewed in, [2, 26, 41]). Old stimuli were more positive than new stimuli over posterior, superior regions, and the effect peaked temporally around 600 ms. However, it should be acknowledged that the posterior, superior P600 effect is often left lateralized, and laterality differences were not reliable in the present experiments. The finding that the P600 old/new effect was larger for words than pseudowords is also consistent with a relationship to recollection. Introspective research indicates that better recognition of words than pseudowords is primarily attributable to greater detailed 'remembering' of words than pseudowords [9, 14].

A novel finding related to the P600 was the opposite polarity pattern (old $<$ new) over anterior, inferior regions suggesting the possibility that the late old/new effect is partially generated by an electrical dipole (or dipoles) situated between the posterior, superior and anterior, inferior regions. There are two primary reasons why previous experiments may not have detected the inferior, anterior aspect of this effect. First, the effect was maximal at recording sites that are more inferior than those typically sampled. Second, the effect was clarified by the average-reference transformation. Old stimuli were more negative than new stimuli near the mastoids (Fig. 6), so typical mastoid-referenced recordings would obscure differences of the same polarity at other sites and magnify opposite-polarity differences at superior sites. The P600 old/new effect at Fp1 and Fp2 (often the most anterior, inferior sites sampled) was significant for words with the average-reference, but not with the average-mastoid reference (Fig. A1).

The P600 old/new effect was distinct from an earlier FN400 old/new effect (300–500 ms) over anterior, superior (new $<$ old) and posterior, inferior regions (new $>$ old). The FN400 and P600 ERP effects were also functionally dissociated in the present experiments. Whereas the P600 old/new effect was significant for words but not pseudowords (replicating Swick and Knight [52]), the FN400 old/new effect did not interact with lexicality. Effects similar to the present FN400 have been previously observed with continuous picture recognition [13], combined single-item recognition and associative recall after studying word pairs [53], and a standard study-test word recognition paradigm [45].

The FN400 may be related to the familiarity component of dual-process recognition theories. Rugg et al. [45] recorded functionally distinct old/new effects over frontal and parietal scalp locations between 300 and 500 ms. They suggested that the frontal FN400-like effect may be associated with familiarity because it did not vary with depth of study processing. The present FN400 old/new effect was similar for words and pseudowords, but the P600 old/new effect was larger for words. If the FN400 effect reflects familiarity and the P600 reflects recollection, these results would be consistent with introspective research indicating that words are more likely to be recognized on the basis of detailed 'remembering' whereas pseudoword recognition relies more on vague feelings of 'knowing' [9, 14]. Hintzman and Curran [19, 20, 22] have differentiated recollection and familiarity with a paradigm that requires subjects to remember the plurality of studied words (e.g., DOGS, TABLE). During recognition testing, words presented in the same plurality (DOGS, TABLE) are as familiar as words presented in the opposite plurality (DOG, TABLES), so subjects rely on recollection to discriminate between studied and plurality-reversed words. Hintzman and Curran [19] found that familiarity effects occur faster than recollection effects—a finding that is consistent with the relative timing of the FN400 and P600. Recent ERP experiments using the plurality recognition procedure (Curran, submitted) indicate that FN400 old/new effects are similar for studied and plurality-reversed words (as would be expected from a fast familiarity process), but P600 effects are greater when subjects respond positively to studied than to plurality-reversed words (as would be expected from a slower recollection process).

Another functionally and topographically distinct ERP old/new effect was recorded from 300 to 500 ms. In the pseudoword recognition condition only, old pseudowords were more positive than new pseudowords over mid-frontal sites directly above the eyes (Fig. 5). This pseudoword recognition effect was the only reliable old/new effect specifically related to retrieval intention in these experiments. The effect was replicated across the two experiments, and it was recorded over sites that are more inferior than those typically sampled. Future research will be needed to reaffirm the reliability of this unexpected effect and clarify its functional significance.

In summary, the P600 ERP old/new effect did not increase with retrieval intention under the present conditions. The effect was greater for words than pseudowords and was maximal over posterior, superior (old $>$ new) and anterior, inferior (old $<$ new) regions. An earlier, but temporally overlapping, FN400 old/new effect also was insensitive to retrieval intention; was similar for words and pseudowords; and was maximal over anterior, superior (new $<$ old) and posterior, inferior (new $>$ old) regions. A third, previously undescribed, old/new effect (also 300–500 ms) was specific to pseudoword recognition over mid-frontal sites (old $>$ new). The FN400 and P600 effects may be related to familiarity and incidental recollection, but the nature of the mid-frontal pseudoword recognition effect is uncertain.

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Appendix

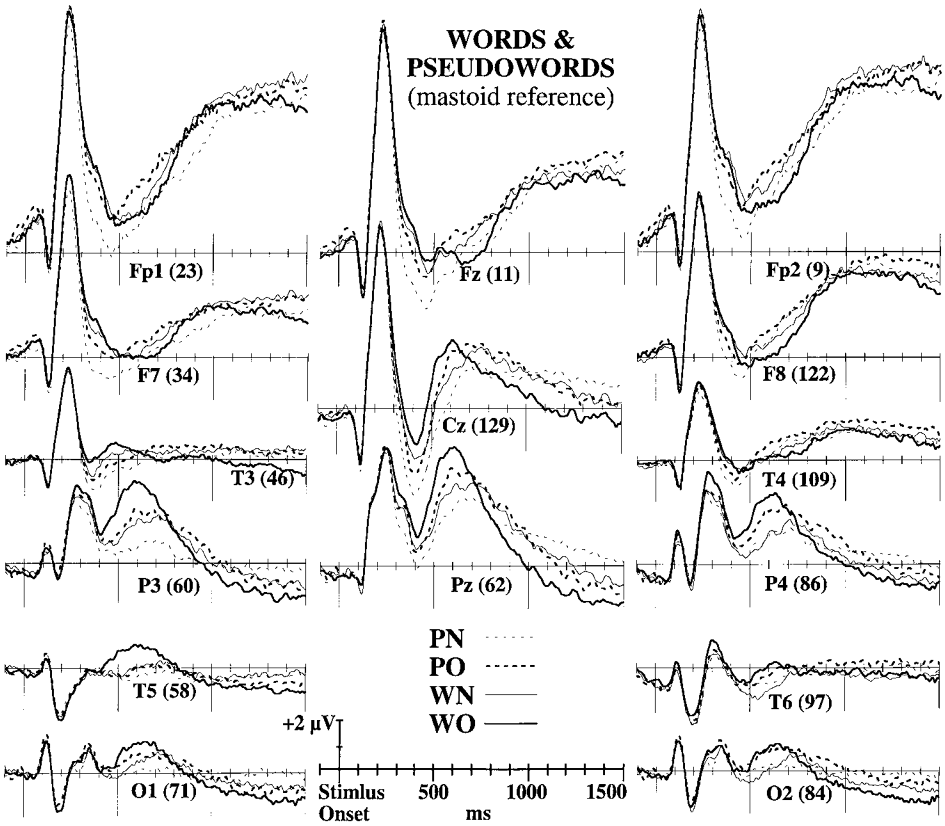

Fig. A1. Grand-average, average-mastoid referenced ERPs from words and pseudowords in Experiments 1 and 2. ERPs are collapsed across the recognition and lexical decision tasks. Each channel is identified by its nearest 10–20 system label along with parenthetical numbers corresponding to the sensor location (Fig. 1). PO = Pseudowords, Old; PN = Pseudowords, New; WO = Words, Old; WN = Words, New.

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