Research report

Neural activity associated with the realization of a delayed intention

Robert West*, Ryan W. Herndon, Stephen J. Crewdson

Department of Psychology, 118 Haggar Hall, University of Notre Dame, Notre Dame, IN 46556, USA

Abstract

This study examines neural activity associated with the realization of a delayed intention within the context of the noticing+search model of prospective memory (PM) using event-related brain potentials (ERPs). The noticing+search model proposes that PM is supported by two related processes, noticing (the detection of a PM cue in the environment) and search (the retrieval of an intention from memory). In two experiments participants performed a PM task that permitted the dissociation of the noticing and search processes. Noticing was associated a phasic negativity over the occipital-parietal region (N320) and search was associated with a sustained modulation (slow-wave) reflecting a negativity over the right frontal region and a broadly distributed positivity over the parietal region. The amplitude of the N320 was greater when the PM cue was associated with an intention than when the cue was irrelevant to task performance, leading to the proposal that noticing may be accomplished through the attentional modulation of neural systems which support processing of the defining features of the PM cue. The topography of the slow-wave resembled that of modulations of the ERP associated with the recollection of information in studies of retrospective memory leading to the suggestion that similar neural processes may support the recovery of information from memory in both prospective and retrospective memory tasks. © 2001 Elsevier Science B.V. All rights reserved.

1. Introduction

Prospective memory (PM) or the realization of delayed intentions represents a fundamental, yet poorly understood, aspect of cognition [15]. PM plays a critical role in activities as mundane as the preparation of a meal where it is necessary to boil the water, chop the vegetables, and set the table in a timely fashion; and as demanding as the task of an air traffic controller who must schedule the movements of a number of aircraft and other vehicles in response to specific temporal or environmental cues. While the importance of PM in daily life is self evident, our knowledge of the neurocognitive mechanisms supporting efficient PM is severely limited.

McDaniel and Einstein [9,14,15] have proposed that the realization of an intention is supported by both a prospec-

tive component (*noticing* — the realization that something is to be done) and a retrospective component (*search* — retrieval of an intended act from memory). Noticing is thought to be a relatively automatic process that shares some of the characteristics of familiarity described in models of recognition memory [4,12]. In comparison, search is thought to reflect a more effortful or controlled interrogation of memory, similar to recollection, that is elicited by the noticing process and may serve to establish the significance of the PM cue or retrieve the associated intention from memory [11,14].

Recent studies have provided evidence that the prospective and retrospective components of prospective memory are dissociable. For instance, in one study the prospective component of PM was more strongly influenced by a change in the characteristics of the PM cue from encoding to realization than the degree of semantic relatedness between the PM cue and intention; while the retrospective component of PM was more strongly influenced by the degree of semantic relatedness between the PM cue and

*Corresponding author. Tel.: +1-219-631-7257; fax: +1-219-631-8883.

E-mail address: west.19@nd.edu (R. West).

intention, than a change in the visual characteristics of the PM cue from encoding to realization [7]. Other evidence for a dissociation between these two aspects of prospective memory can be found in a study where varying the perceptual salience of the PM cue exerted a strong influence on the prospective component of PM and had relatively little effect on the retrospective component of PM [6]. Together these data demonstrate that the prospective and retrospective components of PM are influenced by qualitatively different variables leading to the hypothesis that they may also be supported by distinct neural systems.

In the current study we sought to identify the neural correlates of the realization of a delayed intention through the integration of the recently developed partial cue PM task [25] and event-related brain potentials (ERPs). The neurocognitive architecture supporting PM is currently poorly understood. Evidence from a number of studies indicates that a disruption of the functional integrity of the frontal cortex leads to an impairment of PM [3,5,16] and that greater levels of cerebral blood flow are observed in the frontal cortex and parahippocampal gyrus during performance of a PM task relative to a control condition [18]. However, based upon available data we know nothing about the time course and very little about the functional characteristics of the events supported by these neural systems.

ERPs offer real-time temporal resolution of neural processes, permitting a precise analysis of the time course of neural events supporting task performance. ERPs reflect event locked electrical activity generated by neural ensembles and consist of a series of positive and negative deflections above some pre-stimulus baseline level of activity. For instance, the third positive deflection in the waveform is generally labeled the P3, and a negative deflection occurring at 400 ms post stimulus onset would be labeled N400. By examining the effects of various task conditions on the ERPs one can establish the degree to which various cognitive operations are related to observed patterns of neural activity.

The partial cue PM task includes three types of trials (i.e., semantic judgment, PM cue, and PM lure). For semantic judgment trials, pairs of words are presented in lowercase letters and individuals are required to determine whether or not the words are semantically related. For PM cue trials, the word pair is presented in uppercase letters and the individual is instructed to press a key representing a prospective response other than those keys used to make semantic judgments. For PM lure trials, one of the words is presented in uppercase letters and one in lowercase letters. On these trials individuals are instructed to ignore the change in case and make a semantic judgment. In this task we assume that: (1) PM cue trials are associated with both the detection of a possible PM cue (noticing) and the retrieval of an intention from memory (search); (2) PM lure trials are associated with the detection of a possible PM cue (noticing), but not retrieval of the intention from

memory (search); and (3) semantic judgment trials are associated with neither noticing or search. Based upon these assumptions, an index of noticing can be obtained by considering ERP modulations differentiating PM cue and PM lure trials from semantic judgment trials; and an index of search can be obtained by considering ERP modulations differentiating PM cue trials from PM lure trials and semantic judgment trials.

To our knowledge, this is the first study to apply ERPs to the study of PM. Therefore, it is difficult to make specific predictions with regard to where in the ERP waveform differences between the three task conditions will be observed. Previous studies of retrospective memory (i.e., remembering past events) incorporating visually presented stimuli using ERPs have revealed that automatic or implicit influences on memory are often associated with modulations of the ERPs over the occipital-parietal region observed between 200 and 500 ms after stimulus onset [20,24]. For instance, in a study of recognition memory the ERPs elicited by previously presented words differed from those elicited by new words regardless of whether or not the old words were successfully recognized, leading to the suggestion that this modulation reflected the influence of implicit memory processes [23]. In a similar finding, Schnyer et al. [24] reported that the ERPs elicited by recognized and masked words differed from the ERPs elicited by new words between 200 and 500 ms (evidence for the influence of implicit memory), while the ERPs elicited by recognized words differed from new and masked words between 500 and 1000 ms (evidence for the influence of explicit memory). In contrast to the relatively early effects associated with implicit memory, controlled or explicit influences on memory are often associated modulations of the ERPs that are distant from stimulus onset (i.e., 400–1000 ms) and tend to be distributed over the parietal and frontal regions [1,19]. If there is some overlap between the characteristics of those neural processes supporting prospective memory and those supporting retrospective memory one could expect the ERPs associated with noticing to precede in time and have an occipital-parietal distribution relative to those associated with search that should in contrast be distributed over the parietal and frontal regions.

Experiment 1 was designed to identify the ERP correlates of the realization of an intention within the context of the partial cue PM task. We predicted that noticing would be characterized by an ERP modulation differentiating PM cue and PM lure trials from semantic judgment trials, while search would be characterized by an ERP modulation differentiating PM cue trials from PM lure and semantic judgment trials. Furthermore, if noticing initiates the search process the ERPs associated with noticing should be observed earlier in the trial epoch than the ERPs associated with search. In anticipation of the results, noticing was associated with a phasic negativity that was broadly distributed over the occipital-parietal region

(N320) and search was associated with a slow-wave that reflected negativity over the right frontal region and positivity over the parietal region.

In Experiment 2 we sought to determine the degree to which the N320 was related to the presence of an intention to make a prospective response or simply reflected a neural response to the perceptual change embodied by the PM cue and PM lure trials. To achieve this goal in blocks one to 20 of the task individuals were instructed to make semantic judgment for all trials and that the PM cue and PM lure trials were not relevant to task performance (PM ignore condition). In blocks 21–40 of the task individuals responded to semantic judgment, PM cue, and PM lure trials as in Experiment 1 (PM attend condition). If the N320 is independent of the intention to make a prospective response and simply reflects the detection of the perceptual change from semantic judgment to PM cue and PM lure trials the amplitude of this modulation should be similar in the PM attend and PM ignore conditions. In comparison, if the N320 is providing some index of the noticing process the amplitude of this modulation should be greater in the PM attend condition than the PM ignore condition.

2. Method

2.1. Subjects

Thirty-six volunteers 19–21 years of age participated in the experiments (18 in each experiment with nine females in Experiment 1 and 11 females in Experiment 2). All participants reported normal or corrected to normal visual acuity and reported a right hand preference. Participants received course credit for their participation.

2.2. Materials and procedure

2.2.1. Experiment 1

For the PM task, 600 related word pairs were drawn from 50 categories of the Battig and Montague [2] category norms, excluding the categories girls names, male names, city, state, college or university, and members of clergy. Twelve word pairs were selected from each category. Six hundred unrelated word pairs were formed by randomly repairing exemplars from different categories. This resulted in each word appearing 4 times over the course of the task. These 1200 trials were divided into 40 blocks of 30 trials, with 15 related and 15 unrelated trials in each block. Within each block, 28 trials (14 related and 14 unrelated) were presented in lowercase letters; on these trials the individual was to respond by pressing the (N) key, with the right index finger, if the words were semantically related and the (M) key, with the right middle finger, if the words we not semantically related. One of the remaining trials in each block was a PM cue trial and the other was a PM lure trial. For the PM cue trial both words

appeared in uppercase letters and individuals were instructed to press the (V) key, with the left index finger, upon detecting the PM cue. For the PM lure trial, one of the words was presented in uppercase letters and one of the words was presented in lowercase letters and individuals were instructed to ignore this change in the display and make a semantic judgment. PM cue and lure trials were presented on trials 5–29 and were separated by a minimum of five semantic judgment trials. In 20 blocks of trials the PM cue preceded the PM lure, and in 20 blocks of trials the PM cue followed the PM lure. The word pairs were presented on a computer monitor, centered on the vertical and horizontal axis, until a response was made. Following a response the screen was blank for 500 ms and then the word pair for the next trial was presented.

2.2.2. Experiment 2

The PM task was the same as that used in Experiment 1. For blocks 1–20 individuals were required to make semantic judgments to all stimuli and instructed that the PM cues and PM lures should be ignores. For blocks 21–40 the instructions were the same as those use in Experiment 1.

2.3. Electrophysiological recording and analysis

2.3.1. Experiment 1

The EEG (bandpass 0.01–100 Hz), digitized at 512 Hz, was recorded from an array of 45 tin electrodes (Fpz, Fz, Pz, Oz, Iz, Fp1, Fp2, Af3, Af4, F3, F4, F7, F8, F9, F10, Fc1, Fc2, Fc5, Fc6, Ft9, Ft10, C3, C4, T7, T8, Cp1, Cp2, Cp5, Cp6, P3, P4, P7, P8, Po3, Po4, O1, O2, Po9, Po10, M1, M2, Lo1, Lo2, Io1, Io2). Vertical and horizontal eye movements were recorded from electrodes placed lateral to and below the right and left eyes. During recording all electrodes were referenced to Cz; for data analysis, they were re-referenced to an average reference [22] and a 20-Hz lowpass filter was applied.

ERP analysis epochs were extracted off-line and included 200 ms of pre-stimulus activity and of 1000 ms post-stimulus activity. Trials contaminated by excessive eye or movement artifacts, peak-to-peak deflections over 100 μV, were rejected before averaging. ERPs were averaged for trials associated with correct PM cue and PM lure trials, and semantic judgment trials immediately preceding PM cue and PM lure trials.

All statistical tests were performed on mean voltages averaged over 50-ms windows where modulations of interest were observed relative to mean voltage of the 200 ms pre-stimulus baseline activity. The N320 was measured between 295 and 345 ms, and the slow-wave was measured between 550 and 600 ms. Statistical tests were performed using the multivariate F ratio based upon Wilks' λ in a series of MANOVAs with a $P<0.05$ level of significance.

2.3.2. Experiment 2

The EEG was acquired and analyzed in the same manner as in Experiment 1, with the exception that a 100-ms pre-stimulus baseline was used when averaging the ERPs. The shorter baseline was used in Experiment 2 as a number of subjects tended to blink quite frequently in the 500-ms interval between the response and the next stimulus leading to a large number of trials being lost to artifact when a 200-ms baseline was utilized.

3. Results

3.1. Experiment 1

Mean levels of response accuracy and response time are presented in Table 1. The accuracy of semantic judgments was similar to that reported in previous research using this task [25]. PM cues almost always elicited a correct prospective response and PM lures were generally associated with a semantic judgment. There were reliable differences in response latency for semantic judgment, PM cue, and PM lure trials ($F(2,34)=36.26$, $P<0.001$). Response time was faster for PM cue trials than for semantic judgment trials ($t(17)=2.88$, $P<0.01$), and slower for PM lure trials ($t(17)=5.43$, $P<0.001$) than semantic judgment trials.

Fig. 1 presents the grand averaged ERPs for semantic judgment, PM cue, and PM lure trials at selected electrode locations. An ERP modulation (N320) was observed that differentiated semantic judgment trials from PM cue and PM lure trials (e.g., electrodes Po9, Po10). The N320 was quantified in a 3 (condition)×2 (hemisphere)×4 (region: Af3–Af4, Fc1–Fc2, P7–P8, Po9–Po10) MANOVA. This modulation represented a broadly distributed negativity over the occipital-parietal region and positivity over the frontal-central region for PM cue and PM lure trials relative to semantic judgment trials (condition×region $\lambda=0.28$, $F(6,12)=5.24$, $P<0.007$). Follow-up analyses revealed that the amplitude of the N320 was similar for PM cue and PM lure trials (condition×region $\lambda=0.88$,
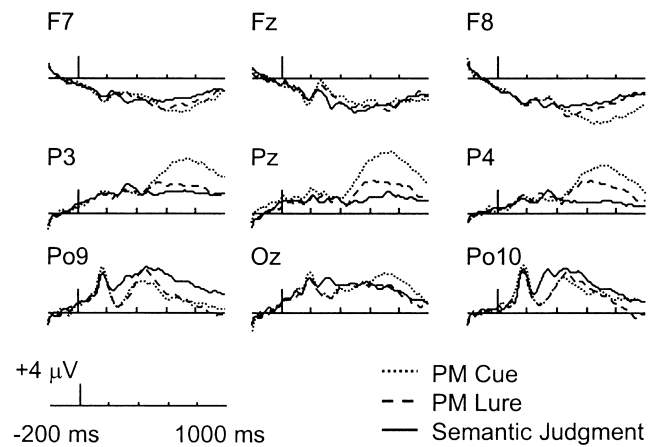

Fig. 1. Grand average ERPs for select electrodes in Experiment 1. Notice the N320 reflecting negativity over the occipital-parietal region, and the slow-wave reflecting a negativity over the right frontal region and positivity over the parietal region. The tall bar reflects stimulus onset.

$F(3,15)=0.65$, $P>0.50$), and that both PM cue trials (condition×region $\lambda=0.52$, $F(3,15)=4.67$, $P<0.02$) and PM lure trials (condition×region $\lambda=0.33$, $F(3,15)=10.30$, $P<0.001$) were significantly different from semantic judgment trials.

A slow-wave was observed that differentiated PM cue trials from PM lure and semantic judgment trials and reflected a negativity over the right frontal region (e.g., electrode F8) and a positivity over the parietal region (e.g., electrodes P3 and P4). Over the right frontal region the ERPs elicited on semantic judgment and PM lure trials were nearly identical and the ERPs elicited on PM cue trials were more negative between 600 and 900 ms after stimulus onset. The slow-wave was quantified in a 3 (condition)×3 (electrode: F8, F10, Ft10) MANOVA over the right frontal region. In this analysis the main effect of condition was significant ($\lambda=0.67$, $F(6,16)=4.21$, $P<0.04$; semantic judgment $M=-1.81$ μV, PM lure $M=-2.52$ μV, PM cue $M=-5.12$ μV). The pattern of neural activity was somewhat different over the parietal region. Over the left hemisphere the ERPs elicited by semantic judgment and PM lure trials were similar in amplitude, while the ERPs elicited by PM cue trials demonstrating a greater positivity between 600 and 900 ms after stimulus onset than either of the other conditions (e.g., electrode P3). In contrast, over the right parietal region the ERPs elicited by both PM cue and PM lure trials demonstrated greater positivity than semantic judgment trials (e.g., electrode P4). Over the parietal region the slow-wave was quantified in a 3 (condition)×2 (hemisphere)×3 (region: Cp1–Cp2, Cp5–Cp6, P3–P4) MANOVA. In this analysis the condition×hemisphere interaction was significant ($\lambda=0.62$, $F(6,12)=5.04$, $P<0.03$), consistent with the observation that the pattern of neural activity differed over the left and right hemispheres.

The right frontal and left parietal topography of the

Table 1
Mean performance accuracy and response time for semantic judgment, PM cue, and PM lure trials in Experiment 1 [a]

		Accuracy	Response time
Semantic judgment	M	0.85	1196
	S.D.	0.03	318
PM cue	M	0.96	1031
	S.D.	0.03	271
PM lure	M	0.99	1464
	S.D.	0.03	343

[a] Accuracy for PM cue trials reflects the probability of making a prospective response and accuracy for PM lure trials reflects the probability of making a semantic judgment.

slow-wave differentiating the ERPs elicited on the PM cue trials from those elicited in the PM lure and semantic judgment trials is similar to that of modulations of the ERP associated with the recollection of information in studies of retrospective memory [19]. Based upon this earlier work, parietal activity is thought to reflect the recovery of information from a long-term store, while frontal activity is thought to reflect the neural processes that serve to monitor the products of memory retrieval [1]. These data are therefore consistent with the noticing+search model of prospective memory where the search process is thought to support a controlled interrogation of memory in order to establish the significance of a PM cue [9].

However, there are other possible interpretations of the parietal positivity observed for PM cue trials. In the study, both PM cue and PM lure trials were low probability events associated with the need to make a response different from that required on the majority of trials (PM cue trials) or suppress a low frequency response in favor of a high frequency response (PM lure trials). Therefore, the prospective memory task utilized in the current study is similar in nature to the oddball paradigm used in studies of the P3 modulation [8] which generally requires a low probability response (either overt or covert) to a low probability stimulus. Based upon the structural similarity of the PM task used in the current experiment and the oddball task used to study the P3, one could wonder whether or not the parietal positivity reflects neural activity associated with the realization of an intention, a P3 elicited by the low probability of the PM cue, or some mixture of these processes. There are a number of findings from the current experiment supporting the idea that the parietal positivity reflects the activity of neural systems supporting both the P3 and memory retrieval processes. First, there is the right frontal negativity observed over a region of the scalp where the P3 would generally not be strongly expressed, that corresponds closely in time course with the parietal positivity observed over the left hemisphere. Second, if the parietal positivity merely reflects the P3, the topography of this component could be expected to be similar for PM cue and PM lure trials. The data presented in Fig. 2 do not support this idea as the parietal positivity for PM lure trials is greatest in amplitude over the right hemisphere, while the parietal positivity for PM cue trials is similar in amplitude to that observed in PM lure trials over the right hemisphere and greater in amplitude over the left hemisphere (see the condition×hemisphere interaction observed in the earlier analyses). However, one could argue that this hemispheric asymmetry results from differences in absolute voltage between the PM cue and PM lure conditions and not the activity of different neural generators contributing to the ERPs observed over the left and right hemispheres for these conditions. To consider this possibility the data were normalized [13], in order to eliminate conditional differences in absolute voltage and considered in a 3 (condition)×2 (hemisphere)×3 (region)
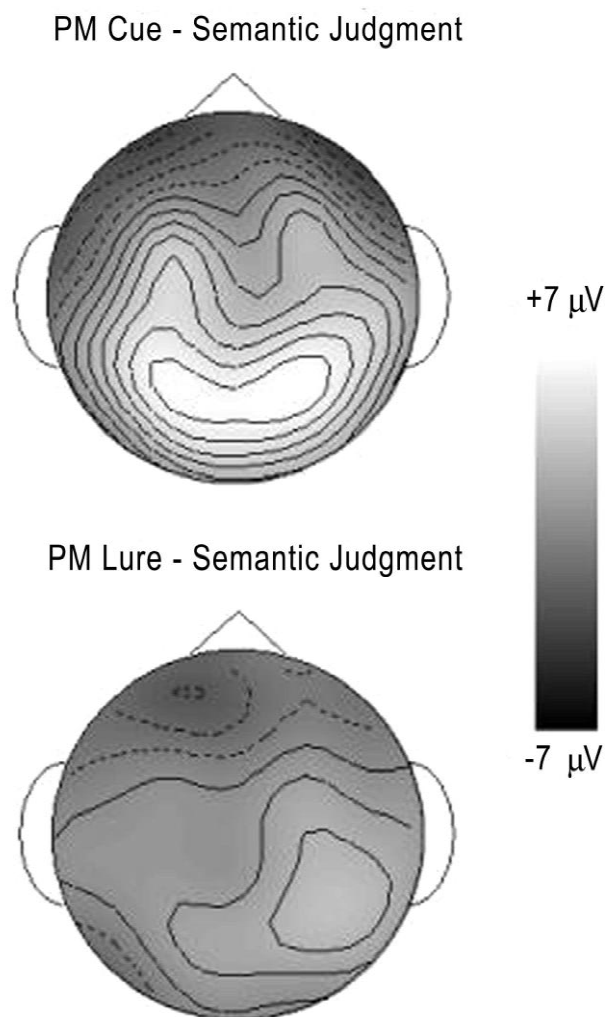

Fig. 2. Spline voltage map demonstrating the difference in topography of the parietal positivity for the PM cue and PM lure conditions. Notice that for the PM lure condition the voltage gradient is maximal over the right hemisphere, while for the PM cue condition the voltage gradient is more broadly distributed over the left and right hemispheres.

MANOVA. In this analysis the condition×hemisphere interaction remained significant (see Fig. 3, $\lambda=0.67$, $F(6,12)=3.91$, $P<0.05$), supporting the idea that different neural generators contribute to the parietal positivity over the left and right hemispheres.

Given previous research demonstrating that the scalp topography of the P3 elicited by Go and No–Go stimuli differ, with the P3 elicited by No–Go stimuli often being greater in amplitude over the central region than the P3 elicited by Go stimuli [21]. It could be argued that differences in the parietal positivity for PM cue (i.e., Go stimulus) and PM lure (i.e., No–Go) trials results from differences in the nature of the response required by these two stimuli and not differences in neural activity underlying P3 and memory retrieval processes. If this were the case one would expect the condition×region interaction to be significant, with the P3s elicited by PM cue and PM lure trials being of similar amplitude at parietal electrodes
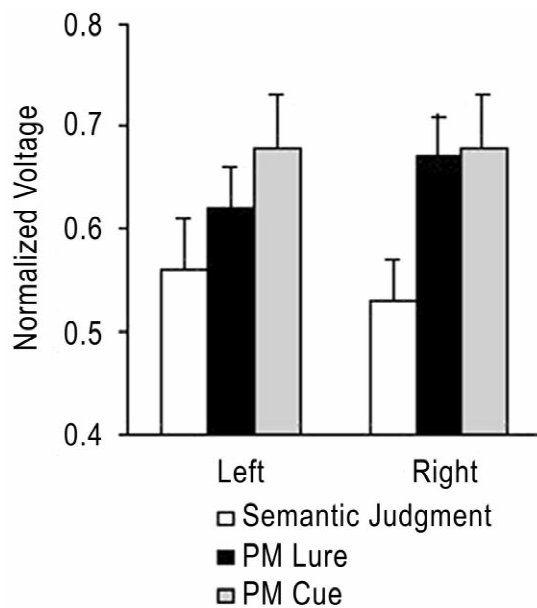
Fig. 3. Mean normalized voltage for the semantic judgment, PM lure, and PM cue conditions over the left and right hemispheres. Notice that the normalized slow-wave is similar for the PM cue and PM lure conditions over the right hemisphere and greater for the PM cue than the PM lure condition over the left hemisphere. Bars reflect the standard error of the mean.

Table 2
Mean performance accuracy and response time for semantic judgment, PM cue, and PM lure trials in PM ignore and PM attend conditions in Experiment 2

		Accuracy	Response time
PM Ignore[a]			
Semantic	M	0.81	1068
judgment	S.D.	0.06	226
PM cue	M	080	1067
	S.D.	0.03	189
PM lure	M	0.85	1093
	S.D.	0.05	193
PM Attend[b]			
Semantic	M	0.88	1025
judgment	S.D.	0.05	185
PM cue	M	0.82	1007
	S.D.	0.14	185
PM lure	M	0.99	1247
	S.D.	0.01	222

[a] For the PM ignore condition accuracy for the PM cue and PM lure trials reflects the probability of making a correct semantic judgment.
[b] For the PM attend conditions accuracy for the PM cue trials reflects the probability of making a prospective response and accuracy for the PM lure condition reflects the probability of making a semantic judgment.

(P3–P4), and greater in amplitude for PM lure trials than PM cue trials at more central electrodes (Cp1–Cp2, Cp5–Cp6). In the current data there is little support for this hypothesis as the condition×region interaction was not significant ($F<1$).

3.2. Experiment 2

Mean levels of response accuracy and response time are presented in Table 2. Semantic judgments were less accurate in the PM ignore blocks than in the PM attend blocks ($t(16)=4.94$, $P<0.001$), probably resulting from an increase in the participants familiarity with the semantic categories used in the study from the first to the second half of the task. PM cues were somewhat less likely to elicit a correct prospective response than in Experiment 1. As in Experiment 1, PM lure trials were almost always associated with a semantic judgment. The response time data were submitted to a 3 (condition: PM cue, PM lure, semantic judgment)×2 (PM ignore–attend) ANOVA. The main effect of condition ($F(2,32)=15.34$, $P<0.001$) and the condition by PM ignore–attend interaction ($F(3,32)=8.94$, $P<0.001$) were significant. This interaction reflects the tendency for response latency to be similar in the PM ignore and PM attend condition for PM cue trials and semantic judgment trials and for response latency to be shorter for PM lure trials in the PM ignore condition than the PM attend condition.

Fig. 4 presents the grand averaged ERPs for semantic judgment, PM cue, and PM lure trials at selected electrode locations in the PM ignore and PM attend conditions. To examine the effect of intention on the N320 the mean voltage data were submitted to a MANOVA similar to that
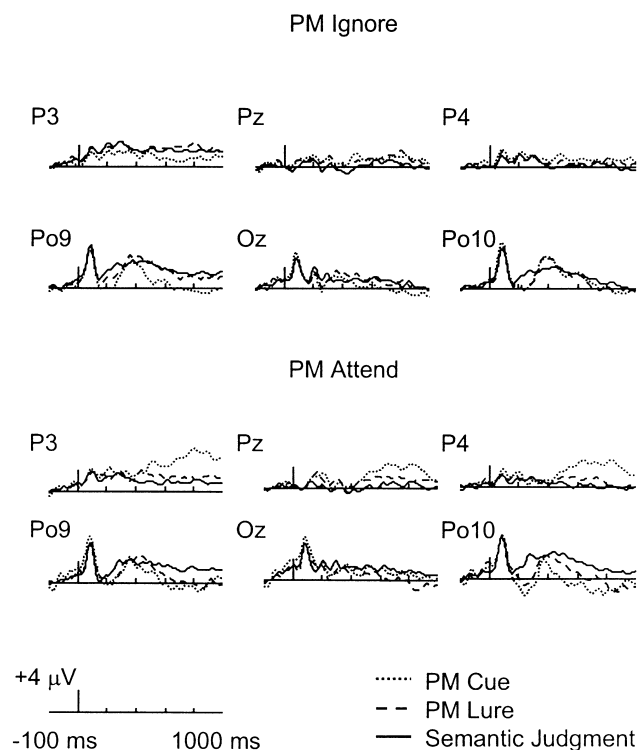

Fig. 4. Grand average ERPs at select electrode positions in Experiment 2. The tall bar reflects stimulus onset.

reported in Experiment 1 including the additional factor PM ignore–attend. The N320 was found to differentiate both PM cue and PM lure trials from semantic judgment trials (condition $\lambda=0.43$, $F(2,14)=9.30$, $P<0.003$). As in Experiment 1, the N320 reversed polarity from the occipital-parietal region to the frontal-central region (condition×region $\lambda=0.18$, $F(6,10)=7.76$, $P<0.003$). Also, the amplitude of the N320 was similar over the right and left frontal-central region and greater in amplitude over the right than left occipital-parietal region (condition×hemisphere×region $\lambda=0.29$, $F(6,12)=4.19$, $P<0.03$). The main effect of PM ignore–attend was significant ($\lambda=0.61$, $F(1,16)=9.57$, $P<0.007$), however, counter to our expectations this variable did not interact with condition.

In an effort to further explore the possible effect of intention on the N320 a second MANOVA was conducted including only the electrodes (Po9–Po10, the site of maximum amplitude of the N320) and data for PM cue and semantic judgment trials. In this analysis the condition×PM ignore–attend×hemisphere interaction was significant (see Fig. 5; $\lambda=0.75$, $F(1,15)=4.91$, $P<0.05$), with the amplitude of the N320 being similar over the left hemisphere in the PM ignore and PM attend conditions and being greater in amplitude over the right hemisphere in the PM attend than PM ignore condition.

To examine the effect of intention on the slow-wave the mean voltage data were examined in a set of MANOVA's similar to those use in Experiment 1 with the additional factor PM ignore–attend. In the analysis of the slow-wave over the right frontal region the PM ignore–attend× condition interaction was marginally significant ($\lambda=0.70$, $F(2,14)=3.09$, $P<0.09$). In the analysis of the slow-wave over the parietal region the PM ignore–attend×condition interaction was significant ($\lambda=0.51$, $F(2,14)=6.64$, $P<0.01$), with mean voltage being similar in the PM ignore and PM attend conditions for semantic judgment trials (PM ignore $M=0.97$ μV, PM attend $M=0.55$ μV) and PM lure trials (PM ignore $M=1.91$ μV, PM attend $M=2.01$

μV) and greater for PM cue trials in the PM attend ($M=3.92$ μV) than PM ignore ($M=0.80$ μV) condition. Furthermore, this effect was stronger at electrodes (Cp1–Cp2, P3–P4) than at electrodes (Cp5–Cp6) indicated by the significant PM ignore–attend×condition×region interaction ($\lambda=0.47$, $F(4,12)=3.35$, $P<0.05$).

4. Discussion

In two experiments we observed two ERP components that were differentially modulated by the semantic judgment, PM cue, and PM lure trials of the partial cue PM task. The N320 differentiated PM cue and PM lure trials from semantic judgment trials, and represented a broadly distributed negativity over the occipital-parietal region and positivity over the midline frontal region. The amplitude of the N320 was greater when the PM cue was associated with the intention to make a prospective response in the PM attend condition than in the PM ignore condition when the PM cue was not associated with an intention, and this effect was stronger over the right than left hemisphere. The slow-wave differentiated PM cues trials from PM lure and semantic judgment trials, and represented a negativity over the right frontal region and a broadly distributed positivity over the parietal region. The amplitude of the slow-wave was much greater in the PM attend condition where the PM cue was associated with the intention to make a prospective response than in the PM ignore condition.

The noticing+search model of PM is founded upon the premise that the realization of a delayed intention is supported by two processes (i.e., noticing and search) [9]. Based upon the results of the present study we propose that the N320 may provide an index of neural activity reflecting the noticing process when the PM cue is defined by a change in letter case. This modulation differentiated trials where a possible PM cue was presented (PM cue and PM lure) from trials where a possible PM cue was not presented (semantic judgment). Noticing has been proposed to be a relatively automatic processes akin to familiarity described in some dual-process models of recognition memory [14] and is thought to be more sensitive to data driven than conceptually driven processes [7]. In the current study the N320 was observed in both the PM ignore and PM attend conditions, suggesting that is was somewhat independent of the intention to make a prospective response and may reflect a relatively automatic neural response to the perceptual change embodied by the PM cue and PM lure trials relative to semantic judgment trials. However, the amplitude of the N320 was greater in the PM attend than PM ignore condition over the right occipital-parietal region, indicating that this component was modulated by the intention to make a prospective response or the need to attend to the environment for a change in letter case. Given these findings it seems that noticing or the detection of a possible PM cue may be
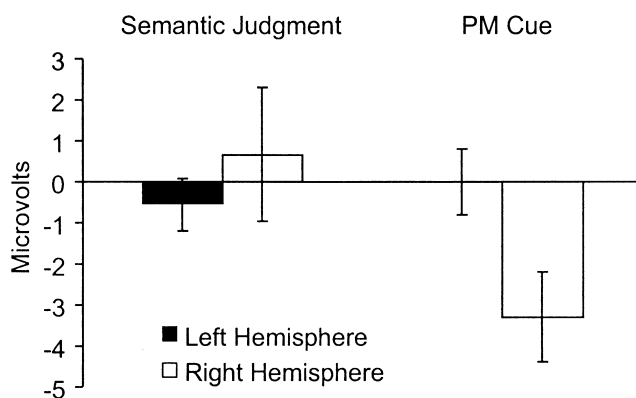
Fig. 5. Mean voltage difference between PM attend and PM ignore conditions at electrode positions Po9 and Po10 for semantic judgment and PM cue trials in Experiment 2. Bars reflect the standard error of the mean.

accomplished through the attentional modulation of those neural systems which support the processing of stimulus features related to detection of the PM cue, in a manner similar to that observed in studies of selective attention [10].

Behavioral studies have demonstrated that other features (e.g., word frequency) [4,9] of the PM cue that make it distinctive from stimuli presented in the background activity and attention to conceptual levels features (e.g., semantic meaning) [17] of the PM cue can serve to enhance the efficiency of prospective memory. Based upon these data and the proposal that noticing is accomplished through the attentional modulation of neural systems supporting processing of the defining features of the PM cue, one might wonder to what extend the topography and/or time course of the N320 would be modulated by the depth of processing required to support detection of the PM cue. We have currently begun to explore this question in other studies where the defining features of the PM cue have been color and word identity [26]. Initial evidence indicates that when the PM cue is defined by color the time course and possibly the topography of the N320 is comparable to that observed in the current experiments. In contrast, when the PM cue is defined by word identify, noticing is associated with a phasic negativity over the temporal region (N470) that differs in both time course and topography from the N320 observed in the current data [26]. These more recent findings are consistent with the idea that noticing reflects a flexible process that is accomplished through the modulation of those neural systems that support processing the defining features of the PM cue. In future studies we hope to further explore this hypothesis by examining experimental settings where there is no perceptual overlap between the cue at the formation and realization of the intention

The slow-wave seems to reflect the activity of a neural system supporting the recovery of an intention from memory. Unlike the N320, the slow-wave was essentially observed only in the PM attend condition when the PM cue was associated with a to-be-realized intention. The right frontal/left parietal topography of the slow-wave was similar to modulations of the ERP associated with the recollection of a prior event in studies of retrospective memory [19,23]. Allan et al. [1] have proposed that parietal activity associated with recollection reflects neural processes supporting the recovery of information from memory, while frontal activity is more related to strategic search and monitoring processes. Based upon these findings, one goal of future research should be to determine whether or not similar dissociation's are born out within the area of prospective memory.

In summary, we observed two ERP modulations that were associated with the realization of an intention (i.e., N320 and slow-wave). The N320 reflects neural activity associated with the noticing process and may involve the attentional modulation of those neural systems responsible for processing the defining features of the PM cue, thereby increasing sensitivity to the PM cue. In comparison, the slow-wave reflects the activity of a neural system that supports the recovery of an intention from memory. Future studies should seek to determine how closely tied the nature of the N320 is to the distinctive features of the PM cue and further explore processes underlying recovery of an intention from memory once a PM cue has been detected.

References

[1] K. Allan, E.L. Wilding, M.D. Rugg, Electrophysiological evidence for dissociable processes contributing to recollection, Acta Psychol. 98 (1998) 231–252.

[2] W.F. Battig, W.E. Montague, Category norms for verbal items in 56 categories: a replication and extension of the Connecticut category norms, J. Exp. Psychol. 80 (1969) 1–46.

[3] P.S. Bisiacchi, The neuropsychological approach to the study of prospective memory, in: M. Brandimonte, G.O. Einstein, M.A. McDaniel (Eds.), Prospective Memory: Theory and Applications, Lawrence Erlbaum Associates, Mahwah, NJ, 1996, pp. 297–318.

[4] M.A. Brandimonte, M.C. Passolunghi, The effect of cue-familiarity, cue-distinctiveness, and retention interval on prospective remembering, Q. J. Exp. Psychol. A 47 (1994) 565–587.

[5] J. Cockburn, Task interruption in prospective memory: a frontal lobe function, Cortex 31 (1995) 87–97.

[6] A.L. Cohen, Prospective memory and aging: The effect of perceptual salience, Unpublished masters thesis, University of Victoria, 1999.

[7] A.L. Cohen, R. West, F.I.M. Craik, Modulation of the prospective and retrospective components of prospective remembering in younger and older adults, Aging Neuropsychol. Cogn. (in press).

[8] E. Donchin, M.G. Coles, Is the P300 component a manifestation of context updating? Behav. Brain Sci. 11 (1989) 357–427.

[9] G.O. Einstein, M.A. McDaniel, Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings, in: M. Brandimonte, G.O. Einstein, M.A. McDaniel (Eds.), Prospective Memory: Theory and Applications, Lawrence Erlbaum Associates, Mahwah, NJ, 1996, pp. 115–142.

[10] S.A. Hillyard, G.R. Mangun, M.G. Woldorff, S.J. Luck, Neural systems mediating selective attention, in: M.S. Gazzaniga (Ed.), The Cognitive Neurosciences, MIT Press, Cambridge, MA, 1995, pp. 665–682.

[11] L.L. Jacoby, A. Hollingshead, Toward a generate/recognize model of performance on direct and indirect tests of memory, J. M. L. 29 (1990) 433–454.

[12] G. Mandler, Recognizing: the judgment of previous occurrence, Psychol. Rev. 87 (1980) 252–271.

[13] G. McCarthy, C.C. Wood, Scalp distributions of event-related potentials: an ambiguity associated with analysis of variance models, Electroencephalogr. Clin. Neurophysiol. 38 (1985) 203–208.

[14] M.A. McDaniel, Prospective memory: progress and processes, in: D.L. Medin (Ed.), The Psychology of Learning and Motivation, Academic Press, San Diego, CA, 1995, pp. 191–221.

[15] M.A. McDaniel, G.O. Einstein, Aging and prospective memory: Basic findings and practical applications, Adv. Learning Behav. Disabilities 7 (1992) 87–105.

[16] M.A. McDaniel, E.L. Glisky, S.R. Rubin, M.J. Guynn, B.C. Routhieaux, Prospective memory: a neuropsychological study, Neuropsychology 13 (1999) 103–110.

[17] M.A. McDaniel, B. Robinson-Riegler, G. Einstein, Prospective

remembering: perceptually driven or conceptually driven processes? Mem. Cogn. 26 (1998) 121–134.

[18] J. Okuda, T. Fujii, A. Yamadori, R. Kawashima, T. Tsukiura, R. Fukatsu, K. Suzuki, L. Masatoshi, H. Fukuda, Participation of the prefrontal cortices in prospective memory: evidence from a PET study in humans, Neurosci. Lett. 253 (1998) 127–130.

[19] K.A. Paller, M. Kutas, H.K. McIsaac, Monitoring conscious recollection via the electrical activity of the brain, Psychol. Sci. 6 (1995) 107–111.

[20] K.A. Paller, M. Kutas, H.K. McIsaac, An electrophysiological measure of priming of visual word-form, Conscious. Cogn. 7 (1998) 54–66.

[21] A. Pfefferbaum, J.M. Ford, B.J. Weller, B.S. Kopell, ERPs to response production and inhibition, Electroencephalogr. Clin. Neurophysiol. 60 (1985) 423–434.

[22] T.W. Picton, S. Bentin, P. Berg, E. Donchin, S.A. Hillyard, R. Johnson, G.A. Miller, W. Ritter, D.S. Ruchkin, M.D. Rugg, M.J. Taylor, Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria, Psychophysiology 37 (2000) 127–152.

[23] M.D. Rugg, R.E. Mark, P. Walla, A.M. Schloerscheidt, C.S. Birch, K. Allan, Dissociation of the neural correlates of implicit and explicit memory, Nature 392 (1998) 595598.

[24] D.M. Schnyer, J.J.B. Allen, K.I. Forster, Event-related brain potential examination of implicit memory processes: masked and unmasked repetition priming, Neuropsychology 11 (1997) 243–260.

[25] R. West, F.I.M. Craik, Age-related decline in prospective memory: the roles of cue accessibility and cue sensitivity, Psychol. Aging 14 (1999) 264–272.

[26] R. West, K. Ross-Munroe, Neural correlates of the formation and realization of a delayed intention (2001) in preparation.