Neural correlates of the formation and realization of delayed intentions

ROBERT WEST and KEISHA ROSS-MUNROE
University of Notre Dame, Notre Dame, Indiana

Prospective memory (PM) can be thought of as the ability to successfully form and later realize intentions that must be delayed over some period of time. In this study, event-related brain potentials were used to explore the neural activity associated with the formation and realization of an intention. Greater negativity over the frontal-polar region was associated with intention formation trials in which the intention was later realized. On PM cue trials, an N300 was associated with the detection of a cue. For PM cue trials, a late positive complex was observed that might have reflected the retrieval of an intention from memory, and a frontal slow wave was observed that might have reflected the activity of a neural system that supported disengagement from the ongoing activity when the cue was detected.

Prospective memory (PM) can be thought of as the ability to form and later realize intentions that must be delayed over some period of time (Einstein & McDaniel, 1990; Meacham & Leiman, 1982). Prospective remembering is a complex activity that can be conceptualized as including at least five phases: *intention formation*, a *delay* period lasting minutes, hours, or days, during which it is not possible to realize the intention, a *performance interval* during which it is appropriate to realize the intention, *realization* of the intention during the performance interval, and *monitoring* the success or failure of an intended action (Ellis, 1996). As an example of these different phases, suppose that I sit down at my computer with the intention of sending a colleague the results of a recently completed experiment as an e-mail attachment (intention formation). I load my e-mail program, open a new message, and then type a brief overview of the results of some preliminary analyses and describe the structure of the data set (delay period). During this time, I am probably not continually rehearsing the desire to attach the file, although the intention is likely to be maintained above some baseline level of activation (Goschke & Kuhl, 1993; Marsh, Hicks, & Bink, 1998). When the message is completed (performance interval), I click the attachment button, locate the appropriate file, and include it with the message (realization). I then send the message off into cyber-space, content with the knowledge that I have completed my task. Or have I? Did I remember to at-

tach the message, should I check my sent mail folder, or can I expect a return message from my colleague, who is somewhat perplexed upon receiving a message with no attachment (monitoring)?

Laboratory-based studies of PM generally try to simulate the various phases of prospective remembering by having individuals form one or more simple intentions at the outset of a task(s) (e.g., press the "C" key any time an animal name—the PM cue—is encountered over the course of the task you are about to perform). The subjects are then engaged in some task, designated the *ongoing activity* (Ellis & Kvavilashvili, 2000), which serves to instantiate the delay period. This task could involve processing words within the context of a short-term recall task (Einstein & McDaniel, 1990) or a semantic judgment task (West & Craik, 1999). The performance interval would reflect instances in which an animal name is presented, and realization of the intention would reflect pressing the appropriate key when an animal is present. When a PM cue is present, the individual is expected to make a prospective response but could just as easily make a response that is appropriate to the ongoing activity, resulting in a failure to realize the intention. Monitoring of successful or failed prospective responses has not been extensively studied, although some evidence has indicated that individuals are sensitive to missed PM cues (West & Craik, 1999).

The duration of the delay between the formation of an intention and the performance interval varies widely in both laboratory and real-world settings, ranging from seconds or minutes to hours or even days. For instance, in the example of attaching a message to an e-mail, the delay period might be as brief as a couple of minutes; in contrast, if in the morning I plan to return a paper to a student in an afternoon class, the delay period could extend over several hours. There is empirical evidence indicating that the length of the delay has relatively little effect on the efficiency of prospective memory for intervals of 15 or 30 min (Einstein, Holland, McDaniel, & Guynn, 1992). In contrast, other

The research described in this paper was supported by grants from the American Foundation for Aging Research and the Faculty Research Program, University of Notre Dame, awarded to the first author. K. Ross-Munroe was supported by the CANDAX McNair Summer Research Program for Minority Students. Portions of the data were reported at meetings of the Psychonomic Society (2000) and the Cognitive Neuroscience Society (2001). Correspondence concerning this article should be addressed to R. West, Department of Psychology, University of Notre Dame, 118 Haggard Hall, Notre Dame, IN 46556 (e-mail: west.19@nd.edu).

evidence has indicated that imposing even a brief delay between the presentation of a PM cue and the opportunity to realize the intention can disrupt the efficiency of prospective remembering (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000; West & Craik, 2001). In the present study, we used a PM task in which the delay period was relatively short, approximately 10–20 sec. If it is the case that there are differences in the neural mechanisms underlying the formation and realization of intentions over short and long delays, the results of the present study should be considered to be most representative of those mechanisms supporting prospective remembering over relatively brief delays.

McDaniel and Einstein (1992) have proposed that the realization of an intention during the performance interval arises through the interaction of multiple component processes. These include a prospective component that supports the recognition of a PM cue and a retrospective component that supports recovery of the intended action from memory. The results of recent behavioral studies have demonstrated that these two aspects of PM can be dissociated. In one study, the prospective component was influenced more strongly by a change in the perceptual characteristics of the PM cue from formation of the intention to presentation of the cue than by the degree of semantic relatedness between the PM cue and the intention (Cohen, West, & Craik, 2001). In contrast, the retrospective component was influenced more strongly by the degree of semantic relatedness between the PM cue and the intention than by a change in the perceptual characteristics of the PM cue from formation of the intention to presentation of the cue. These findings led to the proposal that the prospective component may be most sensitive to data-driven influences and that the retrospective component may be most sensitive to conceptually driven influences (Cohen et al., 2001; Einstein & McDaniel, 1996).

This proposal is consistent with the noticing + search model of PM (Einstein & McDaniel, 1996; McDaniel, 1995). In this model, prospective remembering is thought to arise through the interaction of noticing and directed search processes. Noticing is proposed to be a relatively automatic process that is sensitive to the familiarity of the PM cue, supports the detection or recognition of the PM cue when it is encountered in the environment, and serves to activate the directed search process. In contrast, directed search is proposed to be a more consciously controlled process that serves to attribute meaning to a PM cue when it is detected (Einstein & McDaniel, 1996).

In a recent study in which the neural correlates of PM were explored, we observed distinct modulations of the event-related brain potentials (ERPs) that appear to be associated with detection of a PM and retrieval of an intention from memory (West, Herndon, & Crewdson, 2001). This study incorporated a PM task developed by West and Craik (1999) that included three conditions (PM cue, PM lure, and ongoing activity). For ongoing activity trials, individuals saw pairs of words presented in lowercase letters and were asked to indicate whether or not the words were

semantically related by pressing one of two keys. For PM cue trials, the word pair was presented in uppercase letters, and the individuals were instructed that when this change was recognized, a third key should be pressed, reflecting realization of the intention. Finally, for PM lure trials, one of the words was presented in uppercase letters, and one of the words was presented in lowercase letters. On these trials, the individuals were instructed that this change should be ignored and that a semantic judgment should be made.

In West et al. (2001), we reasoned that if noticing were relatively automatic and sensitive to data-driven influences, such as the change in letter case, it would be reflected by modulations of the ERPs that differentiated PM cue trials and PM lure trials from ongoing activity trials. We also reasoned that search would be associated with modulations of the ERPs that differentiated PM cue trials from PM lure trials and ongoing activity trials, because a prospective response would be required only on PM cue trials. In two experiments, detection of the PM cue was associated with a phasic negativity (N300) that was broadly distributed over the occipital-parietal region of the scalp, peaked around 300 msec after stimulus onset, and differentiated PM cue and PM lure trials from ongoing activity trials. In contrast, realization of the intention was associated with a more sustained parietal-positivity-right-frontal-negativity (late positive complex, or LPC). The amplitude of the LPC was greater for PM cue trials than for PM lure or semantic judgment trials (West et al., 2001).

We also observed that the amplitude of the N300 was modulated by the intention to make a prospective response. This finding seemed somewhat inconsistent with the idea that noticing is a data-driven process (Einstein & McDaniel, 1996) and led to the suggestion that the detection of a PM cue may be achieved through the attentional modulation of those neural systems that support processing of the defining features of the PM cue (West et al., 2001). This proposal was based on extensive evidence indicating that attention to the spatial location of an object or to one of its other features results in an enhancement of the amplitude of modulations of the ERPs associated with stimulus processing (for a review, see Mangun & Hillyard, 1995). In contrast to the N300, the LPC was observed only when the PM cue was associated with an intention, consistent with the proposal that the LPC reflects the activity of a neural mechanism that supports the retrieval of an intention from memory following detection of a PM cue.

Although the findings of West et al. (2001) are generally consistent with predictions derived from multi-component models of PM (Einstein & McDaniel, 1996; McDaniel & Einstein, 1992), these data are limited in a number of ways. First, given the very high levels of response accuracy observed in West et al., it is impossible to know with certainty whether the N300 and the LPC are uniquely associated with the realization of an intention or are, instead, associated with more general neural processes related to processing a low-probability target stimulus (Donchin & Coles, 1988). Second, West et al. considered only a single defining feature of the PM cue (i.e., letter

case). This makes it impossible to know whether the N300 reflects a general response to the presentation of a PM cue or a more specific response that is elicited when the PM cue is defined by a change in letter case. Third, the available data provide information related only to those neural processes that are active during the realization of an intention and provide no information regarding the neural processes that support the formation of an intention.

If the N300 and the LPC are related specifically to the realization of an intention, one would expect these modulations of the ERPs to differentiate PM cue trials that elicit a prospective response (i.e., PM hit) from both PM cue trials that fail to elicit a prospective response (i.e., PM miss) and ongoing activity trials. Consideration of this hypothesis requires a PM task that produces accuracy levels in a more intermediate range (i.e., 50%–75% correct) than that used by West et al. (2001). This would enable separate ERP waveforms to be obtained for PM hit trials and PM miss trials. To achieve this goal, the perceptual salience of the PM cues used in the present experiment was decreased, relative to those used in West et al., by varying the color of the stimuli on a trial-by-trial basis and by defining the PM cue by the presentation of one of two specific colors. This can be contrasted with our earlier work, in which the PM cue was defined by a highly salient change from words presented in lowercase letters to words presented in uppercase letters.

West et al. (2001) proposed that PM cue detection is achieved through the attentional modulation of those neural systems that support processing of the defining features of the cue. However, in that study, a single defining feature of the cue was used (i.e., letter case); this makes it impossible to know whether the N300 was specifically associated with processing letter case or reflected a more general response associated with the detection of a PM cue. In the present experiment, we explored what influence the use of color as the defining feature of the PM cue would have on the N300.

To examine neural activity associated with the formation and later realization of an intention requires a task in which ERPs can be obtained during both the intention formation and the realization phases of prospective remembering. This can be contrasted with the majority of past studies of PM, in which intentions were formed before the ongoing activity began and only PM cues were encountered during performance of the ongoing activity (e.g., Einstein & McDaniel, 1990; for exceptions, see McDaniel, Robinson-Riegler, & Einstein, 1998, and Rendell & Craik, 2000). In the present experiment, individuals were asked to form simple intentions (pressing one of two keys) whose realization was signaled by the presentation of a PM cue (one of two colors). This task permitted us to obtain ERPs associated with both the formation and the realization of an intention.

In the experiment, individuals performed a PM task requiring both the formation and the realization of simple intentions over the course of task performance. For ongoing activity trials, pairs of semantically related or un-

related words were presented in one of four colors, and individuals were instructed to press one of two keys, indicating whether the words were related or unrelated. For intention formation trials, individuals saw strings of letters (e.g., vvvv–vvvv, in magenta) presented in one of two colors different from those occurring in the ongoing activity trials. For these trials, the individuals were expected to form an intention to press the specified key (v) the next time a word pair was presented in that color (train–truck, in magenta). PM cues were defined as the presentation of a word pair in one of two colors that were distinct from those encountered for ongoing activity trials. On these trials, the individuals were expected to press the key (v) that was associated with the color (magenta), rather than to make a semantic judgment. If the N300 is related to the detection of a cue, it would be expected to differentiate the ERPs elicited on PM hit trials from those elicited on PM miss trials and semantic judgment trials. Likewise, if the LPC is related specifically to the retrieval of an intention from memory and execution of the intended act, it was expected to differentiate the ERPs elicited on PM hit trials from those elicited on PM miss trials.

METHOD

Subjects

Twenty volunteers (12 males and 8 females), 19–21 years of age, participated in the experiment. Data for 19 of 20 subjects were used in the reported analyses; the subject not included in the analyses was eliminated because of ceiling performance on PM cue trials, making it impossible to obtain ERPs for unrealized intention trials and PM miss trials. All the subjects reported normal or corrected-to-normal visual acuity and reported a right-hand preference. The subjects received either course extra credit or \$7 per hour for their participation.

Materials and Procedure

For the PM task, there were 1,200 trials equally divided into 12 blocks. Each block included 92 ongoing activity trials, 4 intention formation trials, and 4 PM cue trials. On ongoing activity and PM cue trials, a related or an unrelated word pair was presented in lowercase letters. The word pairs were presented on a computer monitor, centered on the vertical and horizontal axis, until a response was made. Related word pairs were formed by combining category exemplars from 50 categories of the Battig and Montague (1969) category norms, excluding the following categories: girls names, male names, city, state, college or university, and members of clergy. Unrelated word pairs were formed by randomly re-pairing words across categories. A given block was made up of 48 related and 48 unrelated word pairs. For ongoing activity trials, the word pairs were presented in red, green, yellow, or light blue, with the words being presented in the same color for half the trials and in different colors for half the trials. On these trials, the individuals were instructed to respond by pressing the “N” key with the right index finger if the words were related and the “M” key with the right middle finger if the words were unrelated. On intention formation trials, the word pair was replaced by two letter strings presented in light gray or magenta (i.e., cccc–cccc in light gray, cccc–cccc in magenta, vvvv–vvvv in light gray, or vvvv–vvvv in magenta). For intention formation trials, the subjects were to form the intention to press the key associated with the letter the next time a word pair was presented in that color (e.g., if cccc–cccc was presented in magenta, the intention would be to press the “C” key for the next magenta word pair). The individu-

als were instructed that, following formation of the intention, they should press either the "N" or the "M" key in order to proceed to the next trial. For PM cue trials, the word pair was presented in the color corresponding to that represented in the preceding intention formation trial (i.e., light gray or magenta). For these trials, the individuals were to press the key associated with the color on the most recent intention formation trial, instead of making a semantic judgment. There were 8, 10, or 12 ongoing activity trials between an intention formation trial and the associated PM cue trial. Following a response, the screen was blank for 500 msec, and then the word pair or letter string for the next trial was presented. Before the task began, the subjects performed a practice block that included 26 ongoing activity trials, 2 intention formation trials, and 2 PM cue trials. The PM task required approximately 40–45 min to complete, and the entire session required roughly 90 min, including preparation and clean-up.

Electrophysiological Recording and Analysis

The EEG (bandpass of 0.01–100 Hz, digitized at 512 Hz, gain of 2,500, 12-bit A/D conversion) 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, left mastoid M1, right mastoid M2, left lateral ocular Lo1, right lateral ocular Lo2, left inferior ocular Io1, and right inferior ocular Io2) sewn into an Electro-cap or affixed to the skin with an adhesive patch. Inter-electrode impedances were maintained below 10 k Ω during recording. Vertical and horizontal eye movements were recorded from electrodes placed lateral to (Lo1, Lo2) and below (Io1, Io2) the right and left eyes. During recording, all the electrodes were referenced to Cz; for data analysis, they were re-referenced to an average reference, as suggested in guidelines published by the Society for Psychophysiological Research (Picton et al., 2000), and a 20-Hz Butterworth zero phase shift lowpass filter was applied.

ERP analysis epochs were extracted off line and included 200 msec of prestimulus activity and 1,200 msec of poststimulus activity. Trials contaminated by excessive eye or movement artifacts (peak-to-peak deflections over 100 μ V) were rejected before averaging. ERPs were averaged for artifact-free trials associated with ongoing activity trials immediately preceding intention formation trials ($M = 36.47$), ongoing activity trials immediately preceding PM cue trials ($M = 37.74$), intention formation trials later associated with a prospective response (realized intention, $M = 23.79$), intention formation trials later associated with a semantic judgment (unrealized intention, $M = 7.16$), PM cue trials that elicited a prospective response (PM hit, $M = 26.53$), and PM cue trials that failed to elicit a prospective response (PM miss, $M = 7.74$). These averages reflected the retention of 64%–79% of the applicable data for the various conditions, following artifact rejection. There were no significant differences across conditions in the proportions of the data retained [$F(1,108) = 1.76, p > .12$].

All the statistical tests were performed on mean voltages averaged over 50-msec windows, where modulations of interest were observed relative to the mean voltage of the 200-msec prestimulus baseline activity (N300 = 275–325 msec, LPC = 550–600 msec, slow wave = 575–625 msec). A 50-msec window was selected for all the quantified components so that the measurements would have similar levels of stability. This strategy can be contrasted with an approach in which a single time point peak of the N300 is measured and the slow waves are measured by averaging over 200–300 msec of data, which would result in a much more stable estimate of the slow wave than of the N300. Statistical tests were performed using the multivariate F -ratio based upon Wilks's Lambda (λ) in a series of multivariate analyses of variance (MANOVAs) with a $p < .05$ level of significance, including electrode locations used to quantify the N300 and the LPC in previous research (West et al., 2001) or electrode locations at which frontally distributed memory encoding

and retrieval effects had been observed in studies of retrospective memory (see Rugg, 1995). Limited numbers of electrodes were included in each analysis, so that the denominator degree of freedom would not be exhausted in the multivariate model in which degrees of freedom do not propagate with increasing factorial complexity, as is the case under the univariate model.

RESULTS

Behavioral Data

Accuracy on ongoing activity trials ($M = .81$) was consistent with that observed in previous research (West & Craik, 1999; West et al., 2001). For PM cue trials, performance was in an intermediate range ($M = .71$, range, .25–.92). Response times were slightly longer for ongoing activity trials preceding PM cue trials ($M = 1,419$ msec) than for ongoing activity trials preceding intention formation trials ($M = 1,378$ msec), although this difference was not significant [$t(18) = 1.20, p > .20$]. Also, response times for PM hit trials ($M = 1,118$ msec) were faster than response times for PM miss trials [$M = 1,423$ msec; $t(18) = 3.79, p < .001$] in which a semantic judgment was made. There was no difference in response times between PM miss trials ($M = 1,423$ msec) and ongoing activity trials [$M = 1,419$ msec; $t(18) = 0.03, p > .95$]. This finding is consistent with other data indicating that failures of PM in younger adults typically reflect omission errors in which a response appropriate to the ongoing activity is made (West & Craik, 2001).

Electrophysiological Data: Intention Formation Trials

Neural activity associated with the formation of an intention was examined by comparing the ERPs elicited on intention formation trials that were later associated with a realized intention (realized intention trials), unrealized intention trials, and ongoing activity trials immediately preceding intention formation trials (see Figures 1 and 2). This analysis was modeled after the difference due to memory (Dm; Paller, McCarthy, & Wood, 1988), or subsequent memory (Sm; Rugg, 1995), analysis utilized in ERP studies of retrospective memory, in which ERPs acquired at encoding are binned for items that are later remembered and those that are later forgotten. In studies in which tests of both recognition and recall have been used, greater positivity over the frontal and parietal regions of the scalp has often been observed for remembered items, relative to forgotten ones (Paller et al., 1988; Rugg, 1995). The data for intention formation trials revealed three noteworthy modulations of the ERPs (N300, formation LPC, and formation slow wave).

The N300 reflected a phasic negativity that peaked around 300 msec after stimulus onset over the occipital-parietal region. The N300 differentiated the ERPs elicited on realized intention trials and unrealized intention trials from those elicited on ongoing activity trials. This modulation was quantified in a 3 (condition) $\times$ 2 (hemisphere) $\times$ 4 (electrode: Po9–Po10, O1–O2, P7–P8, Po3–Po4) MANOVA. In this analysis, the main effect of condition

Figure 1. Grand averaged ERPs for ongoing activity trials preceding intention formation trials, realized intention trials, and unrealized intention trials and their approximate spatial locations on the scalp.

was significant [$\lambda = .20$; $F(2,17) = 33.14$, $p < .001$], with the amplitude of the N300 being greater for realized intention trials ($M = -3.40 \mu V$) and unrealized intention trials ($M = -3.10 \mu V$) than for ongoing activity trials ($M = 1.11 \mu V$). The condition $\times$ electrode interaction was also significant [$\lambda = .34$; $F(6,13) = 4.19$, $p < .02$], with the amplitude of the N300 being greatest at electrodes Po9 and Po10.

The formation LPC reflected positivity over the parietal region of the scalp and negativity over the lateral frontal regions of the scalp that peaked around 575 msec after stimulus onset. Like the N300, the formation LPC differentiated the ERPs elicited on realized intention trials and unrealized intention trials from those elicited on ongoing activity trials. The LPC probably reflected the P3 that is

commonly observed when a low-probability target stimulus is encountered (Donchin & Coles, 1988) and was not predictive of the later realization of an intention. The formation LPC was quantified in a 3 (condition) $\times$ 2 (hemisphere) $\times$ 4 (electrode: P3–P4, Cp1–Cp2, M1–M2, Ft9–Ft10) MANOVA. In this analysis, the main effect of condition was significant [$\lambda = .58$; $F(2,17) = 6.11$, $p < .01$], as was the condition $\times$ electrode interaction [$\lambda = .10$; $F(6,13) = 20.95$, $p < .001$], consistent with the inversion of the formation LPC from the parietal region of the scalp to frontal regions of the scalp.

The formation slow wave reflected negativity over the frontal-polar region of the scalp that began around 400 msec after stimulus onset and persisted over the remainder of the analyzed epoch. In contrast to the N300 and the for-

Figure 2. ERP difference waves and spline voltage maps reflecting the N300, the LPC, and the slow wave for intention formation trials. For the N300 and the LPC, the waveform reflects the difference between realized intention trials and ongoing activity trials. For the slow wave, the waveform reflects the difference between realized intention trials and unrealized intention trials. The topography reflects the average of the bounded area for each modulation.

mation LPC, the formation slow wave reflected greater negativity for the ERPs elicited on realized intention trials than for the ERPs elicited on unrealized intention trials. Also, the ERPs elicited by both of these types of trials were quite different in morphology from the ERPs elicited on ongoing activity trials. Given this finding, the formation slow wave may reflect a neural correlate of the encoding of an intention into memory, with differences in the amplitude of this modulation being predictive of whether the intention will be realized when the PM cue is encountered. The formation slow wave was quantified in a 2 (condition) $\times$ 2 (hemisphere) $\times$ 2 (electrode: Fp1–Fp2, Af3–Af4) MANOVA. In this analysis, the main effect of condition was significant [$\lambda = .80$; $F(1,18) = 4.58$, $p < .05$], with the amplitude of the formation slow wave being greater for realized intention trials ($M = -1.42 \mu V$) than for unrealized intention trials ($M = 0.05 \mu V$).

Electrophysiological Data: PM Cue Trials

Neural activity associated with the realization of an intention was examined by comparing the ERPs elicited on PM hit trials, PM miss trials, and ongoing activity trials preceding PM cue trials (see Figures 3 and 4). These data revealed three noteworthy modulations of the ERPs (N300, realization LPC, and realization slow wave).

As in previous research (West et al., 2001), the N300 represented a phasic negativity over the occipital-parietal region of the scalp that peaked around 300 msec after stimulus onset. The N300 differentiated the ERPs elicited on PM hit trials from those elicited on PM miss trials or ongoing activity trials. This finding indicates that the N300 is related to successful prospective remembering and is

not merely a neural response elicited by the relative novelty of the PM cues. The N300 was quantified in a 3 (condition) $\times$ 2 (hemisphere) $\times$ 4 (electrode: Po9–Po10, O1–O2, P7–P8, Po3–Po4) MANOVA. In this analysis, the main effect of condition was significant [$\lambda = .33$; $F(2,17) = 16.99$, $p < .001$], with the ERPs elicited by PM hit trials being more negative ($M = -1.11 \mu V$) than the ERPs elicited by PM miss trials ($M = 0.54 \mu V$) or ongoing activity trials ($M = 1.43 \mu V$).

The realization LPC reflected a positivity over the parietal region of the scalp and a negativity over the frontal regions of the scalp. The realization LPC tended to differentiate the ERPs elicited on PM hit trials and PM miss trials from those elicited on ongoing activity trials. The realization LPC was also smaller in amplitude and less peaked in form than was the formation LPC. This modulation was quantified in a 3 (condition) $\times$ 2 (hemisphere) $\times$ 4 (electrode: P3–P4, Cp1–Cp2, M1–M2, Ft9–Ft10) MANOVA. In this analysis, the main effect of condition [$\lambda = .75$; $F(2,17) = 2.85$, $p < .09$] and the condition $\times$ electrode interaction [$\lambda = .46$; $F(6,13) = 2.58$, $p < .08$] were marginally significant. Also, the condition $\times$ hemisphere $\times$ electrode interaction was significant [$\lambda = .26$; $F(6,13) = 6.26$, $p < .005$], resulting from the similar amplitudes of the ERPs elicited by PM hit trials and by PM miss trials over the parietal and right frontal regions of the scalp and the greater negativity for the ERPs elicited by PM hit trials, relative to PM miss trials and ongoing activity trials, over the left frontal region of the scalp (see Figure 5).

In contrast to the formation slow wave, which reflected an enhanced negativity over the frontal-polar region of the scalp for realized intention, the realization slow wave reflected a

Figure 3. Grand average ERPs for ongoing activity trials preceding PM cue trials, PM hit trials, and PM miss trials and their approximate spatial locations on the scalp.

sustained positivity over the frontal-central region of the scalp that onset around 300 msec after stimulus onset and differentiated the ERPs elicited on PM hit trials from those elicited on PM miss trials and ongoing activity trials (see Figures 2 and 4). This modulation was quantified in a 3 (condition) $\times$ 2 (hemisphere) $\times$ 4 (electrode: Fc1–Fc2, F3–F4, Af3–Af4, F7–F8) MANOVA. In this analysis, the main effect of condition was significant [$\lambda = .60$; $F(2,17) = 5.75$, $p < .05$], with the ERPs being less negative for PM hit trials ($M = -0.03 \mu V$) than for PM miss trials ($M = -1.63 \mu V$) and ongoing activity trials ($M = -1.23 \mu V$).

DISCUSSION

ERPs related to Intention Formation

Intention formation trials were associated with three functionally, temporally, and spatially distinct modulations of the ERPs (N300, formation LPC, and formation slow

wave). For intention formation trials, the N300 and the formation LPC did not differentiate between trials wherein the intention was realized when the cue was present and trials wherein the intention was not realized when the cue was present. These findings indicate that for intention formation trials, the N300 and the LPC were not predictive of the later realization of an intention. In contrast to the N300 and the LPC, the formation slow wave reflected greater negativity for the ERPs elicited on realized intention trials than for those elicited on unrealized intention trials, indicating that it was predictive of the later success of prospective remembering. The formation slow wave bears a resemblance to the Sm effect (Rugg, 1995) and the contingent negative variation (CNV; Walter, Cooper, Aldridge, McCallum, & Winter, 1964), modulations of the ERPs observed in previous studies in which the neural correlates of retrospective memory encoding and preparatory attention, respectively, were examined.

Figure 4. ERP difference waves and spline voltage maps reflecting the N300, the LPC, and the slow wave for PM cue trials. For the N300 and the LPC, the waveform reflects the difference between PM hit trials and ongoing activity trials. For the slow wave, the waveform reflects the difference between PM hit trials and PM miss trials. The topography reflects the average of the bounded area for each modulation.

If the formation slow wave is taken to represent a form of the Sm effect within the context of prospective memory, it could be considered to reflect the activity of a frontally mediated neural system supporting the encoding of an intended act into memory. In studies of retrospective memory, it is relatively common to observe Sm effects that represent greater positivity over the parietal and frontal regions of the scalp for materials that are later remem-

bered, relative to materials that are not remembered. Furthermore, Donchin and Fabiani (1991) have proposed that Sm effects over the parietal region of the scalp reflect the influence of nonelaborative mnemonic strategies, whereas Sm effects over the frontal region of the scalp are more closely tied to elaborative strategies and the recollection of materials during memory retrieval (Mangels, Picton, & Craik, 2001). Given this proposal and the frontal-polar

Figure 5. Average voltages for the realization LPC over the parietal and frontal regions of the scalp, representing the condition $\times$ hemisphere $\times$ electrode interaction. Note the greater negativity for the PM hit trials than for the PM miss trials over the left hemisphere than over the right hemisphere.

distribution of the formation slow wave, it seems reasonable to suggest that this modulation of the ERPs reflects the activity of a neural system supporting elaborative processing on intention formation trials that facilitates detection of the PM cue when the cue is later encountered (McDaniel, 2001).

An interesting difference between the formation slow wave and the frontally distributed Sm effects observed in studies of retrospective memory lies in the polarity of these modulations. In studies of retrospective memory, the Sm effect typically reflects greater positivity for remembered materials, relative to not remembered materials (Rugg, 1995). In contrast, the formation slow wave reflects greater negativity for the ERPs elicited on realized intention trials than for the ERPs elicited on unrealized intention trials. These findings may indicate that functionally similar cognitive operations are supported by distinct neural systems in the areas of PM and retrospective memory (Glisky, 1996). This proposal would be consistent with the findings from a number of behavioral studies indicating that similar variables influence the efficiency of both PM and retrospective memory (e.g., semantic context, McDaniel et al., 1998; distinctiveness, Brandimonte & Passolunghi, 1994).

Alternatively, the formation slow wave could represent a form of the CNV observed in studies of preparatory attention (Walter et al., 1964). The CNV reflects a sustained negativity that emerges between the presentations of a warning stimulus and an imperative stimulus and is typically maximal in amplitude over the frontal-central region of the scalp (Hugdahl, 1995). In the present experiment, one could imagine that one way of succeeding in the task would have been to use the intention formation trial as a signal that a PM cue trial was likely to appear in the next several trials, with the greater negativity for realized intention trials than for unrealized intention trials reflecting differences in the efficiency with which this preparatory state could be established. Consistent with this proposal, Einstein et al. (2000) recently observed failures of PM when the realization of an intention had to be postponed for several seconds. However, more evidence would seem to be necessary to support this interpretation of the formation slow wave, since few subjects reported using this kind of strategy while performing the task and it represents a relatively demanding strategy to maintain, based on the personal experience of the authors.

ERPs Related to Intention Realization

For PM cue trials, an N300 was observed that differentiated PM hit trials from PM miss trials and ongoing activity trials. This finding indicates that for PM cue trials, the N300 was related to successful prospective remembering and did not reflect a general neural response to the relative novelty of the colors defining the PM cues. The presence of the N300 for those PM cues that elicited a prospective response is consistent with the idea that this modulation of the ERPs reflects the activity of a neural

mechanism that supports the detection of a PM cue (West et al., 2001).

The realization LPC reflected positivity over the parietal region and negativity over the lateral frontal regions of the scalp for PM cue trials, relative to ongoing activity trials, consistent with the findings of West et al. (2001). This modulation was functionally different from the N300 observed for PM cue trials over the parietal and right frontal regions of the scalp, for which the ERPs elicited on PM hit trials and PM miss trials reflected greater positivity than did those elicited on ongoing activity trials. In contrast, over the left lateral frontal region of the scalp, the realization LPC reflected greater negativity for PM hit trials than for PM miss trials or ongoing activity trials. In West et al., we suggested that the realization LPC reflected the activity of a neural system supporting the directed search process that gives rise to the realization of an intention. This proposal was based on the finding that the realization LPC was observed only when the PM cue was associated with a to-be-realized intention and on the observation that remembered materials are more commonly associated with greater positivity over the parietal region of the scalp than are materials that are not remembered, in studies using ERPs to examine the neural correlates of retrospective memory (see Allan, Wilding, & Rugg, 1998). However, the results of the present experiment are not fully consistent with this proposal since, at least over the parietal and right frontal regions of the scalp, the realization LPC was similar in amplitude for PM hit trials and PM miss trials. The presence of the realization LPC for PM miss trials indicates that this modulation of the ERPs was not strictly associated with the realization of an intention when the PM cue was present, as might be expected if it reflected a neural correlate of the directed search process.

Although the findings of the present study are inconsistent with the interpretation of the realization LPC as reflecting a neural correlate of the directed search process, the nature of this modulation may be consistent with the character of the *automatic associative process* described in a recent model of PM (Guynn, McDaniel, & Einstein, 2001; McDaniel et al., 1998). The automatic associative model represents an extension of Moscovitch's (1994) *working-with-memory* model, proposing that memory is supported by the interaction of modules and central systems (Fodor, 1983). The automatic associative process is thought to reflect the product of a module that serves to bind the PM cue and intention into a durable memory trace when the intention is formed and that delivers the to-be-realized intention in a reflexive manner to consciousness when attention is directed to the PM cue during the performance interval (Guynn et al., 2001). In the working-with-memory and automatic associative models, this associative binding process is believed to be supported by a hippocampally based module whose input is the current contents of consciousness. The finding that the old/new recognition memory effect, which also reflects greater positivity over the parietal region of the scalp, is signifi-

cantly attenuated in patients after hippocampal resection for the treatment of epilepsy (M. E. Smith & Halgren, 1989) is consistent with the idea that the hippocampus participates in a neural system that gives rise to activity over the parietal region of the scalp, as is finding that neural activity over the parietal region varies in amplitude with the richness of the contextual information that is recovered from memory (Allen et al., 1998). This interpretation of the realization LPC would also be consistent with memory- or context-updating interpretations of the P3 (Donchin & Coles, 1988), for which the presentation and/or detection of an attention-demanding stimulus typically elicits a robust positivity over the parietal region that is thought to reflect processing associated with the encoding of a stimulus into working memory or consciousness.

If the realization LPC reflects a neural correlate of the automatic associative process and the automatic associative process serves to deliver a to-be-realized intention to consciousness when a PM cue is encountered, why then was the intention not realized on missed PM cue trials? One possibility is that a recovered intention is but one of multiple sources of information competing for access to the response system. For instance, in the present experiment, one could imagine that there is a fairly strong bias to output the results of the semantic comparison, since this reflects the appropriate response on 92% of the trials. This bias may require individuals to actively disengage from the ongoing activity in order to realize an intention when the PM cue is encountered, with failures to disengage resulting in the intention's going unrealized on PM miss trials. Supporting this interpretation, response times were similar for PM miss trials, which generally reflected semantic judgments, and ongoing activity trials. Also, Cockburn (1995) observed that a patient with frontal lobe damage demonstrated a deficit in PM when realization of the intention required disengagement from an ongoing activity and no PM deficit when realization of the intention did not require disengagement from an ongoing activity. Finally, behavioral studies have demonstrated that, in some instances, failures of PM are associated with late prospective responses, in which the intention is realized some time after presentation of the PM cue (Kvavilashvili, 1998), and that missed PM cues are, in some instances, associated with slowing of response latency following an error (West & Craik, 1999). Together, these behavioral and electrophysiological findings support the idea that intentions are reflexively activated by PM cues but that, on some occasions, activated intentions fail to guide behavior.

The realization slow wave reflected greater positivity for PM hit trials than for PM miss trials or ongoing activity trials over the frontal region of the scalp. The onset of the realization slow wave followed the time course of the N300, a modulation that also differentiated PM hit trials from PM miss trials and ongoing activity trials. This temporal correspondence is interesting, given the proposal of the noticing + search model of prospective memory, wherein the noticing process is believed to result in the activation

of the directed search process (Einstein & McDaniel, 1996). On the basis of these findings, it may be concluded that the realization slow wave reflects a neural correlate of disengagement from ongoing activity (Cockburn, 1995) or of evaluation of information recovered from memory (Einstein & McDaniel, 1996) once a PM cue is detected.

The present study has revealed modulations of the ERPs that seem partially consistent with cognitive mechanisms proposed to support prospective remembering within both the noticing + search (Einstein & McDaniel, 1996) and the automatic associative (McDaniel et al., 1998) models of PM. At first glance, this might seem contradictory, since the automatic associative process was proposed in order to eliminate the need for the cue detection process described in the noticing + search model. However, a parsimonious account of the present findings may reside within the broader context of the working-with-memory model (Moscovitch, 1994) that represents the foundation of the automatic associative model. Within the working-with-memory model, modules and central systems can be thought of as working in concert to produce a goal-directed, contextually integrated representation of the past, present, and future (see Wheeler, Stuss, & Tulving, 1997). The automatic associative process can be thought of as representing a module that is responsible for delivering the contents of an intention to consciousness when a PM cue interacts with a memory trace representing the intention. Being a module, the action of the automatic associative process is obligatory (Moscovitch, 1994), meaning that an intention would be delivered to consciousness when attention is directed to a PM cue. However, once the intention is delivered to consciousness, it would be but one of many sources of information vying for access to the response system. The activation of competing response alternatives would require the intervention of a central system that would serve to bias responding toward the realization of the intention or would serve to inhibit, or disengage from, the ongoing activity (see Stuss, Shallice, Alexander, & Picton, 1995). On the basis of this conceptualization, the realization LPC could be thought to arise from the activity of a hippocampally mediated neural system that serves to deliver the intention to consciousness when the PM cue is attended (Guynn et al., 2001). The N300 and the realization slow wave may then reflect the activity of neural mechanisms, functionally independent from the automatic associative process, that serve to alert the information processing system to the presence of a possible cue in the environment (N300) and to prepare the system to make a prospective response by disengaging from the ongoing activity (realization slow wave). This proposal is consistent with data indicating that individuals are often sensitive to missed PM cues (Kvavilashvili, 1998; West & Craik, 1999), presumably as a result of the activity of the automatic associative process, and that the failure to realize an intention can result from a decrease in the efficiency of a mechanism supporting cue detection (West & Covell, 2001) or disengagement from the ongoing activity (Cockburn, 1995).

Prospective Memory and the Frontal Lobe

There is evidence from the areas of both neuroimaging and neuropsychology that the frontal lobe plays an important role in the realization of intentions. Data from studies in which positron emission tomography was used indicate that PM is supported by a broadly distributed neural network that may involve participation of the frontal-polar, dorsolateral, and middle frontal gyrus of the prefrontal cortex, the inferior parietal lobe, the precuneus region, the parahippocampal gyrus, and the thalamus (Burgess, Quayle, & Frith, 2001; Okuda et al., 1998). Burgess et al. (2001) proposed that the frontal-polar and parietal regions may participate in a neural system that supports maintenance of an intention over the course of the ongoing activity, whereas the thalamus and right dorsolateral prefrontal regions may participate in a neural system specifically related to the realization of an intention.

The findings of these neuroimaging studies are complemented by data from neuropsychological investigations revealing that disruption of the functional integrity of the frontal lobe, resulting from focal lesions (Burgess, Veitch, de Lacy Costello, & Shallice, 2000) or traumatic brain injury (Shum, Valentine, & Cutmore, 1999) or associated with the aging process (McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999), may lead to impairments of PM in laboratory and naturalistic settings. Consistent with the idea that the hippocampal complex is an active participant in successful PM is the finding that patients with diagnoses of Alzheimer's disease or mild cognitive impairment demonstrate marked deficits, relative to controls, when performing PM tasks (Huppert & Beardsall, 1993; G. Smith, Della Sala, Logie, & Maylor, 2000). However, support for a role of the hippocampus in PM is not universal, since McDaniel et al. (1999) have reported that individual differences in "hippocampal function" did not predict the success of PM in community-dwelling older adults.

In previous work (West et al., 2001), we generally failed to observe distinct modulations of the ERPs that seemed to be frontally mediated. One factor that may have contributed to this failure is that the PM task utilized in West et al. may have been relatively undemanding with regard to those neurocognitive processes associated with the frontal lobe. In that study, we used a single PM cue, intention, and response association, which was realized repeatedly over the course of task performance. This habitual cue–intention–response association may have placed few demands on neural processes supporting the retrieval of an intention or on those that serve to monitor the contents of information recovered from memory (see McDaniel & Einstein, 2000). Consistent with this idea, when a more demanding PM task was used in the present study, a pair of frontally distributed slow waves was elicited on intention formation and PM cue trials in which the intention was ultimately realized. Together, these findings may indicate that the involvement of the frontal lobe in supporting efficient PM becomes particularly important in a context in which nonhabitual prospective responding is required.

SUMMARY

In summary, the formation and realization of an intention were associated with a number of temporally, spatially, and functionally distinct modulations of the ERPs. Intention formation trials were associated with a slow wave over the frontal-polar region of the scalp that reflected greater negativity for realized intention trials than for unrealized intention trials. Given work in the area of retrospective memory, this modulation may reflect a neural correlate of a system supporting elaborative processing that facilitates detection of the PM cue when it is later encountered. PM cue trials were associated with an N300, a realization LPC, and a realization slow wave. The realization LPC reflected greater positivity over the parietal region of the scalp and negativity over the right frontal region of the scalp for PM cue trials, regardless of whether or not the intention was realized. Given this finding, the realization LPC may reflect the activity of a neural system supporting the recovery of an intention from memory but is not necessarily associated with its realization. Finally, PM cue trials were associated with a frontal slow wave that differentiated PM hit trials from PM miss trials and that may reflect the activity of a neural system supporting disengagement from ongoing activity.

REFERENCES

- ALLAN, K., WILDING, E. L., & RUGG, M. D. (1998). Electrophysiological evidence for dissociable processes contributing to recollection. *Acta Psychologica*, **98**, 231-252.
- BATTIG, W. F., & MONTAGUE, W. E. (1969). Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology Monographs*, **80**, 1-46.
- BRANDIMONTE, M. A., & PASSOLUNGH, M. C. (1994). The effect of cue-familiarity, cue-distinctiveness, and retention interval on prospective remembering. *Quarterly Journal of Experimental Psychology*, **47A**, 565-587.
- BURGESS, P. W., QUAYLE, A., & FRITH, C. D. (2001). Brain regions involved in prospective memory as determined by positron emissions tomography. *Neuropsychologia*, **39**, 545-555.
- BURGESS, P. W., VEITCH, E., DE LACY COSTELLO, A., & SHALLICE, T. (2000). The cognitive and neuroanatomical correlates of multitasking. *Neuropsychologia*, **38**, 848-863.
- COCKBURN, J. (1995). Task interruption in prospective memory: A frontal lobe function. *Cortex*, **31**, 87-97.
- COHEN, A. L., WEST, R., & CRAIK, F. I. M. (2001). Modulation of the prospective and retrospective components of prospective remembering in younger and older adults. *Aging, Neuropsychology, & Cognition*, **8**, 1-13.
- DONCHIN, E., & COLES, M. G. (1988). Is the P300 component a manifestation of context updating? *Behavioral & Brain Sciences*, **11**, 357-427.
- DONCHIN, E., & FABIANI, M. (1991). The use of event-related brain potentials in the study of memory: Is P300 a measure of event distinctiveness? In J. R. Hennings & M. G. H. Coles (Eds.), *Handbook of cognitive psychophysiology: Central and autonomic system approaches* (pp. 471-498). Chichester, U.K.: Wiley.
- EINSTEIN, G. O., HOLLAND, L. J., MCDANIEL, M. A., & GUYNN, M. J. (1992). Age-related deficits in prospective memory: The influence of task complexity. *Psychology & Aging*, **7**, 471-478.
- EINSTEIN, G. O., & MCDANIEL, M. A. (1990). Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **16**, 717-726.
- EINSTEIN, G. O., & MCDANIEL, M. A. (1996). 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* (pp. 115-142). Mahwah, NJ: Erlbaum.
- EINSTEIN, G. O., MCDANIEL, M. A., MANZI, M., COCHRAN, B., & BAKER, M. (2000). Prospective memory and aging: Forgetting intentions over short delays. *Psychology & Aging*, **15**, 671-683.
- ELLIS, J. (1996). Prospective memory or the realization of delayed intentions: A conceptual framework for research. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 1-22). Mahwah, NJ: Erlbaum.
- ELLIS, J., & KVAVILASHVILI, L. (2000). Prospective memory in 2000: Past, present, and future directions. *Applied Cognitive Psychology*, **14**, S1-S10.
- FODOR, J. A. (1983). *The modularity of mind*. Cambridge, MA: MIT Press.
- GLISKY, E. (1996). Prospective memory and frontal lobes. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 249-266). Mahwah, NJ: Erlbaum.
- GOSCHKE, T., & KUHL, J. (1993). The representation of intentions: Persisting activation in memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **19**, 1211-1226.
- GUINN, M. J., MCDANIEL, M. A., & EINSTEIN, G. O. (2001). Remembering to perform intentions: A different type of memory? In H. D. Zimmer, R. L. Cohen, M. J. Guynn, J. Engelkamp, R. Kormi-Nouri, & M. A. Foley (Eds.), *Memory for action: A distinct form of episodic memory?* (pp. 25-48). Oxford: Oxford University Press.
- HUGDAHL, K. (1995). *Psychophysiology: The mind-body perspective*. Cambridge, MA: Harvard University Press.
- HUPPERT, F. A., & BEARDSALL, L. (1993). Prospective memory impairment as an early indicator of dementia. *Journal of Clinical & Experimental Neuropsychology*, **15**, 805-821.
- KVAVILASHVILI, L. (1998). Remembering intentions: Testing a new method of investigation. *Applied Cognitive Psychology*, **12**, 533-554.
- MANGELS, J. A., PICTON, T. W., & CRAIK, F. I. M. (2001). Attention and successful episodic encoding: An event-related potential study. *Cognitive Brain Research*, **11**, 77-95.
- MANGUN, G. R., & HILLYARD, S. A. (1995). Mechanisms and models of selective attention. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 40-84). Oxford: Oxford University Press.
- MARSH, R. L., HICKS, J. L., & BINK, M. L. (1998). Activation of completed, uncompleted, and partially completed intentions. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **24**, 350-361.
- MCDANIEL, M. A. (1995). Prospective memory: Progress and processes. In D. L. Medin (Series Ed.) and J. Busemeyer & R. Hastie (Vol. Eds.), *The psychology of learning and motivation* (Vol. 32, pp. 191-221). San Diego: Academic Press.
- MCDANIEL, M. A. (2001, March). *Retrieval processes in prospective memory: A multiprocess framework*. Paper presented at the meeting of the Southeastern Psychological Association, Atlanta.
- MCDANIEL, M. A., & EINSTEIN, G. O. (1992). Aging and prospective memory: Basic findings and practical applications. *Advances in Learning & Behavioral Disabilities*, **7**, 87-105.
- MCDANIEL, M. A., & EINSTEIN, G. O. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Applied Cognitive Psychology*, **14**, S127-S144.
- MCDANIEL, M. A., GLISKY, E. L., RUBIN, S. R., GUINN, M. J., & ROUTHIAUX, B. C. (1999). Prospective memory: A neuropsychological study. *Neuropsychology*, **13**, 103-110.
- MCDANIEL, M. A., ROBINSON-RIEGLER, B., & EINSTEIN, G. O. (1998). Prospective remembering: Perceptually driven or conceptually driven processes? *Memory & Cognition*, **26**, 121-134.
- MEACHAM, J. A., & LEIMAN, B. (1982). Remembering to perform future actions. In U. Neisser (Ed.), *Memory observed* (pp. 327-336). San Francisco: Freeman.
- MOSCOVITCH, M. (1994). Memory and working with memory: Evaluation of a component process model and comparisons with other models. In D. L. Schacter & E. Tulving (Eds.), *Memory systems* (pp. 269-310). Cambridge, MA: MIT Press.
- OKUDA, J., FUJII, T., YAMADORI, A., KAWASHIMA, R., TSUKIURA, T., FUKATSU, R., SUZUKI, K., MASATOSHI, I., & FUKUDA, H. (1998). Participation of the prefrontal cortices in prospective memory: Evidence from a PET study in humans. *Neuroscience Letters*, **253**, 127-130.
- PALLER, K. A., MCCARTHY, G., & WOOD, C. C. (1988). ERPs predictive of subsequent recall and recognition performance. *Biological Psychology*, **26**, 269-276.
- PICTON, T. W., BENTIN, S., BERG, P., DONCHIN, E., HILLYARD, S. A., JOHNSON, R., MILLER, G. A., RITTER, W., RUCHKIN, D. S., RUGG, M. D., & TAYLOR, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, **37**, 127-152.
- RENDELL, P. G., & CRAIK, F. I. M. (2000). Virtual week and actual week: Age-related differences in prospective memory. *Applied Cognitive Psychology*, **14**, S43-S62.
- RUGG, M. D. (1995). ERP studies of memory. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 132-170). Oxford: Oxford University Press.
- SHUM, D., VALENTINE, M., & CUTMORE, T. (1999). Performance of individuals with severe long-term traumatic brain injury on time-, event-, and activity-based prospective memory tasks. *Journal of Clinical & Experimental Neuropsychology*, **21**, 49-58.
- SMITH, G., DELLA SALA, S., LOGIE, R. H., & MAYLOR, E. A. (2000). Prospective and retrospective memory in normal aging and dementia: A questionnaire study. *Memory*, **8**, 311-321.
- SMITH, M. E., & HALGREN, E. (1989). Dissociation of recognition memory components following temporal lobe lesions. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **15**, 50-60.
- STUSS, D. T., SHALLICE, T., ALEXANDER, M. P., & PICTON, T. W. (1995). A multidisciplinary approach to anterior attention functions. In J. Grafman, K. J. Holyoak, & F. Boller (Eds.), *Structure and functions of the human prefrontal cortex* (Annals of the New York Academy of Sciences, Vol. 769, pp. 191-212). New York: New York Academy of Sciences.
- WALTER, W. G., COOPER, R., ALDRIDGE, V. J., MCCALLUM, W. C., & WINTER, A. L. (1964). Contingent negative variation. *Nature*, **203**, 380-384.
- WEST, R., & COVELL, E. (2001). Effects of aging on event-related neural activity related to prospective remembering. *NeuroReport*, **12**, 2855-2858.
- WEST, R., & CRAIK, F. I. M. (1999). Age-related decline in prospective memory: The roles of cue accessibility and cue sensitivity. *Psychology & Aging*, **14**, 264-272.
- WEST, R., & CRAIK, F. I. M. (2001). Influences on the efficiency of prospective memory in younger and older adults. *Psychology & Aging*, **16**, 682-696.
- WEST, R., HERNDON, R. W., & CREWDSON, S. J. (2001). Neural activity associated with the realization of a delayed intention. *Cognitive Brain Research*, **12**, 1-10.
- WHEELER, M. A., STUSS, D. T., & TULVING, E. (1997). Toward a theory of episodic memory: The frontal lobes and autonoetic consciousness. *Psychological Bulletin*, **121**, 331-354.