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Is detecting prospective cues the same as selecting targets? An ERP study

ROBERT WEST and NICHOLAS WYMBS
University of Notre Dame, Notre Dame, Indiana

Prospective memory represents our ability to realize intentions that must be delayed for some period of time. In this study, we examined modulations of the event-related brain potentials (ERPs) associated with target selection in visual working memory and prospective-cue detection in prospective memory. Targets and prospective cues elicited an N2pc, indicating that a common neural mechanism supports selection in working memory and prospective memory. Partial least squares analysis revealed that the N300 and prospective positivity were associated with a latent variable that contrasted the ERPs elicited by prospective-cue trials with those elicited by target-present and target-absent trials, in agreement with the idea that these modulations of the ERPs are uniquely related to prospective memory.

Prospective memory represents our ability to realize intentions that must be delayed for minutes, hours, or days (Ellis, 1996; Meacham & Leiman, 1982) and can be conceptually distinguished from recognition memory, which involves the recollection of information related to previous episodes (Tulving, 1983), and working memory, which involves the active maintenance of a limited amount of information for a relatively brief period of time (Baddeley, 1986). Considerable evidence indicates that a variety of experimental variables have similar effects on the efficiency of prospective memory, recognition memory, and working memory, leading to the suggestion that similar cognitive processes and neural mechanisms may support these different forms of memory (for a review, see McDaniel & Einstein, 2000). Given these findings, one might wonder what differentiates prospective memory from other forms of memory. The prevailing view is that prospective memory requires self-initiated attentional processes that facilitate the recognition of a stimulus as a prospective memory cue when it is encountered in the absence of an external agent that serves to prompt retrieval (Craik, 1986; Graf & Uttl, 2001; Smith, 2003). In contrast, within the context of recognition or working memory, an external agent almost always prompts memory retrieval. For instance, in laboratory tasks in which recognition memory is measured, individuals are often instructed to indicate whether any of a series of stimuli was presented in an earlier study episode. Evidence from recent studies has begun to elucidate the nature of the neural mechanisms and cognitive processes that differentiate prospective memory from other forms of memory (Burgess, Quayle, & Frith, 2001; McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999; Smith, 2003). In the present study, we expanded on this growing body of literature by examining the degree to which common and distinct modulations of the event-related brain potentials (ERPs) were associated with the detection of prospective memory cues (West, Herndon, & Crewdson, 2001) and the selection of target stimuli represented in visual working memory (Eimer, 1996).

The contribution of attentional processes to the detection of prospective memory cues has been described in two models (Guynn, McDaniel, & Einstein, 2001; Smith, 2003). In the automatic associative model, Guynn et al. propose that prospective remembering occurs when a focally attended prospective memory cue interacts with a memory trace that represents the cue–intention association, resulting in delivery of the intention to conscious awareness. In agreement with this proposal, data from a number of studies have demonstrated that prospective memory is less efficient when individuals are engaged in processing that is incongruous with that required for the detection of a prospective memory cue (Marsh, Hicks, & Hancock, 2000; Meier & Graf, 2000), presumably resulting from the allocation of focal attention to attributes of the stimulus that are unrelated to its role as a prospective memory cue. In the preparatory attention and memory (PAM) processes theory of prospective memory, Smith proposes that the allocation of preparatory attentional processes, which are thought to consume working memory capacity, is required for a stimulus to be recognized as a prospective memory cue. In agreement with this proposal, an index of preparatory attentional processes was found to correlate with the accuracy of prospective memory and individual differences in working memory capacity (Smith, 2003).

In agreement with predictions derived from the automatic associative and PAM models, work from our laboratory indicates that the amplitude of the N300—a mod-

This work was supported by a grant from the American Foundation for Aging Research. N.W. is now in the Brain Research Imaging Center in the Department of Neurology at the University of Chicago. Correspondence should be sent to R. West, Department of Psychology, University of Notre Dame, Notre Dame, IN 46556 (e-mail: west.19@nd.edu).

ulation of the ERPs associated with the detection of prospective memory cues (West et al., 2001; West & Ross-Munroe, 2002)—is modulated by the allocation of attention in prospective memory tasks. The N300 is a phasic modulation of the ERPs that peaks 300–400 msec after stimulus onset over the occipital-parietal and frontal regions (West et al., 2001) and differentiates prospective memory hits from prospective memory misses and ongoing activity trials (West & Ross-Munroe, 2002). West et al. (2001) investigated the influence of attention on the N300 in a study in which individuals were told to ignore highly salient prospective cues for half of the blocks and to make a prospective response when the prospective cues were detected in the remaining blocks. In that study, the amplitudes of the N300 in the attend and ignore conditions were similar over the left hemisphere, indicating that this modulation probably reflected the N2 component, which is elicited by perceptually salient stimuli (Mangun & Hillyard, 1995). In contrast, the amplitude of the N300 over the right hemisphere was greater in the attend condition than in the ignore condition, presumably reflecting the influence of attention on prospective remembering. Further evidence that attentional processes contribute to generation of the N300 comes from a study that revealed that the amplitude of this modulation is sensitive to the working-memory demands of the ongoing activity (West, Bowry, & Krompinger, 2004). In that study, the amplitude of the N300 was attenuated when prospective memory cues were embedded in a 3-back working memory task relative to when cues were embedded in a 1-back working memory task, supporting the proposal that preparatory attentional processes that consume working memory capacity underlie successful prospective remembering (Smith, 2003).

The ERP correlates of target selection for information represented in visual working memory have been examined by a number of investigators. One component, the N2pc, is associated with target selection in visual search tasks (Luck & Hillyard, 1994) and visual discrimination tasks (Eimer, 1996). The N2pc reflects an enhancement of the N2 component 200–300 msec after stimulus onset over the occipital-parietal region of the scalp that is contralateral to the visual field in which the target is presented (Luck & Hillyard, 1994). Luck and Hillyard argued that the N2pc was associated with distractor suppression during visual search. However, the observation that the N2pc is elicited when a single target and a single distractor are presented in the display led Eimer to argue that the N2pc was related to target selection rather than to distractor suppression.

The N300 associated with the detection of a prospective memory cue and the N2pc associated with target selection are similar in a number of ways. Both are maximal in amplitude over the occipital-parietal region of the scalp (Eimer, 1996; West et al., 2001) and appear to reflect subcomponents of the N2, which is generally elicited by the presentation of a task-relevant stimulus. The N300 is elicited by prospective memory cues that are defined by letter case (West et al., 2001), color (West & Ross-Munroe, 2002), and word identity (West & Krompinger, in press). Like the N300, the N2pc is elicited by targets that are defined by a single feature or a conjunction of features (e.g., orientation, color, or size; Luck, Fan, & Hillyard, 1993; Luck & Hillyard, 1994) and by those that are defined by letter and word identity (Eimer, 1996). Together, these similarities lead one to wonder whether a common neural mechanism that supports the selection of task-relevant information contributes to generation of the N300 and the N2pc.

In addition to the N300, prospective memory hits elicit a prospective positivity that reflects a sustained modulation over the parietal region of the scalp 600–1,000 msec after stimulus onset (West & Krompinger, in press; West & Ross-Munroe, 2002). The prospective positivity has been dissociated from the P3 component, which is associated with target categorization (West, Wymbs, Jakubek, & Herndon, 2003), and from the recognition old–new effect, which is associated with the retrieval of a previously studied item from memory (West & Krompinger, in press). The functional significance of processes contributing to generation of the prospective positivity is not clearly understood; however, some evidence indicates that this modulation of the ERPs is associated with postretrieval processes that support the coordination of the prospective and ongoing activity components of the task following retrieval of the intention from memory (West et al., 2003).

The present study was designed to compare the functional characteristics of the neural generators of the N300 with those of the N2pc when prospective memory cues were embedded in a target discrimination task similar to that used by Eimer (1996). If a common neural mechanism contributes to the detection of prospective memory cues and target selection, the functional characteristics of the N300 and N2pc should be similar. Specifically, the amplitude of these modulations of the ERPs should be greater over the hemisphere that is contralateral to the visual field in which the prospective cue or target appears. In contrast, if distinct processes contribute to the detection of prospective memory cues and target selection, the N300 and N2pc should demonstrate different functional characteristics. We also sought to replicate the finding that the prospective positivity can be dissociated from the target P3 (West et al., 2003).

To evaluate these hypotheses, a prospective memory component was embedded in a target discrimination task. In the task, individuals indicated whether a trial-specific target letter presumably represented in visual working memory was present or absent, or made prospective responses to prospective memory cue letters. Test displays included a fixation cross flanked by two letters. This aspect of the design allowed us to compare the N2pc elicited by targets and the N300 elicited by prospective cues presented in the left or right visual field; further-

more, our design differs from those used in previous studies of the N300 in which cues have been presented at fixation, making it difficult to distinguish the N300 from other subcomponents of the N2 (see, e.g., West et al., 2001; West & Ross-Munroe, 2002).

Two analytic methods were used to quantify modulations of the ERPs associated with target selection and the detection of prospective memory cues. Multivariate analysis of variance (MANOVA) in combination with measures of mean amplitude at select electrodes was used to quantify the presence of the N2pc and P3 elicited by target-present trials, and the presence of the N300 and prospective positivity elicited on prospective-cue trials. These analyses allow one to establish the presence of the various modulations of interest within a conventional data-analytic framework. However, MANOVA and other methods based on the general linear model are not ideally suited for making comparisons across task conditions when spatial and temporal overlap among components is present, as is the case for the N2pc and N300 on one hand, and for the P3 and prospective positivity on the other (McCarthy & Wood, 1985). Therefore, partial least squares (PLS) analysis (Lobaugh, West, & McIntosh, 2001; McIntosh, Bookstein, Haxby, & Grady, 1996) was used to examine the latent structure of the ERPs elicited by target-present, target-absent, and prospective memory cue trials. PLS analysis is a multivariate data-analytic technique that allows one to simultaneously consider the full spatial and temporal distribution of task-related effects in ERP data sets across all time points, electrode locations, task conditions, and participants in a single analysis. PLS analysis is particularly powerful when the objective is to identify modulations of the ERPs that overlap in time course and topography that are differentially affected by task conditions (Lobaugh et al., 2001).

METHOD

Participants

Nineteen individuals (age range 18–24 years, $M = 19.84$ years) participated in the study. There were 13 males, and all the participants reported a right hand preference. The individuals received extra course credit for their participation in the study.

Materials and Procedure

The stimuli for the task were 19 consonants from the English alphabet presented in the color yellow. The letters B and N were not used in the study, given the potential for confusion with D and M, which were used as prospective memory cues. The stimuli were displayed in uppercase letters measuring 5 × 5 mm, and were viewed from approximately 50 cm.

The task included 1 practice block of 18 trials and 10 test blocks of 108 trials each. The practice block included 4 prospective-cue trials, 7 target-present trials, and 7 target-absent trials. The test blocks included 12 prospective-cue trials, 48 target-present trials, and 48 target-absent trials. For 6 of the prospective-cue trials, the cue letter (D or M) was presented on the left side of the display, and for the remaining prospective-cue trials the cue letter was presented on the right side of the display. Within a block, each of the prospective cues D and M appeared three times on each side of the display. For prospective-cue trials, a nontarget letter was presented in the display opposite the cue. For the target-present trials, the target letter was presented on the left or right of the display and a nontarget letter was presented opposite the target letter. The target letter appeared on the left side of the display in 24 trials and on the right side of the display in 24 trials. For the target-absent trials, two letters were presented in the display that were neither the target letter, nor the prospective-cue letters, nor the target letters from the previous 2 trials.

Each trial included three displays (target, fixation, and test). For the target display, the target letter was presented in the center of the computer monitor for 150 msec. The target was then replaced by a fixation cross for 400 msec, which was in turn replaced by the test display. The test display included a fixation cross and two letters presented to the right and left of the fixation cross. The outer edges of the letters were separated by 35 mm. The test display was presented for 400 msec and was then replaced by a blank screen until the response was made. The screen remained blank for an additional 500 msec after the response, and then the target letter for the next trial was presented. For the first trial of each block, the screen was blank for 1,000 msec after the space bar was pressed to initiate the block.

Before data collection began, a description of the target selection task was given to the participants. They were told that on each trial a target letter would be presented briefly, followed by a fixation cross and then a test display. The participants were told to press the C key with the left index finger if the target letter was present in the test display and to press the V key with the right index finger if the target letter was not present in the test display. Additionally, the participants were told to press the X key with the left middle finger when the letter D was presented in the test display and the B key with the right middle finger when the letter M was present in the test display. The participants were instructed that a present–absent judgment was not required for trials in which a prospective response was made, and that the prospective letters and the target letter for a given trial would never appear together in the test display. Finally, the participants were told that the test display would be presented for approximately one half of a second and that they would have as much time as necessary to respond.

Electrophysiological Recording and Analysis

The EEG (bandpass .01–100 Hz, digitized at 256 Hz, gain 2,500, 12-bit A/D conversion) was recorded from an array of 45 tin electrodes sewn into an Electro-cap (Electro-Cap International, Eaton, OH) or affixed to the skin with an adhesive patch (at 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, and Io2). Vertical and horizontal eye movements were recorded from the ocular electrodes. During recording, all the electrodes were referenced to Electrode Cz; for data analysis they were re-referenced to an average reference, Electrode Cz was reinstated, and a 20-Hz zero-phase shift low-pass filter was applied.

ERP analysis epochs were extracted offline and included −200 msec of prestimulus activity and 1,000 msec of poststimulus activity. Ocular artifacts associated with blinks were corrected using a covariance technique that simultaneously modeled artifact and artifact-free EEG (Electromagnetic Source Estimation; Source-Signal Imaging, San Diego). Trials contaminated by other artifacts (peak-to-peak deflections over 50 μV) were rejected before averaging. ERPs were averaged for correct responses to target-absent, target-present-left, target-present-right, prospective-cue-left, and prospective-cue-right trials. As an additional precaution against artifacts arising from horizontal saccades to the test display letters, the individual ERP waveforms were inspected for all participants and conditions. If a noticeable left–right inversion was found for an

individual's lateral ocular electrodes, the data for that individual were excluded from the analyses. This procedure resulted in the exclusion of data for three individuals.

Partial least squares analysis (Lobaugh et al., 2001; McIntosh et al., 1996). PLS analysis operates on an ERP data matrix containing participants and conditions in the rows and the amplitudes for all time points and electrodes in the columns. The input matrix for PLS was obtained by mean-centering the columns of the ERP data matrix with respect to the grand mean. The averages within task were thus expressed as deviations around zero. Singular value decomposition (SVD) was performed on the deviation matrix to identify the structure of the latent variables (LVs). Three outputs were derived from the SVD that were used to interpret the relationships between ERP amplitudes and task design. The first was a vector of singular values, which represent the unweighted magnitude of the LVs and can be used to calculate the proportion of the cross-block covariance (i.e., task-related variance) attributable to each LV. The second and third outputs contain the structure of the LVs and are orthogonal pairs of vectors (saliences). One vector defines the contrasts among conditions (design scores) and is used to determine which conditions differ from one another within the context of a given LV. The other vector (ERP saliences) identifies when and where the effects in the design scores are expressed for the LV. The significance of the LVs' singular values was determined using a permutation test (500 replications) that provides an exact probability of observing the singular value by chance (e.g., $p = .001$); the stability of the ERP saliences at each time point and location in space was established through bootstrap resampling (200 replications), which provides a standard error for each of the saliences (McIntosh et al., 1996). The ratio of the salience to its bootstrapped standard error is approximately equivalent to a z score; therefore, bootstrap ratios greater than 2.5 can be taken to indicate stable saliences or time points that differ from zero.

RESULTS

Behavioral Data

Response accuracy was quite high for target-absent trials ($M = 95\%$), indicating that target or prospective-cue false alarms were rare. There was a left–right advantage in accuracy for target-present and prospective-cue trials, with accuracy being higher for stimuli presented in the left visual field (target $M = 91\%$, cue $M = 77\%$) than for those presented in the right visual field (target $M = 88\%$, cue $M = 73\%$). Accuracy was also higher for target-present trials than for prospective-cue trials. A 2 (stimulus: target vs. prospective cue) $\times$ 2 (visual field: left vs. right) analysis of variance (ANOVA) confirmed that these effects were significant [stimulus, $F(1,18) = 16.80$, $p < .01$; visual field, $F(1,18) = 17.37$, $p < .01$] and did not interact (stimulus $\times$ visual field, $F < 1$).

The response time data were consistent with the response accuracy data. Response time was shorter for target and prospective-cue trials presented in the left visual field (target $M = 696$ msec, cues $M = 1{,}056$ msec) than for those presented in the right visual field (target $M = 744$ msec, cue $M = 1{,}103$ msec) and shorter for target-present trials than for prospective-cue trials. A 2 (stimulus: target vs. prospective cue) $\times$ 2 (visual field: left vs. right) ANOVA confirmed that these effects were significant [stimulus, $F(1,18) = 104.36$, $p < .01$; visual field, $F(1,18) = 18.60$, $p < .01$] and did not interact (stimulus $\times$ visual field, $F < 1$). Response time for target-absent trials ($M = 934$ msec) fell between the response times for target-present and prospective-cue trials.

Electrophysiological Data

Mean voltage. The grand average ERPs at electrodes demonstrating the N2pc, N300, P3, and prospective positivity are presented in Figure 1. These modulations of the ERPs were quantified in a series of MANOVAs including data from electrode locations utilized in previous studies. The mean voltage of the N2pc was quantified as 250–270 msec; that of the N300, as 340–360 msec; that of the P3, as 400–425 msec; and that of the prospective positivity, as 725–750 msec.

The analysis of the N2pc reflected a 5 (condition) $\times$ 2 (electrode: Po9–Po10 vs. P7–P8) $\times$ 2 (hemisphere) design. In this analysis, the condition $\times$ hemisphere interaction was significant [Wilks's $\lambda = .18$, $F(4,14) = 16.47$, $p < .001$], reflecting the greater negativity for targets and prospective cues presented in the left visual field over the right hemisphere of the scalp and the greater negativity for targets and prospective cues presented in the right visual field over the left hemisphere of the scalp (Table 1). Follow-up analyses contrasting target-present with target-absent trials and prospective-cue with target-absent trials revealed that the N2pc was elicited by targets [condition $\times$ hemisphere: Wilks's $\lambda = .43$, $F(2,16) = 10.49$, $p < .001$] and prospective cues [condition $\times$ hemisphere: Wilks's $\lambda = .66$, $F(2,16) = 4.06$, $p < .04$]. An additional comparison revealed that the amplitude of the N2pc was greater for targets than for prospective cues [condition $\times$ hemisphere: Wilks's $\lambda = .19$, $F(3,15) = 21.81$, $p < .001$].

The analysis of the N300 reflected a 5 (condition) $\times$ 2 (electrode: Po9–Po10 vs. P7–P8) $\times$ 2 (hemisphere) design. In this analysis, the main effect of condition was significant [Wilks's $\lambda = .31$, $F(4,14) = 7.92$, $p < .001$], reflecting greater negativity for prospective-cue trials than for target-present or target-absent trials (Table 2), and the condition $\times$ hemisphere interaction was not significant [Wilks's $\lambda = .65$, $F(4,14) = 1.92$, $p > .15$]. Follow-up analyses revealed that the amplitude of the N300 was greater for prospective-cue trials than for target-present [Wilks's $\lambda = .38$, $F(3,15) = 8.22$, $p < .01$] and target-absent [Wilks's $\lambda = .35$, $F(2,16) = 14.93$, $p < .001$] trials, that the difference between target-present and target-absent trials was not significant [Wilks's $\lambda = .88$, $F(2,16) = 1.11$, $p > .30$], and that the amplitude of the N300 for prospective-cue trials was greater for prospective cues presented in the left visual field than for those presented in the right visual field [Wilks's $\lambda = .76$, $F(1,17) = 5.26$, $p < .04$].

The analysis of the P3 represented a single-factor design including data for the five conditions at Electrode Pz. In this analysis, the effect of condition was significant [Wilks's $\lambda = .07$, $F(4,14) = 48.29$, $p < .001$], with the amplitude of the P3 being greater for target-present trials than for prospective-cue or target-absent trials

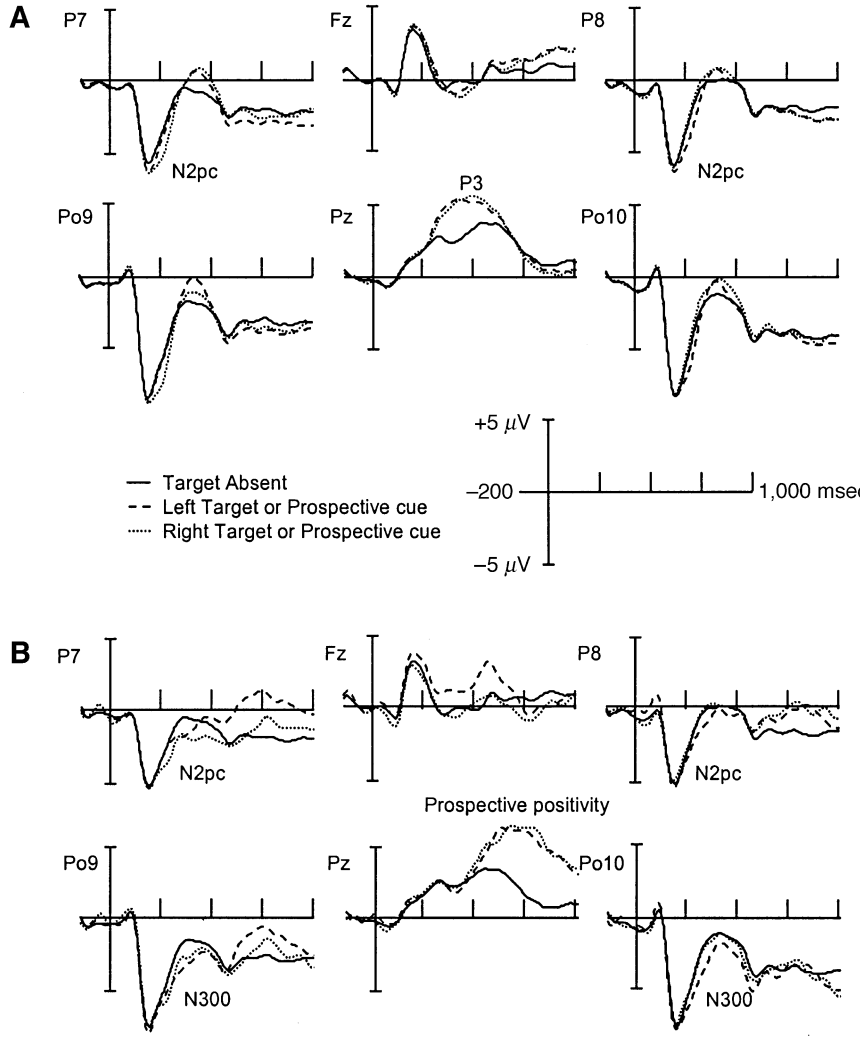

Figure 1. Grand average event-related potentials (ERPs) at electrodes demonstrating the N2pc, N300, P3, and prospective positivity. (A) ERPs for target-absent trials and left and right target-present trials. (B) ERPs for target-absent trials and left and right prospective-cue trials. The tall bars represent stimulus onsets, and the short bars represent 250-msec increments.

(Table 2). Follow-up analyses revealed that the difference between prospective-cue trials and target-present trials was significant [Wilks's $\lambda = .21, F(3,15) = 18.86, p < .001$] and that the difference between prospective-cue and target-absent trials was not significant [Wilks's $\lambda = .97, F < 1$].

The analysis of the prospective positivity represented a single-factor design including data for the five conditions at Electrode Pz. In this analysis, the effect of condition was significant [Wilks's $\lambda = .23, F(4,14) = 11.51, p < .001$], with the amplitude of the prospective positivity being greater for prospective-cue trials than for target-present or target-absent trials (Table 2). Follow-up analyses revealed that the difference between prospective-cue trials and target-present trials was significant [Wilks's $\lambda = .24, F(3,15) = 16.07, p < .001$] and that the difference between target-present and target-absent trials was not significant [Wilks's $\lambda = .94, F < 1$].

Partial least squares analysis. The PLS analysis included the ERPs (0–1,000 msec) elicited by correct responses for target-present and prospective-cue trials presented in the left and right visual fields and for target-absent trials, and included data for all but the ocular electrodes. The permutation test revealed that the first two LVs were significant ($p = .000$ and $p = .032$) and that the third LV was marginally significant ($p = .082$); these LVs accounted for 80.60%, 9.24%, and 8.24% of the crossblock covariance, respectively. As is illustrated in Figure 2, LV1 expressed the ERP correlates of prospective memory, representing a contrast between prospective-cue trials and target-present and target-absent trials and reflecting an occipital-parietal negativity between 300

Table 1
Mean Voltage (in Microvolts) in the Range of the N2pc Collapsed Across Electrodes for Targets and Cues Presented to the Left (Electrodes P7, Po9) and Right (Electrodes P8, Po10) Visual Fields, and on Target-Absent Trials, for the Left and Right Hemispheres

	Target Left		Target Right		Cue Left		Cue Right		Target Absent	
Hemisphere	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Left	−4.96	.61	−6.34	.77	−4.91	.53	−5.60	.64	−4.65	.57
Right	−5.76	.77	−4.28	.78	−5.40	.96	−4.52	.84	−4.64	.75

Table 2
Mean Voltage (in Microvolts) for the N300 (Electrodes P7–P8 and Po9–Po10), P3 (Electrode Pz), and Prospective Positivity (Electrode Pz) for Targets and Cues Presented to the Left and Right Visual Fields, and on Target-Absent Trials

	Target				Cue					
	Left		Right		Left		Right		Target Absent	
Modulation	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
N300	−.88	.57	−.81	.55	−2.74	.43	−1.78	.57	−1.17	.46
P3	5.51	.52	5.35	.57	2.11	.57	2.50	.73	2.50	.48
Prospective positivity	1.47	.58	1.25	.61	6.72	1.02	7.08	1.03	1.62	.73

and 500 msec (N300), a frontal positivity between 300 and 500 msec, and a broadly distributed sustained occipital-parietal positivity from 600 msec (prospective positivity). LV2 expressed an effect of visual field of presentation on the neural correlates of prospective memory, representing a contrast between prospective cues presented in the left and right visual fields and reflecting a phasic right occipital-parietal positivity between 200 and 400 msec (N300), frontal negativity between 300 and 800 msec, and a left central-parietal negativity between 400 and 800 msec. LV3 expressed the neural correlates of target selection, representing a contrast between target-absent trials on one hand and target-present and prospective-cue trials presented in the right visual field on the other, and reflecting a left occipital-parietal postivitity that peaked between 200 and 300 msec (N2), a right occipital-parietal negativity that peaked slightly later, a broadly distributed occipital-parietal negativity that peaked at around 400 msec (P3), and a left central sustained negativity from 300 to 1,000 msec (slow wave).

DISCUSSION

This study was designed to examine similarities in and differences between modulations of the ERPs associated with the selection of target stimuli maintained in visual working memory and the detection of prospective memory cues. The study was motivated by work indicating that both target selection and the detection of prospective memory cues are associated with phasic negativities over the occipital-parietal region of the scalp that are elicited when prospective cues and targets are defined by a number of different attributes and more sustained positivities over the parietal region (Eimer, 1996; West et al., 2001). The behavioral data revealed a robust left–right advantage in terms of response time and accuracy for targets and prospective cues. The ERP data revealed common (i.e., N2pc) and distinct (i.e., N300, P3, prospective positivity) modulations of the ERPs elicited by target trials and prospective-cue trials. These findings demonstrate that a common neural mechanism supports selection processes in visual working memory and prospective memory, and that processes that are unique to prospective memory further support the realization of delayed intentions (Graf & Uttl, 2001).

The behavioral data were largely consistent with findings from previous research. Response time was shorter and response accuracy higher for target-present and prospective-cue trials presented in the left visual field than for those presented in the right visual field. Response accuracy was lower and response time longer for prospective-cue trials than for target-present trials when these two classes of stimuli were embedded in a single task. The reduction in response accuracy for prospective-cue trials relative to target-present trials was consistent with evidence from a recent study in which the behavioral and ERP correlates of prospective memory, recognition memory, and cued recall were compared (West & Krompinger, in press). In that study, the frequency of prospective-cue hits was lower than that of recognition or cued-recall hits when the characteristics of the prospective and retrospective components of the task were closely matched. West and Krompinger argued that the difference in response accuracy for the prospective and retrospective components of the task arose from demands placed on processes that are distinct from those of prospective memory such as the need to detect prospective cues and to coordinate the ongoing and prospective components of the task (West & Krompinger, in press).

The N2pc was elicited by targets and prospective cues, in agreement with the hypothesis that a common neural mechanism supports the selection of task-relevant stimuli regardless of whether the stimuli are represented in visual working memory or associated with a delayed intention. This finding indicates that the N2pc can be elicited by target stimuli that remain static over an extended pe-

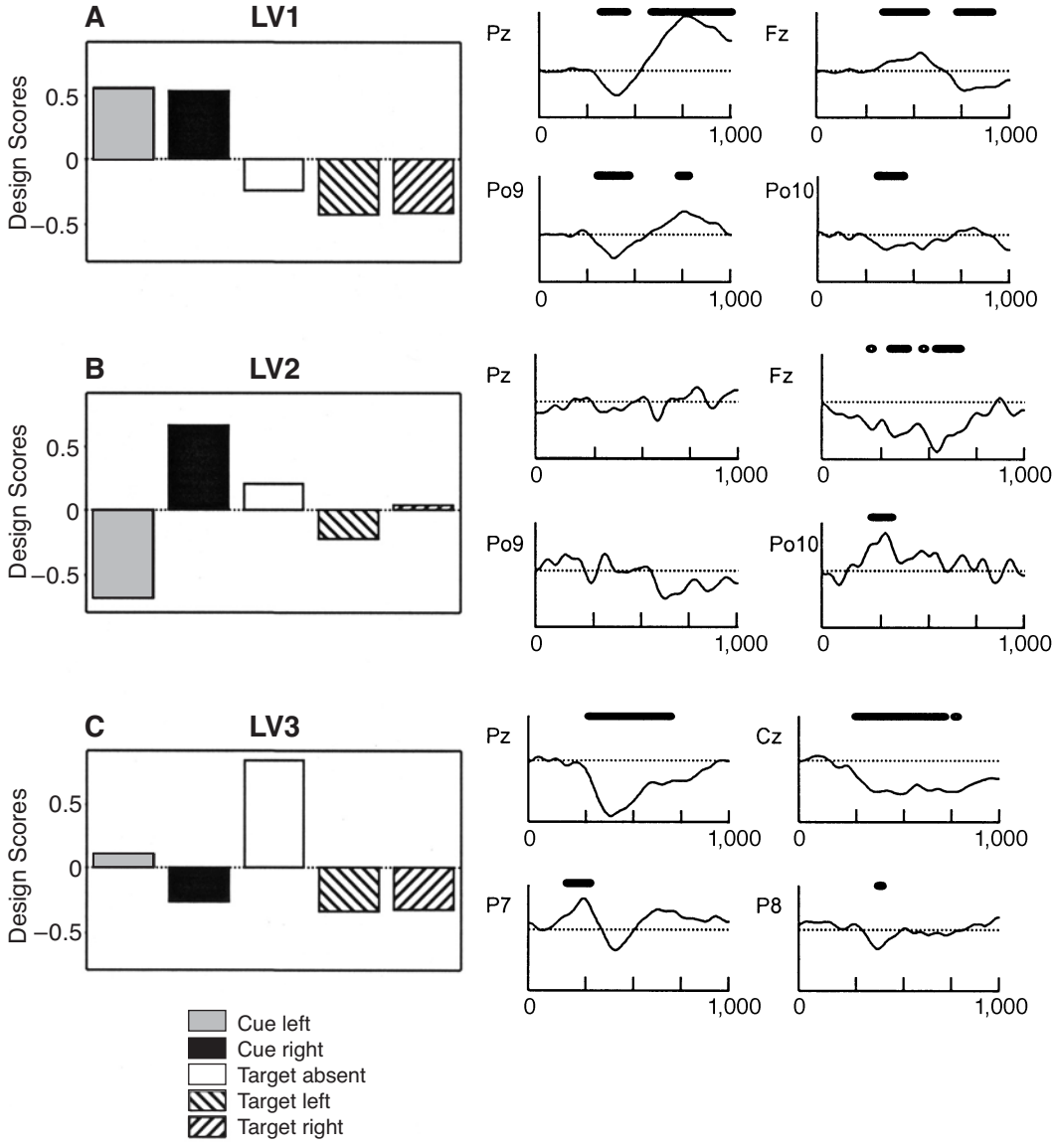

Figure 2. Design scores demonstrating task contrasts and electrode saliences at select electrodes demonstrating the time course of the three latent variables (LVs). (A) LV1 reflects the contrast of prospective-cue trials with the other conditions and represents the prospective positivity (Pz), a frontal positivity (Fz), and the N300 (Po9–Po10). (B) LV2 reflects the contrast of prospective-cue trials presented to the left and right visual fields and represents a sustained frontal modulation (Fz) and a phasic right-hemisphere modulation between 200 and 400 msec (N300; Po10). (C) LV3 reflects the contrast of target-absent trials with target-present and prospective-cue trials presented in the right visual field and represents the P3 (Pz), the slow wave (Cz), a left-hemisphere positivity between 200 and 400 msec (N2Pc; P7), and a right hemispheric negativity around 400 msec (P8). The scale for LV1 ranges from −4 to 6 μV and that for LV2 and LV3 from −2 to 1 μV. The short bars reflect 250-msec increments. The time points at which the bootstrap ratios exceeded 2.5 are plotted as circles above the salience waveforms.

riod of time (e.g., prospective cues), in agreement with evidence from previous studies using search and discrimination tasks (Eimer, 1996; Luck & Hillyard, 1994), and by target stimuli that are updated dynamically on a trial-by-trial basis (e.g., the targets in the present study). The amplitude of N2pc was greater for target trials than for prospective-cue trials. It seems unlikely that this difference would have arisen from differences in trial probability of prospective memory cues and of target trials, given that Luck and Hillyard (1994) found that target probability did not influence the amplitude of the N2pc in a visual search task. Instead, this finding may indicate that the representation of targets in visual working memory differed from that of prospective cues in prospective memory, in agreement with evidence indicating that information associated with delayed intentions is repre-

sented differently than information in other memory stores (Goschke & Kuhl, 1993).

Unlike the N2pc, the N300 was limited to prospective-cue trials. The amplitude of the N300 was greater for prospective memory cues presented in the left visual field than for those presented in the right visual field, and this effect did not interact with hemisphere. This finding is consistent with previous data indicating that the influence of attention on the N300 is greater over the right hemisphere than over the left (West et al., 2001). Complementing these ERP data, studies examining the functional neuroanatomy of prospective memory using PET and fMRI have revealed differential activation in the right inferior parietal cortex when individuals are expecting a prospective memory cue relative to when cues are not expected (Burgess et al., 2001), and in right extrastriate and parietal cortices when individuals make prospective responses (Reynolds, West, & Braver, 2003). Together, findings related to hemispheric differences in the N300 and differential activation of regions within the right parietal and extrastriate cortices lead to the suggestion that the right hemisphere contributes to an attentional process that facilitates the detection of prospective memory cues.

The PLS analysis revealed three reliable LVs: two that captured modulations of the ERPs related to prospective memory and a third that captured modulations of the ERPs related to target selection. The first LV contrasted prospective-cue trials with target and nontarget trials, expressing the neural correlates of prospective memory. This LV reflected the N300 over the occipital-parietal and frontal regions and the prospective positivity over the parietal region. The association of the N300 and prospective positivity with a distinct LV is consistent with previous research demonstrating that these two modulations of the ERPs are unique to prospective memory (West et al., 2004; West & Krompinger, in press). The second LV seemed to express the influence of attention on the ERPs elicited by prospective memory cues. This LV contrasted prospective memory cues presented in the left and right visual fields and reflected a component of the N300 over the right occipital-parietal region and a more sustained modulation over the frontal region. The electrode saliences for the second LV were near zero over the parietal region for the entire analyzed epoch, indicating that the prospective positivity was not expressed by this LV. The sensitivity of subcomponents of the N300 to the influence of attention and the insensitivity of the prospective positivity to the influence of attention is consistent with other work from our laboratory (West et al., 2004). Together, these findings provide support for the proposal that the fundamental contribution of attention to prospective remembering is to facilitate the detection of prospective memory cues when they are encountered in the environment (Guynn et al., 2001; Smith, 2003).

The third LV expressed the neural correlates of target selection (Eimer, 1996; Luck & Hillyard, 1994), contrasting the ERPs elicited by nontarget trials with those elicited by target trials and prospective memory cue trials presented in the right visual field. This LV reflected the N2 or N2pc over the occipital-parietal region, the P3 over the parietal region, and a slow wave over the right frontal central region. The association of the P3 with the third LV and that of the prospective positivity with the first LV is consistent with the proposal that these modulations of the ERPs reflect the activity of different neural mechanisms rather than the notion that the prospective positivity simply reflects a delayed P3 (West et al., 2003). Supporting this idea, data from two other studies indicate that different factors influence the amplitude of the P3 and that of prospective positivity. In one study, the amplitude of the P3, but not that of the later portion of the prospective positivity, was modulated by perceptual salience, whereas the prospective positivity, but not the P3, was modulated by the number of prospective memory cues (West et al., 2003). In a second study, West et al. (2004) demonstrated that the amplitude of the P3 elicited by target trials was modulated by working memory load in the *n*-back task, whereas the amplitude of the prospective positivity was not sensitive to differences in working memory load. Also, simulation work in the performance of PLS analysis when applied to ERP data reveals that latency-shifted components tend to be associated with the same LV at which the latency shift is captured by the presence of a sign-wave-like component in the electrode saliences (Lobaugh et al., 2001). This finding leads to the expectation that the P3 and prospective positivity should be associated with the same LV if the prospective positivity was merely a delayed P3, which was not the case in the present analysis. Together, these findings support the idea that the P3 and prospective positivity reflect distinct components of the ERPs associated with different cognitive processes.

In this study, we have argued that performance of the two components of the task was dependent on different forms of memory, with target selection being supported by visual working memory and the detection of prospective memory cues being supported by prospective memory. Alternatively, one could argue that the two components of the task are commonly supported by working memory and differ only in the length of the delay interval between encoding and stimulus presentation (i.e., less than 1 sec for target stimuli and several seconds for prospective-cue trials). No distinction between these two alternatives can be made on the basis of the present data; however, data from a study in which prospective memory cues were embedded in an *n*-back working memory task provide insight into this issue (West et al., 2004). In that study, 1-back targets were associated with amplitude modulations of the N2 and P3 components, as occurred in target trials in the present study; in contrast, 3-back targets were associated with modulations over the frontal and parietal regions similar to those observed in studies of recognition memory. These findings are consistent with

the proposal that information can be represented in one of two states in working memory—namely, that which is in the focus of attention (1-back targets) and that which is activated but outside of the focus of attention (i.e., 3-back targets; Cowan, 1995; McElree, 2001). In West et al. (2004), the N300 and prospective positivity elicited by prospective memory cues were associated with an LV that was distinct from those expressing modulations of the ERPs associated with 1-back and 3-back targets. This finding led to the suggestion that the detection of prospective memory cues was supported by processes other than those supporting the recognition of target stimuli represented in working memory (West et al., 2004).

A persisting question within the prospective memory literature is the degree to which prospective memory tasks may reflect a form of dual-task paradigm (Smith, 2003). If one assumes that for the current task the target-present and prospective memory judgments were performed in a sequential fashion across trials, the adoption of a dual-task strategy in this paradigm would be expected to result in a delayed N2pc for prospective-cue trials, since individuals would be expected initially to arrive at a target-absent decision and then recognize the prospective-cue letter. Findings from the analyses of the mean amplitude data were not consistent with the adoption of such a strategy, since the N2pc occurred at the same time for target and prospective-cue trials (i.e., in the 250–270-msec interval) and the interaction of visual field of presentation and hemisphere was absent in the 340–360-msec interval used to quantify the N300. Alternatively, if individuals were performing the two components of the task in parallel, this could be expected to result in an N2pc that had a similar time course for targets and prospective cues. The present data do not allow us to distinguish a parallel dual-task account of our results from an account in which the cognitive processes related to prospective remembering are limited to those trials in which a candidate prospective cue is detected (Einstein & McDaniel, 1996).

In summary, the findings of the present study indicate that there are both commonalities and differences between the ERP correlates of target selection for stimuli maintained in visual working memory and the ERP correlates of the detection of prospective memory cues. Targets and prospective memory cues elicited an N2pc, revealing that a common neural mechanism contributes to the selection of task-relevant stimuli in prospective memory and working memory. In contrast, the N300 was elicited only by prospective memory cue trials and appears to reflect the activity of distinct subcomponents that are differentially sensitive to the influence of attention. These findings are consistent with those of a growing body of literature indicating that an attentional mechanism possibly supported by the right hemisphere serves to facilitate the detection of prospective memory cues when they are encountered, thereby enhancing the efficiency of prospective memory (Burgess et al., 2001; Smith, 2003).

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