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Investigating the encoding and retrieval of intentions with event-related potentials

P. Andrew Leynes,[a,*] Richard L. Marsh,[b] Jason L. Hicks,[c]
Joseph D. Allen,[b] and Christopher B. Mayhorn[d]

[a] *Department of Psychology, The College of New Jersey, P.O. Box 7718, Ewing, NJ 08628-0718, USA*
[b] *Department of Psychology, University of Georgia, Psychology Building, Athens, GA 30602-3013, USA*
[c] *Department of Psychology, Louisiana State University, 229 Audubon Hall, Baton Rouge, LA 70803, USA*
[d] *Department of Psychology, North Carolina State University, Box 7801, Raleigh, NC 27695-7801, USA*

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Abstract

Strong evidence exists in the literature that remembering to complete intentions involves executive processing subserved by the frontal lobes. Event-related potentials were measured during the encoding of actions with the intention to perform versus more neutral material about which there was no such intentionality. Event-related potentials were also measured in a two-alternative discrimination task requiring identification of the to-be-performed actions and to-be-memorized actions. The results suggest that formation and retrieval of intentions differs from encoding and retrieval of similar material committed to memory. Additionally, the results suggest that right frontal areas may play an important role in the formation of prospective actions and that intentions are kept active in memory by processing mediated by the left frontal pole.

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[*] Corresponding author. Fax: +609-637-5178.
E-mail address: leynes@tcnj.edu (P.A. Leynes).

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1. Introduction

Loosely defined, prospective memory is memory for an intention to perform some action in the future. By necessity, the overarching construct is not well defined because humans establish a variety of intentions that vary in their essential characteristics. For example, in event-based prospective memory tasks people establish the intention to perform an action when the environment cues them to do so (e.g., a pink slip of paper from a secretary reminds one to return a phone call; Einstein & McDaniel, 1990). In time-based tasks, people monitor the passage of time until a critical action must be taken (e.g., taking medication at scheduled times; Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995). Many other distinctions concerning types of prospective memory have been made such as whether an intention concerns novel or habitual responses (Harris, 1980), whether the retention interval is short or long (Loftus, 1971), or whether the action is to be performed at a specific time or within some window of opportunity (Ellis, 1988). Although this list of distinctions is not exhaustive (Kvavilashvili & Ellis, 1996), it does highlight the fact that people establish a variety of intentions and the factors that affect successful remembering will be specific to the type of intention that is formed.

Because of the diverse nature of prospective memories, specifying general factors that might affect a variety of prospective tasks is often difficult. Neuroscience promises to provide some help in this regard because the mental processes that comprise elaborate forms of cognition can often be separated using brain activity measures in addition to traditional response measures. Thus, measures of brain activity might provide valuable information that can be used to inform theory as well as practical information that can be used to predict how injury or medications might affect prospective memory processes.

One generalization that appears to be emerging in the literature is that prospective memory involves the frontal lobes (Bisiacchi, 1996; Cohen & O'Reilly, 1996; Glisky, 1996; Shallice, 1996); however, most of the evidence is correlational (for a review see Glisky, 1996). For example, Marsh and Hicks (1998) reported that individual differences in frontal lobes measures such as the Wisconsin Card Sorting Task or measures of verbal fluency correlated with prospective memory performance in an event-based laboratory task. Marsh, Hicks, and Landau (1998b) also suggested that the same could be true of successfully completing everyday intentions. In case studies, patients with damage to the frontal lobes often have trouble performing simple prospective memory tasks (e.g., Shallice & Burgess, 1991). Neurological evidence also suggests that the prefrontal cortex is significantly diminished in capacity by aging (e.g., Martin, Friston, Colebatch, & Frackowiak, 1991), and many researchers have attempted to determine whether age-related declines are found in prospective memory tasks. The results from event-based prospective performance have been mixed (e.g., Einstein et al., 1995, versus Maylor, 1996), but time-based tasks do show a consistent impairment in older populations (e.g., Einstein et al., 1995).

The drawback to these general conclusions is that the specific role that the frontal lobes play in prospective memory has not been identified, which is partly due to the many cognitive functions that the frontal lobes support. For example, the prefrontal cortex is believed to coordinate multiple behaviors, and in general, the frontal lobes may perform integrative or central executive functions (e.g., Baddeley, 1986; Shallice, 1982; Stuss & Benson, 1984, 1986). The frontal lobes are also hypothesized to coordinate activities that are highly related to certain aspects of prospective memory such as planning and monitoring both future and ongoing activities. Unfortunately, damage to the frontal lobes has also been known to affect language, memory, problem solving, and a variety of other cognitive functions and therefore is not uniquely involved with intentions to perform an action in the future (see Stuss & Benson, 1986). Thus, our knowledge about prospective memory would be enhanced by experimental evidence that can identify what aspects of prospective memory are supported by the frontal lobes; however, experimental evidence in this area is lacking.

Okuda et al. (1998) used positron emission tomography (PET) to image the brain activity of participants while they completed control and prospective memory tasks. The prospective memory task that they used was adapted from the paradigm developed by Einstein and McDaniel (1990). Participants studied 10 target words that served as prospective cues to perform a response (i.e., tap the left hand) in the first phase of the experiment. During the scanning period, participants engaged in a working memory task. They were instructed to tap their left hand if any one of the prospective cue words appeared during the working memory task. The control task was similar in that the same participants learned 10 words and performed a working memory task during the scanning period. However, no targets appeared during the control task. Okuda et al. found that several areas were more active during the prospective memory task as compared with the control task. These areas included the right dorsolateral prefrontal cortices (BA 8 and 9), right ventrolateral prefrontal cortex (BA 47), left frontal pole (BA 10), left anterior cingulate gyrus (BA 24), midline medial frontal lobe (BA 8), and left parahippocampal gyrus (BA 28). By comparing these activations to other imaging studies, they reasoned that holding intentions to complete a future task is mediated by the left frontal pole and right ventrolateral prefrontal region. They further argued that monitoring for the appearance of the prospective targets activated the left parahippocampal region and that dividing attention between the working memory and the prospective task activated the medial frontal regions.

West and colleagues have conducted event-related potential (ERP) investigations of prospective memory (West, Herndon, & Ross-Munroe, 2000). ERPs are measures of brain electrical activity that are time-locked to a stimulus event which emerge when the EEG is averaged over multiple trials. The ERP technique is high in temporal resolution but lower in spatial resolution compared to PET and functional magnetic resonance imaging (fMRI), but a gross indication of the brain areas involved in a cognitive process can be inferred when electrodes are placed across the scalp. Unfortunately, ERPs (as well as the other imaging techniques) require multiple events (or trials) to extract brain signals from the background brain activity (approximately 15 trials are required to form a reliable ERP average for an individual participant). West and colleagues addressed this problem by using the partial cue task (West & Craik, 1999). This task yields 30 to 40 prospective trials intermixed with two other types of trials. On most of the trials, participants make a simple semantic judgment. When the prospective cue (e.g., words in uppercase letters) appears, people are instructed to make a prospective response, such as pressing a key on the keyboard. An additional set of trials (prospective lure trials) begins with a cue that resembled the prospective cue; however, participants are instructed to ignore these cues and continue the semantic judgment.

West et al. (2000) have observed a number of ERP differences using this paradigm which they attribute to different prospective memory processes. More specifically, noticing the prospective cue was associated with a negative ERP approximately 300 ms after the presentation of the cue. The topography of this ERP effect appears to be influenced by the features of the cue. Accompanying this early negative ERP, West et al. observed more positive frontal-central ERP activity for successfully completed prospective memory trials, which they suggested might reflect retrieval and execution of an intention.

Although these results are extremely valuable especially given the lack of comparable experimental data, the above studies measured brain activity during complex tasks with multiple components, making it difficult to attribute specific brain activity to prospective memory aspects of the task. For example, a prospective task recruits several cognitive processes, such as forming and holding an intention in memory, dividing attention between two ongoing tasks, monitoring for the appearance of prospective cues, retrieving the retrospective memory of the task, and planning/executing the response to the prospective cue. In addition, the prospective responses that were used in these previous studies were rather simple (i.e., tap hand or press a key) and might require fewer brain structures to support and execute as compared with more complex actions.

While no one study will be able to clarify the role of each brain structure or address every question regarding prospective memory, the purpose of the present experiment was to investigate one aspect of prospective memory—the neural processes related to forming and holding intentions in memory. Although prospective memory is clearly more complex, memory for intentions is not altogether different from prospective memory because one must form an intention and maintain that intention over time (in some way) in order to execute a task in the future. Beginning such an inquiry promises to provide insight into how memory for intention is (or is not) related to prospective memory and has two important advantages over the typical event-based lab paradigm (i.e., Einstein & McDaniel, 1990). First, paradigms used to investigate memory for intentions frequently have more observations than the typical event-based lab paradigm, making it easy to adapt to an ERP investigation. Second, the tasks can vary in complexity, creating a more naturalistic set of tasks.

There is ample evidence that suggests memory for intentions differ from retrospective memory. For example, Koriat, Ben-Zur, and Nussbaum (1990) compared memory for simple actions (e.g., “touch the stone”) that were studied with the intention to perform later versus actions that were memorized for a recall test. They reported that recall of to-be-performed actions was superior to recall of memorized actions. In subsequent experiments (Experiments 2 and 3), they found that this memory advantage of to-be-performed actions was not dependent on the mode of recall test (i.e., verbal recall vs perform actions). Engelkamp (1997) replicated these results when participants were tested between subjects (as in Koriat et al., 1990) but found no recall advantage of to-be-performed actions when participants were tested within subjects (see also Brooks & Gardiner, 1994).

Although Engelkamp (1997) offered several plausible explanations for the different effects on recall obtained with different designs, memory for intentions appears to affect more sensitive measures of memory activation such as recognition latencies (e.g., Goschke & Kuhl, 1993) and lexical decision latencies (Marsh, Hicks, & Bink, 1998a; Experiment 1) when tested within subjects. More specifically, Goschke and Kuhl (1993) asked participants to study a set of actions (e.g., "spread the table cloth" and "distribute the cutlery") that comprised a larger script (e.g., "setting a dinner table"). Recognition latencies were faster for words that were from scripts that had to be performed later as compared with latencies for words that were from memorized scripts. This latency advantage of memories with associated intention was called the *intention-superiority effect*. It is difficult to attribute this effect to a difference in encoding because the intention was formed *after* encoding. Furthermore, Goshke and Kuhl (Experiment 4) found the intention-superiority effect when both the memorized and the to-be-performed scripts were imagined to an equal degree during encoding and when recall did not differ for these two scripts. Thus, intentions appear to be more active in memory than information that is merely learned for a memory test.

The present experiment investigates the electrophysiological correlates of memory for intentions. If response measures are affected by memory for intentions, then ERPs should also be sensitive to this difference. ERPs might also provide some gross indication of which brain structures keep intentions active in memory. In the experiment reported here, participants learned 90 subject-performed tasks of the form *verb the noun* (e.g., "bend the wire;" Engelkamp, 1997). Half of these were encoded with the expectation that they would be asked to perform them at the end of the experiment, and half were encoded with the expectation that their memory for these actions would be tested. ERPs were recorded during this encoding phase and during a test phase where all of the actions appeared in a discrimination task in which participants were asked to determine which actions they would perform later and which they would not. This procedure will allow us to determine whether there are physiological differences associated with forming an intention as opposed to simply committing an action to memory with no intentionality to perform it. Because recall for to-be-performed actions does not appear to be better than recall of memorized actions when tested within-subjects (Brooks & Gardiner, 1994; Engelkamp, 1997), we hypothesized that the accuracy on the discrimination task might not differ for to-be-performed versus memorized actions. However, we expected to observe the intention-superiority effect in the response latencies.

2. Method

2.1. Participants

Nineteen (8 male and 11 female) University of Georgia undergraduates, ages 17–23, volunteered in exchange for partial credit toward a course research requirement. The data from three additional participants was collected but was not analyzed because these participants reported to the experimenter that they did not believe they would really be asked to perform the actions at the end of the experiment. All participants reported that they were right-handed, had normal or corrected-to-normal vision, and had no known history of neurological disease.

2.2. Materials and procedure

After affixing the electrode cap (see below), participants were instructed that they were going to learn two sets of actions. One set they would have to perform later and one they would not. They were further instructed that their memory for *both* sets of actions (the test details were not specified) would be tested after the study phase and that the only difference between these items was that half would be performed at the end of the session. As a consequence, there should have been no differences in memory test expectancies between the two sets of items and only a difference in the intentionality to perform.

Ninety simple actions were gleaned from the subject-performed task literature under the constraint that each action contained a unique verb and noun and that we could obtain the actual objects needed to perform the task. All of these objects were placed in boxes and shown to participants during the instructions in order to convince them that the actions specified were going to have to be performed later. Each set of actions was composed of 45 unrelated tasks that were randomly assigned by the software for each participant.

During learning, participants were seated in a recliner in a sound attenuated, electrically shielded chamber in front of a computer monitor located 110 cm away. The 90 tasks appeared 1 at a time in the center of the monitor.[1] Each character presented on the monitor extended 0.4° of visual angle vertically and horizontally. The sequence for each learning trial (refer to Fig. 1) began with the presentation of a fixational point, which was replaced 500 ms later by a cue which was either the phrase *perform* or *not perform*. This cue informed learners of the type of action that was being presented on that trial, and it remained on the monitor throughout the study trial. One second after the appearance of the cue, the words of the phrase appeared sequentially (separated by 1000-ms intervals) and remained on the display for the duration of the study trial. Thus, the verb appeared first followed by the word *the* (in two cases the word *some* replaced the word *the*) followed by the noun. The entire three word action remained on the display for an additional 5500 ms to ensure that the action was studied thoroughly; therefore, the entire length of each study trial was 9000 ms. Trials were separated by a random 4- to 7-s ITI.

After encoding, participants completed a discrimination task where they had to decide whether each action was to be performed later or was an action that they did

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[1] When research participants encoded intentions to be performed later at an unspecified time they might expect the experimenter to cue them when they are to be performed. Thus, the intentions being studied may not be identical to an intention to perform some activity by self-initiated means. This criticism is common to many laboratory-based tasks and has been addressed more fully by Marsh et al. (1998a).

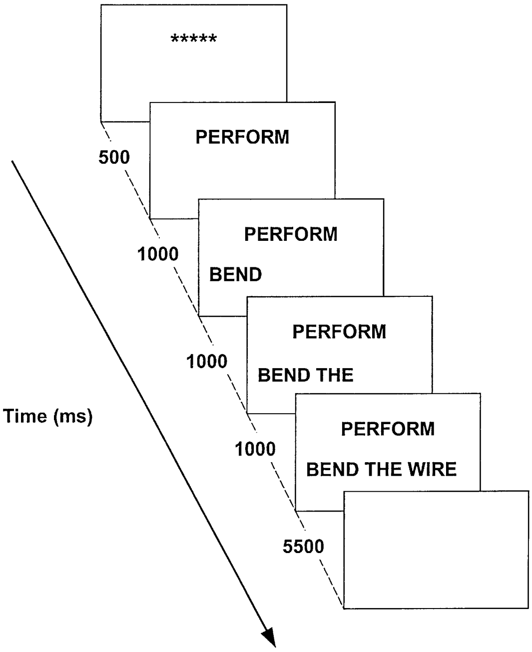

Fig. 1. Schematic of the stimulus display during the study phase. The trial shown is an action that was to be performed at the end of the experiment.

not have to perform. No new actions were presented during the discrimination task. Test trials began with a fixation point that was replaced 500 ms later by the entire action phrase. The action phrase remained on the screen until participants pressed one of two keys to indicate whether the action was to be performed. A random 4- to 6-s ITI was placed in between test trials. All 90 tasks were tested and they were tested in a different random order than they were learned.

Following the discrimination task, the experimenter entered the ERP recording chamber and began to describe how the participant would perform some of the tasks that were learned to during the study phase. It was only necessary for participants to *believe* that they would be asked to perform tasks for the purpose of this study because executing intentions obviously involves additional cognitive processing that may or may not draw on the same neural circuitry. Thus, the experimenter questioned participants about the experiment to determine if they really believed they would be performing some of the actions. At this stage, the experiment was terminated and participants were fully debriefed.

2.3. ERP recording procedures

Potentials were sampled from 19 tin electrodes mounted in a elastic cap (Electro-Cap) according to the International 10–20 system (Jasper, 1958) referenced to the left earlobe. Scalp recordings were taken at the frontal poles (Fp1 and Fp2), frontal sites (F7, F3, Fz, F4, and F8), central sites (C3, Cz, and C4), temporal sites (T3, T4, T5, and T6), and parietal sites (P3, Pz, and P4) and in the occipital region (O1 and O2). Vertical (vEOG) and horizontal (hEOG) eye movements were recorded by two separate bipolar channels. Interelectrode Impedance was below 3 kΩ. EEG and EOG signals were sampled at 150 Hz using a Contact Precision Instruments amplifier with a 0.01- to 40-Hz (−3 dB) bandpass (gain = 10,000×). The data were digitally filtered off-line using a 30-Hz lowpass filter (−3 dB/octave). Occular artifacts were corrected using the algorithm developed by Semlitsch, Anderer, Schuster, and Presslich (1986).

3. Results

We present the behavioral data first followed by the ERP data. The ERP data recorded during study are presented before the ERP data recorded during the test.

3.1. Behavioral data

Participants correctly identified the same percentage of to-be-performed tasks ($M = 86.2$, $SD = 12.6$) as they did the tasks that were merely to be remembered [$M = 83.5$, $SD = 11.2$; $t(18) = 1.1$, $p > .05$]. However, they identified the to-be-performed tasks faster ($M = 1779$ ms, $SD = 385$) than the to-be-remembered tasks [$M = 1988$, $SD = 521$; $t(18) = 2.54$, $p = .02$]. This reaction time difference is important because it replicates the intention superiority effect (e.g., Goschke & Kuhl, 1993; Marsh et al., 1998a; Marsh, Hicks, & Bryan, 1999) using a different task.

3.2. ERPs during study

ERPs were sampled from 500 ms before the onset of the fixation point until 1500 ms after the presentation of the noun (total recording time 5500 ms). Trials on which ERP amplitudes exceeded ±150 μV were excluded from the analyses (17% of the total number of trials evenly distributed across the two encoding conditions).[2] Trials were averaged according to study condition (i.e., perform vs not perform) for actions that were correctly classified on the subsequent discrimination test. After these procedures, a mean number of 33 trials comprised the to-be-performed ERPs and a mean number of 32 trials comprised the to-be-remembered ERPs [$t(17) < 1$, $p > .1$].

Fig. 2 plots the grand average ERPs recorded during encoding of tasks that were to-be-performed at the end of the experiment versus those tasks that were to-be-memorized for the memory test. Due to the enormous data yield and lack of comparable ERP studies on this topic, we performed a preliminary statistical

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[2] The data from one participant was excluded from this analysis due to an insufficient number of artifact-free trials (i.e., only eight trials were available for the to-be-performed ERP) leaving a total of 18 participants (7 males and 11 females) in this sample.

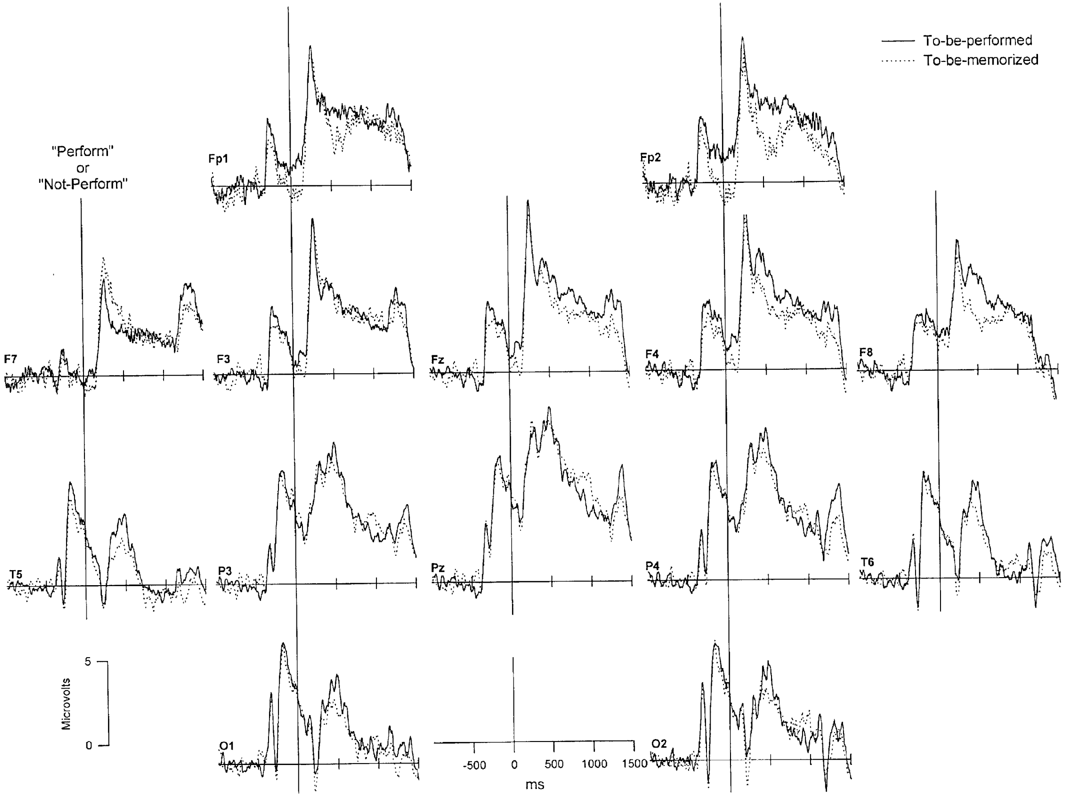

Fig. 2. Event-related potentials at selected electrode sites recorded during the encoding of to-be-performed and to-be-remembered phrases. Electrodes placed over the left hemisphere are depicted in the left side of the figure. Electrodes toward the front of the scalp appear at the top of the figure. The zero value on the *x* axis (vertical bar) coincides with the onset of the learning cue. Positive voltage is plotted upward on all graphs.

analysis of ERP amplitudes averaged over consecutive 500 ms intervals beginning with the onset of the cue. This analysis suggested that the encoding ERPs for the to-be-performed and to-be-memorized actions differed within a few hundred milliseconds after the onset of the cue and did not differ at any point during the remainder of the recording epoch. This preliminary analysis was followed with a more sensitive analysis where ERP amplitudes were averaged over five consecutive 100-ms intervals beginning at the onset of the cue.[3] Each of these intervals were analyzed with an analysis of variance that contained factors of condition (perform vs memorize), anterior/posterior electrode regions, and electrode site. The Anterior/Posterior factor compared 12 electrodes divided into frontal (i.e., Fp1, Fp2, F7, F3, Fz, and F4) and parietal regions (i.e., T5, P3, Pz, P4, T6, O1, and O2). All analyses incorporated the Huynh–Feldt correction for nonsphericity. Interactions involving the factor of condition were evaluated on scaled amplitudes (McCarthy & Wood, 1985). Only significant effects ($\alpha = 0.05$) involving the factor of condition are reported below.

The analyses of the ERP amplitudes quantified during the first three intervals (0–100, 100–200, and 200–300 ms after the onset of the cue) revealed no reliable differences (largest $F = 1.75$, all ps $> .10$). Beginning 300 ms after the onset of the cue, ERPs elicited by the perform cue differed from the ERPs elicited by the not perform cue [300–400 ms: condition × anterior/posterior × electrode site: $F(6,102) = 3.85$, $\varepsilon = 0.57$]. Similarly, the factor of condition interacted with electrode site for the 400–500 ms epoch [$F(6,102) = 5.56$, $\varepsilon = 0.52$] and for the 500–600 ms epoch [$F(6,102) = 3.85$, $\varepsilon = 0.56$].

To evaluate the topographic differences between conditions at each of these time intervals, post-hoc analyses compared ERPs for each condition at frontal and parietal electrode regions separately. For all three time intervals, the factor of condition interacted with electrode site in the frontal region [300–400 ms: $F(6,102) = 3.70$, $\varepsilon = 0.47$; 400–500 ms: $F(6,102) = 3.61$, $\varepsilon = 0.49$; 500–600 ms: $F(6,102) = 3.92$, $\varepsilon = 0.55$]. The analysis of parietal ERPs revealed no significant effects (all ps $> .05$). Inspection of Fig. 2 suggests that the cue for to-be-performed actions elicited more positive ERPs than the cue for to-be-remembered actions during the study phase. The interaction of condition with electrode site reflects the fact that these ERP differences were largest at right hemisphere electrode sites. This difference in ERP topography suggests that the encoding of these two types of material night have activated different regions within the frontal lobes. The importance of this result is described further under Discussion.

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[3] Upon visual inspection of the ERP data depicted in Fig. 2, the baseline activity recorded during the presentation of the fixation point appears to differ between the two types of tasks at the frontal poles. However, statistical analysis of the ERP activity during the presentation of the fixation point (100-ms intervals) revealed no reliable differences. Furthermore, the reliable ERP differences at encoding that are reported in this article did not depend on the inclusion of these electrodes in the analyses because the ERP effects were still reliable in a subsequent set of analyses that omitted the frontal pole electrodes.

3.3. ERPs during test

ERPs were sampled from 500 ms before the fixation point until 1800 ms after the onset of the action phrase (total recording time 2800 ms). Trials on which ERP amplitudes exceeded ±150 μV were excluded from the analyses (< 4% of the total number of trials evenly distributed across conditions). Trials were averaged according to study condition (i.e., perform vs not perform) for actions that were correctly identified on the test. A mean number of 37 trials comprised the grand average ERPs for the to-be-performed actions, whereas a mean number of 35 trials comprised the ERPs for the to-be-memorized actions [$t(18) = 1.6$, $p > .1$]. The grand average ERPs for each condition are displayed in Fig. 3. The ERPs for the two types of memories were very similar at all electrode locations except at the frontal poles (Fp1 and Fp2; see top row of the figure).

To quantify the ERP effects at test, ERP amplitudes were averaged over six consecutive 300-ms intervals beginning with the presentation of the test item (i.e., 0–300, 300–600, 600–900, 900–1200, 1200–1500, 1500–1800 ms). Each interval was analyzed separately in the same manner as ERPs recorded during encoding. All analyses incorporated the Huynh–Feldt correction for nonsphericity and interactions involving the factor of condition were evaluated on scaled amplitudes (McCarthy & Wood, 1985). Only significant effects ($\alpha = 0.05$) involving the factor of condition are reported below.

No significant effects were detected in the analyses of the first two time intervals (all ps > .05). Analyses revealed significant effects of condition × anterior/posterior × electrode site for the 600–900 ms interval [$F(6,108) = 4.21$, $\varepsilon = 0.40$] and the 900–1200 ms interval [$F(6,108) = 4.25$, $\varepsilon = 0.65$]. In addition, the condition × electrode site effect was significant for the 900–1200 ms interval [$F(6,108) = 3.03$, $\varepsilon = 0.55$]. Subsidiary analyses examined ERP amplitudes at frontal and parietal electrode regions separately for the 600–900 ms and 900–1200 ms intervals. The analysis of both time intervals revealed a significant condition × electrode site interaction in the frontal electrode region only [600–900 ms; $F(6,108) = 3.83$, $\varepsilon = 0.49$; 900–1200 ms: $F(6,108) = 4.20$, $\varepsilon = 0.61$]. The analyses of the ERPs in the parietal electrode region revealed no significant effects. Inspection of Fig. 3 suggests that the condition × electrode site interaction in the frontal region was due to a difference in ERP amplitudes at the frontal poles. Thus, additional analyses compared ERP amplitudes for the two conditions at the frontal poles and the remaining frontal electrode sites separately. To-be-memorized actions elicited more positive ERPs than the to-be-performed actions at the frontal poles [600–900 ms: $F(1,18) = 4.69$, $p = .04$; 900–1200 ms: $F(1,18) = 5.24$, $p = .03$]; however, ERPs did not differ at the other frontal electrode sites (largest $F = 1.68$).

3.4. Summary of ERP effects

During encoding, the cue indicating that tasks were to-be-performed later elicited more positive ERPs beginning 300 ms after the onset of the cue and ending 300 ms later. This ERP difference was observed over several areas but was largest at right

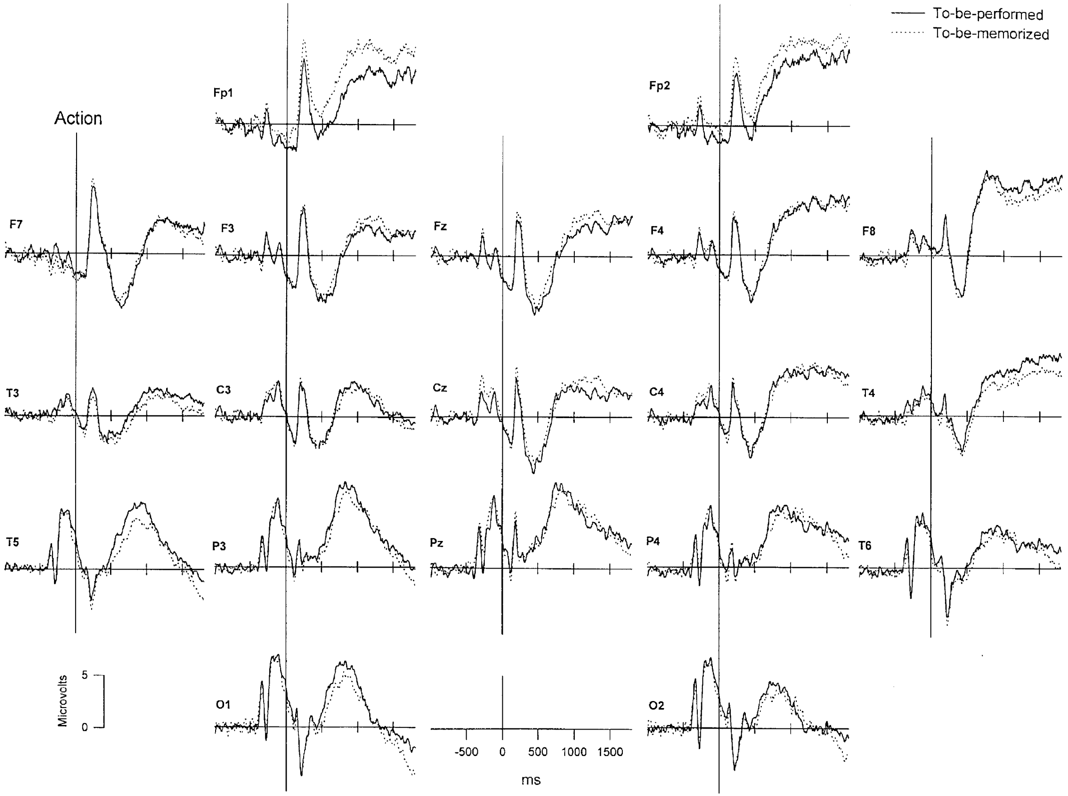

Fig. 3. Event-related potentials recorded during the identification of actions that were to be performed versus studied earlier in the experiment. The zero value on the x axis (vertical bar) coincides with the onset of the action.

frontal electrodes. No other ERP differences were detected between the two types of actions.

At test, to-be-memorized actions elicited more positive ERP activity than to-be-performed actions. This ERP difference was largest at the frontal pole electrodes and began 600 ms after the onset of the action and ended 600 ms later.

4. Discussion

Prospective memory enables people to complete a wide range of important tasks such as keeping appointments or taking medication. Investigating the neuroscience of prospective memory might provide valuable information that can be used to clarify theories, aid in the investigation of age-related changes in prospective memory, as well as point out potential types of brain damage that might impair prospective memory. Unfortunately, imaging the brain during prospective remembering is very difficult because the standard laboratory-based prospective tasks contain no more than a very small number prospective responses and prospective memory draws on a number of cognitive processes. Our approach was to image the formation and retrieval of experimenter-provided intentions, which are two of the several cognitive processes that contribute to prospective memory.

Participants encoded 90 tasks. Half of these they believed that they would have to perform in a later portion of the experiment. Thus, half of the scripts should have been encoded with the intention to perform the task at a later time. The study phase was followed by a discrimination task where participants indicated which would be performed later and which were simply read during the study phase.

The results of the ERP data recorded during encoding can be summarized as follows. ERPs elicited by actions for which participants should have established some intentionality to perform the task were more positive than the ERP activity elicited by memorized tasks particularly at right frontal electrode sites. This topographic difference in ERP activity suggests that the cue to encode tasks with the intention of performing the action later activated different areas within the frontal lobes than the cue to simply encode phrases into memory. Previous ERP studies of encoding have found differences when subsequently remembered items are compared to subsequently forgotten items (see Van Petten & Senkfor, 1996, for a brief review); however, both ERPs in the present experiment were averaged from items correctly classified on the discrimination test. Therefore, this activity does not merely reflect differences in the ability to remember. Rather, we believe the ERP differences during encoding reflect the cognitive processing associated with establishing an intention in memory to perform an action later. Although this effect could be labeled uncharitably as the simple result of "more" processing at encoding, several pieces of evidence suggest otherwise. First, if the intention to perform an activity functioned as a more elaborate form of encoding, then the ERP effects would resemble those produced by elaborate encoding of word stimuli. Paller, Kutas, and Mayes (1987) reported larger ERP amplitudes for words encoded with a deeper semantic task versus words encoded with a shallower orthographic task; however, the ERPs did not differ in topography as they did in the present experiment. Second, more elaborate encoding would result in better accuracy. As we reported earlier, the accuracy was equivalent for two types of material. Thus, the ERP data combined with the response measures on the discrimination task suggest that forming intentions is qualitatively different from encoding information into explicit memory and not simply the product of "more elaborate" processing.

These ERP results during encoding extend the current knowledge regarding the formation of intentions. Okuda et al. (1998) argued that areas within the frontal lobes (i.e., the left frontal pole and the right ventrolateral prefrontal cortex) mediated memory for intentions. These results combined with the fact that prefrontal areas have been repeatedly implicated in encoding (see Nyberg, Cabeza, & Tulving, 1996) led us to suspect that these areas might also be active during the encoding and formation of intentions also. The fact that ERPs elicited by the prospective cue (i.e., "perform") were more positive than the cue to memorize the action at the right frontal electrode sites, in particular F8, suggests that the approximate brain regions lying beneath these electrode sites (e.g., the right ventrolateral prefrontal cortex; Jasper, 1958) were more active. Recall that Okuda et al. argued that the right ventrolateral prefrontal cortex mediated the holding of intentions and that West et al. (2000) reported a frontal-central ERP difference that they linked to retrieving and executing an intention. In light of the encoding effects that we report here, perhaps the right ventrolateral prefrontal cortex mediates the formation and retrieval of intentions. During the encoding phase in the present experiment, the cue to form an intention appeared to elicit additional activity in right frontal areas, indicating that these areas play an important role in the formation of intentions. Similar activity may have been produced after the prospective cue was noticed in the Okuda et al. and West et al. investigations using a traditional event-based laboratory paradigm. In these studies, right frontal areas might be responsible for retrieving an intention (cf. West et al., 2000). Taken together, the results from different paradigms and brain imagining techniques indicate that areas within the frontal lobes might mediate the formation and retrieval of intentions. Future studies should attempt to directly compare the brain activity elicited by these to processes to determine if they activate the same neural network.

The results of the data taken during the discrimination task further support a distinction between to-be-performed and to-be-memorized actions. Recall that the discriminations were faster for to-be-performed tasks as compared with to-be-memorized actions. As discussed earlier, these results are consistent with the intention superiority effect (Goschke & Kuhl, 1993; Marsh et al., 1998a, 1999). In these previous experiments, participants learned pairs of scripts to criterion. After learning, one script was made a prospective script by informing the participant it would have to be performed later. Reaction times were consistently faster for the prospective script as compared to the script that had no intentionality about it, and this was true in a standard old–new recognition test and a lexical decision task, as well. The present results converge on the notion that items related to an intention may reside in memory with an above-baseline level of activation or are able to be revived faster as compared with more neutral material with no associated intentionality (see Marsh et al., 1998a, for a discussion of alternative meanings of being privileged in memory). The only difference between the two paradigms is that learners do not know at encoding which script will be performed, whereas in the current paradigm (explicitly by design) they know which actions will be performed. Therefore, there appears to be some generality to the fact that intentions may have a privileged status in memory.

The ERP data recorded during the discrimination task revealed that the intention superiority effect was associated with less positive ERP amplitudes and that these differences were slightly larger at the left frontal pole (i.e., FP1). This finding seems to suggest that retrieval of intentions resulted in less activation of prefrontal areas. However, less positive ERP amplitudes may also reflect more activation depending on the orientation and depth of the underlying neural generator. Given that Okuda et al. (1998) linked more activity in the left frontal pole with holding of intentions, we believe that the ERP results during the memory test similarly suggest that the frontal pole is more active when memory possesses intentionality. This conclusion is further strengthened when one considers that the convergent evidence emanates from two different paradigms using two different brain-imaging techniques (each with different data processing techniques as well). Furthermore, the similarity of the results from these two studies gives support for the contention that experimental investigations of intention formation and retrieval tap into some of the very same processes that subserve prospective memory elicited by event-based laboratory paradigms.

Although the present experiment provides evidence that intentions differ from retrospective memories, future research should investigate the qualities that distinguish intentions from other memories. One likely candidate is motor imagery that might accompany the formation of intentions because execution of most prospective tasks involves movement at some level.[4] Perhaps, the ERP differences reported in this article reflect the differences in motor imagery engaged when intentions are formed. This issue can be effectively addressed by comparing formation of intentions with motor imagery tasks. Motor imagery research has revealed that similar cortical areas (i.e., supplementary motor area and primary motor cortex) are recruited for motor imagery and motor preparation (Decety, 1996) and have been hypothesized to be equivalent processes (Jeannerod, 1994). Leynes, Allen, and Marsh (1998) found that the neural areas active during motor preparation differed from those that were active during preparation to encode information into long-term memory. Although both types of preparation produced negative slow potentials in that investigation, the topographic distribution of the negative slow waves differed between tasks in that motor preparation produced maximal amplitudes at central sites, whereas ERPs were maximal at frontal sites when people prepared to encode information. Similar differences should be observed between tasks that are to be memorized versus tasks that are to be performed later if forming intentions involves motor imagery. Thus, subsequent investigations of the intentions in memory should include a condition that elicits motor imagery to investigate the qualities that distinguish intentions from other kinds of memory.

On a more general level, these results add to a growing body of literature that demonstrate ERPs are a viable technique for studying the cognitive neuroscience of

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[4] We thank William Banks for raising this point.

prospective memory and identifying the temporal activation of brain structures that subserve intention formation and retrieval. As discussed before, if the prefrontal cortex is the one brain region most markedly affected by normal aging (e.g., Martin et al., 1991), then the present results provide an important basis for future investigations of prospective memory in older adults. Perhaps more important is the fact this paradigm can be used with other neuroimaging techniques as well. Future research endeavors should include examining ERPs in the more traditional intention superiority paradigm with intentions that better mirror real-world intentions than the tasks used here. Additionally, data processing techniques that improve signal extraction should be aggressively pursued so that the number of intentions formed or executed can be investigated using brain imaging techniques. This is a nontrivial point because committing several intentions to memory or executing several prospective responses in an experimental session may engage different processes than many individual cases of prospective memory used in everyday life.

References

Baddeley, A. D. (1986). *Working memory*. Oxford, UK: Oxford University Press.

Bisiacchi, P. S. (1996). The neuropsychological approach in the study of prospective memory. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 297–317). Hillsdale, NJ: Erlbaum.

Brooks, B. M., & Gardiner, J. M. (1994). Age differences in memory for prospective compared with retrospective subject-performed tasks. *Memory and Cognition, 22*(1), 27–33.

Cohen, J. D., & O'Reilly, R. C. (1996). A preliminary theory of the interactions between prefrontal cortex and hippocampus that contribute to planning and prospective memory. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 267–295). Hillsdale, NJ: Erlbaum.

Decety, J. (1996). The neurophysiological basis of motor imagery. *Behavioural Brain Research, 77*, 45–52.

Einstein, G. O., & McDaniel, M. A. (1990). Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 717–726.

Einstein, G. O., McDaniel, M. A., Richardson, S. L., Guynn, M. J., & Cunfer, A. R. (1995). Aging and prospective memory: Examining the influences of self-initiated retrieval processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 996–1007.

Ellis, J. A. (1988). Memory for future intentions: Investigating pulses and steps. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues* (Vol. 1, pp. 371–376). Chichester, UK: Wiley.

Engelkamp, J. (1997). Memory for to-be-performed tasks versus memory for performed tasks. *Memory and Cognition, 25*, 117–124.

Glisky, E. L. (1996). Prospective memory and the frontal lobes. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 249–266). Hillsdale, NJ: Erlbaum.

Goschke, T., & Kuhl, J. (1993). The representation of intentions: Persisting activation in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 1211–1226.

Harris, J. E. (1980). Memory aids people use: Two interview studies. *Memory and Cognition, 8*, 31–38.

Jasper, H. H. (1958). Report of the committee on methods of clinical examination in electroencephalography. *Electroencephalography and Clinical Neurophysiology, 10*, 370–375.

Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral Brain Sciences, 17*, 187–245.

Koriat, A., Ben-Zur, H., & Nussbaum, A. (1990). Encoding information for future action: Memory for to-be-performed tasks versus memory for to-be-recalled tasks. *Memory and Cognition, 22*, 723–728.

Kvavilashvili, L., & Ellis, J. (1996). Varieties of intention: Some distinctions and classifications. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective, memory: Theory and applications* (pp. 23–52). Hillsdale, NJ: Erlbaum.

Leynes, P. A., Allen, J. D., & Marsh, R. L. (1998). Topographic differences in CNV amplitude reflect different preparatory processes. *International Journal of Psychophysiology, 31*, 33–44.

Loftus, E. F. (1971). Memory for intentions: The effect of presence of a cue and interpolated activity. *Psychonomic Science, 23*, 315–316.

Marsh, R. L., & Hicks, J. L. (1998). Event-based prospective memory and executive control of working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 336–349.

Marsh, R. L., Hicks, J. L., & Bink, M. L. (1998a). The activation of completed, uncompleted, and partially completed intentions. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 350–361.

Marsh, R. L., Hicks, J. L., & Bryan, E. S. (1999). The activation of unrelated and cancelled intentions. *Memory and Cognition, 27*, 320–327.

Marsh, R. L., Hicks, J. L., & Landau, J. D. (1998b). An investigation of everyday prospective memory. *Memory and Cognition, 26*, 633–643.

Martin, A. J., Friston, K. J., Colebatch, J. G., & Frackowiak, R. S. J. (1991). Decreases in regional blood flow with normal aging. *Journal of Cerebral Blood Flow and Metabolism, 11*, 684–689.

Maylor, E. A. (1996). Age-related impairment in an event-based prospective memory task. *Psychology and Aging, 11*, 74–79.

McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology, 62*, 203–208.

Nyberg, L., Cabeza, R., & Tulving, E. (1996). PET studies of encoding and retrieval: The HERA model. *Psychonomic Bulletin and Review, 3*, 135–148.

Okuda, J., Toshikatsu, F., Yamadori, A., Kawashima, R., Tsukiura, T., Fukatsu, R., Suzuki, K., Ito, M., & 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., Kutas, M., & Mayes, A. (1987). Neural correlated of encoding in an incidental learning paradigm. *Electroencephalography and Clinical Neurophysiology, 67*, 360–371.

Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology, 23*, 696–703.

Shallice, T. (1982). Specific impairments of planning. *Philosophic Transactions of the Royal Society of London B, 298*, 199–209.

Shallice, T. (1996). The neuropsychology of prospective memory. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 319–325). Hillsdale, NJ: Erlbaum.

Shallice, T., & Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain, 114*, 727–741.

Stuss, D. T., & Benson, D. F. (1984). Neuropsychological studies of the frontal lobes. *Psychological Bulletin, 95*, 3–28.

Stuss, D. T., & Benson, D. F. (1986). *The frontal lobes*. New York: Raven.

Van Petten, C., & Senkfor, A. J. (1996). Memory for words and novel visual patterns: Repetition, recognition, and encoding effects in the event-related brain potential. *Psychophysiology, 33*, 491–506.

West, R., & Craik, F. I. M. (1999). Age-related decline in prospective memory: The roles of cue accessibility and cue sensitivity. *Psychology and Aging, 14*, 264–272.

West, R., Herndon, R. W., & Ross-Munroe, K. (2000). Event-related neural activity associated with prospective remembering. *Applied Cognitive Psychology, 14*(7), S115–S126.