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The temporal dynamics of prospective memory: A review of the ERP and prospective memory literature

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ABSTRACT

This review article examines the literature using event-related brain potentials (ERPs) to study the temporal dynamics of the neurocognitive processes underpinning event-based prospective memory (PM). The successful encoding of delayed intentions is associated with slow wave activity over the frontal region in younger adults and this activity is attenuated in older adults. The realization of delayed intentions is associated with distinct components of the ERPs that are associated with the detection of a PM cue in the environment (N300), the retrieval of an intention from memory (recognition old-new effect), signaling the need to switch from the ongoing activity (frontal positivity), and configuration of the PM task set (parietal positivity). The development of prospective memory across the lifespan appears to reflect development of processes associated with retrieval of the cue-intention association from memory, and executive processes related to cue detection. The final section of the review examines the nature of executive processes that support PM within the context of a theory of the supervisory attentional system.

1. Introduction

As can be seen from the review and empirical articles included in this special issue, tremendous advances have been made in our understanding of the neurocognitive architecture underpinning prospective memory (PM) in the last decade. The field of PM research has moved from rather general descriptions of the cognitive processes that support prospective memory (Ellis, 1996; McDaniel & Einstein, 1992) to well developed verbal descriptive (McDaniel & Einstein, 2007) and mathematical (Smith & Bayen, 2004) theories. Complimenting the cognitive behavioral work, studies of patients with various neurologic and psychiatric disorders (see, Kliegel, Jäger, Altgassen, & Shum, 2008; Kliegel, MacKinlay, & Jäger, 2008), and those incorporating functional neuroimaging techniques (event-related brain potentials (ERPs), functional magnetic resonance imaging (fMRI), and positron emission tomography (PET)) have served to map the functional neuroanatomy underpinning PM (Burgess, Quayle, & Frith, 2001; Burgess et al., 2008).

My laboratory and others have invested considerable energy in exploring the temporal dynamics of the neurocognitive processes underpinning event-based PM over the last decade in studies using ERPs (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009; West, 2007; West, Herndon, & Crewdson, 2001; West & Krompinger, 2005). ERPs reflect positive or negative going voltage deflections of the EEG measured at the scalp that are time-locked to a relevant event (e.g., stimulus or response onset). The polarity of a given ERP component is often demarcated by a P for positive (e.g., P3) or a N for negative (N2). The polarity of a component is primarily determined by two factors including the orientation of the underlying neural generator relative to the recording electrode on the scalp and in some cases the reference that is used in plotting the data. The findings of research using ERPs to study PM reveal that distinct components of the ERPs are associated with the detection of PM cues in the environment, the retrieval of intentions from memory, and possibly switching from the ongoing activity to the PM component of the task so that a delayed intention can be realized. The current article provides a comprehensive review of the literature using ERPs to examine the neural correlates of PM. Throughout the review the findings of this research are discussed within the context of current theories of PM that are largely derived from studies using cognitive behavioral methods. As the reader will discover, there is a high degree of correspondence between theories of PM and the functional characteristics of components of the ERPs related to PM. However, there are also some findings that do not fit nicely into existing theories of PM. Many of the discordant findings seem to point to the contribution of executive control processes that are not well described in current theories of PM. Given this, the final section of the paper presents a discussion of findings from the ERP and PM literature within the context of a theory of executive control developed by Stuss, Shallice, Alexander, and Picton (1994).

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The review of the literature is organized around three broad topics. Section 2 of the article considers the literature using ERPs to examine the neural correlates of processes recruited during the encoding of delayed intentions. Section 3 considers the ERP correlates of processes associated with the realization of a delayed intention including the detection of a PM cue in the environment, the retrieval of an intention from memory, and possibly configuration of the prospective task set. Finally, section 4 explores the role of executive processes in PM within the context of the ERP and PM literature.

2. ERPs and encoding delayed intentions

ERPs have been used in a limited number of studies to examine the neural correlates of processes associated with encoding delayed intentions (Leynes, Marsh, Hicks, Allen, & Mayhorn, 2003; West & Ross-Munroe, 2002; Zöllig, Martin, & Kliegel, 2010). Three of theses studies have used variations of the PM encoding/retrieval paradigm developed by West and Ross-Munroe (2002), and the other used a paradigm where individuals encoded short action phrases (e.g., bend the wire; Leynes et al., 2003).

2.1. The PM encoding/retrieval paradigm

In the PM encoding/retrieval paradigm, a series of PM encoding and cue trials are embedded in an ongoing activity requiring semantic comparisons of word pairs (West & Ross-Munroe, 2002). For PM encoding trials, one of two letters (e.g., C) is presented in one of two colors (e.g., magenta) that are different from the colors used for the ongoing activity trials (i.e., semantic comparison trials). On these trials individuals are to encode the intention to press the key associated with the letter when the prospective color is next encountered (e.g., press C when a word pair appears in magenta). The pairings of the letters and colors vary over time, so individuals must remember the specific letter-color association to be successful in the task. Following from the ERP and episodic memory literature (Paller, McCarthy, & Wood, 1988; Rugg, 1995), the PM encoding trials are sorted into hits and misses based on whether the intention is later realized (i.e., a PM subsequent memory effect). West and Ross-Munroe (2002) reported that three components of the ERP distinguished PM encoding trials from ongoing activity trials (N2, P3, frontal slow wave) (Fig. 1). However, the frontal slow wave was the only component to reveal a subsequent memory effect, reflecting greater negativity for PM hits than for PM misses. This finding is interesting within the context of the episodic memory literature where successful encoding is often associated with slow wave activity over the frontal region of the scalp that is related to the use of elaborative encoding strategies (Donchin & Fabiani, 1991) and recollection at retrieval (Mangels, Picton, & Craik, 2001). In contrast to PM, successful encoding in episodic memory tends to be associated with greater positivity over the frontal region (Mangels et al., 2001). Differences between the existing PM and episodic memory literature may be related to variation in task demands, as Leynes et al. (2003) found that encoding intentions that were not embedded in a continuous ongoing activity was associated with a positive slow wave over the frontal region similar to that typically observed in studies of episodic memory.

2.2. Development and encoding delayed intentions

The PM encoding/retrieval paradigm has been used in two studies to examine the influence of development on the neurocognitive processes associated with encoding delayed intentions. West, Herndon, and Covell (2003) compared the neural correlates of encoding delayed intentions in younger and older adults using this paradigm. The ERP data for the younger adults replicated the findings of West and Ross-Munroe (2002). In the older adults the amplitude of the N2 and P3 were greater for PM encoding trials than for ongoing activity trials, and the N2 reflected a sustained modulation over the posterior region in contrast to the more transient effect observed in younger adults. This finding may indicate that older adults engaged in extended high level visual processing while encoding intentions relative to younger adults. In the older adults the frontal slow wave distinguished PM encoding trials from ongoing activity trials. However, the amplitude of this component did not differ for PM hits and PM misses indicating that the frontal slow wave did not reveal a subsequent memory effect in the older adults. Additionally, in the older adults there was a slow wave over the temporal-parietal region that differentiated PM hits from PM misses. This finding led to the suggestion that younger and older adults may recruit somewhat different neural generators when encoding delayed intentions (West, Herndon et al., 2003; West, Wymbs, Jakubek, & Herndon, 2003).

Zöllig et al. (2010) extended the findings of West, Herndon, et al. (2003) in a study comparing the neural correlates of encoding delayed intentions in adolescents, younger adults, and older adults. In the adolescents and younger adults there was a frontal slow wave that distinguished PM encoding trials from ongoing activity trials, and the amplitude of this component was greatly attenuated in the older adults. In addition there was a slow wave over the temporal-parietal region that differentiated PM encoding trials from ongoing activity trials in the older adults, but not the adolescents or younger adults. Zöllig et al. (2010) interpreted this pattern of data as reflecting neural activity related to compensatory processing in the older adults (Cabeza, 2002; Park & Reuter-Lorenz, 2009). This conclusion may however be premature based upon the results of a re-analysis of the data published by West, Herndon, et al. (2003). Specifically,

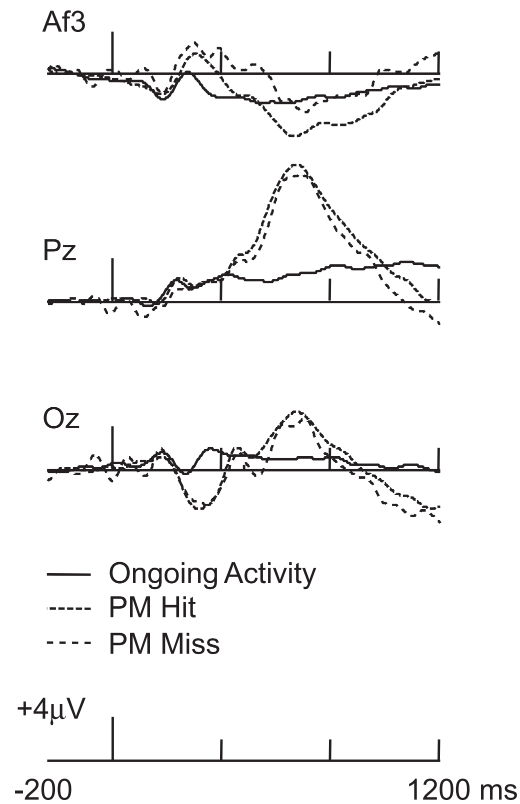

Fig. 1. Grand-averaged ERPs portraying the N2, P3b, and frontal slow wave elicited during the encoding of a delayed intention. Note that only the frontal slow wave differentiates PM hits from PM misses. The tall bar represents stimulus onset and the short bars represent 400 ms increments. Adapted from West and Ross-Munroe (2002).