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Brain regions and their dynamics in prospective memory retrieval: A MEG study

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Abstract

We measured brain activity using magnetoencephalography in five participants during ongoing tasks that included prospective memory, retrospective memory, and oddball trials. Sources were identified in the hippocampal formation and posterior parietal and frontal lobes. Posterior parietal cortex activation had an earlier onset in the prospective memory condition than retrospective memory or oddball conditions, a higher level of theta activity in the retrospective condition, and higher levels of upper alpha in the prospective and oddball conditions. Activation of the hippocampal formation had a longer duration in the retrospective memory and prospective memory conditions than the oddball condition, but prominent alpha and theta band activity was present in all three conditions. We interpret the early (87 ms) onset of activity in parietal cortex as evidence for an initial noticing of appropriate conditions for a PM response. Hippocampal activity may reflect a subsequent memory search for the intended action.

Keywords: Prospective memory; Retrospective memory; Magnetoencephalography

Prospective memory (PM) refers to the ability to remember and perform an intended action at some future point in time. A central feature of PM is that the appropriate action can be recalled without an external agent prompting retrieval (Craik, 1986; Einstein et al., 1992; McDaniel and Einstein, 2000; McDaniel et al., 2004). This observation raises fundamental theoretical questions about both the cognitive processes involved in PM and the brain processes that mediate PM. This article focuses on the latter question – the brain regions involved in PM and the dynamics associated with activation of these regions – to help elucidate the underlying cognitive processes. To frame the investigation of the neuronal substrate for human PM, we first consider current cognitive theoretical approaches to PM and review results from prior neuroimaging studies. We then report the results of the first study that uses magnetoencephalography (MEG) to explore the spatio–temporal dynamics of brain processes involved in PM. We note at the outset that our focus is on event-based PM tasks (Einstein and McDaniel, 1990) in which the intended action is remembered when an external event (target or marker) occurs in the environment.

1. Theoretical approaches to PM and implications for brain activation

PM is often viewed as a multi-component process consisting of a prospective component and a retrospective component (Burgess and Shallice, 1997; Driscoll et al., 2005; Einstein and

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McDaniel, 1996; McDaniel and Einstein, 1992; Smith, 2003). The prospective component involves recalling an intention (e.g., buy needed items) upon encountering an appropriate event (e.g., a grocery store). The retrospective component involves remembering the contents of the encoded intention (e.g., buy bread at the grocery store). Although theorists generally agree on this broad analysis of PM, there is divergence about the processes and potential neural substrates mediating PM. One model suggests that supervisory executive processes are involved throughout the PM task (Burgess and Shallice, 1997; Shallice and Burgess, 1991). These processes recruit and maintain attentional resources during monitoring for an environmental marker (environmental event) that signals the appropriateness of performing the PM task (Burgess and Shallice, 1997; Guynn, 2003; Smith, 2003) and participate in the initiation of PM task performance (cf. Guynn et al., 2001; McDaniel et al., 1998). We will label this model the *supervisory model*.

Because frontal areas are explicitly assumed to be involved in supervisory executive functions (e.g., Fuster, 1999; Shallice and Burgess, 1991), the supervisory model implies that frontal areas are involved in PM. Some support for this idea comes from neuroimaging and neuropsychological studies (e.g., Burgess et al., 2000; Martin et al., 2003; McDaniel et al., 1999). Using positron emission tomography (PET), Burgess et al. (2001) and Okuda et al. (1998) observed greater activation in frontal areas during a PM task compared to a control task, and concluded that frontal areas are involved in maintaining and realizing a PM intention. However, the limited temporal resolution of PET did not permit disentangling target detection, decision processes, and executive scheduling.

Most cognitive theories of PM assert that episodic retrieval processes are invoked when the PM target is encountered. For example, the *preparatory attention and memory process* (PAM) model proposes that monitoring of the environment initiates a recognition decision about whether the stimulus is a PM target or a nontarget (Smith and Bayen, 2004). Additionally, more extensive retrieval activity for the intended action might be initiated following a positive recognition decision (Smith, 2003). Attempted recognition of the target would occur on every trial (assuming that high levels of PM performance are evidenced). In terms of brain activity, this process implies that structures supporting recognition processes should be activated on every trial, perhaps followed by a recall process reflecting episodic retrieval of the intended action. The hippocampal formation appears to be a good candidate for this process as it is implicated in neuropsychological and evoked potential investigations of recognition (Smith and Halgren, 1989) and has been implicated in PM by Okuda et al. (1998) using PET. The noticing plus search view suggests that associative retrieval processes similar to those involved in cued recall are engaged to retrieve the intended action, and these also would appear to be supported by the hippocampal formation (Isaac and Mayes, 1999; Moscovitch, 1994). Thus, PM retrieval activities and retrospective memory may involve similar neuronal dynamics in the hippocampal formation. Animal studies have supported distinct contributions of hippocampus and other brain structures, including the parietal lobes, in PM tasks (Kametani and Kesner, 1989).

A distinguishing feature between PAM and the *noticing-plus-search model* is that the latter assumes that monitoring is not necessary for the recognition of a PM target (Einstein and McDaniel, 1996; McDaniel, 1995; McDaniel et al., 2004). In this model, PM "noticing" involves processes that are relatively automatically stimulated by features of the specific target event, features that are perhaps more highly activated (as a consequence of the prospective memory instruction; Freeman and Ellis, 2003; Goschke and Kuhl, 1993) or more fluently processed (McDaniel, 1995). A critical implication of the noticing plus search model is that when the target is encountered, it is noticed as being significant (McDaniel et al., 2004) prior to retrieval of the intended action (and possibly the episodic features associated with initial encoding of the prospective memory intention). Thus, on this view hippocampal activation would follow noticing.

It is unclear *a priori* which brain system would support this noticing, but recent work has identified one possibility. West and Ross-Munroe (2002) observed an N300 peak over the occipital–parietal area that was greater in amplitude on successful trials than trials on which the PM task was not correctly executed. The N300 is modulated by perceptual noise but not memory load (West et al., 2003) and is distinguishable from other evoked components associated with sensation and perception (West and Wymbs, 2004). The parietal positivity peaked around 500–700 ms after target onset over parietal areas (with a negativity over frontal areas) only when the stimulus was for a PM task (West et al., 2001). Thus the parietal positivity distinguishes PM targets from other stimuli. The N300 component has been interpreted as reflecting the noticing of a PM target and is consistent with the noticing-plus-search model, whereas the parietal positivity has been interpreted as reflecting retrieval of the intended action (West et al., 2003). Taken together, the N300 and parietal positivity suggest the involvement of parietal cortex in PM, with early activity associated with noticing a PM target and later activity, possibly from a different source, associated with retrieval of the intended action.

2. The present study

The purpose of the current study was twofold. First, no single experimental design or set of tasks has been decisive in revealing theoretical mechanisms, and it would be useful to address some of the limitations of past studies with a different experimental paradigm. Using a new paradigm, we hoped to provide converging evidence for past findings. Second, brain mechanisms that mediate PM are poorly understood. The addition of source modeling of neurophysiological (MEG/EEG) data may provide information on brain dynamics that is useful in teasing apart different stages of PM.

One possible limitation of previous PM tasks involving semantic judgments is that processing of linguistic stimuli may involve processes different from those involved in such everyday tasks as remembering to pick something up from the store or to mail a letter. For instance, the ongoing semantic judgment component of the partial cue PM task (West et al., 2000) had a large memory component that may have biased the