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Differential components of prospective memory? Evidence from fMRI

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Abstract

Two of the principal components of prospective memory (i.e., remembering to carry out delayed intentions) are recognizing the appropriate context to act ("cue identification") and remembering the action to be performed ("intention retrieval"). In this experiment, the demands on these components were manipulated while measuring brain activity using fMRI to explore whether the two components share a common neural basis. The results showed significant behavioral differences between the cue identification and intention retrieval conditions. However, a consistent pattern of hemodynamic changes was found in both prospective memory conditions in anterior prefrontal cortex (BA 10), with lateral BA 10 activation accompanied by medial BA 10 deactivation. These effects were more pronounced when demands on intention retrieval were high. This is consistent with the hypothesis that anterior prefrontal cortex (area 10) supports the biasing of attention between external events (e.g., identifying the cue amid distracting stimuli) and internal thought processes (i.e., maintaining the intention and remembering the intended actions). Together, the results suggest that whilst cue identification and intention retrieval may be behaviorally separable, they share at least some common neural basis in anterior prefrontal cortex.

Keywords: Anterior prefrontal cortex; Rostral prefrontal cortex; Frontal lobes; Functional magnetic resonance imaging (fMRI); Executive function

1. Introduction

Prospective memory (PM[1]), remembering to perform an intended action after a delay (Meacham & Singer, 1977), may involve a number of processing stages: forming an intention, maintaining the intention in memory over an interval while being engaged in another (or ongoing) task, executing the intended action at the appropriate moment, and evaluating the outcome (Freud, 1901; Ellis, 1996). Much research into PM has focused on the third of these stages, involving recognition of the appropriate moment to act and remembering what action was to be performed (see Table 1 in Burgess, Scott, & Frith, 2003, for a list of cardinal properties of PM). The most often studied example is where an action needs to be performed when an external event occurs, such as remembering to stop and buy a loaf of bread when you drive past the grocery store ("event-based PM"; Einstein, Holland, McDaniel, & Guynn, 1992). McDaniel and Einstein (1992) proposed a division of event-based PM into two components: cue identification and intention retrieval. Cue identification involves the detection of the cue event (e.g., the grocery store) signaling that the intended action should be performed; intention retrieval involves the subsequent recovery of that intention (e.g., buying the bread) from memory. There are a considerable number of behavioral studies that have investigated these components (e.g., Brandimonte & Passolunghi, 1994; Cohen, West, & Craik, 2001; Marsh, Hicks, Cook, Hansen, & Pallos, 2003; Einstein et al., 1992; Einstein, McDaniel, Manzi, Cochran, & Baker, 2000; Ellis & Milne, 1996; West, Herndon, & Crewdson, 2001; West & Ross-Munroe, 2002; West, Wymbs, Jakubek, & Herndon, 2003).

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[1] Delegates at the 2nd International Conference on Prospective Memory, Zurich, July 2005, voted that the use of the abbreviation "PM" for prospective memory was preferable to other extant forms.

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Much of this research has focused on one or other of the two components, such as on the effect of cue characteristics in triggering a response. It has been shown that cues that are particularly salient tend to be noticed more frequently (Einstein et al., 2000), that unfamiliar cues benefit prospective remembering (Brandimonte & Passolunghi, 1994), and that when an intention has been formed to respond to a particular category of cues, highly typical category members evoke the intention more often than less typical exemplars (Ellis & Milne, 1996). Studies of intention retrieval have concentrated primarily on the association between the cue and the stored intention. When this association is strong, retrieval may be relatively automatic, as opposed to more effortful processing when the association is weak (McDaniel & Einstein, 2000; McDaniel, Einstein, Guynn, & Breneiser, 2004).

Despite the extensive research on PM processes, however, relatively few studies have investigated whether cue identification and intention retrieval might rely on separable cognitive processes. Cohen et al. (2001) evaluated in separate experiments the hypothesis that cue identification and intention retrieval are primarily supported by stimulus-driven and conceptually driven processes, respectively. Cue identification was manipulated by a change in format of the cue from study session to test session and, in a second experiment, intention retrieval was manipulated by a change in semantic relatedness between the cue and the intention from study session to test session. The authors found that a change in cue format reduced the number of PM cues detected, while semantically unrelated intentions were less often correctly recalled upon detection of the cue, consistent with their hypothesis. However, only accuracy data were reported, although many PM studies have reported an effect of prospective memory retrieval on reaction times (e.g., Burgess, Scott, & Frith, 2003; Marsh, Hicks, & Watson, 2002; Marsh et al., 2003; West et al., 2001). Marsh et al. (2003) examined reaction times while investigating the extent to which maintenance of a PM intention might affect cognitive processing of the ongoing task at the time a PM cue is encountered (see also Smith, 2003). Marsh et al. manipulated cue identification and intention retrieval demands separately and found differential effects on reaction times in the ongoing task. However, despite showing a differential effect of maintaining a PM intention on performance of the ongoing task, these authors did not study the effect of manipulating cue identification and intention retrieval on the PM task itself.

The few available results thus suggest that cue identification and intention retrieval might be separable behaviorally, in that manipulating the demand on the two components may differentially affect error rates and/or reaction times. However, even if this is the case, it may not necessarily follow that the two components are supported by exclusively different brain regions. Previous neuroimaging studies of PM have used a variety of paradigms which, although not designed to manipulate cue identification and intention retrieval as experimental variables, have nevertheless involved cue identification and intention retrieval processes to differing extents. In all of these studies, a consistent pattern of activation has been observed, involving particularly anterior prefrontal cortex (approximating Brodmann area 10) (Burgess, Quayle, & Frith, 2001; Burgess et al., 2003; den Ouden, Frith, Frith, & Blakemore, 2005; Okuda et al., 1998). It is not clear, therefore, whether the anterior prefrontal cortex network is involved in PM function to a similar degree irrespective of the demands on cue identification and intention retrieval, or whether varying cue identification and intention retrieval as experimental variables will reveal that the key neural correlate of PM reflects processing relating to one of the hypothesized components more than the other.

The experiment presented here examined these issues by scanning participants using fMRI while they were undertaking a task in which PM trials were embedded in an ongoing task in such a way as to prevent participants from actively rehearsing the intentions. Two PM conditions were used, one with high cue identification demand and low intention retrieval demand (the 'cue identification PM condition'), and one with low cue identification demand and high intention retrieval demand (the 'intention retrieval PM condition'). Cue identification was manipulated by altering the perceptual salience of the PM cues (Brandimonte & Passolunghi, 1994; Einstein et al., 2000). In the low cue identification demand condition, the cues were perceptually distinct from the ongoing trials, while in the high demand condition, the cues were perceptually similar but conceptually distinct. Intention retrieval demand was manipulated by varying the number of actions participants needed to perform in order to determine the appropriate response. If, as predicted by previous neuroimaging studies (Okuda et al., 1998; Burgess et al., 2001, 2003; den Ouden et al., 2005), an anterior prefrontal cortex network supports PM function regardless of the demands on cue identification and intention retrieval, then substantial overlap can be expected between the patterns of activation associated with each PM condition.

The use of word and shape versions of the task enabled analysis involving conjunction contrasts across tasks to identify brain regions that are commonly activated across stimulus types, and might be considered to reflect "central", task-independent PM processes, as opposed to those that might be specific to a particular stimulus type or task. In addition, to examine the effect of maintaining a PM intention on performance of the ongoing task (Marsh et al., 2003; Smith, 2003), a session consisting solely of ongoing trials was included at the beginning of the experiment, before participants had received any instructions concerning PM trials. Previous studies have shown that once instructed about a PM condition, the expectation that a PM trial will occur continues even if participants are subsequently instructed that there will be no PM trials in the upcoming block (Burgess et al., 2003; Einstein et al., 2005; Holbrook, Bost, & Cave, 2003). Ongoing trials presented before exposure to a PM condition should not be contaminated by the expectation of a PM trial, so were termed 'uncontaminated' ongoing trials, with ongoing trials occurring after presentation of PM instructions termed 'contaminated' ongoing trials. Burgess et al. (2001) have shown that not only the execution, but also the expectation, of a PM trial can be associated with lateral anterior prefrontal cortex activation. If this region is involved in maintenance of the PM intention, it should show greater activation in the present experiment during contaminated versus uncontaminated ongoing trials and, indeed,