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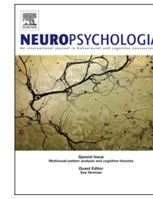

# The functional neuroanatomy of spontaneous retrieval and strategic monitoring of delayed intentions

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ABSTRACT

An intention stored in prospective memory (PM) for later execution can be retrieved either strategically through preparatory attentional processes such as active monitoring for PM targets or spontaneously through automatic retrieval processes when encountering a relevant cue. Using functional MRI to identify distinct brain areas involved in spontaneous retrieval of intentions and to dissociate them from monitoring-related processes, we compared brain activity in PM blocks in which subjects had to maintain and execute an intention in response to rarely occurring PM cues with blocks in which the previous intention had been completed. Although the PM task incurred performance costs in the ongoing task and was associated with increased block-related activation in the rostro-lateral prefrontal cortex (RLPFC), performance costs and RLPFC activation were no longer observed after the intention had been completed, providing further evidence for an involvement of RLPFC in strategic monitoring during PM tasks. By contrast, event-related activation induced by PM cues was observed in the ventral parietal cortex (VPC), precuneus and posterior cingulate cortex even after the intention was completed. These activations are consistent with the notion of spontaneous intention retrieval possibly mediated through a bottom-up driven re-activation of intention representations still persisting in a heightened state of activation in episodic memory. In conclusion, the results highlight the functional relevance of VPC and precuneus in prospective memory retrieval, possibly reflecting spontaneous, cue-based processes as opposed to top-down controlled strategic monitoring.

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## 1. Introduction

Successfully managing the wealth of one's daily tasks depends critically on the ability to remember to execute an intention at the right time or in the appropriate situation. The term prospective memory (PM) denotes processes that support remembering future intentions in the absence of an explicit external instruction to engage in a retrieval process and execute the associated action when the appropriate future event is encountered (Kliegel, McDaniel, & Einstein, 2008; McDaniel & Einstein, 2007a). The importance of PM for successfully managing everyday life becomes most obvious when PM failures occur: forgetting to stop at the grocery store on our way home or posting a letter when passing a mail box are just a few examples demonstrating the range of situations where PM is relevant.

According to the *multiprocess framework* two types of processes may support PM retrieval: resource consuming *strategic monitoring* for intention-relevant stimuli as well as automatic *spontaneous retrieval* of the intention triggered by specific pre-defined PM cues (Einstein et al., 2005; McDaniel & Einstein, 2000; Scullin, McDaniel, Shelton, & Lee, 2010). Studies using functional brain imaging consistently showed activation in rostro-lateral prefrontal cortex (RLPFC) during PM tasks (Burgess, Gonen-Yaacovi, & Volle, 2011), and there is provisional evidence suggesting that this RLPFC activation reflects strategic monitoring for intention-related PM targets (Burgess, Quayle, & Frith, 2001; Reynolds, West, & Braver, 2009). However, to our knowledge, to date only one study has begun to investigate BOLD activation patterns associated with spontaneous processes in PM retrieval (McDaniel, LaMontagne, Beck, Scullin, & Braver, 2013). In particular, to our knowledge there is no further research on neural activation components of *spontaneous retrieval* and how they differ from *monitoring* processes. Thus, the central aim of our study was to use functional magnetic resonance imaging (fMRI) to isolate brain activations related to spontaneous retrieval and to investigate whether distinct or common regions are activated by strategic monitoring and spontaneous retrieval processes.

### 1.1. Monitoring

A central assumption of monitoring-based explanations of PM retrieval is that it depends on constantly operating and resource consuming cognitive processes. According to the *preparatory*

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*attentional and memory theory* (*PAM*) of PM, successful retrieval of a prospective intention always requires preparatory attentional processes that comprise monitoring the environment for intention-relevant target events through constant item checking and maintaining a prospective memory retrieval mode (Smith, 2003; Smith & Bayen, 2004). These preparatory attentional processes can take the form of conscious strategic monitoring or can operate outside of awareness while nevertheless consuming cognitive resources (Smith, Hunt, McVay, & McConnell, 2007). Indicators for preparatory attentional processes are increased response times (RT) or error rates in the ongoing task when simultaneously performing a PM task (usually referred to as *monitoring costs*) (Guynn, 2003; Smith, 2003; Smith et al., 2007).

### 1.2. Spontaneous retrieval

By contrast, the spontaneous retrieval account assumes that intention retrieval can occur without resource consuming monitoring processes. Rather, the target event automatically triggers successful retrieval of the intention (Einstein et al., 2005; McDaniel & Einstein, 2000, 2007b). Spontaneous retrieval of intentions can be mediated by two mechanisms: first, the PM cue may trigger a reflexive-associative process by which the intended action is automatically retrieved from long-term memory (Bugg, McDaniel, & Einstein, 2013; Einstein et al., 2005; McDaniel, Guynn, Einstein, & Breneiser, 2004). This process rests on a strong association between the PM cue and the intended action that was formed during encoding and is stored in long-term memory, as reflexive retrieval depends on a strong association between a cue and an action (Einstein et al., 2005; Moscovitch, 1994; McDaniel & Einstein, 2007b; McDaniel et al., 2004). Once a PM cue is encountered, an automatic associative system delivers the intended action to consciousness (Einstein et al., 2005). That is, when encountering a PM cue, the processing of this cue activates the memory code of the intention, most likely via spreading activation through a long-term memory network (Collins & Loftus, 1975). As the PM cue and the intended action are linked together in the now activated intention representation, the intended action becomes also activated, delivered to awareness and thus spontaneously retrieved.

Second, when encountering a target event, a person may experience a discrepancy in processing quality, which elicits a sense of significance and triggers a search process in memory for possible causes of the discrepancy. As a result, the target is identified as a cue for the intended action, delivering the intention to awareness (Breneiser & McDaniel, 2006; McDaniel et al., 2004; McDaniel & Einstein, 2007b).

### 1.3. Aftereffects of completed intentions

Spontaneous retrieval of intentions has recently been investigated by experimental paradigms including the presentation of PM cues after the completion of the PM task (Einstein et al., 2005; Scullin & Bugg, 2012; Scullin, Bugg, & McDaniel, 2012; Scullin, Bugg, McDaniel, & Einstein, 2011). Recent studies using similar completed intention paradigms have demonstrated systematic *aftereffects* of repeated (yet no longer relevant) PM cues in terms of increased ongoing-task RTs and/or error rates on repeated PM cues compared to control trials as well as erroneous repetitions of the no-longer relevant intention-related response, a *commission error* (Scullin & Bugg, 2012; Scullin et al., 2011, 2012; Walser, Fischer, & Goschke, 2012; Walser, Goschke, & Fischer, 2013; Walser, Plessow, Goschke, & Fischer, 2013). Different conceptualizations of the cognitive processes underlying these aftereffects of completed intentions have been proposed.

First, special dynamic properties of intentions that are gained already during encoding of the intention might underlie aftereffects. Previous research investigating the content of intentions has concluded that intention-related representations in long-term memory are characterized by a heightened or more sustained subthreshold level of activation (*intention-superiority effect*) (Goschke & Kuhl, 1993, 1996; Marsh, Hicks, & Bink, 1998; Marsh, Hicks, & Bryan, 1999). This persisting activation for intentional content cannot be accounted for by controlled strategies, but rather reflects an intrinsic property of intention-related memory representations as opposed to neutral memory content (Goschke & Kuhl, 1993). After intention completion, this heightened state of activation might still persist, thus causing the observed aftereffects (Cohen, Dixon, & Lindsay, 2005; Penningroth, 2011; Walser et al., 2012). Thus, aftereffects on repeated PM cue trials might result from interference of the intention-related response with the ongoing task (similar to incongruence effects in a conflict task caused by interference of the irrelevant dimension and the to-be-responded-to dimension).

A second view arises from the spontaneous retrieval account suggesting that during a PM task, PM cues that are strongly associated with the intention can spontaneously trigger the retrieval of the intended action in the absence of top-down controlled strategic monitoring (Einstein et al., 2005; Scullin & Bugg, 2012). A strong cue-action link will spontaneously deliver an intention to consciousness, even after the intention is completed. Based on these assumptions, aftereffects were interpreted as evidence for a cue-triggered spontaneous retrieval of the completed intention (Scullin & Bugg, 2012; Scullin et al., 2011, 2012). This assumption is also supported by the fact that aftereffects were stronger for salient PM cues as well as increased after enhanced initial PM encoding (Bugg, Scullin, & McDaniel, 2013; Scullin & Bugg, 2012; Scullin et al., 2012; Scullin, Einstein, & McDaniel, 2009; Walser et al., 2012), manipulations generally assumed to increase spontaneous retrieval (McDaniel & Einstein, 2000, 2007b). Further, aftereffects, especially commission errors, might depend on spontaneous re-activation of the intended action and a subsequent failure to recruit sufficient executive control to suppress this no longer relevant response tendency (Scullin & Bugg, 2012). The spontaneous retrieval explanation for aftereffects does not necessarily depend on the intention representation being in a heightened state of activation (Scullin & Bugg, 2012). Nevertheless, both accounts might go hand in hand as the proposed residual activation of intention representations might facilitate spontaneous cue triggered retrieval by making it easier for the intention to be delivered to consciousness once a repeated PM cue is encountered (Walser et al., 2012).

Moreover, further explanations for aftereffects that are not specific to a PM task are conceivable. Previous studies have discussed the possibility that aftereffects reflect an attentional orienting reaction to more salient stimuli, familiarity effects to cues that have been experienced before or response priming of the PM task response (Einstein et al., 2005; Scullin et al., 2009; Walser et al., 2012). Still, evidence has been provided that aftereffects persist when experimentally controlling for familiarity, priming or salience effects (Einstein et al., 2005; Scullin et al., 2009, 2011; Walser et al., 2012), thus making it unlikely that these processes can fully explain aftereffects of completed intentions.

### 1.4. Neuroimaging of PM

Neuroimaging studies of PM showed a consistent pattern of RLPFC activation during PM tasks that can be differentiated from event-related responses specific to the processing of PM targets (Burgess et al., 2001, 2011; Reynolds et al., 2009). The assumption that this RLPFC activation reflects a strategic monitoring mode is

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