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Effects of cue frequency and repetition on prospective memory: An ERP investigation

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ABSTRACT

Prospective memory involves the formation and completion of delayed intentions and is essential for independent living. In this study ($n = 33$), event-related potentials (ERPs) were used to systematically evaluate the effects of PM cue frequency (10% versus 30%) and PM cue repetition (high versus low) on ERP modulations. PM cues elicited prospective positivity and frontal positivity but not N300, perhaps due to the semantic nature of the task. Results of this study revealed an interesting interaction between PM cue frequency and PM cue repetition for prospective positivity and frontal positivity, highlighting the importance of taking both factors into account when designing future studies.

1. Introduction

Prospective memory (PM) involves the formation and completion of intentions that cannot be carried out at the time they are initially created (Kliegel and West, 2007). The capacity for autonomy and independence is, in many situations, reliant upon the ability to carry out intended actions at the appropriate time, with often-cited examples ranging in importance from remembering to take medication with a meal, to the more mundane collection of an item from a store on the way home (Kliegel and West, 2007; Zöllig et al., 2007). Typically, an experimental PM task involves asking participants to engage in an ongoing task and they are also instructed to perform an additional action when a comparatively rare PM cue appears (Einstein and McDaniel, 1990). The aim of the present investigation was to address an important potential ecological validity problem in the use of frequent cues required by the research paradigm. While behavioural studies use relatively few PM cues interspersed amidst a large number of ongoing trials, the extension of PM research to the measurement of event-related potentials (ERPs) has required a dramatic shift to several times the number of PM cues in order to compute average waveforms for analysis. The important question posed by this is whether cue frequency and repetition affect the PM phenomenon under investigation.

Studies of ERP correlates of PM indicate three distinct ERP components: the N300, frontal positivity and prospective positivity (West, 2011). The N300 is a negative deflection occurring over the occipital–parietal region of the scalp 300–400 ms (mean amplitude) after stimulus onset, and is believed to be associated with the detection of PM cues within a variety of ongoing activities (West, 2008). The amplitude of the N300 is greater for correct responses (PM hits) than for incorrect trials (PM misses) (West and Krompinger, 2005) and is also attenuated when PM cues are harder to detect against background stimuli (West et al., 2003b). The N300 can be dissociated from the N2pc component which reflects an earlier, more general process of attending to task-relevant stimuli (West and Wymbs, 2004). While both visual targets and PM cues elicit the N2pc, only PM cues elicit the N300. This indicates that the neural processes supporting PM contain elements that are shared with visual attention processes, and those that are unique to PM (West, 2008). However, in some reported studies the N300 was not observed (Chen et al., 2011; McNerney, 2006, cited in West, 2011; Wang et al., in press), possibly because these studies used a semantic characteristic as the PM cue. Most of the studies that showed N300 used perceptual cues (West, 2011; Wang et al., in press).

The N300 is often accompanied by a sustained frontal midline positivity persisting beyond the duration of the N300 (West, 2008). The frontal positivity may support disengagement from ongoing activities because injury to the frontal lobe has been found to lead to an inability to disengage from the ongoing task (West, 2005). While ERPs provide excellent temporal resolution, functional neuroimaging research (using PET and fMRI both with excellent spatial resolution) has provided evidence for the role of the rostral prefrontal cortex (Brodmann Area 10) in supporting PM (Burgess et al., 2003). This area is believed to support the attentional and control aspects of PM performance such as monitoring for PM cues and dividing or switching attention between the PM and ongoing tasks (Burgess et al., 2008). Further fMRI research on PM is

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needed to examine this possible role of the prefrontal cortex in disengagement from the ongoing task.

The prospective positivity occurs over the central, parietal and occipital regions of the scalp between 400 and 1200 ms (mean amplitude) after stimulus onset, and is associated with the retrieval of the content of an intention from memory (West, 2008) or configuration of the PM task set or task switching (West, 2011). As with the N300, the prospective positivity is elicited in a variety of experimental paradigms. Ongoing tasks have included N-back tasks (West et al., 2006) and semantic judgement tasks (West and Krompinger, 2005), while PM cues have been defined by attributes including, but not limited to, word identity (West, 2007) and colour (West et al., 2003a; Zöllig et al., 2007). There are some similarities and differences between prospective positivity and P300. The similarities include that they occur in a similar time window (although the prospective positivity often peaked later than the P300), and that they are both elicited by rare stimuli (West, 2008, 2011). The differences are that prospective positivity is more limited to PM cues but not P300, and prospective positivity and P300 are differentially sensitive to working memory load. For example, West and Wymbs (2004) embedded a PM task in a target selection task, and showed that P300 differentiated PM cue trials and target trials from non-target trials, whereas prospective positivity differentiated PM cue trials from target trials and non-target trials. West and Bowry (2005) demonstrated that the amplitude of P300 was sensitive to N-back load but the amplitude of prospective positivity was not.

1.1. Factors that may influence PM ERP modulation

A defining feature of PM tasks is that the intention is not maintained actively in working memory. The PM task must occur against a background of ongoing activities and involve the interruption of an ongoing task to perform the PM task (McDaniel and Einstein, 2007). Since this dual-task paradigm is similar to tasks commonly used to assess working memory, to avoid the experimental paradigm becoming one of working memory or pure dual-task, strategies must be introduced to ensure that the PM task is not actively rehearsed (West, 2008). Ongoing activities that require deep processing or require working memory may discourage rehearsal (West et al., 2001; West and Krompinger, 2005). In addition, West (2008) has suggested that PM cues be held at between 5 to 10% of total trials. The low frequency of cues combined with an ongoing task which is sufficiently engaging ensures that the cues are not actively rehearsed. However, different studies have used different PM cue frequencies. Behavioural studies usually adopt a low PM cue frequency (usually less than 5%), and studies examining neural correlates often adopt a relatively higher PM cue frequency (e.g., 11–20%) (Czernochowski et al., 2012). While behavioural studies may present 5 or 6 PM cues, typically an ERP-based PM experiment will need a minimum 20 to 30 trials (PM cues) to achieve sufficient signal-to-noise reduction for identifying 1–5 μV components against the background 50–100 μV EEG (Luck, 2005). If the PM cue frequency affects the strategy of PM monitoring, the results of previous neural correlates studies of PM would be limited. This is because most of these studies used high PM cue frequency and their results would only be applicable for the PM monitoring strategy associated with this type of cue frequency (Czernochowski et al., 2012). However, the question of whether PM cue frequency affects the ERP modulations or changes the nature of cognitive processing is not well studied in the literature. Most recently, one study (Czernochowski et al., 2012) explored the effect of PM cue frequency on ERP modulations, and found that although the behavioural performance patterns were different between PM-rare (3% PM cue) and PM-frequent (20% PM cue) conditions, the ERP modulations were similar, and they suggested that successful PM performance was associated with the adoption of a PM retrieval mode irrespective of PM cue frequency. Given the novelty of the finding and importance of these results for ERP studies requiring adequate trials for signal averaging, it is of interest to study this further.

West (2008) has also suggested that, where possible, PM cues should not be repeated within a block of trials as repetition of specific cues may affect the amplitude of the ERPs. Repetition of cues may obscure important effects such as differences in ERPs for correct trials versus misses (West, 2008). West and Ross-Munroe (2002) used repeated cues and found no difference in the amplitude of the prospective positivity for correct PM trials and PM misses. In contrast, when West and Krompinger (2005) used unique cues they found a significantly stronger neural response for correct trials compared with misses (which did not differ significantly from the ongoing task). If repeated stimuli engage a habituation process then this may result in an attenuation of the ERPs. However, the effect of cue repetition on ERP amplitude has not been systematically evaluated in PM. In addition, it is unclear if this task factor might also interact with other factor such as PM cue frequency. Finally, it is worth considering that ERP studies of priming and repetition for indices of implicit and explicit memory have demonstrated attenuated ERPs for repeated stimuli (Harris et al., 2009; Rugg et al., 1998). However the potential impact of cue repetition on later ERPs (prospective positivity and frontal positivity) is unclear. It is possible that repetition of cues may result in processing becoming more habitual over time and attenuated in amplitude.

This study was designed to evaluate the effects of cue frequency and cue repetition on the neural correlates of PM. Since in a high PM cue frequency condition, the successfully detected PM cues would serve as reminders of PM intention (Czernochowski et al., 2012), the high frequency condition should be less demanding and may cause a reduced ERP difference between PM cue and ongoing trials compared to low PM cue frequency condition. It was hypothesised that mean amplitudes for the N300, frontal positivity and prospective positivity would be larger (relative to ongoing trials) for low frequency cues compared to high frequency cues. Additionally, given West's (2008) observation that repetition of PM cues may reduce ERP amplitudes in PM, it was anticipated that mean amplitudes for the N300, frontal positivity and prospective positivity would be larger (relative to ongoing trials) with a low level of cue repetition compared to high repetition. We hypothesised that there might be interaction between cue frequency and cue repetition. However, given that PM cue frequency and repetition have not previously been studied together, no specific direction of their interaction was formulated.

2. Method

2.1. Participants

Thirty-three individuals (11 males; *M* age = 21.94 years, *SD* = 5.51 years) participated in the experiment. The data of three participants were excluded from analysis due to insufficient correct trials to produce a stable average waveform. The mean age of the remaining 30 participants (10 males) was 22.17 years (*SD* = 5.72). Participants were undergraduate psychology students at Griffith University and were offered course credit for their involvement. All spoke English as their first language and reported no history of neurological disorder. Information about the study was provided, and written consent obtained prior to participation in the study. Experiments were conducted with the approval of the Griffith University ethics committee and in agreement with the Declaration of Helsinki.

2.2. Design

Illustrated in Table 1, the experiment employed a mixed factorial design with between-subjects factor of cue repetition (low, high) and within-subjects factor of cue frequency (low, high). There were 15 participants in each repetition condition. A mixed design was chosen for this experiment because a full within-subjects design