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The influence of time on task on mind wandering and visual working memory

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ABSTRACT

Working memory relies on executive resources for successful task performance, with higher demands necessitating greater resource engagement. In addition to mnemonic demands, prior studies suggest that internal sources of distraction, such as mind wandering (i.e., having off-task thoughts) and greater time on task, may tax executive resources. Herein, the consequences of mnemonic demand, mind wandering, and time on task were investigated during a visual working memory task. Participants (N = 143) completed a delayed-recognition visual working memory task, with mnemonic load for visual objects manipulated across trials (1 item = low load; 2 items = high load) and subjective mind wandering assessed intermittently throughout the experiment using a self-report Likert-type scale (1 = on-task, 6 = off-task). Task performance (correct/incorrect response) and self-reported mind wandering data were evaluated by hierarchical linear modeling to track trial-by-trial fluctuations. Performance declined with greater time on task, and the rate of decline was steeper for high vs low load trials. Self-reported mind wandering increased over time, and significantly varied as a function of both load and time on task. Participants reported greater mind wandering at the beginning of the experiment for low vs. high load trials; however, with greater time on task, more mind wandering was reported during high vs. low load trials. These results suggest that the availability of executive resources in support of working memory maintenance processes fluctuates in a demand-sensitive manner with time on task, and may be commandeered by mind wandering.

1. Introduction

The capacity to use working memory, which is the ability to maintain and manipulate information over short intervals, can become derailed by task-unrelated thought, a phenomenon known as mind wandering (MW; Smallwood & Schooler, 2006). Although there is growing evidence that working memory and MW are related (e.g., Mrazek et al., 2012), their precise relationship is still poorly understood, thus limiting our ability to offer solutions for minimizing errors that may be driven by internally-generated distraction. One prominent model of MW, referred to as the *executive-resource account* (Smallwood & Schooler, 2006; see also Thomson, Smilek, & Besner, 2014), proposes that MW may compete with working memory processing demands for a limited pool of executive resources (Kam & Handy, 2014; Smallwood, Nind, & O'Connor, 2009; Teasdale et al., 1995).

A prediction of the executive-resource account is that the likelihood of MW's occurrence will be tied to the resource requirements of the primary task at hand (Smallwood, McSpadden, & Schooler, 2007; Smallwood & Schooler, 2006). Support for this prediction comes from studies, such as Smallwood et al. (2009), in which less MW was reported by participants during a working memory task versus a choice reaction time task, two tasks differing in the amount of executive resources devoted to working memory processes. The working memory task required executive resources to be used in the service of encoding memoranda, as well as maintaining and updating information over short intervals, while the choice reaction time task did not (see also Smallwood & Schooler, 2015). In a related study by Forster and Lavie (2009), in which the level of demand was manipulated by varying perceptual load in a visual search task, greater MW was reported during low vs. high demand conditions. Thus, when resource requirements for the primary task are high, MW may be reduced (see also Giambra, 1995; Smallwood, Obonsawin, & Heim, 2003; Smallwood, Obonsawin, & Reid, 2002).

However, a task's resource requirements may change with practice and greater time on task. With more practice time comes more experience, leading some tasks to become automated. When this occurs, the reliance on executive resources may diminish, increasing the available pool of resources to engage in MW. For example, a verbal

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encoding task that may be highly demanding when first encountered could become less demanding as it becomes familiar and automated. In task contexts in which such automation occurs, MW has been shown to increase with greater time on task (e.g., Smallwood et al., 2003; Mason et al., 2007). As such, when tasks require fewer executive resources for successful task performance, either due to low demand or practice-related automation, remaining resources may be commandeered by MW.

Yet, not all tasks are amenable to practice-related automation. As Smallwood et al. (2002) found, attention-demanding tasks fail to demonstrate improvements with greater time on task. In their study, MW was probed while participants performed a verbal fluency task, in which both task performance and self-reported MW remained stable despite block length. Furthermore, in continuous performance tasks emphasizing sustained attention, performance has been found to wane over time, a pattern referred to as the vigilance decrement phenomenon (see Mackworth, 1948). One prominent theoretical explanation for vigilance decrement is the *resource-depletion hypothesis*, in which greater time on task is proposed to deplete a limited pool of executive resources, resulting in fewer resources available to successfully perform the task (Caggiano & Parasuraman, 2004).

Recently, Thomson, Besner, and Smilek (2015) suggested that MW may play a role in vigilance decrements. According to their *resource-control account*, motivational factors may lead to a reduction in task engagement over time, causing executive resources to shift away from the task at hand toward MW. In line with this view, studies that used vigilance tasks in which MW was indexed, report that performance decreases and MW increases with greater time on task (Thomson, Seli, Besner, & Smilek, 2014; McVay & Kane, 2012; Cunningham, Scerbo, & Freeman, 2000). Prior studies have found that the rate of performance decline over time is greater in tasks with high vs. low demand (Helton & Russell, 2011; Smit, Eling, & Coenen, 2004). Thomson et al. (2015) hypothesized that if these decrements are driven by task disengagement in the service of MW, there should be greater MW over time for high vs. low demand tasks. Testing this hypothesis would require an experimental paradigm in which: (1) executive demands are varied over trials so that the effects of high vs. low demand on performance and MW can be evaluated; (2) MW is probed at regular intervals over the course of the experiment; and (3) performance degradation is observed with greater time-on task (i.e. vigilance decrement).

Motivated by Thomson et al. (2015), the current study employed a paradigm to satisfy all three of these requirements, in order to investigate this hypothesis in the context of a visual working memory task. Here, we assessed participant performance during a delayed-recognition visual working memory task, in which demand was manipulated by varying mnemonic load and MW was probed throughout the experiment. Although prior studies have investigated MW during complex span tasks of WM (Mrazek et al., 2012), we used a visual delayed-recognition task to understand maintenance-related processes for visual information over short intervals (Ranganath, DeGutis, & D'Esposito, 2004; Luck & Vogel, 2013; Fuster & Bressler, 2012; D'esposito & Postle, 2015; see Cowan (2016) for review); this is in contrast to working memory span tasks, which have multiple demand-sensitive task components tied to verbal information (e.g., maintenance, task-switching, retrieval). Our manipulation of mnemonic demand, on the other hand, could be better constrained to maintenance processes, allowing us to examine the influence of time on task and MW on working memory. Our key question of interest was to determine if working memory task performance and MW fluctuate with greater time on task in a demand-sensitive manner. To answer this question, task performance and MW data were analyzed using hierarchical linear modeling (HLM; Raudenbush & Bryk, 2002).

2. Methods

2.1. Participants

Undergraduate students ($N = 143$, females = 88, $M_{age} = 19.09$, $SD_{age} = 1.37$) were recruited from the University of Miami psychology subject pool. Participants received course credit for their participation. All participants provided informed consent in accordance with the Institutional Review Board of the University of Miami.

Before beginning the working memory delayed-recognition task (described below), participants were instructed to emphasize the accuracy of their response over speed. Participants first received instructions for the working memory task and completed a practice session of 10 trials. Following this practice, participants received instructions about the MW probes and concrete examples of each question. Participants then practiced 10 trials of the working memory task with thought probes, as described below.

2.2. Procedure

To measure working memory across 2 levels of cognitive load, we used a modified version of the delayed-recognition task from Jha and Kiyonaga (2010). All presented stimuli were displayed as grayscale images, centrally located on the computer screen on a gray background. Each trial began with the presentation of a memory array, consisting of either two faces (high mnemonic load) or one face and a noise mask (low mnemonic load), appearing side by side for 3000 ms. The memory item was followed by a 3500 ms delay period with a fixation cross, after which a test item was presented centrally for 2500 ms (depicted in Fig. 1).

Two levels of load were selected (low vs. high) based on results of prior studies (Jha, Fabian, & Aguirre, 2004; Jha & McCarthy, 2000), which indicated that participants' performance was significantly better for 1 face vs. 2 faces; and performance was at near-chance levels when participants were required to remember 3 faces. In addition, past studies have found larger differences in activation in prefrontal regions between one vs. two faces, but not two vs. three faces (Jha & McCarthy, 2000). Stimuli were presented using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2001).

The inter-trial interval was 500 ms, for a total of 9500 ms per trial. For half of the trials, the test item was a single face from the memory item array (match trials), and on the remaining trials, the test item was a novel face that had not previously appeared in the experiment (non-match trials). Stimuli were randomized prior to the experiment but appeared in the same order for all participants. Participants were instructed to determine whether a test item matched a face in the memory item array by pressing match or non-match designated buttons. They were again instructed to emphasize the accuracy of their response over speed. The experiment included an equal number of trials for each level of mnemonic load (low or high) with a total of 102 memory item trials. Item trials were divided into three equally sized blocks of 34 trials each with three self-timed breaks. Accuracy was calculated based on correct responses to the match and non-match trials. Failures to respond were coded as incorrect.

MW was assessed using probe questions presented throughout the task. There were 47 instances of thought probes throughout this experiment, with 15–17 MW probes in each of the three blocks. The thought probes, which were counterbalanced to follow an approximately equal number of high and low load trials, were presented after the test item during the inter-trial-interval. Probes were dispersed pseudo-randomly throughout the task and occurred after every 1–4 working memory trials. There were four questions presented one at a time as part of the probe, but only the first question ("Where was your attention focused on average during the last trial?") was used to probe MW and is considered herein. The response to this question was presented on a 6-point likert scale with 1 as indicating being 'on-task' to 6