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Following the Wandering Mind in the Eyes: Tracking Distraction by the Self in a Complex Working Memory Task

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Introduction

Do you recognize the experience of being distracted by your own thoughts? Your answer is very likely to be 'yes'. Indeed, a self-report study by Killingsworth and Gilbert (2010) has shown that people spent on average half of their daily activities on thought processes that distract them from their current task. This phenomenon is commonly known as *mind-wandering* and refers to a process of self-generated thought, uncoupled from the external (task) environment (e.g. Smallwood & Schooler, 2015). Although prominent in our lives, cognitive scientists have long ignored it as a subject of study. Until recently, mind-wandering was viewed as a contamination of data and has only been considered as noise in cognitive models (see Vandekerckhove & Tuerlinckx, 2007). This negative view, however, is not entirely ungrounded. According to Smallwood (2015), there are three core challenges that complicate investigating mind-wandering. First of all, it is difficult to experimentally induce due to its, oftentimes, spontaneous occurrence. Moreover, when you do have a working manipulation, the occurrence of mind-wandering is hard to track as it produces little observable overt behavior. Lastly, because it is difficult to measure, self-report is oftentimes resorted to as the only 'valid' measuring technique. However, with mental states such as mind-wandering, there is always a risk that the introspection involved in self-report changes it as well, effectively reducing the validity of this introspection measure (Schooler, 2002). From these three core challenges, we conclude that there is demand for valid experimental manipulations to induce mind-wandering, and for objective measures to capture it. In this paper, we introduce a novel experimental method to track mind-wandering, which can help to validate the specific predictions of a PRIMs model of this process.

Related work

A recent study that tackled the aforementioned issues comes from Daamen, van Vugt, and Taatgen (in press). In this study, an adapted version of a verbal complex working memory (CWM) task was designed to measure and induce mind-wandering. Although many variations of CWM tasks exist, all share the key characteristic that a to-be-remembered item (e.g., a letter) is interleaved by a processing task (e.g., is 'BLICK' a word yes/no) that makes it harder to memorize the items. What is interesting about this study is that a novel manipulation for mind-wandering was introduced: a self-referential processing (SRP) task. SRP refers to a process of thinking about the self (Rogers, Kuiper, & Kirker, 1999) and was induced by asking the participant to judge if a presented trait adjective described themselves yes or no. Alongside the SRP condition, a control condition was used in which participants had to decide whether a presented object word fitted in a shoebox. The results of this study showed a decline in performance for the SRP condition compared to the shoebox condition, possibly reflecting that mind-wandering caused by self-referential processing interfered with rehearsal of the items. This idea was formalized in a cognitive model using the primitive elements model of skill (PRIMs; Taatgen, 2013), which is a symbolic architecture like ACT-R, but is unique in the fact that it supports having multiple competing goals. A key characteristic of the proposed model is that during the processing phase, there is a chance for trait information to remain in working memory where it can initiate productions, or recruit operators in PRIMs terms, that trigger elaborating thoughts on the traits. These 'distraction' operators are modeled to compete with task goal operators to rehearse the items, hence mind-wandering is caused by distraction operators winning the competition. Results showed that the model accounted well for the behavioral data, suggesting that elaborating thoughts on the traits (i.e., mind-wandering) likely interfered with rehearsal and therefore resulted in reduced performance.

The study of Daamen et al. (in press) proposed an interesting and novel way to manipulate and measure the occurrence of mind-wandering. However, there are still some important open issues. First of all, it was only measured indirectly, leaving the question whether the decline in performance in the SRP condition was really due to mind-wandering. Furthermore, although the rehearsal interference mechanism of the model explained the behavioral results well, there was no empirical data to support this mechanism. Therefore, in order for SRP to be confirmed as an objective manipulation for mind-wandering, research is needed to examine if rehearsal interference is an occurring mechanism. Moreover, valid direct measures of mind-wandering need to be identified to follow the occurrence of it across conditions.

Research aims and approach

In the present study, we aim to provide more insight in how mind-wandering can be measured in an objective way.

Specifically, we will attempt to track rehearsal in a CWM task similar to the one employed by Daamen et al. (in press). We test the model prediction that as participants mind-wander, rehearsal will be absent.

Study approach

Behavioral To be able to track rehearsal, we will examine eye movements in a spatial variant of the CWM task. In this task, participants have to memorize the locations of targets (an 'X') in a 4x4 matrix interleaved with a processing sub-task. On every trial, a storage target will be presented first for 1 second. This allows participants to encode the targets' position and to perform rehearsal. Thereafter, a 4 seconds self-paced processing phase will start. Similar to the study of Daamen et al. (in press), this phase will include a SRP and shoebox condition, with the main difference being that the processing words will be presented on the same matrix as the targets. The locations of the words will be random and change every second from position to ensure interference with rehearsal during the processing task itself (thereby restricting it to the 2-s blank periods immediately after the processing phase, which is the rehearsal period according to our model).

The storage phase, processing phase, and blank will be repeated a number of times equal to the span (three and four in this experiment). Thereafter the trial ends with a prompt to recall the storage target locations in the order of presentation.

Thought probes This study will also use thought probes, which are self-report questions aimed at assessing current thought content at various moments in the task. The thought probes will be presented at equally but randomly distributed moments throughout the experiment (48 in total, 9 every block). Although we mentioned that self-report has issues regarding validity, we have chosen to include them alongside eye movement and pupil size, to have a second measure of mind-wandering as control (see section *Eye Tracking* below). Combining both self-report and physiological measures will allow us to give an account on mind-wandering without being tied to one measuring technique.

In this study, we will use an adapted version of the probe question used by Unsworth and Robison (2016). The question is, 'What were you thinking about before you were prompted to answer?', with the following response options: (1) I tried to remember the location of the X's'; (2) I was still thinking about the words from the decision task; (3) I was evaluating aspects of the task (e.g. my performance, how long it takes, difficulty task), (4) I was distracted by my environment (sound/ temperature etc.) or by my physical state (hungry/thirsty); (5) I was daydreaming/ I thought about task-unrelated things, (6) I wasn't paying attention, but I didn't think about anything specifically. Response options 2 to 6 will be counted as attentional lapses, with options 2 and 5 as indicators of mind-wandering.

Eye Tracking The main advantage of using a spatial version of the CWM task is that rehearsal is shown in overt behavior. Memory researchers have found that rehearsal of spatial locations is accompanied with eye movements to these locations (see e.g. Logie, 1995), and that the eye movements can be measured with an eye tracker (Tremblay, Saint-Aubin, & Jalbert, 2006). In this study, eye movements in accordance with the location of previous target locations would be indicative of an active effort to rehearse the target locations from memory. On the other hand, random or absent eye movements would imply that rehearsal is not performed, but that other, possibly goal-irrelevant, processes interfere with rehearsal. Mind-wandering can also be inferred from patterns in the pupil dilation (PD), which is claimed to reflect changes in the attentional state through an indirect link with the norepinephrine system of the locus coeruleus (LC-NE; see e.g, Aston-Jones & Cohen, 2005). Research from e.g. Unsworth and Robison (2016) has indicated that off-task thinking is correlated with low pre-stimulus baseline PD, reflecting a state of relative low arousal and alertness. Moreover, evoked increase in PD due to stimulus processing was found to be lower, further supporting this claim. In this study, we therefore expect that the baseline PD during blanks will be lower on SRP trials and that evoked PD will also be lower during storage. Novel in this study will be that such patterns in PD will be used to predict if participants reported either being on-task (option 1 on thought probe) or off-task (options 2-6).

Conclusion

We have previously shown that a SRP manipulation can impair performance on a CWM task. We have modeled this effect as arising from mind-wandering instigated by the SRP words, which prevents rehearsal. Here we presented a method to test this model by tracking participants' eye movements and pupil size during a spatial analogue of Daamen's CWM task. When successful, this allows us to track mind-wandering by following the eyes.

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