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## Differential recruitment of executive resources during mind wandering

Julia W.Y. Kam<sup>\*</sup>, Todd C. Handy

Department of Psychology, University of British Columbia, Canada

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### ABSTRACT

Recent research has shown that mind wandering recruits executive resources away from the external task towards inner thoughts. No studies however have determined whether executive functions are drawn away in a unitary manner during mind wandering episodes, or whether there is variation in specific functions impacted. Accordingly, we examined whether mind wandering differentially modulates three core executive functions—response inhibition, updating of working memory, and mental set shifting. In three experiments, participants performed one of these three executive function tasks and reported their attentional state as either on-task or mind wandering at random intervals. We found that mind wandering led to poorer performance in the response inhibition and working memory tasks, but not the set-shifting task. These findings suggest that mind wandering does not recruit executive functions in a monolithic manner. Rather, it appears to selectively engage certain executive functions, which may reflect the adaptive maintenance of ongoing task performance.

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### 1. Introduction

Whether fantasizing about vacation plans, worrying about an upcoming exam, or reliving an unforgettable event, we often find ourselves engaged intensely in our own thoughts. This common experience, mind wandering, has been closely tied to our transient emotional states and daily functioning. Importantly, research has begun to reveal its widespread impact on the neurocognitive processing of external events. In addition to attenuated sensory and cognitive processing (Braboszcz & Delorme, 2011; Kam et al., 2011; O'Connell et al., 2009; Smallwood, Beach, Schooler, & Handy, 2008), mind wandering has also been associated with disrupted attentional orienting (Kam, Dao, Stanculescu, Tildesley, & Handy, 2013) and performance monitoring (Kam et al., 2012). Given the wide range of attenuation in sensory-motor responses, does mind wandering also impair the higher-order processing of stimulus inputs, and in particular, the allocation of executive resources to the given task at hand?

Aligning with this possibility, it has been proposed that when we mind wander, executive resources are drawn away from the ongoing task to facilitate inner trains of thought (see Smallwood & Schooler, 2006 for a review). This is consistent with the observation that internally-generated thoughts recruit the same domain-specific processes as stimulus in the external world (e.g. Schooler et al., 2011; Smallwood, 2013; Smallwood & Schooler, 2006). Similarly, visual imagery (e.g., Kosslyn, Thompson, & Alpert, 1997) and auditory imagery (e.g., Zatorre & Halpern, 2005) have been shown to activate many

<sup>\*</sup> Corresponding author. Address: Department of Psychology, 2136 West Mall, Vancouver, B.C. V6T 1Z4, Canada.  
 E-mail address: [kamjulia@gmail.com](mailto:kamjulia@gmail.com) (J.W.Y. Kam).

domain-specific regions of cortex that are also activated during interactions with the outside world. To the extent that task-unrelated thoughts parallel mental imagery, then both lines of evidence indicate that externally and internally guided thoughts can engage similar processes. Therefore, if executive resources are critical to maintaining internal thoughts, then these resources become unavailable for processing external stimuli during periods of mind wandering.

Direct evidence in support for the executive function model of mind wandering comes from both behavioral and neuro-imaging findings. For example, executive processing as indexed by performance on a random number generation task was disrupted during task-independent thoughts (Teasdale et al., 1995), suggesting that mind wandering can recruit executive resources that would normally be devoted to the external task. Moreover, mind wandering has been shown to recruit not only the brain's default mode network (DMN; Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Kirschner, Kam, Handy, & Ward, 2012; Mason et al., 2007), but also the executive network as well (e.g., Christoff, 2012; Christoff et al., 2009). These findings indicate that the facilitation of task-unrelated thoughts does indeed require executive functions.

Support for the executive function model notwithstanding, the term “executive functions” in previous studies of mind wandering has been defined loosely, and it is unclear which facet of executive functions are specifically recruited during mind wandering. To wit, executive functions are higher-level cognitive functions that regulate other thought and behavioral processes (e.g. Alvarez & Emory, 2006; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). In particular, they are considered “general purpose control mechanisms that modulate the operation of various cognitive subprocesses and thereby regulate the dynamics of human cognition” (Miyake et al., 2000, p. 50). According to the model by Miyake and colleagues (2000), the three commonly postulated executive functions, inhibition of prepotent responses, updating of working memory representations, and mental set-shifting, show some underlying commonality but are clearly distinct constructs.

Specifically, prepotent response inhibition concerns the deliberate inhibition of a dominant or automatic response (e.g. Blasi et al., 2006; Mostofsky & Simmonds, 2008; Vendrell et al., 1995), and is considered to be the hallmark of executive control (e.g. Aron, 2007; Logan, 1994). This function has been examined beyond the experimental context and linked to performance-based measures of daily functioning (Vaughan & Giovanello, 2010). In contrast, information updating pertains to monitoring and evaluating the relevance of current stimulus inputs. It requires the active manipulation of content in working memory to ensure that task-relevant information is enhanced while irrelevant inputs are suppressed (e.g. Baddeley, 1986; Cohen et al., 1997; D'esposito et al., 1995; Morris & Jones, 1990; Smith & Jonides, 1997). This executive function is closely related to working memory capacity, which has been shown to predict performance in laboratory-based and real-world cognitive tasks (e.g. Engle, 2002; Kane et al., 2007; McVay & Kane, 2009). Finally, mental set-shifting refers to the ability to shift from one task or operation to another (e.g. Monsell, 2003; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001). Evidence suggests this involves overcoming active interference, especially when the new task relies on previously used stimuli (e.g. Allport & Wylie, 2000; Gilbert & Shallice, 2002). This cognitive flexibility to efficiently switch between tasks or mental sets is considered to play a critical role in cognitive control (e.g. Monsell, 1996, 2003).

Given this understanding, the current study examined whether mind wandering engages all these executive functions in a unitary or monolithic manner, or whether there can be a dissociation in which specific executive functions are actually engaged during a mind wandering episode. In three separate experiments, participants performed one of three tasks that required response inhibition, information updating or set-shifting. At frequent and random intervals throughout the task, participants reported their attentional state at that moment as on-task or mind wandering. We then examined behavioral performance as a function of whether it immediately preceded an on-task or mind wandering report. If mind wandering does differentially recruit *specific* executive resources, and if these resources are presumably finite in that they cannot be utilized to facilitate both mind wandering and task performance simultaneously, then tasks requiring deployment of these *specific* executive functions should be disrupted during mind wandering.

## 2. Experiment 1

The first experiment examined the extent to which mind wandering impairs response inhibition. To address this question, participants performed the Stroop task (Jensen & Rohwer, 1966; Macleod, 1991; MacLeod & MacDonald, 2000; Stroop, 1935), in which they responded to the ink color that word stimuli were presented in, and reported their attentional states frequently throughout the task. The words in this task were one of three colors, and were printed in one of those three colors. Given that we tend to automatically respond to the meaning of the word (e.g. red), when that particular word is presented in blue ink, we have to inhibit our dominant response of red, and accurately report it as blue instead. Previous studies have found significantly slower reaction time to trials in which words were incongruent with the ink color they were presented in compared to congruent or neutral trials (e.g. Ilan & Polich, 1999; van Maanen, van Rijn, & Borst, 2009). We hypothesized that mind wandering relative to on-task states would further slow down reaction time to incongruent trials.

### 2.1. Methods

#### 2.1.1. Participants

46 undergraduate students participated in the experiment in exchange for extra course credits, however six were excluded due to insufficient reports of a particular attention state (<15%), and three were excluded due to technical errors. In the end, of the 37 participants included in our analyses (28 females; mean age = 19.75 years, *S.D.* = 2.83), 31 were right

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