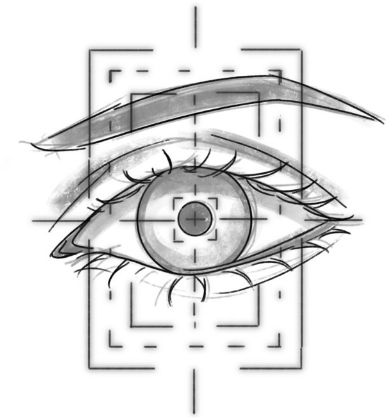

The Effects of Mindfulness on Mind Wandering: An Eye-Tracking Study

Aleksandrs Baskakovs

Aarhus University

Department of Linguistics, Cognitive Science and Semiotics

Otto Sejrskild Santesson

Aarhus University

Department of Linguistics, Cognitive Science and Semiotics

Abstract

Mind wandering is a pervasive phenomenon, accounting for as much as 50% of the total waking lifespan. While not necessarily harmful, in a context where one engages in an attentionally demanding task, mind wandering can be costly. Preliminary studies have shown that mindfulness can reduce the number of mind wandering episodes. There is less evidence, however, for how mindfulness affects mind wandering episodes themselves. This is mostly due to mind wandering being treated as a dichotomy: either attention is decoupled from the external environment or it is not. In this study, we use eye-tracking to pilot a method for investigating mind wandering in a continuous, rather than binary, manner. Subsequently, we measure how mindfulness affects the intensity of mind wandering episodes. Six university students completed a reading task and had to report whether they were mind-wandering every time a probe popped up. Prior to the task, participants in the mindfulness group had to go through a 10-minute audio-based guided meditation. Eye-tracking was used to analyze 10 seconds of eye movements prior to when participants indicated that they were mind wandering. It was found that eye movement behaviours typical for mind wandering episodes (prolonged fixation duration and decreased fixation count) were generally lesser for mind wandering episodes of participants in the mindfulness condition compared to the control condition.

Keywords: **mind wandering, mindfulness, eye tracking.**

Introduction

Mind wandering

Prevalence and status quo of the field

Mind wandering is the ubiquitous phenomenon of when the attention drifts from the task at hand to other unrelated trains of thought (Christoff, 2012; Smallwood & Schooler, 2015). The contents of mind wandering can vary from fantasizing about winning the lottery to deliberate planning about future events, such as thinking about what to make for dinner (Barnett & Kaufman, 2020; Mooneyham & Schooler, 2013). Other typical examples of mind wandering include walking into a room and forgetting why you went there, thinking about family-related manners while driving to work, or reading a paragraph of text and then realizing that none of the read text had been meaningfully processed. The prevalence of mind wandering is so pronounced, that 96% of American adults experience mind wandering on a daily basis (Singer & McCraven, 1961), further underscored by the estimate of mind wandering occupying up to 50% of the contents of the awake mind (Barnett & Kaufman, 2020; Killingsworth & Gilbert, 2010; Klinger, 2009; Klinger & Cox, 1987; McMillan et al., 2013). It is therefore perplexing that it is only in the past decade that mind wandering has gained significant traction as a topic of study within the academic community (Smallwood & Schooler, 2006, 2015). A viable explanation to this might be that it is due to the reverberations from the behaviourist era of cognitive research, which had a pronounced skepticism directed toward the study of the inner workings of the mind, the scientific community has been more tentative toward studying mind wandering (Callard et al., 2012; Smallwood & Schooler, 2015).

Another challenge that the field faces is similar to the one of creativity, which has faced problems with incoherent terminology: there are a plethora of different terms for the same cognitive phenomenon (Barnett & Kaufman, 2020). A multitude of the words are synonyms of each other while some of the terms slightly differ from each other in their definitions. The terminology has such a lack of consistency that a multitude of researchers have in their article included an extensive nomenclature of the different terms used within the field (e.g., Christoff, 2012; Gruberger et al., 2011). This variability is showcased by the following, non-exhaustive list of terms that have been used in lieu of "mind wandering": "daydreaming, spontaneous thought, fantasy, zoning out, thought intrusions, task-irrelevant thoughts, perceptual decoupling, stimulus-independent thought, unconscious thought, internally generated thoughts, offline thought, incidental self-processing, undirected thought, and self-generated thought" (Barnett & Kaufman, 2020, p. 6). To address this complication, Barnett and Kaufman (2020) propose "mind wandering" to be the preferred term in onward research to build common phraseology within the field and to facilitate "current researchers to connect their work with the work of scholars who trod similar paths before them" (McMillan et al., 2013, p. 1). As a continuation, they proceed to posit that the two most essential components of mind wandering are intentionality (whether the mind wandering is deliberate or spontaneous) and plausibility (how close the contents of the mind wandering episode are to reality)" (Barnett & Kaufman, 2020, p. 7). However, multiple authors more so emphasize the stimulus-dependence aspect of mind wandering (Christoff, 2012; Mason et al., 2007; Smallwood & Schooler, 2015). Stimulus-independent thought (SIT) is the term used when the internal mental contents occur with little to no relation to external events. In other words, it is when the train of thought is decoupled from current sensory information (known as perceptual decoupling) (Antrobus, 1968; Christoff, 2012; Schooler et al., 2011; Teasdale et al., 1993). Conversely, stimulus-dependent thought (also referred to as stimulus-oriented thought) "reflects attention towards the current external sensory environment" (Christoff, 2012, p. 53).

There are other proposals on how the taxonomy of mind wandering should be structured (e.g., Smallwood & Schooler, 2015), but a full assessment of the different taxonomy used within the field is beyond the scope of this paper—the above delineation was simply to outline the status quo of mind wandering and the difficulties that the field faces. For the remainder of this paper, in alignment with the abovementioned proposal by Barnett and Kaufman, the term "mind wandering" will be employed when referring to the mental phenomenon of when one's thoughts and attention shift away from the task at hand.

The behavioural and neurocognitive response to mind wandering

Due to mind wandering being such a common mental occurrence, it has been an incentive for researchers to investigate the width and depth of how both behavioural and neurocognitive measures are affected. In their study investigating mind wandering's influence on general aptitude, Mrazek and colleagues (2012) found working memory capacity (WMC, measured with complex span tasks) and the reported amount of mind wandering episodes to be significantly negatively correlated, a relationship which since has been replicated numerous times (McVay & Kane, 2012; Robison & Unsworth, 2018). In addition, they found that measures of gF (fluid intelligence, measured using Raven's Progressive Matrices [RPM]) were significantly negatively correlated with mind wandering. Both of these measures were found to be correlated with the participants'

SAT (Scholastic Aptitude Test) scores. By employing structural equation modelling based on the measures of general aptitude and mind wandering occurrences, they extracted two latent variables: one denoting mind wandering episodes during the WMC and gF tasks and the other denoting general aptitude based on these two measures, along with SAT scores. The latent variable of mind wandering was found to explain 49% of the variance in the latent variable of general aptitude. By extrapolating these results, it is plausible that mind wandering would be correlated with deficits in cognitive performance in other areas, contingent on the predictive power that the aforementioned measures of general aptitude have on performance in a wide variety of contexts (Conway et al., 2008; Deary et al., 2007; Frey & Detterman, 2004; Kane et al., 2005; Rohde & Thompson, 2007; Schmitt et al., 2009; te Nijenhuis et al., 2007). This proposition is in line with mind wandering being linked to reduced reading performance and comprehension (McVay & Kane, 2012; Reichle et al., 2010; Smallwood, McSpadden, et al., 2008), reduction of retention of new information in academic settings (Seli, Wammes, et al., 2016; Smallwood et al., 2007), and reduced driving performance, including increased risk of causing traffic accidents (Galera et al., 2012; Yanko & Spalek, 2014) and medical malpractice (Smallwood et al., 2011).

A possible account of the interrelation between mind wandering and diminution in cognitive performance is that problem-solving and working memory involve recruitment of executive resources (Alvarez & Emory, 2006), which is also the case for mind wandering (Smallwood & Schooler, 2006). Mind wandering therefore competes with the task at hand, such as a lecture or a complex span task, for the coordination and control of working memory resources, which can result in performance impairment (Kane et al., 2007; Mrazek, Smallwood, Franklin, et al., 2012; Smallwood & Schooler, 2006). The prioritization of allocating cognitive resources on either the task at hand or mind wandering rely on a number of different factors, such as the incentive for attending the task at hand (e.g., if an individual is not motivated to attend a lecture, they are more likely to move their attention to task-unrelated thoughts that are more aligned with their goals) (Seli, Wammes, et al., 2016; Smallwood et al., 2007) or the demands of the task at hand (e.g., a proficient driver is more likely to switch their attention to unrelated thoughts, such as planning what to make for dinner, than to attend the undemanding task of driving the car) (Kane et al., 2007; Levinson et al., 2012; Mrazek, Smallwood, Franklin, et al., 2012; Smallwood & Schooler, 2006; Teasdale et al., 1995).

Multiple studies that have investigated the neurocognitive response to mind wandering have found evidence that the brain areas involved with mind wandering overlap with areas constituting the default mode network (DMN), a set of cortical regions where activity within is associated with the absence of a task or when the brain is "at rest" (Mason et al., 2007; Seli et al., 2016). Researchers have mapped the most prominent constituents of the DMN, which include the medial prefrontal cortex (medial PFC), the posterior cingulate/ precuneus region, and the temporoparietal junction (TPJ), and found strong evidence for neural activity in this network is associated with mind wandering episodes (Christoff et al., 2009a; Christoff, 2012; Fox et al., 2015; Mason et al., 2007; McKiernan et al., 2006; Raichle et al., 2001). Additionally, recruitment of the frontoparietal-control network, which comprises the dorsolateral PFC and the dorsal anterior cingulate (a network associated with executive control) (Schooler et al., 2011), has also been observed during mind wandering (Christoff et al., 2009a; Fox et al., 2015). This positive functional connectivity between these two networks "might represent a dynamic interplay whereby executive control regions guide, evaluate, and select among the various spontaneous streams of thoughts, memories, and imaginings offered up to consciousness by the DMN" (Fox et al., 2015, p. 617). Evidence from a brain imaging study has also showcased the negative functional connectivity between the DMN and the primary sensory cortices, which is an indication of the perceptual decoupling that coincides with mind wandering (Christoff, 2012; Schooler et al., 2011). This correlation is supported by results from a study conducted by Smallwood and colleagues (2008), where the amplitude of a late positive component of the event-related potential (ERP) (known as the P3), which is associated with task-relevant cortical processing, was found to be significantly reduced during mind wandering compared to on-task cognition. This trend was also present for both of the amplitudes of the visual P1 and auditory N1 ERP components, which are associated with sensory-level processing of visual and auditory information, respectively (Kam et al., 2011) (Figure 1).

The above findings of decreased neurocognitive response to external stimuli depict the cognitive mechanics behind mind wandering: When attention is shifted from the external sensory environment to internal trains of thought, due to an interplay between the DMN and executive function, it interferes with the online processing of sensory information. Exactly what role perceptual decoupling plays in mind wandering has yet to be assessed, although some speculations have been put forth: One possibility is that perceptual decoupling is necessary in terms of the generation and sustainment of mind wandering. According to this view, perceptual decoupling displays the "flexible reorganization of processes to facilitate a conscious focus on self-generated information" (Smallwood & Schooler, 2015, p. 501). Similar to when attention prioritizes one modality of sensory

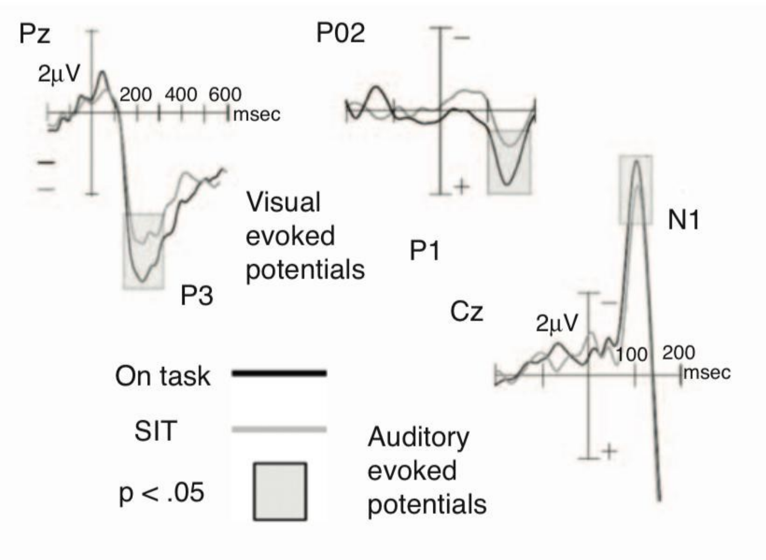

Figure 1. *Differences in task-evoked neural responses between SIT (stimulus-independent thought, i.e. mind wandering) and on-task cognition. EEG measurements exhibit lower amplitudes in the P3, P1, and N1 ERP components during mind wandering, indicating that the mental phenomenon tends to be decoupled from perceptual information from the external environment. Abbreviations: Cz, central midline electrode (according to the International 10–20 system for EEG recording, localized by the central region); Pz, posterior midline electrode (localized by the parietal lobe); PO2, posterior right lateral electrode (localized by the parietal -occipital lobe); SIT, stimulus-independent thought; EEG, electroencephalography; ERP, event-related potential. (Figure reprinted from Schooler et al., 2011).*

information over another to receive preferential processing (Posner & Petersen, 1990), perceptual decoupling may enable mind wandering by interfering with the processing of information unrelated to its contents (i.e., external sensory information). Another account is that perceptual decoupling is not a process whose main function is to insulate mind wandering from the external environment, but more so a corollary of the limited resources of the attentional system (Franklin et al., 2013; Smallwood & Schooler, 2015).

The neurocognitive activation profile of mind wandering is similar to the one of creative thinking, where the parallel recruitment of the DMN and executive brain regions is also present (Christoff, 2012; Kounios et al., 2006; Kounios et al., 2008; Subramaniam et al., 2009). This similarity illuminates one of the beneficial aspects of mind wandering, namely its relation to incubation, creative problem-solving, and ideation (Gable et al., 2019; Schooler et al., 2011). Evidence for this relationship was found through the meta-analysis conducted by Sio and Ormerod (2009), which showed that the creative benefits of incubation intervals are greatest when individuals are occupied by a non-demanding (and thus mind-wandering-inducing) task relative to either a demanding task or no task at all (Schooler et al., 2011). Another beneficial aspect of mind wandering is that since it is often occupied with autobiographical future thinking (D'Argembeau et al., 2011; Smallwood, Beach, et al., 2008), it is believed that this type of mental simulation can prepare the individual for different potential future outcomes, or in other words, plan ahead, thus functioning as a tool which is necessary to successfully navigate the complex social world" (Schooler et al., 2011, p. 321).

The case of mind wandering is therefore not simply something to be encapsulated as a purely detrimental phenomenon, but that it also comprises positive aspects. This is although the case for the majority of the research there has been on mind wandering: In their review of two decades of articles that addressed the costs and benefits of mind wandering, Mooneyham and Schooler (2013) found 30 papers that focused on the negative aspects of mind wandering whereas they only found 6 that addressed the possible benefits. One of the paradoxical features of mind wandering is that even though it poses some beneficial aspects, as outlined above, it is nevertheless detrimental to the goals of the moment, such as reading a book, completing a written assignment, or other tasks of everyday life. An important research question that has emanated from this conflict is whether it is possible to retain the positive aspects of mind wandering while diminishing the negative ones—to be able to tune the attentional system in order to both have the ability to engage in imaginative simulation while concurrently curtailing the detrimental consequences of losing focus on the goals of the moment. Initial research on mindfulness has shown auspicious results indicating it could serve as an efficacious technique for ameliorating the negative impact mind wandering has on cognitive performance, both in terms of reading comprehension and working memory capacity (Jha et al., 2010; Mrazek et al., 2013).

Mindfulness

Mindfulness is the notion of a mental mode that is broadly defined as "receptive attention to and awareness of present events and experience" (Good et al., 2016, p. 116). The concept dates back several millennia and has its roots in Buddhist traditions, where conscious attention and awareness are actively cultivated through mindfulness practice, typically in the form of meditation (Schmidt, 2011). Being in a mindful state of cognitive processing is hallmarked by attending stimuli simply "as they are", meaning that it is involved with experiential processing as opposed to conceptual processing: "It does not compare, categorize, or evaluate, nor does it contemplate, introspect, reflect, or ruminate upon events or experiences based on memory" (Brown et al., 2007, p. 213; Good et al., 2016). Furthermore, it is being aware of thoughts as *thoughts,* without engaging in them, but simply being a neutral observer of the contents of one's own mind (Brown et al., 2007). Another key aspect imputed to mindfulness is its attentional flexibility, which is the ability to direct one's attention to different levels. In other words, using visual perception as an analogy, one can choose to hyperfocus on one object in a visual scenery, such as an individual leaf on a tree, thus centring one's attention on one of the lowest levels. With attentional flexibility, the spotlight focus of attention can be widened from focusing on the branch, to the whole tree, and on to the whole forest, thus adeptly shifting between the different levels or scopes of attention. In that way, by using attention more mindfully, one can cultivate a more meta-aware and neutral view of one's own thoughts and emotions, and analyze them from a distance without acting upon them (Brown et al., 2007; Good et al., 2016). This phenomenological account of increased attentional control is congruent with the findings of mindfulness practice being linked to betterment of attentional control in terms of reductions in habitual allocation of attention and attention to distracting information (Jha et al., 2007; Tang et al., 2007; Wadlinger & Isaacowitz, 2011; Zylowska et al., 2008). Neurocognitive measures of mindfulness are in accordance with this finding as brain imaging studies have shown activation in brain regions are associated with executive function, namely the PFC and the ACC, of which selective attention is a component process (Alvarez & Emory, 2006; Zeidan, 2015). Another area that seems to benefit from mindfulness practice is cognitive capacity, showcased by observed increments in measurements of WMC (Jha et al., 2010; Roeser et al., 2013) and gF (Gard et al., 2014; Tang et al., 2007) followed by meditation, which is hypothesized to be due to the augmentation of the attentional control induced by mindful practice (Good et al., 2016; see also Jha, 2002; Redick & Engle, 2006). Consequently, these findings substantiate the positive relationship between mindfulness and cognitive performance (Mrazek et al., 2013; Smallwood & Schooler, 2015), since measures of WMC and gF are positively correlated with performance in a variety of contexts, as mentioned previously, such as SAT score (Smallwood et al., 2007; Smallwood & Schooler, 2006).

By juxtaposing the above findings with the cognitive correlates of mind wandering, as outlined in the previous section, it is possible to draw out similarities between the two mental states, although in opposite directions: Mind wandering is negatively correlated with scores of WMC and gF along with general performance, while mindfulness is positively correlated with these same measures. This seeming polarity indicates that these are two opposing constructs; this is further highlighted by the robust findings of significant dampening of activity in the DMN for all levels of mindfulness (Brefczynski-Lewis et al., 2007; Brewer et al., 2011; Farb et al., 2007, 2010; Garrison et al., 2013; Grant et al., 2011; Pagnoni, 2012; Tang et al., 2009; Taylor et al., 2013; Zeidan et al., 2011) along with increased activity in brain regions involved in sensory processing (Brewer et al., 2011; Hasenkamp & Barsalou, 2012; Manna et al., 2010; Zeidan, 2015), since mind wandering is linked to increased activity in the DMN and perceptual decoupling (i.e. curtailed neural response to sensory information). There is therefore substantial evidence to warrant an inquiry into whether mindfulness practice is a viable option to ameliorate the detrimental effects of mind wandering. Such an investigation has already taken place: Mrazek and colleagues (2012) found that mindfulness training significantly decreased the amount of mind wandering episodes whereas Rahl and colleagues (2017) showed that mindfulness training had beneficial effects on behavioural measures of mind wandering performance outcomes, thus establishing "a causal relationship between the cultivation of mindfulness and subsequent reduction in mind wandering" (Mrazek, Smallwood, & Schooler, 2012, p. 446). To give an account of the neural mechanisms behind this causal relationship between mindfulness practice and mind wandering, Brewer and colleagues (2011) hypothesize that the dampening of the activity in the DMN induced by mindfulness is the basis of the observed mitigation of mind wandering, although future research is needed to directly test whether this is the case or not.

Gauging effects

The previous section suggests mindfulness practice is promising in ameliorating mind wandering. It is unclear, however, how great the effect of mindfulness is on the reduction of mind wandering.

It has been previously shown (Mrazek et al., 2013) that mindfulness can reduce the number of mind wandering episodes in healthy individuals. It should be noted that this study investigates the effect of mindfulness on the occurrence of mind wandering episodes, rather than the intensity or strength of these episodes.

Indeed, most mind wandering research deals with mind wandering in a binary nature: whether the participant is currently mind wandering or not.

A false dichotomy?

The mind is generally described as consisting of different cognitive processes organized at different hierarchical levels, from early perceptual-motor processes to abstract representations at higher levels (Gazzaniga, 2009). Mind wandering, however, is dominantly treated as a dichotomy.

> [T]he dichotomy-hypothesis proposes that different levels of cognitive processing are decoupled from external input in an all-or-none fashion: during task focus all hierarchical levels of cognitive processing are coupled to the external environment, but when the mind wanders this coupling breaks down at all levels. (Schad et al., 2012, p. 180)

The above quote is from an article by Schad et al. (2012), appropriately titled “Mind wanders weakly, mind wanders deeply”. The study addresses the problem of the dichotomy hypothesis and introduces a model of graded attentional decoupling, which predicts that cognitive processing of external input fails at different hierarchical levels. This leads to different degrees of attentional decoupling—from weak to deep—which is supported by the findings of the study.

An additional argument for the continuous nature of mind wandering can be drawn from the dampening effects mindfulness has on activity in the DMN; since activation of the DMN can be measured in a continuous matter, one could argue that this should be extended to measuring mind wandering on different levels, since the two have shown to be positively correlated (Brewer et al., 2011; Raichle et al., 2001).

Furthermore, the continuous nature of mind wandering has been showcased in a tDCS study by Filmer et al. (2019). The effect of stimulation polarity and the intensity on mind wandering was investigated, where mind wandering was assessed via a probe asking "To what extent have you experienced task-unrelated thoughts prior to the probe? 1 (minimal) - 4 (maximal)" (Filmer et al., 2019). Indeed, it was found that increments in tDCS intensity led to linear increases in the reported extent of experienced mind wandering.

The prevalence of the dichotomy-hypothesis within the field of mind wandering can be attributed to the most commonly used method used for detecting mind wandering episodes, namely probes appearing during tasks with a dichotomous "Yes/No" answer option (e.g., Levinson et al., 2012; Uzzaman & Joordens, 2011).

Self-reports

The most widely used method for collecting mind-wandering data is the so-called *probe-caught* method, which involves sampling the participants for whether their focus is currently on- or off-task at random intervals during the task.

Whilst an inherently subjective measure, the probe-caught method has been shown to correlate with objective methods of mind wandering detection: performance measures such as reaction times (Cheyne et al., 2006), text comprehension (Smallwood, McSpadden, et al., 2008), memory (Risko et al., 2012) and physiological measures such as eye movements (Reichle et al., 2010; Smilek et al., 2010).

The probe itself often consists of a simple binary question on whether the subject's attention is currently directed or not directed toward the task. In some cases, binary response is replaced with a scale (e.g., a 5-point Likert scale, see Mrazek, Smallwood, & Schooler, 2012). Even more rarely do the measurements include participants' reports of the contents of their thoughts at the time of the probe (Klinger, 1984).

Another approach is the *self-caught* method, which is based on participants indicating, at any moment during the execution of the task, whether their attention has shifted (Giambra, 1989). The advantage of this method over the probe-caught method is that there can be an unlimited number of reports, as the reports are not limited by probe placement. However, this type of reporting requires the participants to be aware of their internal state, which is also referred to as meta-awareness (Schooler, 2002), which people often fail to achieve. This lack of self-awareness of mind wandering episodes is thought to be caused by mind wandering recruiting the brain regions that are necessary in order to notice its occurrence (Schooler et al., 2011).

Utilizing self-reports is a necessary measure required to detect mind wandering episodes. But it is only that—a measure for detection. In order to escape the dichotomy problem, self-report methods should be enriched with other sources of data (Hawkins et al., 2015). These would include posture (Seli et al., 2014), reading speed (Kopp et al., 2015), brain activity (Christoff et al., 2009), eye movements (Foulsham et al., 2013a), eye blinks (Frank et al., 2015), and pupil diameter (Franklin, Broadway, et al., 2013).

As seen above, in addition to industry-established *self-caught* and *probe-caught* techniques, mind wandering can be confidently detected using multiple ocular metrics, which speaks to the reliability and robustness of utilizing eye-tracking. Indeed, multiple studies (Bixler & D'Mello, 2014; Schad et al., 2012; Uzzaman & Joordens, 2011), since the mainstream introduction of the method by Reichle and colleagues (2010), have used eye-tracking to investigate mind wandering episodes. Considering the reliability of both methods, this study relies on both *reports by participants* and *eye-tracking metrics* to examine the effect mindfulness has on mind wandering.

Dissecting mind wandering using eye movements

The confidence in the ability to measure mind wandering using eye-tracking stems from decades of research on how eye movements are modulated by attention (Corbetta et al., 1998). What is specifically useful in the case of mind wandering detection, is that whenever attention shifts from an external stimulus (e.g., a text) to an internal stimulus (e.g., a thought), the change is reflected by overt embodied components whereby external input is blocked at the sensory level—the movement of the eyes (Just & Carpenter, 1980).

One of the theorized functions of eye blinks is to modulate the trade-offs between attention to mind wandering thoughts and to external, task-related stimuli. This trade-off is achieved physically by the closing of the eyelids and through the suppression of neural activity of visual processing before and after the actual lid closure (Smilek et al., 2010).

It has been shown that eye movements during reading exhibit a consistent pattern, which is impacted by lexical features such as word length and word frequency (Rayner, 1998). In an episode of mind wandering, the regularity of eye movements breaks down, and people tend to, for example, focus on low-frequency words for a shorter time span and vice-versa, indicating inadequate processing of the text, or "mindless reading" (Schad et al., 2012). Such propensity can be related to perceptual decoupling, since the decrement of time spent fixated on the infrequent words indicates that the attentional resources are being allocated to other processes unrelated to the external stimuli, i.e., mind wandering.

Whilst utilization of such non-standard variables has been productive for studying the ocular-motoric nature of lexical processing, standard variables of eye gaze, such as fixation duration and fixation count, have been shown to be differentiable between episodes of mind wandering and reading. People tend to have fewer and longer fixations during mind wandering episodes, indicating the state of being "zoned-out" and thus being interrupted from in-depth text comprehension (Reichle et al., 1998, 2010; Uzzaman & Joordens, 2011).

The field of mind wandering research has been dominantly fixed on viewing mind wandering categorically. As showcased in the previous sections, recent literature has justifiably argued for a more continuous look at mind wandering. Eye-tracking is perfectly suited to do that in an ecologically valid setting, as opposed to fMRI scans, where the participant is confined to complete the experiment in a noisy and poky setting. The employment of eye-tracking allows us to dissect mind wandering episodes moment-to-moment and compare one mind wandering episode to another one. Thus, it is possible to shed light on the question of how great the effect of mindfulness is on mind wandering.

Present study

This pilot study leverages previous insights from eye-tracking studies investigating mind wandering to 1) investigate the effect mindfulness has on mind wandering, and 2) showcase how eye-tracking can be used to look at mind wandering in a continuous, rather than binary, manner.

It has been shown that during mind wandering episodes, fixation duration tends to increase and fixation count tends to decrease (Reichle et al., 2010). It is also known that mindfulness reduces the activity of the default mode network, a brain area associated with mind wandering (Tomasino et al., 2013), and that oculomotor and attentional processes are tightly integrated at a neural level (Corbetta et al., 1998). Taking this into consideration, we predict that the effect mind wandering has on eye movement behaviours will be lessened in participants who underwent a guided meditation session prior to the experiment.

H1: Total fixation count during a mind wandering episode will be generally greater for participants in the mindfulness condition compared to the participants in the control condition

H2: Fixation duration during a mind wandering episode will be generally shorter for participants in the mindfulness condition compared to the participants in the control condition

Methods

Participants

Six undergraduates (50% female and 50% male, with a mean age of 23 years and a range of 22–25 years) from Aarhus University participated in the experiment. All subjects were proficient English speakers with normal, uncorrected vision. None of the participants had an in-depth familiarity with the text used in the study. The participants were assigned to either the experimental or control condition using a stratified random procedure.

Apparatus

An EyeLink 1000 eye-tracker (SR Research, Ottawa, Ontario, Canada) monitored the gaze location of participants' dominant eye during reading. The sampling rate was set at 500Hz. Participants viewed the stimuli binocularly on a monitor 60 cm away from their eyes; a chin and forehead rest was used to minimize head movements.

Materials

Mindfulness Exercise

A pre-recorded, 10-minute long, audio-based guided meditation from the *Waking Up*[1] application was played for the participants in the experimental condition. The specific meditation used in the experiment consisted of welcoming the participant, instructing the participants on how to direct and maintain their attention on their breathing, allowing the participant to practice on his/her own, and reminding the participant of the task (maintaining their attention on their breathing) every 2 to 3 minutes.

Participants in the control condition proceeded straight to the eye-tracker calibration routine and subsequent reading task.

Experiment

The experimental set-up was re-created from a study by Uzzaman and Joordens (2011), which was successful in inducing and observing mind wandering episodes in subjects, and differentiating between mind wandering and focused reading episodes using eye movement

[1] https://www.wakingup.com/

patterns. The only addition made to the experimental set-up was the inclusion of the meditation session. The experiment was programmed in Python (v 3.10.1) using the PsychoPy environment and conducted on a computer.

Stimulus

Participants read the first 12 pages of War and Peace by Leo Tolstoy, which were presented on a computer screen with a resolution of 1680 x 1050. The pages were read in a single sitting. Each participant read the text at their own pace, with a mean duration of 27.5 minutes to complete all 12 pages.

Procedure

A research assistant greeted the participants, outlined the procedure, and acquired informed consent. The participants in the experimental condition had to go through a 10-minute guided meditation. Participants in the control condition proceeded straight to the calibration of the eye tracker. Calibration involved locating the dominant eye of the participant and subsequent calibration of the eye tracker to the individual pattern of the participants' eye movements.

After calibration, participants proceeded to the reading part of the experiment. Before the showcase of the first page, participants were shown information about:

- What they are going to read
- How to switch between pages
- The description of the prompt that will appear at random intervals to ask whether the participant is zoned out
- How to answer the prompt
- The definition of mind wandering to support participants in answering the prompt accurately

Following the instructions, participants proceeded to read the 12 pages of the text at their own pace. Every 2 to 3 minutes (time sampled randomly from a uniform distribution) a probe would appear in the middle of the screen asking:

"ARE YOU ZONED OUT AT THIS PARTICULAR MOMENT? Y/N"

The participants had to press the respective "Y" or "N" keys on the keyboard to answer the probe. The participants were unable to continue reading without answering the probe. The probe could only appear 20 seconds after the participants have shifted to the page, as a new page would refresh attention.

Variables

Eye-tracking

Six standard eye-movement variables were collected: fixation duration, fixation start (time), fixation end (time), and fixation position (X & Y coordinates). Whilst previous studies (Reichle et al., 2010; Uzzaman & Joordens, 2011) included additional non-standard variables such as within-word regressions and run-count to measure mind wandering, the general consensus is that the fixation duration and fixation count is a sufficient amount of eye-tracking metrics needed to assess mind wandering episodes.

Results

Behavioural measures

Table 1 shows descriptive behavioural measures for each participant: whether the participant was in the control or mindfulness group, the number of probes received, and the number of probes that caught the participant zoning out (probe-caught zone outs). In order to adjust for the difference between the total number of probes shown to the

Table 1: *Behavioural measures—the probe-caught ratio is calculated by dividing the number of probe-caught zone outs by the number of probes*

Participant ID	**Condition**	**Number of probes**	**Number of probe-caught zone outs**	**Probe-caught ratio**
1	Control	16	7	0.44
2	Control	12	3	0.25
3	Mindfulness	9	2	0.22
4	Mindfulness	6	4	0.66
5	Control	12	1	0.08
6	Mindfulness	8	0	0
Mean	-	*10.50*	*2.88*	*0.275*
Standard deviation	-	*3.56*	*2.48*	*0.24*

participant, the ratio between the number of probes and probe-caught zone outs is provided.

Eye movement measures

Measurements of participants' eye movements were filtered to include only the periods of 12 seconds preceding the answer to the probe until 2 seconds preceding the answer to the probe. The reason behind excluding the 2 seconds before the showcase of the probe is that we employ a conservative estimate that it might take up to 2 seconds to reflect about whether one was mind wandering and answer the probe. Moreover, previous research (Reichle et al., 2010) suggests that significant differences in eye movement patterns between mind wandering and normal reading episodes go as far back as 120 seconds prior to the display of the probe. One period includes multiple individual fixations with fixation coordinates, start time, end time, and total duration for each respective fixation. Furthermore, periods were categorized into either control or experimental conditions.

The two variables analyzed were fixation duration and fixation count. Whilst, as previously mentioned, other studies have used other standard and non-standard variables, fixation duration and fixation count have been shown to robustly differentiate episodes of mind wandering from normal reading (Foulsham et al., 2013b; Rayner, 1998; Reichle et al., 1998; Uzzaman & Joordens, 2011a).

All periods preceding probes answered as "N" (as in "not mind wandering at this particular moment") were filtered out, as this study aims to look at mind wandering episodes only. Thus, we are left with mind wandering episodes from both control and experimental groups.

We used a mixed-effects linear regression model to analyze the differences between the two.

To answer *H1*, a linear mixed effects regression model predicting *fixation count* from condition (control or mindfulness) was constructed. ID was included as a random intercept to account for individual differences. The syntax of the described model was the following:

$$\text{Fixation Count} \sim \text{Condition} + (1|\text{ID})$$

A significant effect on participants' fixation count by condition, in the hypothesized direction, was found: $b = 0.19$ ($SE = 0.09$), $z = 1.99$, $p < .05$. The relationship is plotted in Figure 2.

To answer *H2,* a nearly identical linear regression model pre dicting *fixation duration* from the condition was constructed. syntax was the following:

$$\text{Fixation Duration} \sim \text{Condition} + (1|\text{ID})$$

An effect in the hypothesized direction, approaching significance, was found by condition on participants' fixation duration, $b = -0.14$ ($SE = 0.1341$), $t = -1.1$, $p > .05$. The relationship is plotted in Figure 3.

Discussion

In this pilot study, we investigated the effects mindfulness meditation has on mind wandering episodes during reading. Mind wandering has been dominantly treated as a dichotomy, where attention is either decoupled from the external stimuli or not. Subsequently, the effects of potential interventions for mind wandering have been evaluated in terms of the number of occurrences of mind wandering episodes. The central aim of this study is to showcase eye-tracking as a viable method for investigating the continuous nature of mind wandering and to provide an in-depth look at the effects mindfulness meditation has on mind wandering.

This was achieved by first recreating an experimental set-up by Uzzaman and Joordens (2011) to induce and detect mind wandering episodes in participants during reading. Mind wandering episodes

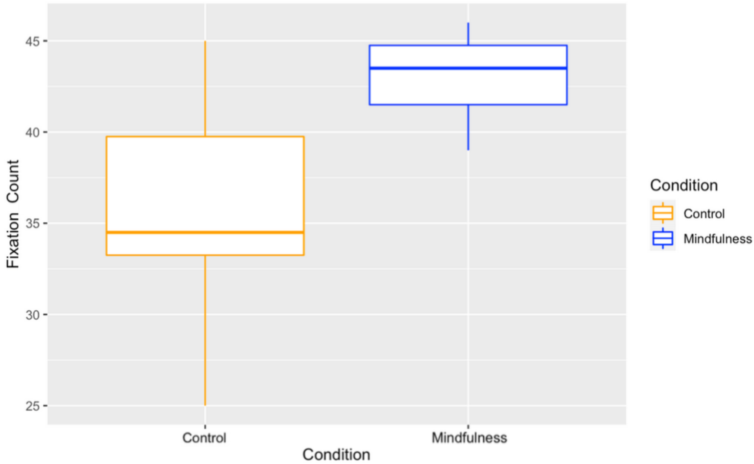

Figure 2. *A boxplot of fixations counts during mind wandering episodes in the two conditions. Condition 1 is the control condition, meaning that no meditation session was performed prior to the experimental task. Condition 2 is the mindfulness condition, meaning that a 10-minute guided meditation session was carried out prior to the experimental task. The Y-axis indicates the number of fixations made during the 10-second probe period (as described earlier in this section).*

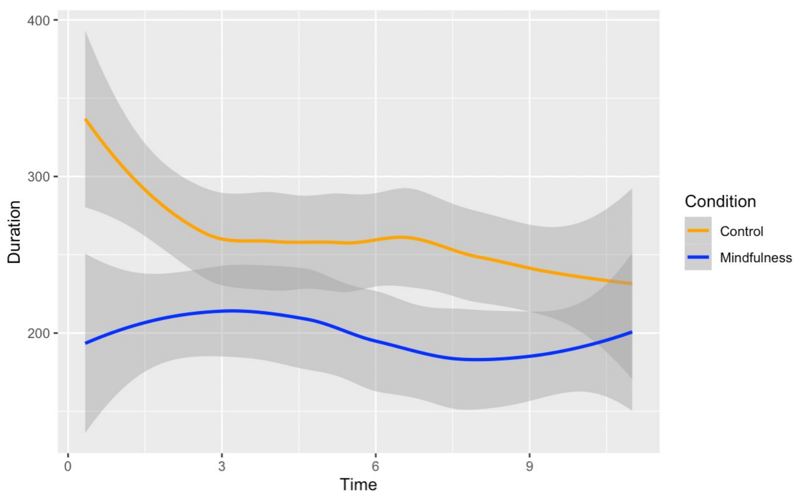

Figure 3. *Time series of fixation duration throughout mind wandering episodes in the two conditions. The X-axis is the time in seconds of the probe period, while the Y-axis specifies the fixation duration measured in milliseconds. The grey areas enwrapping the graphs of the two conditions are the associated confidence intervals of the fixation duration.*

were detected using the probe-caught method where participants are sampled at semi-random intervals about whether they are currently mind wandering or not. One limitation of the study is the lack of control for the expectancy effect in regard to the occurrence of the probes. Even though this experimental set-up has been successfully used in the past (Uzzaman & Joordens, 2011), a debrief with one of the participants revealed that the expectation of the appearance of the probes impacted the reading experience, negatively impacting the ecological validity of the experimental set-up. Participants were divided into control and mindfulness groups, where the mindfulness group completed a short, mindfulness meditation prior to the task. Finally, eye-tracking was used to analyze periods of 10 seconds prior to participants answering affirmatively to the probe.

Another limitation of the study is that the procedure used for inducing mind wandering was not validated. In order to validate the procedure, the 10s periods preceding probes which were answered as "N" by participants, meaning they did not mind wander at the time of the probe, would need to be compared to 10s periods of probes where the answer was affirmative. The procedure was, however, validated in previous studies (Uzzaman & Joordens, 2011).

It was predicted that the eye movement behaviours typical for mind wandering—increased fixation duration and decreased fixation count—would be of lesser magnitude for participants in the mindfulness condition.

Mindfulness for mind wandering

It was found that fixation count during mind wandering episodes in the mindfulness group was significantly greater than in the control group, supporting our first prediction (*H1*). In addition, fixation duration was found to be shorter in the mindfulness group, with the effect approaching significance, thus supporting to a certain extent our second prediction (*H2*). Both eye movement behaviour traits associated with mind wandering—increased fixation duration and decreased fixation count—were less extreme in the mindfulness condition, indicating the present effect of mindfulness.

These findings of reduced mind wandering as measured by eye movement behaviours are congruent with accounts that mindfulness training leads to reduced activation of the default mode network, an area often associated with mind wandering (Christoff et al., 2009). It is known that attentional and oculomotor processes are tightly integrated at the neural level (Corbetta et al., 1998). However, the exact relationship between the default mode network and eye movement behaviours remains unclear. Future work on neural correlates of mind wandering should take these into consideration and investigate how they interact with default mode network activity. Reduced activation of the default mode network was observed in long-term meditators and individuals who completed a two-week mindfulness training (Brefczynski-Lewis et al., 2007; Tang et al., 2009). Our results showcase that reduction in mind wandering can be achieved with as little as 10 minutes of meditation prior to the task. Future research should validate the results by directly measuring the activity of the default mode network post the 10-minute guided meditation session. If the efficacy of such a short mindfulness exercise is demonstrated, it would be important to compare the effects of a short mindfulness exercise versus a long one. One could imagine that mindfulness and gains associated with it follow a power law; each unit of gain requires progressively more effort or time. Comparing mindfulness exercises of different durations would potentially indicate the optimal duration for the practice. It is important to add that the inquiry suggested above would require a specific task context (such as working memory (Mrazek et al., 2013), emotional information processing

(Pavlov et al., 2015), or affective experience (Jha et al., 2010)), as we can not expect the effects to exactly be the same for tasks that engage different cognitive processes.

One obvious limitation of this pilot study was its small sample size of 6 participants, which is not enough to reliably determine whether the observed behaviours would generalize across the general population.

Approaching mind wandering continuously

Mind wandering is dominantly treated as a dichotomy and, subsequently, measured in a binary manner (Christoff, 2012; Levinson et al., 2012; Reichle et al., 2010; Smallwood & Schooler, 2015; Uzzaman & Joordens, 2011). Recently, graded and/or continuous models of mind wandering have been put forward (Mittner et al., 2016; Schad et al., 2012). New models, however, require new methods. When viewing mind wandering in terms of, for example, intensity, established binary self-reports of mind wandering are insufficient. Eye-tracking is a method perfectly suited to fill this gap. It is relatively inexpensive with high ecological validity and has been used extensively in mind wandering research. Albeit, mostly to research eye movement patterns of mind wandering when compared to non-mind wandering episodes. This pilot study suggests that the same behaviours can be used to compare mind wandering episodes to one another. Future research could rely on this method to evaluate other interventions for mind wandering, such as intelligent interfaces (D'Mello et al., 2016), mindfulness therapy with a specific focus on acceptance practice (Rahl et al., 2017), or to further investigate the link between depression and mind wandering (Killingsworth & Gilbert, 2010).

Efficacy of an online, single-session meditation

This study also makes a contribution to the question of whether online, app-based meditation sessions are effective, and specifically whether single sessions are effective in evoking increased mindfulness in participants.

While the efficacy of guided meditations by *Waking Up* have not been previously assessed, the specific meditation used for the purposes of the experiment (attention-to-breathing) is the primary meditation type used in Headspace, another mindfulness-based application whose efficacy has been shown in prior studies (Morrison Wylde et al., 2017; H. Taylor et al., 2022; Yang et al., 2018).

However, recently, a study by Mohd Zahid Juri (2022) showed no improvement in attention regulation in subjects who underwent a single session of guided meditation by Headspace.

Further investigation into the efficacy of single, guided meditation sessions is required to make confident conclusions on the matter.

Conclusion

This study aimed to investigate how mindfulness affects mind wandering measured by online external metrics provided by the eye-tracking equipment utilized. Even though we acknowledge several limitations to our experimental set-up, this pilot study showed preliminary findings of the effects that short mindfulness practice has on mind wandering, namely that the eye-tracking measures associated with mind wandering while reading (i.e., prolonged fixation duration and reduced fixation count), were found to be less pronounced in the experimental condition, where participants completed a 10-minute guided meditation prior to the commencement of the reading. This study thus builds on top of and combines previous research on measuring mind wandering with eye-tracking technology along with the ameliorating effects of mindfulness. Furthermore, it also goes beyond the established dichotomous model of mind wandering by drawing upon new evidence that points toward a novel, continuous understanding of the ubiquitous mental phenomenon. Future investigations will possibly provide more evidence for such a theoretical standpoint, such as a fully-fledged version of this pilot study.

Closing remark

We hope you did not mind wander too much while reading this paper. If you did, then don't worry—it happens to all of us.

References

Alvarez, J. A., & Emory, E. (2006). Executive Function and the Frontal Lobes: A Meta-Analytic Review. *Neuropsychology Review, 16(1),* 17–42. https://doi.org/10.1007/s11065-006-9002-x

Antrobus, J. S. (1968). Information Theory and Stimulus-Independent Thought. *British Journal of Psychology, 59(4),* 423–430. https://doi.org/10.1111/j.2044-8295.1968.tb01157.x

Barnett, P. J., & Kaufman, J. C. (2020). Mind wandering. In *Creativity and the Wandering Mind (pp. 3–23).* Elsevier. https://doi.org/10.1016/B978-0-12-816400-6.00001-8

Bixler, R., & D'Mello, S. (2014). Toward Fully Automated Person-Independent Detection of Mind Wandering. In V. Dimi trova, T. Kuflik, D. Chin, F. Ricci, P. Dolog, & G.-J. Houben (Eds.), *User Modeling, Adaptation, and Personalization (Vol. 8538, pp. 37–48).* Springer International Publishing. https://doi.org/10.1007/978-3-319-08786-3_4

Brefczynski-Lewis, J. A., Lutz, A., Schaefer, H. S., Levinson, D. B., & Davidson, R. J. (2007a). Neural correlates of attentional expertise in long-term meditation practitioners. *Proceedings of the National Academy of Sciences, 104(27),* 11483–11488. https://doi.org/10.1073/pnas.0606552104

Brefczynski-Lewis, J. A., Lutz, A., Schaefer, H. S., Levinson, D. B., & Davidson, R. J. (2007b). Neural correlates of attentional expertise in long-term meditation practitioners. *Proceedings of the National Academy of Sciences, 104(27),* 11483–11488. https://doi.org/10.1073/pnas.0606552104

Brewer, J. A., Worhunsky, P. D., Gray, J. R., Tang, Y.-Y., Weber, J., & Kober, H. (2011). Meditation experience is associated with differences in default mode network activity and connectivity. *Proceedings of the National Academy of Sciences, 108(50),* 20254–20259. https://doi.org/10.1073/pnas.1112029108

Brown, K. W., Ryan, R. M., & Creswell, J. D. (2007). Mindfulness: Theoretical Foundations and Evidence for its Salutary Effects. *Psychological Inquiry, 18(4),* 211–237. https://doi.org/10.1080/10478400701598298

Callard, F., Smallwood, J., & Margulies, D. (2012). Default Positions: How Neuroscience's Historical Legacy has Hampered Investigation of the Resting Mind. *Frontiers in Psychology, 3,* 321. https://doi.org/10.3389/fpsyg.2012.00321

Cheyne, J. A., Carriere, J. S. A., & Smilek, D. (2006). Absent-mindedness: Lapses of conscious awareness and everyday cognitive failures. *Consciousness and Cognition, 15(3),* 578–592. https://doi.org/10.1016/j.concog.2005.11.009

Christoff, K. (2012). Undirected thought: Neural determinants and correlates. *Brain Research, 1428,* 51–59. https://doi.org/10.1016/j.brainres.2011.09.060

Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009a). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences, 106(21),* 8719–8724. https://doi.org/10.1073/pnas.0900234106

Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009b). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences, 106(21),* 8719–8724. https://doi.org/10.1073/pnas.0900234106

Conway, A. R. A., Jarrold, C., Kane, M. J., Miyake, A., & Towse, J. N. (2008). Variation in Working Memory: An Introduction. In A. Conway, C. Jarrold, M. Kane, A. Miyake, & J. Towse (Eds.), *Variation in Working Memory (pp. 3–18).* Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195168648.003.0001

Corbetta, M., Akbudak, E., Conturo, T. E., Snyder, A. Z., Ollinger, J. M., Drury, H. A., Linenweber, M. R., Petersen, S. E., Raichle, M. E., Van Essen, D. C., & Shulman, G. L. (1998). A Common Network of Functional Areas for Attention and Eye Movements. *Neuron, 21(4),* 761–773. https://doi.org/10.1016/S0896-6273(00)80593-0

D'Argembeau, A., Renaud, O., & Van der Linden, M. (2011). Frequency, characteristics and functions of future-oriented thoughts in daily life. *Applied Cognitive Psychology, 25(1),* 96–103. https://doi.org/10.1002/acp.1647

Deary, I. J., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence, 35(1),* 13–21. https://doi.org/10.1016/j.intell.2006.02.001

D'Mello, S., Kopp, K., Bixler, R. E., & Bosch, N. (2016). Attending to Attention: Detecting and Combating Mind Wandering during Computerized Reading. *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems,* 1661–1669. https://doi.org/10.1145/2851581.2892329

Farb, N. A. S., Anderson, A. K., Mayberg, H., Bean, J., McKeon, D., & Segal, Z. V. (2010). Minding one's emotions: Mindfulness training alters the neural expression of sadness. *Emotion, 10(1),* 25–33. https://doi.org/10.1037/a0017151

Farb, N. A. S., Segal, Z. V., Mayberg, H., Bean, J., McKeon, D., Fatima, Z., & Anderson, A. K. (2007). Attending to the present: Mindfulness meditation reveals distinct neural modes of self-reference. *Social Cognitive and Affective Neuroscience, 2(4),* 313–322. https://doi.org/10.1093/scan/nsm030

Filmer, H. L., Griffin, A., & Dux, P. E. (2019). For a minute there, I lost myself … dosage dependent increases in mind wandering via prefrontal tDCS. *Neuropsychologia, 129,* 379–384.

https://doi.org/10.1016/j.neuropsychologia.2019.04.013

Foulsham, T., Farley, J., & Kingstone, A. (2013a). Mind wandering in sentence reading: Decoupling the link between mind and eye. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale, 67*(1), 51–59. https://doi.org/10.1037/a0030217

Foulsham, T., Farley, J., & Kingstone, A. (2013b). Mind wandering in sentence reading: Decoupling the link between mind and eye. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale, 67*(1), 51–59. https://doi.org/10.1037/a0030217

Fox, K. C. R., Spreng, R. N., Ellamil, M., Andrews-Hanna, J. R., & Christoff, K. (2015). The wandering brain: Meta-analysis of functional neuroimaging studies of mind-wandering and related spontaneous thought processes. *NeuroImage, 111,* 611–621. https://doi.org/10.1016/j.neuroimage.2015.02.039

Frank, D. J., Nara, B., Zavagnin, M., Touron, D. R., & Kane, M. J. (2015). Validating older adults' reports of less mind-wandering: An examination of eye movements and dispositional influences. *Psychology and Aging, 30*(2), 266–278. https://doi.org/10.1037/pag0000031

Franklin, M. S., Broadway, J. M., Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2013). Window to the Wandering Mind: Pupillometry of Spontaneous Thought While Reading. *Quarterly Journal of Experimental Psychology, 66*(12), 2289–2294. https://doi.org/10.1080/17470218.2013.858170

Franklin, M. S., Mrazek, M. D., Broadway, J. M., & Schooler, J. W. (2013). Disentangling decoupling: Comment on Small wood (2013). *Psychological Bulletin, 139*(3), 536–541. https://doi.org/10.1037/a0030515

Frey, M. C., & Detterman, D. K. (2004). Scholastic Assessment or g?: The Relationship Between the Scholastic Assessment Test and General Cognitive Ability. *Psychological Science, 15*(6), 373–378. https://doi.org/10.1111/j.0956-7976.2004.00687.x

Gable, S. L., Hopper, E. A., & Schooler, J. W. (2019). When the Muses Strike: Creative Ideas of Physicists and Writers Routinely Occur During Mind Wandering. *Psychological Science, 30*(3), 396–404. https:/doi.org/10.1177/0956797618820626

Galera, C., Orriols, L., M'Bailara, K., Laborey, M., Contrand, B., Ribereau-Gayon, R., Masson, F., Bakiri, S., Gabaude, C., Fort, A., Maury, B., Lemercier, C., Cours, M., Bouvard, M.-P., & Lagarde, E. (2012). Mind wandering and driving: Responsibility case-control study. *BMJ, 345*(dec13 8), e8105–e8105. https://doi.org/10.1136/bmj.e8105

Gard, T., Taquet, M., Dixit, R., Hölzel, B. K., de Montjoye, Y.-A., Brach, N., Salat, D. H., Dickerson, B. C., Gray, J. R., & Lazar, S. W. (2014). Fluid intelligence and brain functional organization in aging yoga and meditation practitioners. *Frontiers in Aging Neuroscience, 6,* 76. https://doi.org/10.3389/fnagi.2014.00076

Garrison, K., Santoyo, J., Davis, J., Thornhill, T., Kerr, C., & Brewer, J. (2013). Effortless awareness: Using real time neurofeedback to investigate correlates of posterior cingulate cortex activity in meditators' self-report. *Frontiers in Human Neuroscience, 7,* 440. https://doi.org/10.3389/fnhum.2013.00440

Gazzaniga, M. S. (2009). *The cognitive neurosciences.* MIT press.

Giambra, L. M. (1989). Task-unrelated thought frequency as a function of age: A laboratory study. *Psychology and Aging, 4* (2), 136–143. https://doi.org/10.1037/0882-7974.4.2.136

Good, D. J., Lyddy, C. J., Glomb, T. M., Bono, J. E., Brown, K. W., Duffy, M. K., Baer, R. A., Brewer, J. A., & Lazar, S. W. (2016). Contemplating Mindfulness at Work: An Integrative Review. *Journal of Management, 42*(1), 114–142. https://doi.org/10.1177/0149206315617003

Grant, J. A., Courtemanche, J., & Rainville, P. (2011). A non-elaborative mental stance and decoupling of executive and pain-related cortices predicts low pain sensitivity in Zen meditators. *PAIN®, 152*(1), 150–156. https://doi.org/10.1016/j.pain.2010.10.006

Gruberger, M., Simon, E., Levkovitz, Y., Zangen, A., & Hendler, T. (2011). Towards a Neuroscience of Mind-Wandering. *Frontiers in Human Neuroscience, 5,* 56. https://doi.org/10.3389/fnhum.2011.00056

Hasenkamp, W., & Barsalou, L. (2012). Effects of Meditation Experience on Functional Connectivity of Distributed Brain Networks. *Frontiers in Human Neuroscience, 6,* 38. https://doi.org/10.3389/fnhum.2012.00038

Hawkins, G. E., Mittner, M., Boekel, W., Heathcote, A., & Forstmann, B. U. (2015). Toward a model-based cognitive neuroscience of mind wandering. *Neuroscience, 310,* 290–305. https://doi.org/10.1016/j.neuroscience.2015.09.053

Jha, A. P. (2002). Tracking the time-course of attentional involvement in spatial working memory: An event-related potential investigation. *Cognitive Brain Research, 15*(1), 61–69. https://doi.org/10.1016/S0926-6410(02)00216-1

Jha, A. P., Krompinger, J., & Baime, M. J. (2007). Mindfulness training modifies subsystems of attention. *Cognitive, Affective, & Behavioral Neuroscience, 7*(2), 109–119. https://doi.org/10.3758/CABN.7.2.109

Jha, A. P., Stanley, E. A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the protective effects of mindfulness training on working memory capacity and affective experience. *Emotion, 10*(1), 54–64. https://doi.org/10.1037/a0018438

Just, M. A., & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review, 87* (4), 329–354. https://doi.org/10.1037/0033-295X.87.4.329

Kam, J. W. Y., Dao, E., Farley, J., Fitzpatrick, K., Smallwood, J., Schooler, J. W., & Handy, T. C. (2011). Slow Fluctuations in Attentional Control of Sensory Cortex. *Journal of Cognitive Neuroscience, 23*(2), 460–470.

https://doi.org/10.1162/jocn.2010.21443

Kane, M. J., Brown, L. H., McVay, J. C., Silvia, P. J., Myin-Germeys, I., & Kwapil, T. R. (2007). For Whom the Mind Wanders, and When: An Experience-Sampling Study of Working Memory and Executive Control in Daily Life. *Psychological Science, 18(7),* 614–621. https://doi.org/10.1111/j.1467-9280.2007.01948.x

Kane, M. J., Hambrick, D. Z., & Conway, A. R. A. (2005). Working Memory Capacity and Fluid Intelligence Are Strongly Related Constructs: Comment on Ackerman, Beier, and Boyle (2005). *Psychological Bulletin, 131(1),* 66–71. https://doi.org/10.1037/0033-2909.131.1.66

Killingsworth, M., & Gilbert, D. (2010). A Wandering Mind Is an Unhappy Mind. *Science, 330(6006), 932.*

Klinger, E. (1984). A consciousness-sampling analysis of test anxiety and performance. *Journal of Personality and Social Psychology, 47(6),* 1376–1390. https://doi.org/10.1037/0022-3514.47.6.1376

Klinger, E. (2009). Daydreaming and fantasizing: Thought flow and motivation. In *Handbook of imagination and mental simulation (pp. 225–239).* Psychology Press.

Klinger, E., & Cox, W. M. (1987). Dimensions of Thought Flow in Everyday Life. *Imagination, Cognition and Personality, 7 (2),* 105–128. https://doi.org/10.2190/7K24-G343-MTQW-115V

Kopp, K., D'Mello, S., & Mills, C. (2015). Influencing the occurrence of mind wandering while reading. *Consciousness and Cognition, 34,* 52–62. https://doi.org/10.1016/j.concog.2015.03.003

Kounios, J., Fleck, J. I., Green, D. L., Payne, L., Stevenson, J. L., Bowden, E. M., & Jung-Beeman, M. (2008). The origins of insight in resting-state brain activity. *Neuropsychologia, 46(1),* 281–291. https://doi.org/10.1016j.neuropsychologia.2007.07.013

Kounios, J., Frymiare, J. L., Bowden, E. M., Fleck, J. I., Subramaniam, K., Parrish, T. B., & Jung-Beeman, M. (2006). The Prepared Mind: Neural Activity Prior to Problem Presentation Predicts Subsequent Solution by Sudden Insight. *Psychological Science, 17(10), 882–890. https://doi.org/10.1111/j.1467-9280.2006.01798.x*

Levinson, D. B., Smallwood, J., & Davidson, R. J. (2012). The Persistence of Thought: Evidence for a Role of Working Memory in the Maintenance of Task-Unrelated Thinking. *Psychological Science, 23(4),* 375–380. https://doi.org/10.1177/0956797611431465

Manna, A., Raffone, A., Perrucci, M. G., Nardo, D., Ferretti, A., Tartaro, A., Londei, A., Del Gratta, C., Belardinelli, M. O., & Romani, G. L. (2010). Neural correlates of focused attention and cognitive monitoring in meditation. *Brain Research Bulletin, 82(1–2),* 46–56. https://doi.org/10.1016/j.brainresbull.2010.03.001

Mason, M. F., Norton, M. I., Horn, J. D. V., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Wandering Minds: The Default Network and Stimulus-Independent Thought. *Science.* https://doi.org/10.1126/science.1131295

McKiernan, K. A., D'Angelo, B. R., Kaufman, J. N., & Binder, J. R. (2006). Interrupting the "stream of consciousness": An fMRI investigation. *NeuroImage, 29(4),* 1185–1191. https://doi.org/10.1016/j.neuroimage.2005.09.030

McMillan, R., Kaufman, S., & Singer, J. (2013). Ode to positive constructive daydreaming. *Frontiers in Psychology, 4,* 626. https://doi.org/10.3389/fpsyg.2013.00626

McVay, J. C., & Kane, M. J. (2012). Why does working memory capacity predict variation in reading comprehension? On the influence of mind wandering and executive attention. *Journal of Experimental Psychology: General, 141(2),* 302–320. https://doi.org/10.1037/a0025250

Mittner, M., Hawkins, G. E., Boekel, W., & Forstmann, B. U. (2016). A Neural Model of Mind Wandering. *Trends in Cognitive Sciences, 20(8),* 570–578. https://doi.org/10.1016/j.tics.2016.06.004

Mohd Zahid Juri. (2022). *Mindful, Neurotic, or Both: Efficacy of Online Single-Session Mindfulness.*

Mooneyham, B. W., & Schooler, J. W. (2013). The costs and benefits of mind-wandering: A review. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale, 67(1),* 11–18. https://doi.org/10.1037/a0031569

Morrison Wylde, C., Mahrer, N. E., Meyer, R. M. L., & Gold, J. I. (2017). Mindfulness for Novice Pediatric Nurses: Smartphone Application Versus Traditional Intervention. *Journal of Pediatric Nursing, 36,* 205–212. https://doi.org/10.1016/j.pedn.2017.06.008

Mrazek, M. D., Franklin, M. S., Phillips, D. T., Baird, B., & Schooler, J. W. (2013). Mindfulness Training Improves Working Memory Capacity and GRE Performance While Reducing Mind Wandering. *Psychological Science, 24(5),* 776–781. https://doi.org/10.1177/0956797612459659

Mrazek, M. D., Smallwood, J., Franklin, M. S., Chin, J. M., Baird, B., & Schooler, J. W. (2012). The role of mind-wandering in measurements of general aptitude. *Journal of Experimental Psychology: General, 141(4),* 788–798. https://doi.org/10.1037/a0027968

Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2012). Mindfulness and mind-wandering: Finding convergence through opposing constructs. *Emotion, 12(3),* 442–448. https://doi.org/10.1037/a0026678

Pagnoni, G. (2012). Dynamical Properties of BOLD Activity from the Ventral Posteromedial Cortex Associated with Meditation and Attentional Skills. *Journal of Neuroscience, 32(15),* 5242–5249. https://doi.org/10.1523JNEUROSCI.4135-11.2012

Pavlov, S. V., Korenyok, V. V., Reva, N. V., Tumyalis, A. V., Loktev, K. V., & Aftanas, L. I. (2015). Effects of long-term meditation practice on attentional biases towards emotional faces: An eye-tracking study. *Cognition and Emotion, 29(5),* 807–815. https://doi.org/10.1080/02699931.2014.945903

Posner, M. I., & Petersen, S. E. (1990). The Attention System of the Human Brain. *Annual Review of Neuroscience, 13(1),* 25 –42.

Rahl, H. A., Lindsay, E. K., Pacilio, L. E., Brown, K. W., & Creswell, J. D. (2017). Brief mindfulness meditation training reduces mind wandering: The critical role of acceptance. *Emotion, 17(2),* 224–230. https://doi.org/10.1037/emo0000250

Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., & Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences, 98(2),* 676–682. https://doi.org/10.1073/pnas.98.2.676

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124 (3),* 372–422. https://doi.org/10.1037/0033-2909.124.3.372

Redick, T. S., & Engle, R. W. (2006). Working memory capacity and attention network test performance. *Applied Cognitive Psychology, 20(5),* 713–721. https://doi.org/10.1002/acp.1224

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105(1),* 125–157. https://doi.org/10.1037/0033-295X.105.1.125

Reichle, E. D., Reineberg, A. E., & Schooler, J. W. (2010a). Eye Movements During Mindless Reading. *Psychological Science, 21(9),* 1300–1310. https://doi.org/10.1177/0956797610378686

Reichle, E. D., Reineberg, A. E., & Schooler, J. W. (2010b). Eye Movements During Mindless Reading. *Psychological Science, 21(9),* 1300–1310. https://doi.org/10.1177/0956797610378686

Risko, E. F., Anderson, N., Sarwal, A., Engelhardt, M., & Kingstone, A. (2012). Everyday Attention: Variation in Mind Wandering and Memory in a Lecture: Mind wandering. *Applied Cognitive Psychology, 26(2),* 234–242. https://doi.org/10.1002/acp.1814

Robison, M. K., & Unsworth, N. (2018). Cognitive and contextual correlates of spontaneous and deliberate mind-wandering. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 44(1),* 85–98. https://doi.org/10.1037/xlm0000444

Roeser, R. W., Schonert-Reichl, K. A., Jha, A., Cullen, M., Wallace, L., Wilensky, R., Oberle, E., Thomson, K., Taylor, C., & Harrison, J. (2013). Mindfulness training and reductions in teacher stress and burnout: Results from two randomized, waitlist-control field trials. *Journal of Educational Psychology, 105(3),* 787–804.

Rohde, T. E., & Thompson, L. A. (2007). Predicting academic achievement with cognitive ability. *Intelligence, 35(1),* 83–92. https://doi.org/10.1016/j.intell.2006.05.004

Schad, D. J., Nuthmann, A., & Engbert, R. (2012). Your mind wanders weakly, your mind wanders deeply: Objective measures reveal mindless reading at different levels. *Cognition, 125(2),* 179–194. https://doi.org/10.1016/j.cognition.2012.07.004

Schmidt, S. (2011). Mindfulness in East and West – Is It the Same? In H. Walach, S. Schmidt, & W. B. Jonas (Eds.), *Neuroscience, Consciousness and Spirituality (pp. 23–38).* Springer Netherlands. https://doi.org/10.1007/978-94-007-2079-4_2

Schmitt, N., Keeney, J., Oswald, F. L., Pleskac, T. J., Billington, A. Q., Sinha, R., & Zorzie, M. (2009). Prediction of 4-year college student performance using cognitive and noncognitive predictors and the impact on demographic status of admitted students. *Journal of Applied Psychology, 94(6),* 1479–1497. https://doi.org/10.1037/a0016810

Schooler, J. W. (2002). Re-representing consciousness: Dissociations between experience and meta-consciousness. *Trends in Cognitive Sciences, 6(8), 339–344. https://doi.org/10.1016/S1364-6613(02)01949-6*

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences, S1364661311000878.* https://doi.org/10.1016/j.tics.2011.05.006

Seli, P., Carriere, J. S. A., Thomson, D. R., Cheyne, J. A., Martens, K. A. E., & Smilek, D. (2014). Restless mind, restless body. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40(3),* 660–668. https://doi.org/10.1037/a0035260

Seli, P., Risko, E. F., Smilek, D., & Schacter, D. L. (2016). Mind-Wandering With and Without Intention. *Trends in Cognitive Sciences, 20(8),* 605–617. https://doi.org/10.1016/j.tics.2016.05.010

Seli, P., Wammes, J. D., Risko, E. F., & Smilek, D. (2016). On the relation between motivation and retention in educational contexts: The role of intentional and unintentional mind wandering. *Psychonomic Bulletin & Review, 23(4),* 1280–1287. https://doi.org/10.3758/s13423-015-0979-0

Singer, J. L., & McCraven, V. G. (1961). Some Characteristics of Adult Daydreaming. *The Journal of Psychology, 51(1),* 151–164. https://doi.org/10.1080/00223980.1961.9916467

Sio, U. N., & Ormerod, T. C. (2009). Does incubation enhance problem solving? A meta-analytic review. *Psychological Bulletin, 135(1),* 94–120. https://doi.org/10.1037/a0014212

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the Brain: Mind Wandering Reduces

Cortical Analysis of External Events. *Journal of Cognitive Neuroscience, 20(3),* 458–469. https://doi.org/10.1162/jocn.2008.20037

Smallwood, J., Fishman, D. J., & Schooler, J. W. (2007). Counting the cost of an absent mind: Mind wandering as an under recognized influence on educational performance. *Psychonomic Bulletin & Review, 14(2),* 230–236. https://doi.org/10.3758/BF03194057

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008a). When attention matters: The curious incident of the wandering mind. *Memory & Cognition, 36(6),* 1144–1150. https://doi.org/10.3758/MC.36.6.1144

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008b). When attention matters: The curious incident of the wandering mind. *Memory & Cognition, 36(6),* 1144–1150. https://doi.org/10.3758/MC.36.6.1144

Smallwood, J., Mrazek, M. D., & Schooler, J. W. (2011). Medicine for the wandering mind: Mind wandering in medical practice: Mind wandering in medical practice. *Medical Education, 45(11),* 1072–1080. https://doi.org/10.1111/j.1365-2923.2011.04074.x

Smallwood, J., & Schooler, J. W. (2006). The Restless Mind. *Psychological Bulletin, 132(6),* 946–958. https://doi.org/10.1037/0033-2909.132.6.946

Smallwood, J., & Schooler, J. W. (2015). The Science of Mind Wandering: Empirically Navigating the Stream of Consciousness. *Annual Review of Psychology, 66(1),* 487–518. https://doi.org/10.1146/annurev-psych-010814-015331

Smilek, D., Carriere, J. S. A., & Cheyne, J. A. (2010a). Out of Mind, Out of Sight: Eye Blinking as Indicator and Embodiment of Mind Wandering. *Psychological Science, 21(6),* 786–789. https://doi.org/10.1177/0956797610368063

Smilek, D., Carriere, J. S. A., & Cheyne, J. A. (2010b). Out of Mind, Out of Sight: Eye Blinking as Indicator and Embodiment of Mind Wandering. *Psychological Science, 21(6),* 786–789. https://doi.org/10.1177/0956797610368063

Subramaniam, K., Kounios, J., Parrish, T. B., & Jung-Beeman, M. (2009). A Brain Mechanism for Facilitation of Insight by Positive Affect. *Journal of Cognitive Neuroscience, 21(3),* 415–432. https://doi.org/10.1162/jocn.2009.21057

Taberna, S. (2018, March 23). Sunshine [Tumblr]. *Kitten Rain.* https://hoppip.tumblr.com/post/172179523878/i-close-my-eyes-and-let-the-sun-shine-this-one

Tang, Y.-Y., Ma, Y., Fan, Y., Feng, H., Wang, J., Feng, S., Lu, Q., Hu, B., Lin, Y., Li, J., Zhang, Y., Wang, Y., Zhou, L., & Fan, M. (2009). Central and autonomic nervous system interaction is altered by short-term meditation. *Proceedings of the National Academy of Sciences, 106(22),* 8865–8870. https://doi.org/10.1073/pnas.0904031106

Tang, Y.-Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., Yu, Q., Sui, D., Rothbart, M. K., Fan, M., & Posner, M. I. (2007). Short-term meditation training improves attention and self-regulation. *Proceedings of the National Academy of Sciences, 104(43),* 17152–17156. https://doi.org/10.1073/pnas.0707678104

Taylor, H., Cavanagh, K., Field, A. P., & Strauss, C. (2022). Health Care Workers' Need for Headspace: Findings From a Multisite Definitive Randomized Controlled Trial of an Unguided Digital Mindfulness-Based Self-help App to Reduce Healthcare Worker Stress. *JMIR MHealth and UHealth, 10(8),* e31744. https://doi.org/10.2196/31744

Taylor, V. A., Daneault, V., Grant, J., Scavone, G., Breton, E., Roffe-Vidal, S., Courtemanche, J., Lavarenne, A. S., Marrelec, G., Benali, H., & Beauregard, M. (2013). Impact of meditation training on the default mode network during a restful state. *Social Cognitive and Affective Neuroscience, 8(1),* 4–14. https://doi.org/10.1093/scan/nsr087

te Nijenhuis, J., van Vianen, A. E. M., & van der Flier, H. (2007). Score gains on g-loaded tests: No g. *Intelligence, 35(3),* 283–300. https://doi.org/10.1016/j.intell.2006.07.006

Teasdale, J. D., Dritschel, B. H., Taylor, M. J., Proctor, L., Lloyd, C. A., Nimmo-Smith, I., & Baddeley, A. D. (1995). Stimulus-independent thought depends on central executive resources. *Memory & Cognition, 23(5),* 551–559. https://doi.org/10.3758/BF03197257

Teasdale, J. D., Proctor, L., Lloyd, C. A., & Baddeley, A. D. (1993). Working memory and stimulus-independent thought: Effects of memory load and presentation rate. *European Journal of Cognitive Psychology, 5(4),* 417–433. https://doi.org/10.1080/09541449308520128

Tomasino, B., Fregona, S., Skrap, M., & Fabbro, F. (2013). Meditation-related activations are modulated by the practices needed to obtain it and by the expertise: An ALE meta-analysis study. *Frontiers in Human Neuroscience, 6.* https://doi.org/10.3389/fnhum.2012.00346

Uzzaman, S., & Joordens, S. (2011a). The eyes know what you are thinking: Eye movements as an objective measure of mind wandering. *Consciousness and Cognition, 20(4),* 1882–1886. https://doi.org/10.1016/j.concog.2011.09.010

Uzzaman, S., & Joordens, S. (2011b). The eyes know what you are thinking: Eye movements as an objective measure of mind wandering. *Consciousness and Cognition, 20(4),* 1882–1886. https://doi.org/10.1016/j.concog.2011.09.010

Wadlinger, H. A., & Isaacowitz, D. M. (2011). Fixing Our Focus: Training Attention to Regulate Emotion. *Personality and Social Psychology Review, 15(1),* 75–102. https://doi.org/10.1177/1088868310365565

Yang, E., Schamber, E., Meyer, R. M. L., & Gold, J. I. (2018). Happier Healers: Randomized Controlled Trial of Mobile Mindfulness for Stress Management. *The Journal of Alternative and Complementary Medicine, 24(5),* 505–513. https://doi.org/10.1089/acm.2015.0301

Yanko, M. R., & Spalek, T. M. (2014). Driving With the Wandering Mind: The Effect That Mind-Wandering Has on Driving Performance. *Human Factors, 10.*

Zeidan, F. (2015). The Neurobiology of Mindfulness Meditation. In *Handbook of mindfulness: Theory, research, and practice (pp. 171–189).* The Guilford Press.

Zeidan, F., Martucci, K. T., Kraft, R. A., Gordon, N. S., McHaffie, J. G., & Coghill, R. C. (2011). Brain Mechanisms Supporting the Modulation of Pain by Mindfulness Meditation. *Journal of Neuroscience, 31(14),* 5540–5548. https://doi.org/10.1523/JNEUROSCI.5791-10.2011

Zylowska, L., Ackerman, D. L., Yang, M. H., Futrell, J. L., Horton, N. L., Hale, T. S., Pataki, C., & Smalley, S. L. (2008). Mindfulness Meditation Training in Adults and Adolescents With ADHD: A Feasibility Study. *Journal of Attention Disorders, 11(6),* 737–746. https://doi.org/10.1177/1087054707308502