Go the EF to Sleep: The importance of sleep on executive function, intrusive thoughts, and pre sleep cognition.

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Table of Contents

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Dedication

To everyone who has no special talents but are just unreasonably persistent

Abstract

Mind wandering is a ubiquitous cognitive experience, whether it involves daydreaming about an upcoming vacation, reflecting on a conflict during a commute, or zoning out during a meeting. At its most prototypical, mind wandering consists of, unintentional, task unrelated, stimulus independent, and unguided thought. Although poor sleep is consistently linked to attention difficulties, it is unclear whether this relationship reflects impaired executive functioning, pre-sleep cognition, or both. To test these competing explanations, participants completed three sustained attention tasks and self-report measures assessing executive function, sleep quality, and pre-sleep cognition. It was hypothesized that (1) poor sleep would predict daytime mind wandering through impaired executive functioning and (2) individual differences in pre-sleep cognition will be positively related to daytime mind wandering. Consistent with previous research, lower executive functioning was associated with greater subjective feelings of inattention. However, executive functioning was not significantly associated with sleep disturbances. Indicating that executive function alone does not explain why poor sleepers experience more daytime mind wandering. Instead, the strongest and most consistent findings showed that poorer sleep quality was associated with more negatively valenced mind wandering across multiple measures. Insomnia symptoms and sleep disturbances were linked to increased negative mind wandering, while reporting less positive mind wandering. These findings suggest that poor sleep may influence the emotional content of internally generated thoughts. Consequently, the effects of poor sleep may extend beyond impaired attention to altered emotional regulation. Interventions targeting pre-sleep cognition, such as cognitive offloading, may, therefore, improve both sleep quality and the emotional quality of mind wandering.

Keywords: sleep, subjective feelings of inattention, executive function, emotional regulation

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Mind Wandering as a Natural Category

Mind wandering is a near-universal experience: people daydream about upcoming vacations, work through conflicts on the commute home, or zoning out during meetings. Yet, despite its familiarity, researchers are still unable to universally define what mind wandering is or agree on the mechanisms underlying mind wandering.

Mind wandering is most typically defined as a shift in attention from the focal task to task-unrelated thoughts. Although this is the most common conceptualization, there have been many other subtle ways, including self-generated thought, rumination, and daydreaming to name a few. With so many ways to describe the same phenomenon it can be difficult to find a "one size fits all" definition, criticism of the field (Christoff et al., 2016; Seli et al., 2018), which limits our ability to compare results across studies. The family resemblance view presented by Seli et al. (2018) offers a unifying framework for consolidating this variety of definitions. According to this view, there is no single, rigid definition of mind wandering and instead, they propose that mind wandering is a category of experiences with a graded membership. At its most prototypical, mind wandering consists of thoughts that are task unrelated, unintentional, stimulus independent, and unguided. However, I argue that experiences do not need to exhibit all these features to qualify as mind wandering, and the presence or absence of each characteristic exists on a continuum rather than as a binary distinction. The following sections examine each of these prototypical features in detail and how they contribute to our understanding of mind wandering as a complex cognitive phenomenon that defies single-feature definitions.

Task-Unrelated

Task unrelated thought (TUT) has been a long-established way to describe mind wandering. Giambra (1995) first coined the term task unrelated imagery and thought (TUIT) and described mind wandering as an intentional shift to an off-task thought. Giambra argued that mind wandering is the default state of mind and any thoughts that were not on a specific task were considered mind wandering. This definition was later popularized by Smallwood and Schooler (2006), who understood that TUT encompassed a broader understanding of mind wandering and argued that any form of TUT would be considered mind wandering regardless of intentionality. Under this definition, boredom in class, daydreaming about weekend plans and zoning out with no recollection of what you were thinking about all count as task-unrelated thought.

Task-relatedness becomes difficult as a strict definition of mind wandering when the 'focal' task is ambiguous. For example, Murray et al. (2020) argue that there are instances where mind wandering is more than task unrelated thought, and, also, considers that some scenarios can be considered task ambiguous. They use the example of someone riding a bus to get groceries, is the task at hand the bus ride? Or is the task grocery shopping? Murray et al. (2020) considers these moments task ambiguous or task free and therefore any mind wandering that happens cannot be considered mind wandering under the strict definition of task unrelated thought.

TUT is the broadest and most recognizable definition of mind wandering, but it does come with limitations as there can be an inherent ambiguity about what is considered the specific task. Not knowing what the task is should not necessarily make some thoughts mind wandering or not. Instead, this reinforces that mind wandering exists on a gradient, and thoughts can be classified as mind wandering even in contexts where the primary task is ambiguous.

Unintentional

Intentionality is another prototypical feature of mind wandering. Mind wandering is most commonly thought of as 'unintentional' or 'spontaneous' (McVay & Kane, 2010). In fact, it is a common assumption that when participants report mind wandering during a laboratory task, it occurred despite their best intentions to stay on task (Seli et al., 2015) and any mind wandering that happened was spontaneous and unintentional. Killingsworth & Gilbert (2010) found that people reported a significant amount of spontaneous, unintentional mind wandering across a wide range of daily activities. People who reported more unintentional mind wandering also performed worse, felt less in control, and reported more negative affect. According to some research, unintentional mind wandering was seen as a failure of control over salient thoughts, (McVay & Kane, 2010) implying a lack of intention. Thus, it is often assumed that a lack of intention is a defining feature of mind wandering, typically used in conjunction with task-relatedness, where mind wandering is defined as an unintentional or spontaneous task-unrelated thought (e.g., Smallwood and Schooler, 2006).

However, there are now numerous studies demonstrating that participants sometimes *intentionally* engage in mind wandering during laboratory tasks (Carriere et al., 2008; Seli et al., 2015; Seli, Risko, & Smilek, 2016; Seli, Risko, Smilek, et al., 2016). Mind wandering is more typically unintentional, but a significant proportion of mind wandering experiences are reportedly intentional (34-41%; Seli et al., 2015). This intentional form of mind wandering occurs when individuals consciously choose to engage in off-task thoughts rather than maintain attention on the primary task. Compared with unintentional mind wandering, intentional mind wandering occurs less often and is more strongly associated with positive daydreaming than with confusion or loss of control (Seli et al., 2016). Seli, Risko, and Smilek (2016) argue that mind

wandering may begin unintentionally but become intentional once it enters awareness. Seli et al. (2016) argued that they believed that intentional mind wandering required higher levels of cognitive control and information processing. In fact, they found that a significant portion of mind wandering done during a sustained attention task, was in fact intentional. These findings suggest that, even in cases where mind wandering happened without conscious thought, the participant continues to allow their mind to wander.

For this reason, unintentionality cannot be considered the defining characteristic of mind wandering because intentional mind wandering represents nearly half of all instances. Without a graded membership framework, these experiences would be excluded entirely.

Stimulus Independent

Stimulus independence is another key characteristic of mind wandering that some have used to define mind wandering (Teasdale et al., 1993). Stimulus independent thoughts (SITs) refers to thoughts that are decoupled from the immediate sensory environment. This contrasts with stimulus-dependent thoughts, which are directly cued by perceptual events in one's environment. For example, thinking about the weekend plans while trying to write an in-class exam would be considered a stimulus-independent thought, as these thoughts arise independently of external cues. In contrast, if the same student hears a dog barking outside and begins to think of their dog, this represents stimulus-dependent thought, since it was cued by the immediate sensory environment.

Under the SIT definition of mind wandering, only the weekend-related thoughts would qualify as mind wandering, since they emerged independently rather than being prompted by environmental stimuli. Note, however, that both would be considered mind wandering from the task-relatedness definition, since both thoughts were unrelated to writing the exam.

Like the other definitions, stimulus independence is both too narrow and too broad. It excludes some experiences that resemble mind wandering and includes some that do not. For example, strategically rehearsing lines for an upcoming theatre performance during a lecture is not mind wandering but would be under the SIT definition. Similarly, thoughts that are initially cued by the environment, but follow a fluid, loose associative chain probably should be considered mind wandering, but would not under the SIT definition (e.g., hear a dog bark, think about your dog, think about your childhood pet, and think about some random childhood memory).

Unguided

Finally, Christoff et al., (2016) proposed another definition of mind wandering, arguing that mind wandering research has focused too closely on task unrelated thought while neglecting how these thoughts emerge and evolve over time. They proposed that mind wandering is better defined by the degree to which thoughts move "freely" from topic to topic in an unguided manner. This perspective positions mind wandering on a spectrum between completely unguided thoughts, such as dreaming, to completely guided thoughts, such as goal-directed thinking (e.g., deliberate problem-solving). Importantly, this definition focuses on how thoughts emerge and not on the topical content of thoughts. Therefore, thoughts related to the task might be considered mind wandering if they emerged as part of a freely moving chain of thoughts jumping from topic to topic.

However, again, there is difficulty in categorizing thoughts with a single, catch-all definition. Although prototypical mind wandering is unguided and freely moving, it is possible that not all mind wandering is completely unguided. As Yang et al. (2017) note, rumination and intrusive thoughts are often treated as forms of mind wandering, yet they are constrained to a

single theme or valence. At its essence, rumination or intrusive thoughts is the act of being stuck on a worry or fear. Similarly, daydreaming is often considered a form of mind wandering, yet it may also be singular in its topical focus (Dorsch, 2015).

Finally, despite their attempt to define mind wandering by focusing on process rather than content, it is still bound by your ability to categorize the topic of thoughts and what degree of topical shifts should be considered freely moving and what should not. As such, it often suffers from the same level of ambiguity as the other definitions.

Family Resemblance Framework

Mind wandering has had many definitions over time with each definition with varying strengths and weaknesses. According to the family-resemblances view (Seli et al., 2018), mind wandering is a natural category of experiences with a graded membership. At its most prototypical, mind wandering consists of thoughts that are task unrelated, unintentional, stimulus independent, and unguided.

The family resemblance view provides unique flexibility by allowing researchers the ability to pick and choose aspects of research they are interested in, while still being able to provide a broad definition of mind wandering. Having a graded membership, where there are no concrete definitions allows for flexibility in the field and research. Daydreaming, for example, is task unrelated and is often stimulus independent, but can be guided and intentional, whereas rumination and intrusive thoughts are unintentional, and they can be stimulus dependent and task ambiguous, but they can both be considered mind wandering, opening up this field of research for important collaboration between fields of study.

Theories of Mind Wandering

Mind wandering has been described as task unrelated, stimulus independent, unintentional, and unguided. According to the family resemblance view not all of these characteristics need to be present to be considered mind wandering. This wide range of descriptions allows for multiple opportunities for research. Regardless, if a researcher is studying task-unrelated thoughts, daydreaming, rumination, or some other form of mind wandering, why people mind wander is still being considered. There are three main theories to explain why people may mind wander: attentional resource account, executive failure, or resource management.

Attentional Resource Account

The first theory to discuss is an attentional resource account (ARA). This theory assumes that attention draws from a finite cognitive resource and that mind wandering can take up valuable cognitive resources from the primary task. Giambra (1995) was the first to discuss this, believing that the mind chooses to wander if the task at hand does not require all attentional resources. Many of Giambra's experiments focused largely on the premise that the less cognitively demanding a task is, the more mind wandering will be recorded. In this view, mind wandering is task unrelated, unguided, and unintentional. Giambra believed that mind wandering was an uncontrolled attention shift due to poor inhibitory control (1995).

In support of this, Christoff et al. (2016), explored this theory using the default network. The default network (DN) is a combination of brain areas that are active during mind wandering or low cognitive stimulation. In other words, the DN is responsible for internally oriented thoughts that can be goal directed, episodic memory retrieval, or mentalizing. Research has concluded, by using thought probes, that people mind wander on average 30-50% of their

waking lives, and it is during these episodes of mind wandering that the DN is most active. Additionally, increased activation of the DN and more mind wandering was reported as the cognitive resources of the task decreased, in other words, the easier the task the more the mind was able to wander (for a review see: Christoff et al., 2016).

Smallwood and Schooler (2006) popularized the attentional resource account of mind wandering in their influential paper "The Restless Mind." They argued that mind wandering occurs when executive control fails to maintain focus on the primary task, allowing attention to shift toward internal, task-unrelated thoughts. Additionally, mind wandering is associated with less external awareness and the focus is on internal thoughts and actions. They argue that when task demands are low, executive resources become available that can be captured by task-unrelated thoughts, and that TUTs can be terminated when detected, especially when motivation is high.

In these models, the focus is on cognition as a limited resource, and research has supported this with fMRI studies and a focus on the DN. The attentional resource account describes mind wandering as task unrelated, stimulus independent, and unintentional. Researchers who agree with this theory argue that mind wandering is the default state of cognition and when there are excess resources, they will be directed towards mind wandering. However, as the brain focuses on demanding external activities or tasks, insufficient resources remain available for mind wandering. The attentional resource account does not explain why people may mind wander during difficult tasks or why they mind wander even when motivation is high, suggesting that alternative explanations are needed.

Executive Failure

McVay and Kane (2010) push back on the conclusions that the attentional resource account is the only model of mind wandering. They disagree with Smallwood and Schooler's assumption that mind wandering only happens when there are available resources to do so. They argue that mind wandering is a result of a failure of executive control to inhibit salient thoughts. In other words, it is the brain's inability to appropriately ignore irrelevant internal or external stimuli.

An explanation for why the mind experiences executive failure is found in working memory capacity (WMC). Although theories about WMC have been around since the 1970s, Engle and Kane (2003), first approached the idea that WMC was a function of mind wandering. They explained that WMC is an integral part of systems responsible for executive functioning, this includes, but is not limited to, memory and attention. Using several variations of working memory tasks, they concluded that WMC reflects the ability to control attention especially in distracting situations (Engle & Kane, 2003). Executive attention is needed to hold information in the active memory and for staying focused on a task and responding appropriately (Engle & Kane, 2003). Simply, WMC controls executive attention, or the ability to ignore details or stimuli that are not relevant to the task at hand which results in poorer performance of that task.

Understanding mind wandering and executive control in the context of the laboratory also provides valuable information. To lend support to the theory that mind wandering is a failure of executive control in real world contexts, McVay et al. (2009), believed that lab findings would translate to daily life. Mood was also a moderator for TUTs, with participants who reported being happier mind wandering less, and participants who described themselves as unhappy seemingly exacerbating overall mind wandering. This finding is in line with Killingsworth and

Gilbert's findings in 2010: people who reported higher levels of mind wandering also indicated higher levels of unhappiness

Mind wandering is a complex topic, while attention resource account argues that cognition is a resource that can be allotted depending on task difficulty, other researchers believe that there is more at play. Christoff (2016), for example, touches on ADHD, suggesting that there are markers in the brain that show a lack of constraint of thought. So, there is less cognitive control on the DN and there are failures to de-activate the DN. These findings suggest that there is more going on at an organizational level. McKay and Vane (2009), also argue that cognition as a resource does not explain instances where people mind wander unintentionally, or when the task is difficult.

Resource Management

Whereas the attentional-resource account treats mind wandering as a default state and the executive-failure account treats it as a control failure, the resource management theory is concerned with how people allocate limited attentional resources within and across tasks (Thomson et al., 2015). Thomson et al. (2015), for instance, discuss why some tasks consume more resources than others and why certain tasks cause increased mental effort and performance deterioration. They argue that mental tasks all rest on a simple cost benefit analysis of a task, where executive function mechanisms can only be used for a limited number of tasks at once, creating an opportunity cost. Their understanding of resource management rests more in prioritization of resources on tasks, recognizing that some tasks require more cognitive resources and that using these resources for one task means they cannot be used elsewhere. Kurzban et al. (2013), proposed that the amount of effort a task takes is subjective, and the feeling of effort reflects these opportunity cost calculations. For each task, a subconscious analysis of the

cognitive cost versus benefit of that task is run in order to save on valuable cognitive resources. This analysis is adaptive and can change over time. In terms of mind wandering, this suggests that when the current task has a high opportunity cost or low perceived benefit, cognitive resources may be reallocated to internal thoughts that offer greater subjective value or require less effort.

Thomson et al. (2015), on the other hand, examined vigilance paradigms to explain why it was difficult for people to sustain their attention over longer periods. They argued that existing theories for sustained-attention lapses did not adequately explain the full range of findings in sustained-attention research. Therefore, they proposed a novel "resource-control" framework that combines aspects of the attentional resource theory (Smallwood & Schooler, 2006) and the control failure theory (McVay & Kane, 2010). They argued that attention lapses could occur either because of (1) the availability of excess resources or (2) because of a failure of executive control to maintain resources on the primary task.

Recent research by Mathews et al. (2023) provided empirical support for this dual-mechanism framework using a newly developed thought probe that distinguishes between two types of off-task experiences (1) remembered off-task thoughts, and (2) subjective feelings of inattention. Remembered off-task thoughts are experiences where participants report their thoughts to be off-task and can explicitly recall the content of those thoughts. In contrast, subjective experiences of inattention are instances where participants report their thoughts to be off-task but cannot recall the content of those thoughts - these represent instances where individuals sense their inattentiveness based on metacognitive cues rather than specific thought content. Mathews et al. found that remembered mind wandering was uniquely associated with attentional resource demands (decreasing task demands increased its frequency), while

subjective feelings of inattention were uniquely associated with executive dysfunction (predicting performance deficits on both the primary task and a separate working memory task). These findings align with Thomson et al.'s Resource-Control Framework by demonstrating that remembered mind wandering reflects the allocation of spare resources, while subjective feelings of inattention indicate executive control failures where attention slips despite the intention to maintain task focus.

Resource management theories describe mind wandering as resulting from executive control mechanisms that determine how cognitive resources are allocated between the primary task and off-task thoughts. Unlike the attention resources account and the executive failures framework, mind wandering resulting from resource management can be intentional and suggests that the mind prioritizes tasks that need more resources and uses the rest of its energy to mind wander. This allocation can be influenced by factors such as task difficulty and interest. Resource management accounts recognize that mind wandering can occur either through the allocation of excess resources when task demands are low, or through executive control failures when resources cannot be maintained on the primary task.

Sleep and Pre-Sleep Cognitions

Sleep plays an important role in the overall function of the brain (Chaieb et al., 2022; Tian et al., 2020). This is especially important as a lack of sleep has been known to exacerbate issues of executive failure which increases mind wandering and negative affect. The human body runs on a 24hr internal clock that moderates daily hormonal fluctuations such as when to eat and specifically, when to sleep. People can generally be categorized into either early birds, people who feel more energized in the morning, or people can be categorized as night owls; people who feel more productive in the evening (Van Opstal et al., 2022).

Chronotype, or the preference for either morningness or eveningness, can have a significant impact on all areas of mental health (Jankowski, 2012; Randler, 2008), but specifically there is a significant decrease in overall executive function. People who were more prone to eveningness also reported more mind wandering and overall life dissatisfaction. There could be a number of reasons as to why people with an evening chronotype may struggle more with overall life satisfaction, such as an incongruence with a normative 9-5 job resulting in lower sleep duration. Regardless, the end result is the same; sleep is important, and a lack of sleep can have negative consequences on your overall wellbeing. Krizan and Hisler (2019), highlight this in their study looking at sleep and anger. In this study they looked at reducing sleep times and seeing if that increased the overall stress response when an aversive noise was presented.

Krizan & Hisler (2019) hypothesized that the participants who had reduced sleep would experience more anger and frustration compared to those who did not have their sleep schedule modified. Contrary to their argument, both groups saw a marked increase in frustration. The researchers suggest that, while both saw an increase in anger, the control group was able to recover faster. They suggested that more research should be done with the role that sleep has on the hedonic adaptation and learning processes. Finding that both the sleep deprivation participants and the participants who did not have their sleep schedule disrupted had increased frustration suggests that there is more going on in terms of executive functioning than originally thought.

With sleep being so important, it is important to know what things keep people from sleep. A lot of research has gone into pre-sleep cognition, which refers to the thoughts that a person has as they are trying to go to bed (for a review see: Cárdenas-Egúsquiza & Berntsen, 2022). In another review by Lemyre et al. (2020), they looked at three themes of pre-sleep

cognition: the nature of pre-sleep cognition, the link between pre-sleep cognition and sleep onset latency, and manipulating pre-sleep cognition and insomnia. This research showed that pre-sleep cognition was present in both the normal transition to sleep and with those that struggled with insomnia. They also found that there were fundamental differences between specific types of pre-sleep cognition, recognizing that the negative thoughts, worries, or distressing thoughts are more highly associated with insomnia (2020). Although pre-sleep cognition was present for both conditions, people who went to bed worrying had a harder time falling asleep and staying asleep.

The inability to fall asleep as a result of pre-sleep cognition was also explored by Harrington et al. (2020). In their study they looked at intrusive thoughts and thought suppression. They hypothesized that sleep deprivation would increase the number of intrusive thoughts and would contribute to a reduction in inhibitory control. In their study the ability to control intrusive thoughts was closely related to the success people had at repressing unwanted memories in a think no-think (TNT) task. In line with their hypothesis, sleep deprivation substantially increased their susceptibility to triggering reminders and increased their chances of relapsing into unwanted memories (2020). The argument here is that thought suppression requires a great deal of executive function to repress these thoughts and that sleep helps to increase executive function enough that it will decrease mind wandering.

In order to understand the relationship between rumination and sleep quality, Guastella and Moulds (2007), used several self-report scales to look low and high trait ruminators and sleep quality. They hypothesized that participants who were rated as high trait ruminators would have poorer sleep quality, and more intrusive thoughts in the exam compared to the high trait ruminators in the distraction condition. In other words, if a person is more prone to worry, they

are more likely to experience intrusive task unrelated thoughts compared to those who were distracted (2007). Their first hypothesis was supported, supporting the idea that people who are more prone to worries and intrusive thoughts are more likely to experience disturbed sleep unless they were in the distraction condition. Without something to take their minds off their stress, high trait worriers experienced more pre-sleep cognition. Additionally, they found that those who were evaluated to be low-trait ruminators did not experience the same disruption with pre-sleep cognition suggesting that they are able to suppress these unwanted thoughts more effectively. The authors suggest that this is an indication of some people having a default state of no mind wandering (2007). The immediacy of the worry increased overall pre-sleep cognition making it harder for people to fall asleep because of their worries.

Sleep is an important part of everyday function and not having enough sleep, or having disturbed sleep can cause issues with overall happiness (Smallwood & Schooler, 2006). Specifically, people who reported decreased sleep and poor sleep quality were more likely to report higher rates of mind wandering with people who reported high levels of stress also reporting more pre-sleep cognitions (Guastella & Moulds, 2007, 2007; Harrington et al., 2020; Krizan & Hisler, 2019; Poh et al., 2016). These studies support the importance of sleep on the maintenance of executive function and mind wandering.

Offloading

Pre-sleep cognition decreases the overall amount and quality of sleep (Lemyre et al., 2020). This is especially true when there is a lot of stress and worry on the mind; the more salient and pressing the concerns, the higher the likelihood of pre-sleep intrusive thoughts. Offloading may be an effective, low cost, way of removing these worries, decreasing pre-sleep cognition, and increasing sleep.

Journaling has been at the forefront of research currently. Journaling is a cheap, effective, and low emotional cost way to express one's feelings, concerns and worries.

In their meta-analysis, Sohal et al. (2022), compiled over 3,000 papers that looked at journaling as an intervention for Post-Traumatic Stress Disorder (PTSD), depression, and anxiety. Through this meta-analysis, they found that, on average, journaling helped reduce symptoms of anxiety (9%), PTSD (6%), and depression (2%). The authors did note that the results of these papers should be examined carefully as there was little homogeneity, as many of these studies used different scales, or surveys, and methodology to come to these conclusions. Still, the authors suggest that journaling is a low risk, low cost solution to improve mental health symptoms (Sohal et al., 2022).

Scullin et al. (2017), explored the importance of future worries and rumination. In their article, they point out that a lot of the current research focused on journaling about past worries, but not many focused on current worries. In their study they asked participants to complete a writing task, either writing about all the tasks they completed that day or all the things they needed to complete the next day. They had two contradictory hypotheses: first that writing about the future would lead to increased worry about incomplete tasks or two that writing about incomplete tasks would "offload" the worry and increase sleep quality. The researchers required participants to journal for five (5) minutes prior to sleep, either about completed tasks or journal about their to-do list for the next day. In the end, the second hypothesis was supported. Participants in the offloading task, self-reported better sleep and less trouble falling asleep. This finding suggests that tasks that are unfinished are a significant source of worry and anxiety that cause people to struggle to fall asleep.

What is clear from this body of research is that worries and stress decrease the amount of time asleep and the quality of sleep. Considering the negative relationship between sleep and emotional regulation it is imperative that research thinks of ways to ensure people are getting enough sleep. Pre-sleep cognitions, intrusive thoughts, and rumination are all forms of mind wandering that stop or delay the onset of sleep and decrease the quality of sleep. Offloading, or journaling, seems to be a low risk, low-cost solution to this problem with some research showing that writing before bed can increase sleep length and improve mood.

Mind Wandering, Pre-Sleep Cognition, and Sleep

Mind wandering represents a complex, multifaceted phenomenon that lacks a unified definition (Seli et al., 2018). However, these experiences can be characterized along a continuum of prototypical features, including being task-unrelated, unintentional, stimulus-independent, and unguided. This prototypical approach allows for diverse experiences to be classified as mind wandering even when they exhibit only some, rather than all, of these characteristic features. Despite growing research interest, significant gaps remain in our current understanding of mind wandering's relationship to sleep quality and its connection to pre-sleep cognition.

Sleep has also been shown to have a significant effect on mind wandering, with people consistently reporting higher levels of mind wandering in day-to-day activities (Poh et al., 2016). However, Marcusson-Clavertz found that task unrelated and stimulus independent were not associated with sleep problems (Marcusson-Clavertz et al., 2023), suggesting that there is still a lot about the interaction of poor sleep and mind wandering that needs exploration. What may explain a putative relationship between sleep measures and spontaneous thought? One possibility is changes in executive functions. Evidence suggests that poor sleep quality, sleep disturbances, sleepiness, and sleep deprivation impair executive functioning, specifically executive control

(Anderson et al., 2009; Martella et al., 2011; Nebes et al., 2009; Wilckens et al., 2014). Although it is plausible, there is no direct evidence to support this claim.

Interestingly, mind wandering is rarely discussed in relation to pre-sleep cognition, despite their obvious similarities. Specifically, pre-sleep cognition can be considered mind wandering because it is unintentional task unrelated thought, and stimulus independent, but it would be considered guided as rumination and negative thoughts tend to be themed and negatively valenced. However, current research has not focused on this with the lens of pre-sleep cognition being a form of mind wandering even though it shares many of its characteristics. Following this, it has been established that lack of sleep and perceived sleepiness can exacerbate mind wandering, but little to no research has been done on directly exploring the relationship to determine if poor sleep quality can increase subjective feelings of inattentiveness. Pre-sleep cognition often resembles daytime inattention and mind wandering, though currently there are no studies to date which have examined how they might be related.

While definitions of mind wandering can be ambiguous, so too are the theories behind why people mind wander. The original theory was that mind wandering happened because it was the default state of mind; this was supported through fMRI studies and the default mode network. Researchers believed that mind wandering only happened when the focal task did not take up all the cognitive resources available. When a task was not difficult the mind would use cognitive resources to daydream or mind wander. However, this theory did not explain why mind wandering was reported even when a task was difficult.

Unlike other theories, executive failure acknowledges that people may mind wander without intention, which would explain why mind wandering may happen even when a task is demanding and the person is motivated. Pre-sleep cognition, intrusive thoughts, and rumination

would fit into this theory; as a person is trying to fall asleep, thoughts and worries unintentionally enter the mind. Due to executive failure, the brain is not able to suppress these thoughts which leads to increased TUT and increased pre-sleep cognition. Increased pre-sleep cognition in turn reduces sleep onset and therefore the length and quality of sleep, this lack of sleep increases negative affect and EF. What needs further attention is if lack of sleep increases executive failure and if increased pre-sleep cognition is correlated with more feelings of subjective feelings of mind wandering.

Current Study

Although there are many ways to describe mind wandering, the family resemblance view provides a useful framework for studying experiences that have often been treated separately, including pre-sleep cognition, intrusive thoughts, and subjective feelings of inattention. Poor sleep and perceived sleepiness are reliably associated with mind wandering and negative affect but less is known about which forms of mind wandering are most closely linked to poor sleep. The aim of the present research is to examine the relationships among sleep, executive functioning, and different forms of off-task experience, including remembered mind wandering and subjective feelings of inattention. This approach extends work on mind wandering and sleep by asking whether sleep-related attentional lapses are better understood as executive-control failures, pre-sleep cognition, or broader experiences of spontaneous thought.

In the current study, I tested this question by examining individual differences in sleep quality, perceived sleepiness, laboratory-based mind wandering, and executive functioning. To distinguish between forms of off-task experience, I used the ‘remembered’ versus ‘subjective feelings of inattention’ probe developed by Mathews et al. (2023). This probe separates episodes in which participants can report the content of their off-task thoughts from episodes in which

they feel inattentive but cannot recall what they were thinking. This distinction is central to the present study because subjective feelings of inattention have been linked to executive functioning errors, whereas remembered mind wandering has been linked to excess attentional resources.

I hypothesized that poorer sleep would be associated with more subjective feelings of inattention, but not necessarily remembered mind wandering, and that this association would be mediated by executive functioning. I also hypothesized that poorer sleep would be associated with more negatively valenced mind wandering, but not positively valenced mind wandering (positive-constructive daydreaming; Cárdenas-Egúsquiza et al. 2022), which may also be mediated by EF.

Methods

Participants

Participants were recruited from the University of Manitoba PSYC 1200 online research pool SONA. Participants needed to be fluent in English, have normal or corrected to normal vision, and needed to be 18 years or older to participate. All participants were required to provide informed consent prior to participating. A total of N = 297 participants completed the experiment. Participant ages ranged between 18 and 54 with a majority of the participants between the ages of 18 and 19 (n = 227). The sample consisted of 85 male participants, 206 female participants, and 5 participants who identified as non-binary or another gender, and one (1) participant who declined to answer. A majority n = 119 identified as being white, Filipino and South Asian (n = 42, and n = 41) were the next most represented ethnicity in the sample. Black (n = 32), Indigenous (n = 19), and Southeast Asian (n = 9) and Latin American (n = 9) were the next most represented ethnicities.

Procedure

This study was completed remotely and online on the participants' computer. Once a participant signed up for the study they were directed to an online consent form. Instructions on how to complete the study were presented on screen. Participants were given three sustained attention tasks designed to measure executive functioning: Antisaccade Letters, Antisaccade Arrows, and a SART using animal names. Each task was performed as presented in the methods section of Kane et al. (2021), and a latent executive functioning score was calculated for each participant following the confirmatory factor analysis procedure as outlined by Kane et al. (2021). Following the tasks, participants were given a series of online surveys to measure their regular sleep schedules, sleep habits, mind wandering, and number of overall intrusive thoughts.

To start, an informed consent page was presented, once participants clicked “Next” they were directed to a screen that informed them of what the tasks were and that the task would take roughly an hour to complete. Before each trial, participants were given the chance to practice each task, these practice runs provided feedback that let them know if they responded correctly or incorrectly. The Antisaccade Arrow was the first task and had 32 practice trials, followed by the Antisaccade Letter, which had 36 practice trials, finally, the Semantic Sustained Attention to Response task was last which had 24 practice trials. For each antisaccade task, participants were given detailed instructions reminding participants that the cue appeared on the opposite side of the target.

Sustained Attention Tasks

Antisaccade Letters (ANTI-LET)

Participants were asked to identify a masked letter (B, P, or R) at the opposite side of the screen. They were given a central fixation cue (***) which was be presented for 250-2250 ms, a

flashing cue (=) will appear to the left or right for 100 ms. Following that, the target letter will appear near the fixation for 100 ms before being masked by an "8" (until a response is given or a maximum of 10 s). Participants will identify their responses by using the keyboard keys "B," "P," or "R." Following Kane et al. (2021), response time and accuracy were recorded.

Antisaccade Arrows (ANTI-ARO)

Participants were asked to identify target arrows pointing left, right, up, or down. Trials began with a central fixation cue (***) which will be presented for 250-2250 ms, a flashing cue (=) appeared to the left or right of the fixation for 100 ms. The target will appear in the opposite direction for 100 ms before being masked by a "+" (until a response is given or a maximum of 10s). Participants will respond by using arrow keys "up arrow," "down arrow," "left arrow," and "right arrow." Following Kane et al. (2021), response time and accuracy were recorded.

Semantic Sustained Attention to Response Task (SART)

For this trial, participants were required to press the space bar ("go") when they saw an animal name or withhold a key press ("no-go") when they saw a vegetable name. Each trial started with an array of 12 Xs for 1500ms. Either an animal or a vegetable is presented for 300ms before being covered by the array again. Following Kane et al. (2021), response time and accuracy were recorded. 45 trial block was created with 40 random and unique animals and 5 random and unique vegetables from a list of 177 animals and 20 vegetables. Following this, 9 mini blocks were created with 8 go trials and 1 no-go trial. The thought probe was inserted randomly between the trial count of 40-44. Participants completed three of these mini blocks before moving on.

Thought Probes

Intermittently during the SART, participants were presented with a probe that asked two questions: (1) "Just prior to the thought probe, were you (a) “On task”, (b) “Off task and I DO remember what I was thinking about” or (c) “Off task, but I DO NOT remember what I was thinking about”. (2) "Just prior to the thought probe, I would categorize my thoughts as (a) positive (e.g., pleasant, constructive, and/or rewarding) (b) negative (e.g., unpleasant, anxious, self-critical, and/or confrontational) or (c) Neutral (neither positive or negative).

The thought probes timed out after fifteen (15) seconds. Participants were told that they took too long to respond to the questions and needed to press ‘C’ to continue. This ensured that probes were answered quickly and participants were allowed to take a break if they so chose, increasing the odds that the responses are accurate. During these trials, the experiment would also be paused if a participant failed to respond too many times in a row and were encouraged to press “C” to continue.

Surveys

Once the sustained attention tasks were completed, participants were given a battery of surveys (see the attached document for a full list of questions).

Insomnia Severity Index (ISI)

The Insomnia Severity Index is a short self-report instrument that measures a participant’s subjective feelings of their insomnia and the emotional toll that it takes on their mental health. It is a seven 7-point Likert scale that assesses the severity of sleep onset and sleep maintenance (Bastien, 2001). This scale has showed reasonable internal consistency (α = .88) and total item correlations were moderate.

Sleep Disturbance Scale Short Form (PROMIS)

The Patient-Reported Outcome Measurement Information System Sleep Disturbance Short Form (PROMIS) is a shortened form of the PROMIS. This self-report assessment measures the quality and duration of a participant's sleep based over a seven (7) day period (Yu et al., 2012).

Pittsburgh Sleep Quality Index (PSQI)

The PSQI is a 19 item self-report survey that measures several aspects of sleep and sleep quality. Participants were asked how their sleep has been over three (3) months (Buysse et al., 1989). This assessment has shown high reliability and validity and high internal consistency (α = .70 - .83) (Mollayeva et al., 2016).

Short Imaginal Process Inventory (SIPI)

The Short Imaginal Process Inventory is a 45-question self-report scale that measures the valance of one's thoughts and daydreams (Huba et al., 1982). Participants are asked to rate each item on a 5-point Likert scale (very true or strongly characteristic, moderately true or characteristic, neither particularly characteristic or uncharacteristic of me, moderately untrue or uncharacteristic of me, definitely untrue, or strongly uncharacteristic). For this questionnaire we will be focusing on the points that touch on positive constructive daydreaming as outlined in our hypothesis

Thought Control Questionnaire-Insomnia Revised (TCQI-R)

Is a 36 question self-report survey that explores pre-sleep cognitions as it relates to worries, and insomnia. The assessment is on a four (4) point Likert scale from "almost never" to "almost always." It asks participants how they usually manage thoughts that keep them awake at

night using cognitive tools such as “I decide to put them ‘on hold’ until the morning,” and “I think pleasant thoughts instead.”

Exploratory Surveys

Along with the Spontaneous and Deliberate Mind Wandering Scales, Adult ADHD Self Report (ASRS), participants were asked to complete: the Brief Mind Wandering Three-Factor Scale, the Personal Concerns Scale (modified), the NASA Task Load Index, Environmental Distraction Questions, the Depression and Anxiety and Stress Scale (DASS-21), Attention Check Questions were presented through all surveys, Directed Questions Scale, Simple Known Truths, Attentional Control: Distraction and Shifting Scales, Racing and Crowded Thoughts Questionnaire, Short Imaginal Process Inventory, and the Rumination Responses Scale (RRS). Each of these self-report scales offers a unique understanding and data point to help us understand rumination, current worries, task difficulty, and sleep patterns, and were included for exploratory purposes.

Results

Data Preparation

Through SONA, 295 participants were recruited. Before the analyses, I screened the data to ensure all participants met pre-determined inclusion criteria (Welhaf et al., 2025; Welhaf & Kane, 2024). In the SART participants with omissions error rates greater than 30% were excluded (n = 1). A high omission rate was indicative of insufficient engagement with the task, reducing the reliability of the data. Secondly, four attentional check items were placed in the surveys to assess participant attentiveness. Participants who failed two or more of these checks were also excluded from the analyses. Applying this criterion removed 40 participants, while preserving the sample’s integrity and representativeness. The final analysis included 254 data

points. While the original Kane et al. (2021) study used more rigid criteria that would have removed 85 participants, we felt it necessary to use less stringent criteria to maintain the integrity of the data set.

Latent Executive Functioning Scores

Following Kane et al. (2021), we derived latent executive-functioning (EF) scores from four indicators: accuracy on the letter and arrow antisaccade tasks, and d' and go-trial RT variability from the SART. As in Kane et al. RT variability was reverse scored (each participants' RT SD in seconds subtracted from the sample maximum), so that higher values on all indicators reflect better attention control. Using lavaan (0.6-21), we fit a single-factor CFA in which all four indicators loaded on a common EF factor, with a residual correlation between the two SART measures. Model fit was good, $\chi^2(1) = 3.41$, $p = .065$, robust CFI = .993, robust TLI = .956, SRMR = .015, robust RMSEA = .096, 90% *CI* [.000, .228]. All four indicators loaded significantly on the factor (standardized λs = .989, .595, .492, and .451, respectively; all *p*s < .001), and the SART residual correlation was substantial, $r = .558$, $p < .001$. Notably, antisaccade-letter accuracy loaded near unity, with a residual variance indistinguishable from zero ($p = .877$), meaning the latent factor is largely determined by that single indicator. Individual EF scores were obtained as regression factor score estimates, with higher scores reflecting better attention control.

Executive Functioning

The thought probes assessed both attentional state (subjective feelings of inattention vs. remembered mind wandering) and thought valence (negative, neutral, positive), allowing responses to be summarized at multiple levels of analysis. Accordingly, response proportions were calculated at three levels: (a) mind-wandering type, collapsed across valence; (b) valence,

collapsed across mind-wandering type; and (c) the six fully crossed categories of valenced mind wandering. These levels of aggregation address distinct questions regarding whether executive functioning is related to the form of off-task thought, its emotional valence, or specific combinations of the two.

Executive Function and Mind Wandering

To determine whether executive functioning was related to mind wandering, I first examined their association using a linear regression model. I used the latent executive function variable as the dependent measure and remembered mind wandering and subjective feelings of inattention as predictors. The regression model was significant, $F(2, 252) = 3.33$, $p = .037$, accounting for approximately 2.6% of the variance in EF scores ($R^2 = .026$, adjusted $R^2 = .018$). Specifically, a higher proportion of subjective feelings of inattention were associated with lower EF scores, $\beta = -.161$, $t(254) = -2.55$, $p = .011$. In contrast, remembered mind wandering was not associated with EF score, $\beta = -1.51 \times 10^{-4}$, $t(254) = -0.002$, $p = .998$, indicating no evidence of an association between executive functioning and off-task behaviour in the remembered condition.

Executive Function and Thought Valence

Next, I conducted a linear regression model to examine whether the valence of thoughts were associated with executive functioning. In this model, I used the latent EF score as the dependent measure and the proportion of negative versus positive thought proportions, collapsing over on- and off-task dimension, as predictors. The overall regression model was statistically significant, $F(2, 252) = 4.49$, $p = .012$, accounting for approximately 3.4% of the variance in EF scores ($R^2 = .034$, adjusted $R^2 = .027$). The association between executive functioning and the proportion of negatively valenced thoughts was not significant, $\beta = -.021$,

$t(254) = -0.32$, $p = .750$. In contrast, the proportion of positively valenced off-task thoughts negatively predicted EF scores, $\beta = -.191$, $t(254) = -2.93$, $p = .004$. This negative association suggests that higher levels of executive functioning were associated with lower proportions of positively valenced off-task behaviour.

Executive Function and Valenced Mind Wandering

In the final linear regression model, I used the latent EF scores as the dependent measure and all six types of valenced mind wandering as predictors (i.e., negative/neutral/positive subjective feelings of inattention and negative/neutral/positive remembered mind wandering). The overall regression model was not statistically significant, $F(6, 248) = 1.42$, $p = .207$. The model accounted for 3.3% of the variance in executive function ($R^2 = .033$), with an adjusted R^2 of .010, indicating that the predictors did not collectively explain a significant proportion of variance in executive function.

None of the individual predictors significantly predicted executive function. Negative subjective feelings of inattention condition showed a marginal negative association with EF scores, $\beta = -.107$, $t(254) = -1.68$, $p = .093$. Similarly, the neutral subjective feelings of inattention condition also showed a marginal negative association with executive function, $\beta = -.113$, $t(254) = -1.75$, $p = .082$. However, positive subjective feelings of inattention were not significantly associated with EF scores, $\beta = -.050$, $t(254) = -0.76$, $p = .449$.

None of the remembered mind wandering variables significantly predicted EF scores, including negative remembered mind wandering, $\beta = .004$, $t(254) = 0.06$, $p = .950$, neutral remembered mind wandering, $\beta = .037$, $t(254) = 0.58$, $p = .563$, or positive remembered mind wandering, $\beta = -.060$, $t(254) = -0.90$, $p = .370$.

These findings indicate that executive function was not selectively related to the valence of off-task thoughts in either the remembered or subjective feelings of inattention conditions, although weak trends suggest that greater proportions of negative and neutral off-task thoughts in the subjective feelings of inattention condition may be associated with lower executive function.

SART d' and Valenced Mind Wandering

The confirmatory factor analysis showed that the antisaccade letter accuracy loaded with near unity on the latent EF factor. As such, I also conducted regression analyses using the SART d′ and reaction time variability scores to get a more complete picture of the relationship between valenced subjective feelings of inattention and other measures of executive control. For brevity, I focus only on the model that included all six valenced mind wandering predictors representing the proportions of negatively, positively, and neutrally valenced remembered mind wandering and subjective feelings of inattention.

The overall regression model was significant, $F(6, 254) = 7.00$, $p < .001$, accounting for 14.5% of the variance in the outcome variable ($R^2 = .145$, adjusted $R^2 = .124$). Higher SART d' scores were significantly associated with lower proportions of negative subjective feelings of inattention, $\beta = -.279$, $t(254) = -4.68$, $p < .001$, and lower neutral subjective feelings of inattention $\beta = -.210$, $t(254) = -3.46$, $p < .001$. In contrast, the association between SART d' scores and positive subjective feelings of inattention was not significant, $\beta = .023$, $t(254) = 0.37$, $p = .714$.

For remembered mind wandering, higher SART d' scores were significantly associated with lower proportions of neutral remembered mind wandering, $\beta = -.137$, $t(254) = -2.19$, $p = .030$. However, SART d' scores were not significantly associated with negative remembered

mind wandering, $\beta = -.091$, $t(254) = -1.52$, $p = .129$, or positive remembered mind wandering, $\beta = .078$, $t(254) = 1.31$, $p = .192$.

SART RTSD and Valenced Mind Wandering

To further examine the relation between sustained attention and the emotional valence of off-task thought, a multiple regression analysis was conducted using SART reaction time variability (RTSD) as the predictor. The model included the proportions of negatively, positively, and neutrally valenced off-task thoughts that were either remembered or subjective feelings of inattention. The overall regression model was significant, $F(6, 248) = 4.61$, $p < .001$, accounting for 10.0% of the variance in RTSD ($R^2 = .100$, adjusted $R^2 = .079$). Higher SART RTSD scores were significantly associated with lower proportions of negative subjective feelings of inattention $\beta = -.264$, $t(254) = -4.32$, $p < .001$, and lower proportions of neutral subjective feelings of inattention, $\beta = -.167$, $t(254) = -2.68$, $p = .008$. The association between SART RTSD scores and positive subjective feelings of inattention was not statistically significant, $\beta = -.020$, $t(254) = -0.31$, $p = .755$.

For remembered mind wandering, SART RTSD scores were not significantly associated with negative, $\beta = -.036$, $t(254) = -0.59$, $p = .559$, positive, $\beta = -.045$, $t(254) = -0.71$, $p = .478$, or neutral remembered mind wandering, $\beta = .013$, $t(254) = 0.21$, $p = .831$. Overall, the findings indicate that SART RTSD was associated only with the proportions of negatively and neutrally valenced subjective feelings of inattention. No significant associations emerged for positively valenced off-task thoughts or for any category of remembered off-task thoughts.

Sleep and Valenced Mind Wandering

To assess the relationship between valenced mind wandering and sleep quality, I conducted a series of linear regression models using ISI (insomnia index), PROMIS (sleep

disturbances), and the PSQI (sleep quality) as dependent measures. I used all six types of valenced mind wandering as predictors (i.e., negative/neutral/positive subjective feelings of inattention and negative/neutral/positive remembered mind wandering).

Insomnia Severity Index (ISI)

The overall model was significant, $F(6, 248) = 3.653$, $p = .002$, explaining 8.1% of the variance in the outcome ($R^2 = .081$, adjusted $R^2 = .059$).

Significant positive associations were observed between ISI scores and the proportion of negative subjective feelings of inattention, $\beta = .167$, $t(254) = 2.702$, $p = .007$, as well as negative remembered mind wandering, $\beta = .126$, $t(254) = 2.029$, $p = .044$. These findings suggest that higher levels of insomnia symptoms were associated with a greater proportion of negatively valenced mind wandering.

A significant negative association was also found between ISI scores and the proportion of positive subjective feelings of inattention, $\beta = -.136$, $t(254) = -2.101$, $p = .037$. No significant associations were observed between ISI scores and the proportion of neutral subjective feelings of inattention, $\beta = -.067$, $t(254) = -1.062$, $p = .289$, neutral remembered mind wandering, $\beta = .088$, $t(254) = 1.424$, $p = .156$, or positive remembered mind wandering, $\beta = .030$, $t(254) = 0.469$, $p = .639$. This pattern of results suggests that greater insomnia symptoms were primarily associated with a higher proportion of negatively valenced mind wandering and a lower proportion of positively valenced off-task thoughts.

PROMIS Sleep Disturbance

Next, I conducted a linear regression model using the PROMIS as the dependent measure. The model was significant, $F(6, 248) = 2.581$, $p = .019$, explaining 5.9% of the variance in PROMIS scores ($R^2 = .059$, adjusted $R^2 = .036$). PROMIS scores were positively

associated with the proportion of negative subjective feelings of inattention, $\beta = .143$, $t(254) = 2.289$, $p = .023$, and negative remembered mind wandering, $\beta = .175$, $t(254) = 2.801$, $p = .006$. These findings indicate that higher PROMIS scores were associated with a greater proportion of negative off-task thoughts regardless of whether those thoughts were subsequently remembered.

No significant association was observed between PROMIS scores and the proportion of neutral subjective feelings of inattention, $\beta = -.007$, $t(254) = -0.110$, $p = .913$, neutral remembered mind wandering, $\beta = .043$, $t(254) = 0.688$, $p = .492$, positive subjective feelings of inattention, $\beta = -.045$, $t(254) = -0.693$, $p = .489$, or positive remembered mind wandering, $\beta = .048$, $t(254) = 0.735$, $p = .463$.

The results suggest that higher PROMIS scores were specifically associated with a greater proportion of negatively valenced off-task thoughts, whereas no significant relationships were observed with neutral or positive off-task thought content.

Pittsburgh Sleep Quality Index (PSQI)

Finally, A multiple regression analysis was conducted to examine the relationship between sleep quality, as measured by the Pittsburgh Sleep Quality Index (PSQI), and the emotional valence of mind wandering. The overall model was significant, $F(6, 248) = 4.243$, $p < .001$, explaining 9.3% of the variance in the outcome ($R^2 = .093$, adjusted $R^2 = .071$).

PSQI scores were positively associated with the proportion of negative subjective feelings of inattention, $\beta = .122$, $t(254) = 1.990$, $p = .048$, and negative remembered mind wandering, $\beta = .226$, $t(254) = 3.676$, $p < .001$. These findings indicate that poorer sleep quality was associated with a greater proportion of negatively valenced off-task thoughts, regardless of whether those thoughts were subsequently remembered.

No significant associations were observed between PSQI scores and the proportion of neutral subjective feelings of inattention, $\beta = -.096$, $t(254) = -1.542$, $p = .124$, positive subjective feelings of inattention, $\beta = -.054$, $t(254) = -0.834$, $p = .405$, neutral remembered mind wandering, $\beta = .065$, $t(254) = 1.060$, $p = .290$, or positive remembered mind wandering, $\beta = .020$, $t(254) = 0.312$, $p = .755$.

Overall, the results suggest that poorer subjective sleep quality was specifically associated with a greater proportion of negatively valenced off-task thoughts, whereas no significant relationships were observed with neutral or positive off-task thought content. The strongest association was observed for negatively valenced thoughts that were subsequently remembered.

Although the models explained a modest proportion of the variance in mind wandering, the convergence of results across all three sleep measures provides compelling evidence that poor sleep is selectively associated with negatively valenced off-task thinking rather than with mind wandering more broadly. Overall, these findings suggest that sleep disturbances may increase vulnerability to spontaneous negative thought patterns, potentially reflecting a broader tendency toward negative cognitive and emotional processing among individuals with poorer sleep.

Thought Control Questionnaire–Insomnia Revised (TCQI-R)

A final multiple regression analysis was conducted to look at the relationship between the Thought Control Questionnaire–Insomnia Revised (TCQI-R) questionnaire and valenced mind wandering. The overall model was significant, $F(6, 248) = 3.230$, $p = .004$, explaining 7.2% of the variance in the outcome ($R^2 = .072$, adjusted $R^2 = .050$).

TCQI-R scores were positively associated with the proportion of negative subjective feelings of inattention, $\beta = .210$, $t(254) = 3.382$, $p < .001$, indicating that participants who indicated a greater amount of pre-sleep cognition also experienced a greater amount of negative subjective feelings of inattention. The association between TCQI-R scores and negative remembered mind wandering was marginal, $\beta = .122$, $t(254) = 1.963$, $p = .051$, but non-significant.

No significant associations were observed between TCQI-R scores and the proportion of neutral subjective feelings of inattention, $\beta = -.038$, $t(254) = -0.605$, $p = .546$, positive subjective feelings of inattention, $\beta = -.069$, $t(254) = -1.056$, $p = .292$, neutral remembered mind wandering, $\beta = .044$, $t(254) = 0.707$, $p = .480$, or positive subjective feelings of inattention, $\beta = -.002$, $t(254) = -0.026$, $p = .979$.

Overall, the results suggest that higher TCQI-R scores were specifically associated with a greater proportion of negatively valenced off-task thoughts that were not remembered, whereas no significant relationships were observed with neutral or positive off-task thought content.

Discussion

Mind wandering can take many forms, from deliberate daydreaming to subjective feelings of inattention. In the present study I examined whether sleep quality and pre-sleep cognition were related to executive functioning, and to different forms of mind wandering. I hypothesized that executive functioning would mediate the relationship between poor sleep and subjective feelings of inattention but not remembered mind wandering. I also hypothesized that poor sleep would be associated with more negatively valenced mind wandering and not positively valenced mind wandering. Overall, the findings provide partial support for these hypotheses. Consistent with expectations, executive functioning was modestly associated with

subjective feelings of inattention. However, there was little evidence for the hypothesized link between sleep disturbance, executive functioning, and subjective feelings of inattention. Sleep measures generally showed weak and inconsistent associations with subjective feelings of inattention, limiting support for the proposed mediation model. In contrast, the strongest and most consistent findings linked poor sleep to negatively valenced off-task thought across multiple measures of sleep. This pattern suggests that the relationship between sleep and daytime mind wandering may not be explained entirely by attentional deficits. Instead, poor sleep was more consistently associated with the emotional tone of off-task thought, raising the possibility that emotional regulation—not solely attentional control along—may be the key mechanism linking sleep disturbances to daytime mind wandering.

Executive Functioning and Subjective Feelings of Inattention

Consistent with the first hypothesis, executive functioning was significantly associated with subjective feelings of inattention but not remembered mind wandering. These findings are broadly consistent with prior work linking stronger executive control to fewer attentional lapses (Kane et al., 2021), and more specifically, that these attentional lapses take the form of subjective feelings of inattention (Mathews et al., 2023). Participants with stronger executive functioning appeared to be better able to regulate spontaneous thought and maintain task focus. Conversely, participants with weaker executive functioning reported more subjective feelings of inattention, suggesting that these experiences may reflect lapses in attentional control rather than remembered episodes of off-task thought.

In contrast, executive functioning was unrelated to remembered mind wandering. This dissociation suggests that remembered mind wandering and subjective feelings of inattention may depend on distinct cognitive processes. Subjective feelings of inattention may be more

closely tied to failures of attentional control, whereas remembered mind wandering may require enough metacognitive access for participants to identify and report the content of their off-task thoughts. In this sense, remembered mind wandering may be less a pure marker of executive failure than a form of off-task thought that remains accessible to awareness.

However, despite the association between EF and subjective feelings of inattention, there was little evidence that EF served as a mechanism linking poor sleep to mind wandering as originally predicted. The association between EF and valenced mind wandering was weak and accounted for only a small proportion of the overall variance. Thus, executive functioning appears to be more relevant to whether individuals experience subjective feelings of inattention (Mathews et al., 2023) than to why poor sleep is associated with mind wandering. Although EF appears to help regulate spontaneous thought, it does not fully explain the link between sleep disturbances and off-task thought.

Executive Functioning and Valenced Mind Wandering

Contrary to expectations, executive failure was not selectively associated with negative subjective feelings of inattention. However, there were marginal negative trends for both negative and neutral mind wandering. Interestingly, greater executive functioning was associated with lower proportions of positively valenced mind wandering. This finding is unexpected because previous research suggests that positive constructive daydreaming is adaptive and beneficial and would require stronger executive functioning. One possible explanation is that stronger executive control may facilitate the suppression of internally generated thoughts regardless of emotional content. Alternatively, individuals with stronger attentional control may have an easier time staying on task which would reduce any opportunity for mind wandering altogether.

With the confirmatory factor analysis, I noted that the latent variable of executive-functioning was dominated by antisaccade-letter accuracy, which loaded to near unity. To continue to explore how subjective feelings of inattention relate to sustained attention I also used SART d′ and SART RT to attempt to explain more of the variability. These analyses supported the hypothesis that task performance was related to both negative and neutral subjective feelings of inattention. These additional analyses suggest that sustained attention rather than the broader definition of executive function plays a more important role in valenced mind wandering. Specifically, individuals with lower scores and higher response time variability had higher rates of neutral and negatively valenced subjective feelings of inattention. The absence of significant associations with positively valenced subjective feelings of inattention may indicate that positive internal thoughts may be a result of a different form of cognition that is less dependent on executive function. There needs to be some caution taken when discussing these results as the overall rates of positive off-task thoughts were extremely low, making these results unreliable.

These findings suggest that executive-control failures alone may not explain the emotional quality of off-task thought. Although executive functioning was associated with subjective feelings of inattention, it was not selectively associated with negatively valenced subjective feelings of inattention. In line with Killingsworth & Gilbert (2010), participants who reported higher levels of off-task thoughts were more negative or neutral in valence. However, the present findings suggest that executive-control deficits may help explain why attention drifts from the task at hand, but not why those off-task experiences take on a negative emotional tone. This suggests that factors beyond attentional control such as mood, stress, anxiety, and sleep may play a larger role in determining whether off-task thought is experienced as negative, neutral, or positive.

Following this line of thinking, positive constructive daydreaming may rely on a different cognitive system than the default network that is associated with internal thought production. This supports the possibility that there are multiple forms of mind wandering rather than one single phenomenon. Future research may need to examine the cognitive systems that are associated with creativity, imagination, and positive emotion regulation to see if the mechanisms change or if there is a way to encourage more positive subjective feelings of inattention or off-task thought.

Mind Wandering and Sleep

The strongest and most consistent finding concerned the association between sleep disturbance and negatively valenced mind wandering. Across all three (3) measures—the Insomnia Severity Index (ISI), PROMIS Sleep Disturbances Scale, and Pittsburgh Sleep Quality Index (PSQI)—poorer sleep was associated with a greater proportion of negatively valenced off-task thought. Importantly, this pattern emerged for both subjective feelings of inattention and remembered mind wandering, suggesting that poor sleep may increase overall vulnerability to negative spontaneous thought rather than to mind wandering more generally. In contrast, sleep disturbance showed little evidence of an association with neutral off-task thought and only limited evidence of an association with positively valenced off-task thought.

The PSQI model showed the strongest overall pattern, explaining the most variance and showing the largest association with remembered negative off-task thoughts. This finding suggests that global subjective sleep quality may be especially relevant to the emotional content of spontaneous thought. Taken together, these results support my second hypothesis: poor sleep was most consistently associated with negatively valenced mind wandering, not simply with the frequency of off task thought. This selective pattern is notable because it is not what would

necessarily be expected if the effects of poor sleep on mind wandering were driven primarily by impaired executive control. Rather than showing broader associations with off-task thought, poor sleep was most consistently related to its emotional valence. This pattern suggests that sleep disturbance may influence mind wandering not only through cognitive control processes, but also through mechanisms related to mood and emotion regulation. These findings suggest that poor sleep may impair emotional regulation by increasing negative subjective feelings of inattention and reducing one's ability to shift attention from those negative thoughts.

A broader implication is that sleep appears to influence not only how well people maintain attention, but also the emotional landscape of their internal thoughts. Poor sleep may do more than just make people more distracted in their day-to-day activities; it may also bias subjective feelings of inattention towards more negative thoughts. This could provide a cognitive mechanism linking poor sleep with poorer emotional control. Future studies regarding mind wandering should take into consideration both the frequency and valence of off-task thoughts broadly, and subjective feelings of inattention specifically.

Insomnia symptoms were also associated with fewer positively valenced feelings of inattention. This finding suggests that poor sleep may not only increase vulnerability to negative spontaneous thoughts but may also reduce access to more positive forms of internally generated thoughts, such as positive constructive daydreaming. This pattern is consistent with previous research linking sleep disturbances to greater negative affect, increased rumination, and difficulties with emotion regulation. One possibility is that sleep disturbance as a result of insomnia weakens the cognitive-control processes that help people disengage from intrusive or ruminating thoughts and redirect attention toward more positive thoughts.

The TCQI-R findings were directionally consistent with this interpretation, although the association was not statistically significant. Participants who reported more pre-sleep cognition tended to report more negatively valenced subjective feelings of inattention. This pattern should be interpreted cautiously, but it suggests a possible link between pre-sleep cognition and the negative emotional tone of daytime off-task thought that future research should examine more directly.

These findings have important implications regarding pre-sleep cognitions and worry in general. Pre-sleep cognition, such as intrusive thoughts, rumination, and concerns, may contribute to the negative and neutral valence of mind wandering more than originally thought. Specifically, pre-sleep cognition may not only disrupt quality of sleep but also carry an emotional residue forward, biasing the emotional tone of daytime off-task thoughts. In line with Jankowski (2012) and Randler (2008), people prone to being night owls were more likely to suffer from anxiety and depression. This suggests that there may be an important mechanism that may be linked to chronotype that results in higher rates of negative and neutral subjective feelings of inattention.

Another possibility is that pre-sleep cognition trains attention toward more negative internally generated thoughts. In other words, people who frequently experience pre-sleep rumination and intrusive thoughts may create a habit in their mind towards negative valenced internally generated thoughts. Once attention becomes habitually internally focused, spontaneous thoughts may be more likely to revolve around personal concerns, or unresolved goals, and may become a form of maladaptive mind wandering. This association may reflect reduced cognitive flexibility, with people getting “stuck” in patterns of thought. Instead of moving naturally

between different internal topics, thoughts may be repeatedly, and unconsciously, returning to emotionally salient concerns.

Another consideration is that negative subjective feelings of inattention may represent limitations of cognitive resources. If the mind is pre-occupied with pre-sleep cognition, worries and rumination, without appropriate emotional regulation due to lack of sleep, there may be fewer resources to shift attention to positive constructive daydreaming. In other words, poor sleep and sleep disturbances may not simply increase negative thoughts but pre-sleep cognition, rumination, and intrusive thoughts may crowd out more beneficial spontaneous thoughts.

If the relationship between sleep and mind wandering is not explained entirely by failures of attentional control, and sleep has a larger and more consistent impact on the valence of spontaneous thought, then emotional regulation may play an important role in reducing the negative emotional experiences associated with mind wandering. Offloading may therefore increase cognitive flexibility and heighten awareness of negative internal thoughts, potentially shifting their emotional tone. Additionally, if the concern is not having enough cognitive resources to switch between negative and positive thoughts, offloading could have an important function in freeing up the cognitive resources needed. If pre-sleep cognition also influences daytime mind wandering and subjective feelings of inattention, reducing pre-sleep cognition with an offloading task such as journaling may have broader psychological benefits, such as reduced rumination, improved emotional regulation, and may increase the rates of positive constructive daydreaming.

Limitations and Future Directions

Several limitations should be considered when interpreting the findings of the present study. First, the cross-sectional design of this experiment prevents conclusions about causality.

Although poor sleep was associated with more negatively valenced mind wandering, the direction of this relationship cannot be determined. It remains unclear whether poor sleep contributes to more negative spontaneous thought, whether negatively valenced mind wandering disrupts sleep, or whether both are influenced by other factors such as stress, rumination, or negative affect. Given these results, it is likely that emotional regulation is tied closely to executive control through similar cognitive mechanisms. If this is the case, research into the role that the default network plays during mind wandering tasks would be an interesting avenue.

Future studies would also benefit from incorporating objective physiological and behavioural measures of sleep alongside self-report questionnaires. Methods such as actigraphy or polysomnography could provide a more comprehensive assessment of sleep quality and continuity, while commercially available wearable devices (e.g., Fitbit or Apple Watch) may capture natural variations in sleep across extended periods. Combining objective sleep measures with repeated assessments of mind wandering would help determine whether negative off-task thinking is consistently associated with multiple indicators of poor sleep and would strengthen our understanding of the mechanisms underlying this relationship.

Finally, the current findings highlight the importance of considering sleep within the broader context of emotion regulation and spontaneous cognition. Poor sleep was associated with more negatively valenced mind wandering, suggesting that insufficient or disrupted sleep may increase vulnerability to maladaptive patterns of thought. Because repetitive negative thinking is implicated in the development and maintenance of mental health conditions such as anxiety and depression, future research should investigate interventions that target both sleep quality and pre-sleep cognition. For example, simple cognitive off-loading strategies, such as expressive journaling before bedtime, may reduce rumination, improve sleep quality, and subsequently

decrease negatively valenced mind wandering. Evaluating these interventions within longitudinal or experimental designs would clarify whether improving sleep can alter the emotional tone of spontaneous thought.

Overall, this study contributes to a growing body of evidence demonstrating that sleep quality influences not only cognitive functioning but also the emotional experience of mind wandering. By integrating research on sleep, emotion regulation, executive control, rumination, and spontaneous thought, future work has the potential to develop a more comprehensive understanding of the cognitive and neural mechanisms underlying everyday mental experiences and their relevance to psychological well-being.

Conclusion

The present study provides evidence that executive failure is associated with subjective feelings of inattention, but that this association does not explain the link between poor sleep and mind wandering as predicted. Instead, the clearest finding was that poor sleep was consistently associated with more negatively valenced off-task thought across multiple sleep measures. These findings highlight the importance of distinguishing between remembered mind wandering and subjective feelings of inattention and suggest that the effects of poor sleep may be expressed most clearly in the emotional valence of spontaneous thought. Executive functioning was associated with subjective feelings of inattention, but it explained little of the relationship between sleep disturbance and mind wandering. Instead, poor sleep was most consistently linked to negatively valenced off-task thought, suggesting that affective and emotion-regulation processes may be an important and underappreciated component of the sleep-mind wandering relationship. Understanding these pathways may inform interventions targeting not only sleep

and attentional control, but also the emotion regulation processes that shape spontaneous thought.

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