Meta-awareness, perceptual decoupling and the wandering mind

Jonathan W. Schooler[1], Jonathan Smallwood[2*], Kalina Christoff[3], Todd C. Handy[3], Erik D. Reichle[4] and Michael A. Sayette[4]

[1] Department of Psychological and Brain Sciences, University of California Santa Barbara, Santa Barbara, CA 93105, United States
[2] Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstraße 1A, 04103 Leipzig, Germany
[3] Department of Psychology, University of British Columbia, Vancouver, BC V6T 1Z4, Canada
[4] Department of Psychology, University of Pittsburgh, 3137 Sennott Square, Pittsburgh, PA 15260, United States

Mind wandering (i.e. engaging in cognitions unrelated to the current demands of the external environment) reflects the cyclic activity of two core processes: the capacity to disengage attention from perception (known as perceptual decoupling) and the ability to take explicit note of the current contents of consciousness (known as meta-awareness). Research on perceptual decoupling demonstrates that mental events that arise without any external precedent (known as stimulus independent thoughts) often interfere with the online processing of sensory information. Findings regarding meta-awareness reveal that the mind is only intermittently aware of engaging in mind wandering. These basic aspects of mind wandering are considered with respect to the activity of the default network, the role of executive processes, the contributions of meta-awareness and the functionality of mind wandering.

Mind wandering is indicative of two kinds of attentional fluctuations

From imagining our next vacation on the daily commute, to suddenly catching our eyes mindlessly reading across the page, we constantly generate imaginative thoughts that are unrelated to external circumstances. Despite the frequency of such flights of fancy, we are often startled by the discovery that our minds have wandered away from the situation at hand. Such experiences are indicative of fluctuations in two mental processes that underpin the experience of mind wandering. First, 'variations in the coupling between the mind and perception' depend on a mental shift that allows information unrelated to the current situation to form the centerpiece of conscious thought. Second, 'fluctuations in awareness of the contents of consciousness' (and in particular the fact that the mind has wandered) depend on the intermittent nature of our capacity to take explicit note of the contents of consciousness. In this review, we consider how recent investigations of perceptual decoupling and meta-awareness illuminate the mind-wandering state.

Mental events decoupled from perception

William James famously defined attention as 'the sudden taking possession by the mind, in clear and vivid form of one of what seems several simultaneously possible objects or trains of thought' [1]. Although substantial research has addressed how attention is directed towards external objects (e.g. [2]), historically less research has been devoted to how the mind shifts to an internal train of thought (although see [3–7]). In the past decade cognitive research (e.g. [8–13] has examined how and why consciousness entertains cognitions with little relation to external events (known as stimulus-independent thought, SIT). In cognitive neuroscience, researchers have examined neural processes that occur in the absence of an explicit task (such as in the resting state) in part due to an observation of a coordinated system (including the posterior parietal cingulate, the medial prefrontal cortex (medial PFC) and the medial temporal lobes) now known as the 'default mode network' (DMN) that exhibits neural activity that often continues in the absence of an external task [14–18].

Two common themes have emerged from these different levels of analyses. First, cognition that is independent of perceptual input is very common: experience sampling studies suggest that up to 50% of waking thought is stimulus independent (e.g. [12]), likewise almost all of the brain systems that are active in a task-dependent fashion also exhibit spontaneous activity during rest (e.g. [19]). Second, both internally generated thought and the associated neural processes are anticorrelated or 'decoupled' from concurrent perceptual input. This review next considers evidence demonstrating the association between perceptual decoupling and the common experience of SIT.

Behavioral measures

Absent-minded forgetting An early demonstration of the decoupling of conscious thought from perception during SIT was the observation that such cognitions interfere with the simultaneous encoding of external information. Both trait-based susceptibility to SIT [20] and state-based fluctuations in mind wandering are associated with worse external encoding [21–23].

Reading comprehension If attention is decoupled from perception during SIT, then its occurrence should undermine reading comprehension; this hypothesis is supported by the observation of a negative correlation between mind wandering while reading and comprehension accuracy

Corresponding author: Schooler, J.W. (schooler@psych.ucsb.edu)
* Both authors contributed equally to the ideas and writing of this manuscript.

[24]. Additional evidence indicates that this deficit occurs because SIT interferes with the formation of a situational model with sufficient detail to allow appropriate inferences regarding the narrative to be made [25]. If SIT disrupts perceptual coupling, then it should also affect patterns of gaze durations during reading. In an experiment in which subjects' eye movements were recorded while they read the entirety of Jane Austen's *Sense and Sensibility* [26], intervals of normal reading showed greater evidence of modulation by variables that are known to modulate fixation durations (e.g. word frequency [27]) than during mind wandering (see also [28,29]. These results indicate that the coupling between the mind and the text during normal reading [30] breaks down during SIT [31].

Neurocognitive measures

Variations in the amplitude of task-evoked responses Direct support for the decoupling hypothesis comes from studies that explore the link between SIT and the amplitude of neural response that occur in response to task events. Attention to an external task maximizes the amplitude of event related potentials (ERPs) [32] therefore SIT should lead to reduction in the amplitude of these measures (Figure 1a). Findings from a study [33] in which participants intermittently received experience sampling probes while performing a simple Go/No-go task, known as the Sustained Attention To Respond (SART) task [34], showed that ERP responses to task events had a smaller amplitude in a late positive component (P3) during SIT than during 'on task' thoughts. Further work demonstrated that SIT also attenuates sensory-level cortical processing in both the visual and auditory domain ([35], Figure 1b, see also [36]). SIT also reduces the cortical response to both targets and distracters [37] indicating that the reduction in task focus due to mind wandering arises from the internal focus necessary to maintain an internal train of thought, rather than a process of distraction (Figure 1c). Finally, changes in evoked neurocognitive response resulting from SIT have been observed with pupillary responses [38]. Circumstances that do not demand continuous task-related attention increase the production of SIT and reduce the amplitude of task-evoked changes in pupil diameter (Figure 1d).

Functional Magnetic Resonance Imaging (fMRI) One reason why the DMN is active in the absence of an external task could be because it plays a role in the generation of the SIT that occurs frequently during the mind-wandering

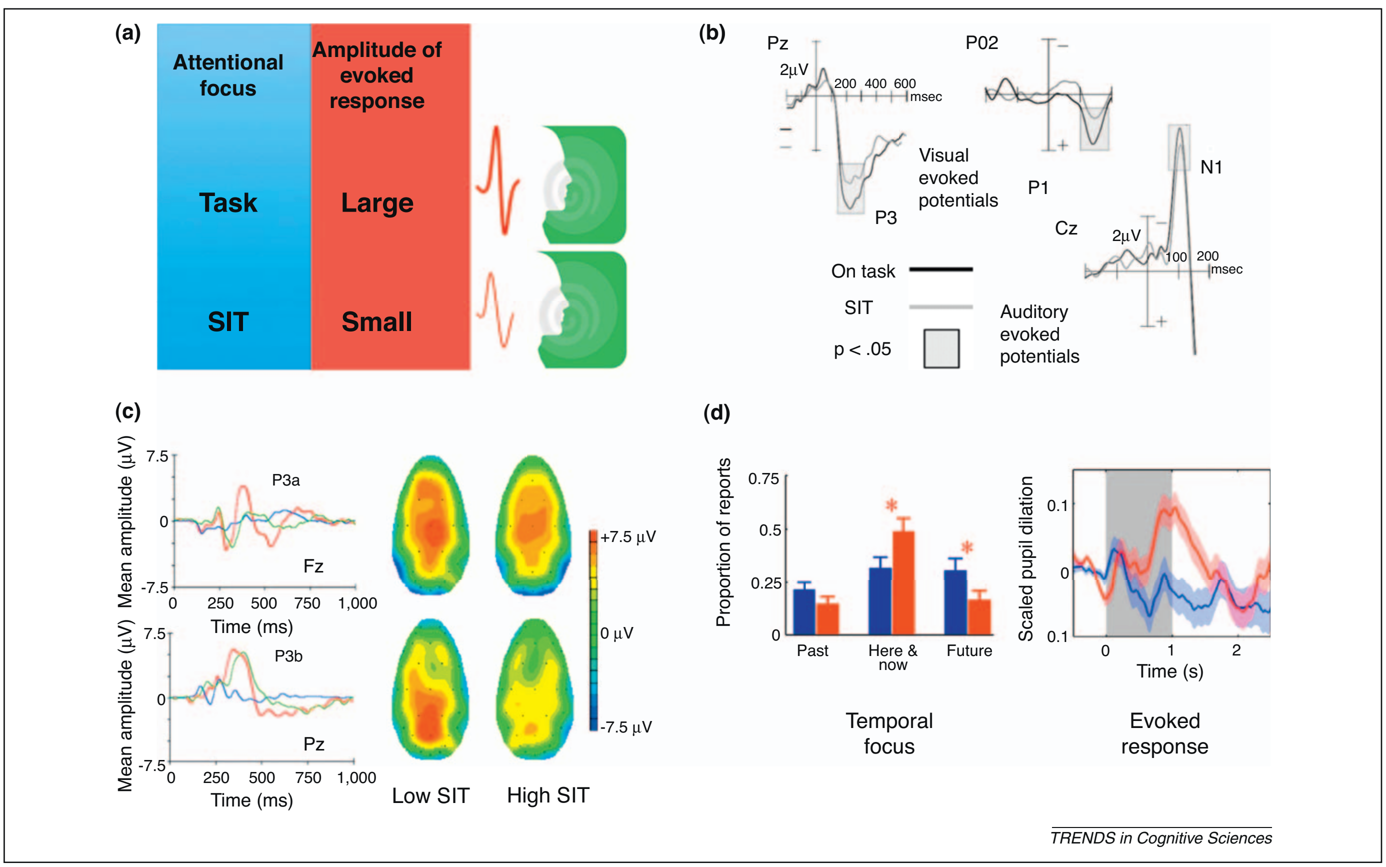

Figure 1. Reductions in the task-evoked neural responses during SIT. According to the decoupling hypothesis the amplitude of evoked neurocognitive responses is reduced during SIT relative to on-task mental states (**a**). One source of evidence for this claim comes from the comparison of periods of SIT and on-task cognition (**b**). The amplitude of a late positive component of the ERP indicated that task-relevant cortical processing (known as the P3) is reduced by SIT. Likewise both the amplitude of ERPs associated with sensory-level processing of visual and auditory information are reduced by SIT as captured by the visual P1 and auditory N1. Figure adapted from [35]. Individual differences also provide support for the covariation of SIT and evoked neural responses (**c**). ERPs were recorded during a 3-stimulus oddball task (left) in which participants detected a target (indicated by the green line) from both an equally frequent distracter stimulus (indicated by the red line) and more frequent nontargets (indicated by the blue line). High retrospective ratings of SIT were associated with reduced cortical processing of both the distracters and targets as can be seen by the reduced intensity of the scalp maps for the high SIT groups for both categories of events (right). Figure adapted from [37]. Finally, task demands modulate both SIT and the evoked neural response (**d**). Individuals engage in greater SIT in tasks (left) that do not require continuous monitoring (such as a 0-Back Choice RT task) and evoked changes in pupil diameter are also reduced (right). Figure adapted from [38].

state. Circumstantial support for this hypothesis comes from observations that the DMN shows a pattern of anticorrelation with the neural systems engaged when performing external tasks (e.g. [39]), thus suggesting a similar process of perceptual decoupling as that observed during SIT. Furthermore, in the same way that SIT impacts on external performance, enhanced DMN activity can be associated with worse performance on tasks that demand a detailed focus on the external environment (e.g. [40,41]).

More direct evidence that the DMN is associated with SIT comes from studies that link this network to reports of conscious thoughts arising in a manner that is unrelated to the current task (for a review see [17]). One approach involves linking retrospective measures of conscious thought to brain activity (e.g. [42]). Other studies have documented that situations that are associated with greater mind-wandering reports (as assessed outside of the scanner) also lead to greater activity in many of the key elements of the DMN [18,43]. However, such approaches fail to reveal whether this neural activity is directly related to the momentary experience of SIT [44]. To provide evidence of a momentary correlation between DMN activity and SIT, Christoff and colleagues [45] combined experience sampling with fMRI while participants engaged in the SART [34] task (Figure 2). During periods of off-task thought, DMN activity was higher than when participants were focused on the task (Figure 3); an observation that has recently been replicated by Stawarczyk and colleagues [46]. Importantly, Christoff and colleagues also demonstrated that DMN activity increased prior to errors (Figure 3); their finding lends support to the claim that this system competes with perception and demonstrates the utility of experience sampling in the study of mind wandering with fMRI.

Perceptual decoupling: future questions

The behavioral and neurocognitive evidence reviewed indicates that when mental events arise that are unrelated to perception they are frequently associated with a decoupling of attention from perception. Christoff and colleagues observed activations in elements of the frontoparietal network [47] (FPN; including the dorsolateral PFC, precuneus and the dorsal anterior cingulate) during SIT. Given that the FPN is usually involved in control and coordination, perhaps the activation of this system is necessary for transforming the self-referential content supported by the DMN into the detailed internal train of thought that we experience when the mind wanders (see [48]). Support for this hypothesis is provided by recent evidence that the ability to engage in autobiographical planning (such as, 'How do I get out of debt?') requires cooperation between the DMN and a system involving attentional control [49,50]. An important question for future work is to explore the degree to which the involvement of control processes (and the neural substrates that underpin them) varies as a function of the specific content of SIT, and whether the action of this control system is responsible for the anticorrelation between conscious thought and perception [48] (see Box 4 for further discussion of the role of control processes in mind-wandering).

The intermittent meta-awareness of mind wandering

In addition to documenting regular fluctuations in focus between external stimuli and SIT, research on mind wandering has also revealed major variations in individuals' capacity to notice that their minds have wandered. The claim that individuals routinely fail (at least temporarily) to notice that their minds have wandered is usefully informed by recent discussions of the nature of meta-awareness [51–58]. Meta-awareness, also known as meta-consciousness or metacognitive awareness, can be defined as one's explicit knowledge of the current contents of thought. A central premise in recent theorizing about meta-awareness is that it corresponds to an intermittent process whereby individuals periodically notice the current contents of their mind. Two methodologies have proven particularly useful in revealing the extent to which individuals are only intermittently aware of the fact that their minds have wandered.

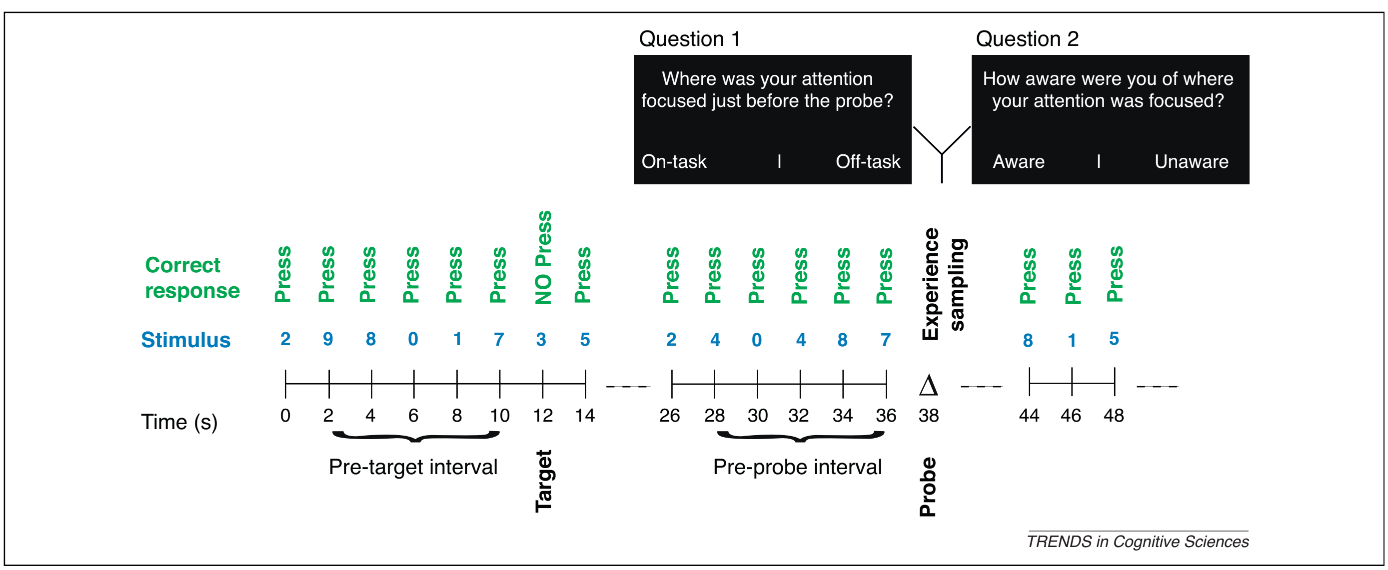

Figure 2. Task design from Christoff *et al.*, 2009. Subjects performed the SART: a Go/No-go task that requires them to respond to all nontargets (the numbers 0–2 and 4–9) by pressing a button while withholding their response to targets (the number 3). An experience sampling approach was used to collect self-reports about the subjects' focus of attention during SART performance.

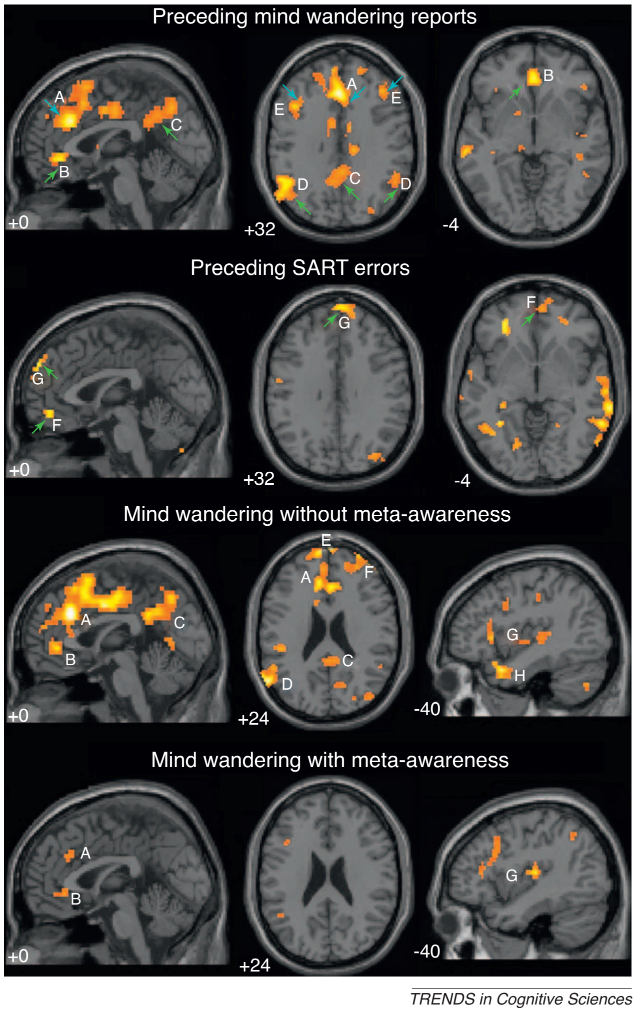

Figure 3. Activation results from Christoff *et al.*, 2009. Activations preceding mind-wandering reports: executive network regions (downward blue arrows) included dorsal anterior cingulate cortex (ACC) (A) and bilateral dorsolateral PFC (E); default network regions (upward green arrows) included ventral ACC (B), precuneus (C) and left temporoparietal junction (D). Activations preceding SART errors: default network regions (upward green arrows) included ventromedial PFC (F) and dorsomedial PFC (G). Activations during mind wandering without awareness included dorsal ACC (A), ventral ACC (B), precuneus (C), posterior temporoparietal cortex (D), dorsal rostromedial PFC (E), right rostrolateral PFC (F); posterior and anterior insula (G) and bilateral temporopolar cortex (H). Activations during mind wandering with awareness activated the same regions but to a lesser degree: dorsal ACC (A), ventral ACC (B), and posterior and anterior insula (G). Figure adapted from [45].

Self-caught / probe-caught methodology One approach to quantifying the extent that meta-awareness occurs during mind wandering is to combine self-catching measures of the mind-wandering state with experience sampling probes. The self-catching measure asks participants to press a response key every time they notice for themselves that they have been mind wandering; this provides a straightforward assessment of the number of mind-wandering episodes that reached meta-awareness. By contrast, the experience sampling probes allow an assessment of the amount of mind wandering that is actually taking place. When such probes catch people mind wandering before they notice it themselves, the experimenter is able to objectively quantify the relative amount of mind wandering that the individual is aware of.

Several studies have effectively used the self-caught/ probe-caught methodology to illuminate the relationship between mind wandering and meta-awareness. This approach was initially used to examine mind wandering while reading [24] and revealed that whereas participants regularly caught themselves mind wandering (approximately 4 times in a 45 min period) they nevertheless were regularly caught mind wandering (about 15% of experience sampling probes). Additional studies have examined the impact of two mind-altering experiences hypothesized to undermine individuals' meta-awareness: alcohol intoxication and cigarette craving. In one study [59] social drinkers consumed a moderate dose of alcohol (0.82 g/kg) or a placebo beverage and then performed a mind-wandering reading task. Participants who drank alcohol were more likely to report that they were mind wandering when probed than those who received the placebo. After accounting for this increase, alcohol also lowered the probability of catching oneself mind wandering. These data suggest that alcohol increases mind wandering while simultaneously reducing the likelihood of spontaneously noticing it. Other studies have documented that alcohol consumption increases both retrospective reports of SIT and the number of errors on the SART relative to placebo [60].

In another study [61], smokers, who were either nicotine-deprived (crave condition) or nondeprived (low-crave condition), performed the same mind-wandering task used in Sayette *et al*. [59]. Smokers in the cigarette-crave condition were significantly more likely than the low-craving smokers to acknowledge that their mind was wandering when they were probed. When this more than threefold increase was accounted for, craving also lowered the probability of participants spontaneously noticing that their minds had wandered. Similar to the alcohol consumption findings, it seems that cigarette craving simultaneously increases mental lapses while reducing the metacognitive capacity to notice them. Taken together the self-caught/ probe-caught paradigm yields data suggesting why both alcohol consumption and cigarette craving are associated with failures of self-regulation [62,63]. In both instances, there is a compromised ability to notice one's current distracted state and thus regulate it accordingly.

Experience sampling of aware/unaware mental states

A second methodology that has been used to examine fluctuations in meta-awareness of mind wandering entails combining the experiential sampling methodology with a judgment of participants' immediately prior state of awareness. In this procedure, participants are intermittently queried regarding whether or not they were mind wandering and if mind wandering they are asked to indicate whether they had been aware of this fact. In response to such queries, participants routinely indicate that they had been unaware of their mind wandering up until the time of the probe. Moreover, when participants classify mind-wandering episodes as unaware, their performance [25] and neurocognitive activity [45] (Figure 3) systematically differ from when they report having known they were mind wandering.

Consistent with findings using the self-caught/ probe-caught methodology, classifications of unaware

Box 1. Does meta-awareness help to regulate mind wandering?

One common component of mind wandering is the sudden recognition that the experience has occurred. This leads to the question of whether meta-awareness serves a self-regulatory function. There are at least three possible ways that the capacity to notice mind wandering might be involved in the process by which conscious thought is regulated.

1. *Noticing of mind wandering aids in the direct control of consciousness.*

Meta-awareness might contribute to the regulation of mind wandering directly. According to this view, the intermittent explicit assessment of the current state of the mind can enable the detection of lapses that could be missed by more low-level implicit monitoring systems [51]. From this perspective, meta-awareness directly aids in the identification of mind-wandering lapses, and the subsequent re-engagement of the primary task. This view also predicts that techniques that facilitate meta-awareness should minimize disruptive mind-wandering lapses.

2. *Noticing of mind wandering produces an illusion of control.*

Mind wandering can terminate for reasons unrelated to meta-awareness (such as when an external event disrupts the internal train of thought or the action of an unconscious monitoring process). Once the episode has ended, individuals might reconstruct their recent conscious experience and in so doing realize that mind wandering had taken place. In this case the strong sense that we have 'caught' our minds wandering could be an illusion of control [68] ('I know I was mind wandering a second ago so I guess I must have caught the experience').

3. *Noticing of mind wandering allows the indirect control of conscious thought.*

A third possibility is that the capacity to notice mind wandering is indirectly related to control. The fact that we can take stock of our conscious experience allows the individual to initiate downstream changes that will ultimately allow mind wandering to be controlled, for example by engaging in appropriate practices (such as engaging in meditative practice or in an enjoyable activity) that subsequently change the frequency that the mind wanders.

Box 2. Why is mind wandering so easy to report but so difficult to spontaneously notice?

Converging evidence from behavioral, neurocognitive and combined paradigms indicate that, when prompted, people can accurately report whether or not they are mind wandering. By contrast, the spontaneous noticing of mind wandering, as assessed using both the self-caught/probe-caught methodology and retrospective classifications, indicates that individuals routinely mind wander without noticing this fact. A contributing factor to difficulties in noticing mind wandering may be that the experience can hijack the very brain regions that are necessary for recognizing its occurrence. Many of the brain regions engaged during mind wandering are implicated in systems that might be expected to contribute to the monitoring of the state itself. Accordingly, our persistent failure to catch ourselves mind wandering could occur because mind wandering occupies the precise brain regions that are necessary for noticing it. The hijacking of the following two processes could contribute to difficulties in noticing mind wandering.

1. *Mental state attribution*

Elements of the medial PFC are recruited both during mind wandering and in tasks that require theory of mind [69]. Because mental state attribution involves the application of metacognitive processes to information of a stimulus-independent nature (e.g. inferences about the mental state of another individual), the engagement of these brain regions during SIT could prohibit their utility in the service of catching the wandering mind.

2. *Cognitive control*

Periods of mind wandering also engage regions such as the dorsal ACC, which are known to be involved in error detection and conflict monitoring, and the anterior PFC, involved in cognitive meta-awareness. If mind wandering engages both metacognition and error-detection systems in the service of generating a coherent stream of SIT, then the fact that these systems are already engaged might make them less capable of detecting a mind-wandering episode.

mind-wandering episodes (termed zoning out) and aware episodes (termed tuning out) indicate that the former are more associated with failures in response inhibition [64,65] and poor mental models during reading [25]. One important question for future research is whether the fact that awareness of mind wandering is often associated with less pronounced performance deficits indicates that meta-awareness itself contributes to the self-regulation of mind wandering. Box 1 considers several different possibilities for the role that meta-awareness might play in regulating mind wandering.

Meta-awareness: future directions

The studies reviewed indicate that although mind-wandering is common our capacity to recognize the experience is poor; this raises the question of why we have such difficulties in catching our minds wandering. In the study conducted by Christoff and colleagues [45], mind wandering with awareness activated similar brain regions to those observed during mind wandering without awareness. These brain regions, however, were more strongly activated when mind wandering occurred without awareness. The anterior PFC, one of the brain regions significantly more strongly recruited during episodes of unaware mind wandering, has been directly linked to engagement of cognitive meta-awareness [66]. The observation that this brain region was recruited during unaware episodes of mind wandering might seem surprising at first. However, the anterior PFC may be involved in the content of mind wandering through its role in the maintenance of an internal train of thought [48]. As discussed in Box 2, if the recruitment of processes associated with meta-awareness is a frequent component of mind wandering, then this could explain why the capacity to notice this cognitive state, and so report its occurrence, is so difficult (Box 2).

Summary and conclusions

Recent investigations of mind wandering reveal fluctuations in both the coupling and meta-awareness of attention. Often, when resources are directed to SIT, a decoupling process takes place that leads to a dampening in the processing of environmental stimuli. Although disruptive of perception, this decoupling process could have important advantages because it allows the mind to focus in detail on an internal train of thought [67] and so allows the mental consideration of goals other than those in the

Box 3. What is the function of mind wandering?

Given that mind wandering is so common (e.g. [12]) the question arises as to whether it offers some functional value [70] that compensates for its disruptions to ongoing tasks [71] and its association with low mood (e.g. [12,72,73]). Here we consider several candidate functions that mind wandering might afford.

1. Future planning

A significant proportion of mind wandering is dedicated to future thinking [33,53]. This process is increased by a period of self-reflection [74,75] and reduced by an unhappy mood [76]. Furthermore, many of the same neural structures engaged by the processes of active consideration of the future are implicated in mind wandering (for a review see [77]). Perhaps a primary function of mind wandering is to generate the autobiographical predictions necessary to successfully navigate the complex social world (see [78]).

2. Creativity

There are numerous anecdotes of creative ideas occurring to individuals during moments of mind wandering [79]. Although direct research exploring this issue is only now underway, a number of indirect sources are consistent with the hypothesis that mind wandering can contribute to creative solutions. For example, the creative benefits of incubation intervals are greatest when individuals are occupied by a non-demanding task relative to either a demanding task or no task at all [80]. Given that mind wandering is more frequent in nondemanding relative to demanding tasks (e.g. [81]), such findings are consistent with the view that SIT (perhaps particularly when it occurs while engaging in an easy task) can contribute to the creative benefit of an incubation interval.

3. Attentional cycling

For an agent with multiple goal states, the ability to cycle through different information streams is adaptive. For example, when at a watering hole an attentional cycling would allow an animal to alternate between the goals of drinking and avoiding predators. In humans, mind wandering could be the extension of this basic tendency for attentional fluctuation that could explain why slow oscillations in performance [64,82,83] and DMN activity [84] have both been linked to SIT.

4. Dishabituation

Various lines of research indicate that learning is enhanced with distributed relative to massed practice [84]. One account of this benefit is that breaks afford an opportunity for dishabituation. It is possible that SIT provides a necessary break in the ongoing task that allows the mind to return to it with a refreshed capacity for dedicated processing.

Box 4. Outstanding questions

- *What is the relationship between control functions and mind wandering?*

Control processes have been hypothesized to be important in explaining the link between mind wandering and goals and plans [8,81,85]. Failures in control process have also been implicated in enabling the mind to wander in the first place [71]. However the respective role of control processes in both the generation of mind-wandering content and the regulating of mind-wandering lapses remains poorly understood. Perhaps the most informative data on this question are the observations of the joint recruitment of the DMN and the FPN during mind wandering [45] and in the explicit act of autobiographical planning [49]. Such coactivation leads to the conclusion that the recruitment of control processes could be necessary when autobiographical information is manipulated in a conscious fashion [71]. To further assess this question it is necessary to identify similarities and differences in states of decoupled attention during demanding and undemanding tasks (such as the resting state). The contribution of control processes to the generation versus regulation of mind wandering will be usefully informed by paradigms that: (i) manipulate the extent to which control processes are required by the primary task (e.g. [85]) and (ii) compare how trait differences in executive capabilities modulate the extent, the neural recruitment and the content of mind wandering.

- *Is it possible to develop techniques for maximizing the functionality of mind wandering while minimizing its costs?*

One of the paradoxical features of the process of decoupling associated with the mind-wandering state is that although it is potentially associated with important adaptive cognitive features such as future planning and creativity (Box 3) it is nonetheless detrimental to the goals of the moment (see section on behavioral consequences of decoupling). Thus one important research question is whether it is possible to tune the attentional system so that the agent receives the benefit of the capacity to engage in imaginative simulation while minimizing the negative consequences of decoupling on the goals of the moment. Strategies such as mindfulness training [86], metacognitive regulation [87], behavioral feedback [88] or biofeedback [89], attentional training [90] and implementation intentions [91] are among the many approaches that could prove useful in maximizing the value and minimizing the costs of mind wandering.

- *What are the processes that underpin the cyclic nature of decoupling and meta-awareness?*

A host of candidate factors could be involved in driving fluctuations in perceptual decoupling and meta-awareness. Although the probable participation of a number of such factors is evident, their precise contribution to the cycles of decoupling and meta-awareness and their relationship to one another remain to be determined. These factors include but are not limited to: innate attentional rhythms [38,89,92], distinctive aspects of the environment, the existence of pressing concerns unrelated to the immediate situation [93], implicit [94] and explicit goals [91], working memory capacity [71], self-awareness [59,95] and explicit and implicit metacognitive regulation [51].

here and now [8] (see Box 3 for a discussion of this and other possible functions of mind-wandering). Although when queried individuals are able to report the occurrence of such decoupled states, they can proceed for some time before being spontaneously noticed indicating that meta-awareness of mind wandering is only intermittent [51]. Collectively, these investigations have not only illuminated the processes by which the mind disengages from the here and now but also how readily it manages to lose track of this fact. It seems that a key element of the human mind's remarkable knack for slipping away from the present is its stealth in doing so.

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