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Everyday Attention: Variation in Mind Wandering and Memory in a Lecture

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Summary: Understanding the factors underlying variation in attentional state is critical in a number of domains. Here, we investigate the relation between time on task and mind wandering (i.e., a state of decoupled attention) in the context of a lecture. Lectures are the primary means of knowledge transmission in post secondary education rendering an understanding of attentional variations in lectures a pressing practical concern. We report two experiments wherein participants watched a video recorded lecture either alone (Experiment 1) or in a classroom context (Experiment 2). Participants responded to mind wandering probes at various times in the lecture in an effort to track variations in mind wandering over time. In addition, following the lecture, memory for the lecture material was tested. Results demonstrate that in a lecture mind wandering increases with time on task and memory for the lecture material decreases. In addition, there was a significant relation between mind wandering and memory for lecture material. Theoretical and practical applications of the present results are discussed. Copyright © 2011 John Wiley & Sons, Ltd.

Attentional state is dynamic, fluctuating in time from points of intense focus to total disengagement. Understanding the nature of these fluctuations is important both theoretically and practically (Davies & Parasuraman, 1993). In the present study, we investigated how the ability to sustain attention changes as a function of time during a lecture. Lecture currently serves as the primary means of knowledge transfer in the post - secondary education system (Bligh, 2000). Thus, understanding attentional fluctuations during lectures can provide important information for the development of pedagogy. In addition, the lecture context provides a novel environment to test extant accounts of time on task effects on mind wandering.

Sustained attention and the vigilance decrement

There exists a large body of work suggesting that the ability to sustain attention decreases as a function of time in certain tasks (Davies & Parasuraman, 1993; Mackworth, 1948; Parasuraman, 1979; Warm, 1984). This decrease in attention with increasing time on task has typically been studied using what is referred to as the vigilance decrement: a decrease in performance as a function of time. The tasks used to study the vigilance decrement were initially modeled after the task of a radar operator. Thus, the tasks consisted of a prolonged visual search for a highly infrequent target. For example, in the Mackworth clock test, participants monitored a pointer that moved in regular steps (similar to a clock hand). Their task was to detect an infrequent double step (e.g. 1 target for every 1200 non targets). Mackworth (1948), amongst many others since, found that the ability to detect the target decreased as a function of increasing time on task. For example, in one experiment the incidence of missed targets increased from approximately 15% to almost 30% over a two-hour session. In the context of a task like radar operation it is clear that the implications of these findings are far reaching.

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Sustained attention in lectures

While research on changes in the ability to sustain attention largely emerged out of military and industrial applications (e.g. radar operation, surveillance, quality control), the idea that attention might wane as a function of time has also caught the interest of educators (Bligh, 2000). Indeed, one does not have to search long before encountering the claim that students' ability to sustain attention during a lecture decreases as a function of time (e.g. Bligh, 2000; Wilson & Korn, 2007). However, in a recent review, Wilson and Korn (2007) noted a distinct weakness in the empirical evidence substantiating this idea and were surprised that there were "so few laboratory studies of attention during a lecture" (p. 88). In addition, lectures are sufficiently different from traditional vigilance tasks, modeled after industrial and military tasks (e.g. detecting low frequency targets), that it could be dangerous simply generalizing from one context to the other (Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003; Kingstone, Smilek & Eastwood, 2008). Given the cultural value placed on education, this lack of research on attention in lectures is surprising in the context of the large amount of research dedicated to understanding attentional variations in tasks designed to mimic industrial and military operations.

Part of this neglect could stem from the challenges inherent in studying attention during lectures. As noted above, the vigilance decrement is typically studied using performance measures. The continuous nature of lectures makes assessing performance online difficult (i.e. there are no repeated discrete events to which the participant's ability to respond can be assessed). This has led some to assess performance with a test after the lecture with questions drawn from different parts of the lecture; however, primacy and recency effects can complicate interpretation of such results (not to mention most "tests" of lecture comprehension do not occur right after the lecture). In a similar vein, lecture content can vary along a number of dimensions (e.g. difficulty) throughout the lecture making it difficult to compare relative retention of content from different time periods (Scerbo, Warm, Dember, & Grasha, 1992). At a more general level, memory for lecture material is going to be influenced by a large number of factors (e.g. prior knowledge) in addition to attention, making it difficult to interpret effects. These difficulties (among others) provide a ready explanation for the variability in the results of studies using performance measures to infer fluctuations in attention during lectures (Wilson & Korn, 2007).

The problems associated with assessing performance as a function of time in lectures has led researchers to use alternative indices of attention. For example, Young, Robinson, and Alberts (2009) used self-reports of subjective mental workload, and Stuart and Rutherford (1978) used students self report of their level of concentration at 5 minute intervals. In addition, Scerbo et al. (1992) measured the amount of note taking, and Bligh (2000) measured heart rate as a function of time. In most cases the results of these studies have supported the general idea that the ability to sustain attention decreases as a function of time in a lecture. However, each measure is limited in both the extent to which there is consensus on whether it reflects 'attention' (e.g., note taking) and in the extent to which one can infer from variations in those measures the potential for performance changes (e.g., heart rate; Wilson & Korn, 2007). In the present investigation we sought a more direct measure of attention that does not rely on performance but nonetheless has a strong track record in being empirically tied to variations in performance.

Mind wandering

Mind wandering represents a decoupling of attention from an external stimulus to internal thoughts (e.g., Smallwood & Schooler, 2006). This decoupling is hypothesized to compromise encoding of information from the external environment. Mind wandering has been demonstrated to have a negative impact on performance across a number of domains (Antrobus, 1968; Giambra, 1995; Schooler, Reichle, & Halpern, 2004; Seibert & Ellis, 1991; Smallwood, McSpadden, & Schooler, 2008). Critically for research on lecture processing, mind wandering has been demonstrated to impair comprehension (Schooler et al., 2004). For example, Smallwood et al. (2008) demonstrated that when participants read a detective story, reports of mind wandering during inference-critical- moments impaired their ability to identify the villian (Smallwood et al., 2008). Such results suggest that mind wandering during a lecture would impair comprehension of the presented material.

Mind wandering and time on task

While time on task effects on mind wandering have rarely been the focus of previous research, it has been demonstrated that mind wandering increases with increases in time on task (McVay & Kane, 2009; Teasdale et al., 1995; Smallwood, Riby, Heim, & Davies, 2006; Smallwood, Obonsawin, & Reid, 2003). One interpretation of this pattern is that these time on task effects are practice effects where time performing a task leads to automation of task performance. According to this idea, practice is thought to reduce the executive control required by the task, thus "freeing up" resources for mind wandering. For example, early in task performance, resources may be required for the maintenance of stimulus response mappings but over time these mappings could be automatized, thus alleviating the cognitive system of needing to devote resources to such maintenance (Mason et al., 2007; Teasdale et al., 1995). With these resources now available, they can be devoted to task unrelated thoughts (i.e., mind wandering). This account has two important components; (1) mind wandering is resource dependent and (2) as time on task increases, task performance becomes less resource dependent due to task automatization. This interpretation is consistent with the types of tasks used, which are typically unfamiliar computer based tasks that are repetitive in nature, therefore permitting practice based improvements within a session. Thus, according to this account, the increase in mind wandering as function of time is caused by the progressive automatization of the task which frees up resources to devote to mind wandering. It is important to note that this is different than the automatic processing that may occur as a result of mind wandering (e.g., you may process stimuli in an automatized manner while mind wandering).

An alternative account of time on task effects can be derived from McVay and Kane's (2010) executive control failure account of mind wandering. According to McVay and Kane (2010), mind wandering results from a failure to maintain attention on the primary task. In terms of time on task, if sustaining attention depletes resources required for executive control (Warm, Dember, & Hancock, 1996; Warm, Parasuraman, & Matthews, 2008), then as time on task increases, the likelihood of a failure in executive control should also increase. Thus, according to this account the increase in mind wandering as a function of time is caused by a time sensitive decrease in the availability of resources rather than the freeing up of resources as a result of task automation.

Both the progressive automatization and executive failure accounts offer general mechanisms to explain time on task effects on mind wandering. Smallwood, Fishman, and Schooler's (2007; see also Smallwood et al., 2008; Smallwood, 2011) cascading inattention account offers an explanation tailored to tasks more similar to lectures. Smallwood et al. (2007), based on research on reading narratives, suggested that mind wandering interferes with the construction of an accurate situation model. The poor situation model impairs the ability of the text to hold the reader's attention (Smallwood et al., 2008; Smallwood, 2011). According to this account, an increase in mind wandering occurs as a result of mind wandering interfering with the ability of the text to hold attention, which leads to further mind wandering which of course leads to further impairments in the situation model and so on. Thus, the increase in mind wandering occurs because of a progressive deterioration of a situation model that impairs foregrounding. It is important to note that the three accounts outlined above are aimed at addressing why mind wandering might increase as a function of time, not necessarily why the mind wanders in all circumstances (though they may of course be related) or what type of processing of external information can occur while mind wandering (Smallwood & Schooler, 2006).

Investigating time on task effects on mind wandering in the context of lectures provides an interesting opportunity to test between the three accounts presented above.

The dynamic nature of lectures combined with the previous experience university students have with lectures make a progressive automatization account of any time on task effect unlikely. This is the case for at least two reasons; (1) lectures lack the consistency in stimulus response mappings that is typically thought to be required to develop automaticity (e.g. Shiffrin & Schneider, 1977; Logan, 1988) and (2) even if listening to a lecture could become automatized, student's extensive experience with lectures prior to the present study would have already lead to that automatized state. The progressive automatization account explains the increase in mind wandering by claiming that the automatization is occurring within the present task. If increases in mind wandering as a function of time are solely the result of task automation, then no time on task effect should be observed in the context of a lecture. The discovery of a time on task effect on mind wandering in the lecture context, however, would be consistent with both the executive failure account (McVay & Kane, 2010) and the cascading inattention account (Smallwood et al., 2007; Smallwood, 2011). Against this background, the investigation of mind wandering in lectures takes on both practical and theoretical significance.

EXPERIMENT 1

Participants were asked to watch a 60-minute lecture in preparation for a test afterward. At four different points in time participants were probed and asked if, at the moment the probe appeared, they were mind wandering. These probes occurred 5, 25, 40 and 55 minutes into the lecture. Thus, there were two probes in each of the first and second halves of the lecture allowing a comparison of mind wandering in the first half to mind wandering in the second half. We decided to be selective in our use of probes so that the act of probing did not disrupt the flow of the lecture. This feature of our design is important as we always run the risk of changing the very nature of what is being studied through reminders that one's state of mind is the subject of investigation (Risko & Kingstone, 2011). For example, too many mind wandering probes could easily lead participants to be in a constant state of reflection about their mental state, a state that we suspect is neither "typical" nor helpful in the context of trying to listen to a lecture. After the lecture participants were given a short test consisting of four multiple-choice questions. The material for each of the four questions was drawn from that presented at the time of each probe (i.e. material for the 5 minute question was drawn from that presented just before the 5 minute mind wandering probe). Thus, the performance measure is similar to that used by Smallwood et al. (2008) where they used probes after inference critical points in a story to investigate the relation between mind wandering and reading comprehension.

The critical test is whether the likelihood that participants report mind wandering is higher in the second half of the lecture than the first half of the lecture. The performance measures also allow both an assessment of time on task effects on memory for lecture material and an assessment of the relation between mind wandering and performance.

Methods

Participants

Sixty undergraduates from the University of British Columbia were paid $5 each or received course credit to participate.

Design

The probes at 5 and 25 minutes were collapsed as were the probes at 40 and 55 minutes in order to create a time on task variable with two levels (i.e. First Half and Second Half). A similar design was used to assess memory for lecture material. The two questions drawn from information presented at the 5 and 25 minute periods (First Half) were combined as were the two questions drawn from information presented at the 40 and 55 minute periods (Second Half).

Stimuli

Three one-hour lectures were used and participants were divided equally across the three lectures. Each lecture was on a different topic (Psychology – Lecture 13, Bloom, 2009; Economics – Lecture 7, Shiller, 2009; Classics – Lecture 2, Kagan, 2009). The lectures were videotaped and consisted of a live lecture in a lecture hall. The camera focused on and followed the lecturer and students were not included in the shot. No slides were presented though in one lecture notes were written on the blackboard (Economics). All of the lectures were obtained from Open Yale Courses (http://oyc.yale.edu/). The mind wandering probe consisted of a black screen that interrupted the lecture. Participants were asked, "Were you mindwandering?" and responded "Y" for yes and "N" for no. The lecture resumed following the participant's response (which typically took less than 10 seconds). The test consisted of four multiple-choice questions created as described above.

Procedure

Participants were brought to the testing room and sat in front of a computer. They were told to watch the lecture and to treat it like a lecture in a course they were taking (i.e. pay attention and try and remember the material) because there would be a test afterward. Participants were also told that at various points in the lecture a screen would appear asking if they were mind wandering at the point the screen appeared. Participants were instructed to consider mind wandering as thinking about something other than the lecture (i.e. task unrelated thought). Following the lecture, the test was administered. The entire experiment took approximately one and a half hours.

Results

Mind wandering

The percentage of 'yes' responses to the mind wandering probes overall was 43%. This amount is comparable to that found in reading tasks (Smallwood & Schooler, 2006). A within subjects ANOVA with Time on Task (First Half vs. Second Half) was conducted on proportion of 'yes' responses to the mind wandering probes. There was a significant effect of time on task, $F(1, 59) = 7.97$, $MSE = 1045.20$, $p < .05$, such that participants reported more mind wandering in the second half (52%) of the lecture than in the first half (35%).

Test performance

Overall participants answered correctly 64% of the questions. This was significantly different than chance (25%), $t(59) = 10.13$, $p < .05$. A within subjects ANOVA with Time on Task (First Half vs. Second Half) was conducted on the proportion of correct responses to the post-lecture test. There was again a significant effect of time on task, $F(1, 59) = 4.72$, $MSE = 1275.07$, $p < .05$, such that participants were more likely to answer questions correctly when they were drawn from the first half of the lecture (71%) than when they were drawn from the second half of the lecture (57%).

Relation between mind wandering and performance

To determine the relation between mind wandering and memory for the lecture material, we split participants into a low mind wandering group ($N = 25$), who self reported mind wandering on less than 50% of the probes, and a high mind wandering group ($N = 35$), who self reported mind wandering on 50% or more of the probes. The low mind wandering group (77%) did significantly better at remembering the lecture material than the high mind wandering group (54%), $F(1, 58) = 9.86$, $MSE = 0.76$, $p < .05$. The dichotomization (into high and low mind wanderers) of a continuous variable could obscure the results (MacCallum, Zhang, Preacher, & Rucker, 2002), thus we also conducted a correlational analysis. This analysis revealed the same pattern, $r = -.32$, $p < .05$, the more an individual mind wandered in the lecture, the poorer they did on the post-lecture test.

Discussion

The results of Experiment 1 demonstrate that mind wandering increases as a function of time during a lecture. Specifically, there was more self-reported mind wandering in the second half of the lecture than in the first half. In addition to the mind wandering results, memory for lecture material was demonstrably worse for questions drawn from the second half of the lecture compared to questions drawn from the first half of the lecture. Lastly, memory for lecture material was related to the amount of self reported mind wandering. Before discussing the implications of these results we report the results of a second study designed to complement Experiment 1.

EXPERIMENT 2

The results of Experiment 1 were based on a small number of observations. As noted in the introduction, the use of a small number of probes was aimed at limiting their influence on lecture processing. For example, we did not want to engage a reflective mental state that was unrepresentative of the mental state of the typical individual listening to a lecture. Nevertheless, a replication would put the results on a stronger footing. In Experiment 2, we replicated Experiment 1. We used the same lectures but choose 4 different probe times (i.e. 2, 20, 35 and 50 minutes) again two in the first half and two in the second half. In addition, we used eight test questions in the post-lecture test. Four of these questions were taken from the time period just prior to the probe and four were taken from the time period after the probe. It is important to note that because the mind wandering probes were moved to different times, the test questions were also different than Experiment 1. Thus, Experiment 2 extends the results of Experiment 1 to a new set of probe times, a new set of questions, and a new sample. A further extension of Experiment 1 was an attempt to better model the lecture setting. Rather than view the lecture individually in the laboratory, we presented the lectures to small groups of participants in a classroom setting.

Methods

Participants

Thirty-five undergraduate students from the University of British Columbia were paid $5 each or received course credit to participate. Twelve participants viewed the Classics and Economics lectures and eleven viewed the Psychology lecture.

Design

The probes at 2 and 20 minutes were collapsed as were the probes at 35 and 50 minutes in order to create a time on task variable with two levels (i.e. First Half and Second Half). A similar design was used to assess memory for lecture material. The two questions drawn from information presented at the 2 and 20 minute periods (First Half) were combined as were the two questions drawn from information presented at the 35 and 50 minute periods (Second Half).

Stimuli

The lectures were the same as those used in Experiment 1. The mind wandering probe consisted of a black screen that interrupted the lecture. Because participants took part in groups in a classroom setting, the lecture was projected onto a screen in the front of the room. In addition, the mind wandering probe remained on the screen for 30 seconds and individuals recorded their response on a piece of paper provided by the experimenter before the lecture began. The test consisted of eight multiple-choice questions created as described above.

Procedure

The procedure was identical to Experiment 1 with the exception that participants took part in groups in a classroom.

Results

Mind wandering

The percentage of 'yes' responses to the mind wandering probes overall was 39%. This is comparable to that found in Experiment 1 (43%). A within subjects ANOVA with Time on Task (First Half vs. Second Half) was conducted on the proportion of 'yes' responses to the mind wandering probes. There was a significant effect of time on task, $F(1, 35) = 5.44$, $MSE = 1109.24$, $p < .05$, such that participants reported more mind wandering in the second half (49%) of the lecture than in the first half (30%).

Test performance

Overall, participants answered correctly on 58% of the questions. This was significantly different than chance (25%), $t(34) = 9.17$, $p < .05$. A within subjects ANOVA with Time on Task (First Half vs. Second Half) was conducted on the proportion of correct responses to the post-lecture test. There was again a significant effect of time on task, $F(1, 34) = 14.72$, $MSE = 660.71$, $p < .05$, such that participants were more likely to answer questions correctly when they were drawn from the first half of the lecture (70%) than when they were drawn from the second half of the lecture (46%).

Relation between mind wandering and performance

We conducted an analysis similar to Experiment 1 comparing memory for the lecture material for a low mind wandering group ($N = 18$), who self reported mind wandering on less than 50% of the probes, and a high mind wandering group ($N = 17$). As in Experiment 1, we compared performance on the pre-probe questions and, despite the smaller sample size, the difference between low (68%) and high mind wanderers (51%) was significant, $F(1, 33) = 2.85$, $MSE = 843.79$, $p = .05$ (one-tailed). A correlation analysis revealed the same pattern, $r = -.32$, $p < .05$ (one tailed), demonstrating that the more an individual mind wandered in the lecture the less accurate their responses on the post-lecture test. Interestingly, this was not true of post-probe questions, $F(1, 33) = .02$, $MSE = 505.11$, $p = .89$ (one-tailed; low mind wanderers = 57%; high mind wanderers 56%), $r = -.15$, $p = .39$., which is consistent with the probes acting as a means of re-orienting attention to the lecture (e.g., Ariga & Lleras, 2011).

Combined experiment 1 and 2 analysis

We also conducted a combined analysis across experiments ($N = 95$). In this combined data set, mind wandering increased as a function of time, $F(1, 94) = 13.55$, $MSE = 1057.67$, $p < .05$, and test performance decreased, $F(1, 94) = 14.07$, $MSE = 1049.69$, $p < .05$. The correlation between overall mind wandering and task performance was also significant, $r = -.30$, $p < .05$. Individuals who mind wandered more performed more poorly on the test. While high mind wanderers performed more poorly overall than low mind wanderers, when considered separately, each group's performance was better in the first than in the second half of the lecture, $F(1, 51) = 6.69$, $MSE = 1229.61$, $p < .05$; $F(1, 42) = 7.64$, $MSE = 856.17$, $p < .05$, for high and low mind wanderers respectively.

We also compared mind wandering and test performance across the three different lectures in two 2 (Time on Task) × 3 (Lecture) mixed ANOVAs. Lecture did not interact with time on task in mind wandering, $F(2, 92) = 2.36$, $MSE = 1027.91$, $p = .10$, but did in terms of test performance, $F(2, 92) = 9.15$, $MSE = 894.48$, $p < .05$. Individual's test performance declined the most in the Classics lecture (73% to 30%), the least in the economics lecture (75% to 77%) and an intermediate amount in the psychology lecture (64% to 51%). This pattern was consistent with the trends in mind wandering, specifically, mind wandering increased the most in the Classics lecture (30% to 61%), the least in the Economics lecture (39% to 47%) and an intermediate amount in the Psychology lecture (31% to 44%). Thus, there is some evidence for across lecture differences in the effect of time on task in terms of both mind wandering and memory for lecture material. Correlations between mind wandering and test performance also revealed evidence for variation across lectures. There was a negative correlation in each lecture, the strongest of which was in the Psychology lecture, $r = -.50$, the correlation in the Economics lecture was intermediate, $r = -.34$, and the weakest correlation was found in the Classics lecture, $r = -.03$. This analysis reveals that in some contexts mind wandering will be a stronger predictor of memory than in other contexts. This result serves as an important reminder that memory for lecture material will be determined by a number of different factors. The evidence presented here (and elsewhere) confirms that one factor that can modulate memory for the lecture material is mind wandering, this much is clear. The variation in the relation between mind wandering and memory, however, underscores the involvement of other factors (e.g. previous knowledge, lecture content, lecture structure). Understanding what modulates the strength of the relation between mind wandering and memory will be important for understanding both the theoretical mechanisms involved and the consequences of mind wandering for education. Importantly, the variability found across lectures in mind wandering, memory and the relation between the two could also be viewed as evidence for malleability. Specifically, it hints that factors exist that could modulate the effect of time on both mind wandering and memory, and the relation between mind wandering and memory. This malleability is critical from an applied perspective and opens up a number of avenues for future investigation.

Discussion

The results of Experiment 2 clearly replicate the results of Experiment 1 with a new sample, different probe times, and different memory test questions. Taken together, Experiments 1 and 2 strongly demonstrate the existence of an increase in mind wandering with time on task in a lecture context and the potentially associated deleterious effects on memory for the lecture. The reported patterns appear to rest on solid ground despite the small number of probes used. This point is methodologically critical as the two experiments provide an existence proof that using just a few thoughtfully placed mind wandering probes can reveal interesting variations in attention with arguably minimal intrusion into the primary task. This would seem to open the door to similar designs being used in other complex domains.

GENERAL DISCUSSION

The results of Experiments 1 and 2 demonstrate clearly that mind wandering increases as a function of time during a lecture. In addition, memory for lecture material appears to decrease as a function of time during a lecture and memory for lecture material was related to the amount of self reported mind wandering. Specifically, individuals who more often self reported mind wandering remembered less about the lecture. The latter two results reinforce the putative relation between mind wandering and memory for lecture material and thus bolster the importance of the central finding regarding the increase in mind wandering as a function of time in a lecture. That said, the decrease in test performance as a function of time should be considered in light of the comments made in the introduction concerning the difficulty in drawing inferences about such effects given the dynamic nature of lectures. Theoretical and practical implications of these findings follow.

Accounting for the time on task effect

The present results are inconsistent with progressive automatization being the cause of time on task effects on mind wandering. Firstly, there is no consistently mapped stimulus response association to automatize in a lecture (e.g. Shiffrin & Schneider, 1977; Logan, 1988) and, more importantly, even if lecture processing could be automatized, it would have been automatized prior to our experiment. The progressive automatization account requires automatization within the task (otherwise no change in mind wandering would be found). Thus, an interpretation in terms of progressive automatization freeing up resources which can be used to mind wander is difficult to maintain in a lecture context. This leaves open the possibility that while mind wandering, individuals process stimuli in an automatized manner. In contrast, McVay and Kane's (2010) executive failure account of mind wandering provides a ready interpretation of the present results. If sustaining attention on the lecture demands executive control and the resources required for control deplete as time on task increases (Parasuraman, 1979), then the likelihood that participants will report mind wandering should also increase as time on task increases. Smallwood et al.'s (2007, 2008; Smallwood, 2011) cascading inattention account can also explain the present results. In this account, mind wandering early on in the lecture impairs the formation of a situation model disrupting the ability of the lecture to hold an individual's attention. The negative feedback loop between mind wandering and disruption to the situation model over time would lead to both an increase in mind wandering over time and a decrease in comprehension. Future work distinguishing between these accounts would provide further insight into fluctuations in attention over time. However, the executive control and cascading inattention accounts likely provide similar predictions (or at least could provide similar predictions) in a number of contexts (e.g. if executive control failures can be viewed as both a cause of situation model impairments and are influenced by the quality of a situation model).

One potential issue with the executive failure account is the assumption that participants prioritize the tasks in the way that they are instructed by the experimenter (i.e. that participants want to pay attention to the lecture). If they do not, then an off task thought (i.e. what we have defined as mind wandering) might not be a "failure" at all (Baars, 2010). With this caveat in mind, it is important to consider accounts of the increase in mind wandering as a function of time in terms of how the motivational state of the participant might change with increases in time on task. For example, recent research on the relation between affect and mind wandering has demonstrated that negative moods lead to an increase in mind wandering (Smallwood, Fitzgerald, Miles, & Phillips, 2009). In addition, research on vigilance tasks and lectures has demonstrated that increasing time on task is associated with increases in frustration (Galinsky, Dember, & Warm, 1993; Warm et al., 2008). This negative affective state, which takes hold as time on task increases, could erode the participant's motivation to stay on task thus leading to an intentional withdrawal of resources from the primary task (Jeffries, Smilek, Eich, & Enns, 2008). For example, participants might withdraw attention in order to focus on less aversive thoughts in order to improve mood or relieve frustration (Smallwood, Fitzgerald, et al., 2009; Smallwood, Nind, & O'Connor, 2009). While in this account the mind wandering remains a result of attentional disengagement, it differs in that the disengagement is caused by the regulation of affective state rather than the failure of executive control. While the former account has focused on mood causing mind wandering, recent work by Killingsworth and Gilbert (2010) suggest that the causal direction may be reversed (i.e. mind wandering decreases mood). Thus, the increase in mind wandering as a function of time in lectures (or the mechanism underlying it) may cause an individual's mood to sour. Interestingly, the role of an individual's affective state (e.g. motivation) in mind wandering has been largely ignored until recently (Kane et al., 2007; Killingsworth & Gilbert, 2010; McVay, Kane, & Kwapil, 2009). Issues concerning affective state (and others) could be investigated by asking participants to provide information about the contents of their "off-task" thoughts and/or their level of interest in the topic. For example, Smallwood, Nind, et al. (2009) demonstrated a prospective (i.e. future thinking) bias in off-task thought that was modulated by level of interest in the material.

Toward an attention aware classroom

The implications of the present work for education are clear. In a standard lecture the ability to sustain attention decreases as a function of time. In addition, the inability to sustain attention is negatively associated with memory for lecture material. Critically, studying mind wandering also provides a straightforward means through which to assess strategies designed to ameliorate this sustained attention decrement. While there exist numerous "methods" for sustaining attention in the classroom (e.g. Bligh, 2000; Frederick, 1986; Young et al., 2009), the effectiveness of these methods is often based on either intuition or speculation. By combining these methods together with measures of mind wandering and memory, the effectiveness of these methods can be determined empirically. For example, rest breaks or task switches are often suggested as a means of maintaining student attention throughout a lecture (Bligh, 2000) and this idea has support in the vigilance literature (e.g. Ariga & Lleras, 2011; Mackworth, 1948). If breaks and task switches are an effective means of improving sustained attention in the later half of a lecture, then this should lead to a reduction in mind wandering in the lecture and an improvement in memory for lecture material post lecture. This method, of course, is not limited to administering a break or a task switch; one could also assess the influence of different forms of media, interactive activities, and variation in content amongst other suggested techniques (e.g. Bligh, 2000; Frederick, 1986; Young et al., 2009). The paradigm can also be used to investigate common student practices (e.g. using laptops in lecture; Fried, 2008) on attention to lecture material.

According to the cascaded inattention account of the increase in mind wandering as a function of time in a lecture (Smallwood et al., 2008; Smallwood, 2011), another means through which to reduce the impact of mind wandering in a lecture would be to periodically attempt to re-instantiate the situation model. Thus, if mind wandering early in lecture impairs an individual's situation model, re-instantiating this model could curb the negative feedback loop between mind wandering and disruption to the situation model over time thus improving comprehension overall. According to this idea, a profitable strategy for the maintenance of student attention in a lecture would involve efforts to sustain attention (e.g. breaks, interactivity) in addition to efforts to limit the impact of inattention (e.g. re-instantiating the situation model periodically).

Another interesting avenue to pursue in terms of addressing the control of attention in lectures is to investigate across-lecture variation in both mind wandering and memory for lecture material. As noted in the combined analysis, there is across-lecture variability in mind wandering and memory for lecture material (and the relation between the two) in the small sample of lectures used here. Other than using a sample of real lectures that were approximately one hour, we did not control content, style, or the relation between the content and our participant's knowledge base. Thus, to some extent across-lecture variation is unsurprising. Nevertheless, as noted above, this variability hints at malleability which will be important to understand from an applied perspective. One potentially relevant note concerning the lectures in the present study is that the students participating would have been largely psychology students and the Psychology and Economics lectures addressed issues that may have been closer to their expertise than the Classics lecture. This might explain why mind wandering would have a greater influence in these lectures (paying attention might permit integration with existing knowledge) and why mind wandering increased and performance decreased the most in the Classics lecture. At this juncture this is only speculation, however, if there is indeed meaningful variation between different lectures, then future studies could include detailed analyzes of lecture characteristics (which would have to include a larger number of different lectures) in order to provide insight into the factors that modulate mind wandering and memory for lecture material. For example, based on the cascaded inattention account, lectures that "build" from beginning to end (i.e. understanding the later parts of a lecture requires understanding earlier parts of the lecture) would be more likely to demonstrate time based increases in mind wandering and memory for lecture material. From this perspective, in addition to aiding in the controlling of attention in lectures, understanding the structural and stylistic aspects of lectures that modulate mind wandering and memory could help distinguish between existing theories. Ultimately, the present work and the avenues it opens up for future research represents a small step in the development of what can be considered an "attention aware" classroom. The goal of which would be to develop a set of principles whose application would enable teachers to maximize student's opportunity to learn by implementing evidence-based practices that optimize student attention.

Everyday attention

The 'everyday cognition' tradition focuses on the investigation of thinking in contexts more akin to those that individuals encounter in the course of their day-to-day lives (Cohen & Conway, 2008). This tradition provides a welcome complement to mainstream cognitive psychology that focuses largely on tasks that bear little to no resemblance to tasks one might encounter beyond the confines of the laboratory (Neisser, 1978). While debate about the relative merits of these different approaches are ongoing (e.g., Banaji & Crowder, 1989; Kingstone et al., 2008; Neisser, 1991; Sebanz, Knoblich, & Humphreys, 2008) and not warranted for comment here, it is interesting to note that research efforts in the everyday cognition tradition have focused largely on memory (Cohen & Conway, 2008), and to a lesser extent on decision making (Woll, 2002); but very little research has been committed to everyday attention despite the obvious importance of attention in the performance of our day-to-day lives. The present work stands as one example (amongst others, for example, attention in driving; Strayer, Drews, & Johnston, 2003) of what could be considered an 'everyday attention' approach. Critically, like the work in memory and decision making, an everyday attention movement would provide an important complement to more mainstream traditions in attention research.

CONCLUSION

The present results demonstrate clearly that mind wandering increases as a function of time while students listen to a lecture. These results put additional constraints on theoretical accounts of time on task as it relates to mind wandering, and extend the mind wandering paradigm to an educational context. Future work combining the presented paradigm with strategies aimed at improving attention in the classroom will certainly help to harness student's learning capabilities.

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