Mind wandering, motivation, and task performance over time

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Here, we examined whether participant motivation plays a role in the fluctuation of attentional engagement and performance over time. We gauged participants' motivation and depth of mind wandering as they completed the metronome response task (MRT) to determine whether fluctuations in inattention (indexed by task performance and depth of mind wandering) would be related to fluctuations in motivation. As in prior work, we found that, with increasing time on task, (a) self-reported depth of mind wandering increased, (b) task performance decreased, and (c) motivation waned. Extending this work, we found an interaction between motivation and mind wandering such that increased rates of motivation were associated with a reduction in the negative effects of mind wandering on performance. These results suggest that motivation may help improve task performance by reducing the depth of mind wandering, while also providing insulation from the negative effects of mind wandering, when it does occur. Data, analysis code, manuscript preparation code, and pre-print available at osf.io/xxxx

Keywords: mind wandering, inattention, motivation time on task

A considerable amount of research has demonstrated that mind wandering and task-performance vary as a function of time on task. In particular, with increasing time on task performance tends to decrease (Helton & Russell, 2011, 2012; Mackworth, 1948; Parasuraman et al., 2009) and mind wandering tends to increase (e.g., Cunningham, Scerbo, & Freeman, 2000; McVay & Kane, 2012; Thomson, Seli, Besner, & Smilek, 2014). Traditionally, time-on=task decreases in performance have been attributed to the depletion of attentional resources (e.g., Caggiano & Parasuraman, 2004; Helton & Russell, 2013; Hirst & Kalmar, 1987; Warm, Dember, & Hancock, 1996). On this view, people are limited in the attentional resources available for information processing at any given moment in time. Moreover, the cumulative cost of sustaining attention over time depletes these resources and results in corresponding decreases in performance.

An alternative view, however, is that increases in time on task result in waning motivation to attend to/perform well on a given task and that such decreases in motivation results in increased mind wandering and decreased task performance (Thomson, Besner, & Smilek, 2015; for similar perspectives, see Hancock, 2013; Kurzban, Duckworth, Kable, & Myers, 2013). Here, we examine the veracity of this motivation account by exploring the role that participant motivation plays in the fluctuation of attentional engagement and performance over time during a laboratory task.

Thomson et al. (2014) have made a strong case for a tight coupling between fluctuations in mind wandering and fluctuations in performance over time-on-task. In their study, participants performed attention tasks (visual search and Flanker tasks) while intermittently responding to thought probes asking them to report whether their current thoughts were "on-task" or "off-task" (i.e., mind wandering). Two particular results are of interest for the current study: First, as in previous research (e.g., Cunningham et al., 2000; McVay & Kane, 2012), when examining rates of mind wandering and task performance over time (i.e., across four blocks), Thomson et al. found a significant linear increase in mind wandering, as well as a significant linear decrease in task performance across both tasks. Second, Thomson et al. examined the possibility that within-subject variations in mind wandering over time were significantly associated with within-subject fluctuations in performance over time. To that end, they calculated individual participant correlations between rates of mind wandering and performance across the experiment to determine whether the average individual correlation was non-zero. Critically, they found (in both the visual search and flanker tasks) that rates of mind wandering did indeed predict task performance. Specifically, at the individual level, blocks with higher rates

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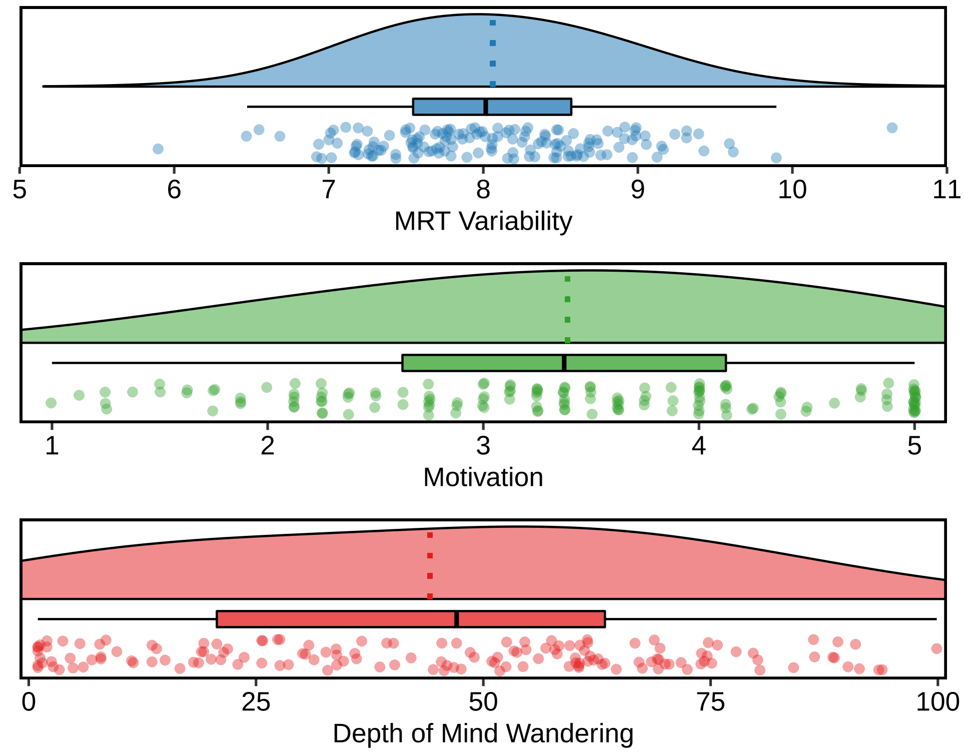

Figure 1. Distributions of participant data for metronome response task (MRT) variability, motivation, and mind wandering, collapsed over trial blocks.

of mind wandering tended to be associated with poorer task performance.

In considering these findings, it may also be useful to also consider Kurzban et al.'s (2013) "opportunity cost" model of the relationship between performance and time-on-task. According to this model, one's attentional resources can be deployed to only a limited number of tasks or mental operations simultaneously. In contrast to resource theorists (e.g., Caggiano & Parasuraman, 2004; Helton & Russell, 2013; Hirst & Kalmar, 1987; Warm et al., 1996), the opportunity cost model suggests that these resources do not decrease over time, but rather, that the prioritization of allocating resources to one task at the expense of other, potentially more rewarding alternatives (i.e., opportunity cost), increases over time. Potentially more rewarding alternatives could include physically performing other tasks (e.g., watching a movie or writing an email to your friend), deliberately thinking about future tasks (e.g., intentional mind wandering), inadvertently finding oneself immersed in task-unrelated thoughts (e.g., unintentional mind wandering). According to the opportunity cost model, when the value of these alternatives exceeds that of the current task, according to the opportunity cost model, one will experience an aversive feeling of mental effort, which causes one to reallocate resources to these alternatives.

Viewing the extant literature on mind wandering through the lens of the opportunity cost model, Thomson et al. (2015) highlighted an important aspect of most research on mind wandering: Namely, that in such research, participants are often presented with monotonous and boring tasks for which good performance tends to confer little in the way of "benefits" (beyond that of pleasing the experimenter and/or contributing to science). Through the lens of the opportunity cost model, then, one ought to expect participants to weigh the costs of attending to such boring and monotonous tasks as greater than the benefits of doing so, and as such, participants should experience relatively high rates of task inattention (or mind wandering) throughout the task. As highlighted by Kurzban et al., however, there is an additional level of nuance to consider. In particular, because the boring and monotonous tasks that researchers provide are often novel to the participants, information pertaining to the expected utility of sustaining attention to the tasks is not immediately available to the participant. Rather, it is only through exposure to such tasks that participants come to gain some appreciation of the costs and benefits of attending to the tasks. Thus, at the outset of the tasks, participants should, given their lack of knowledge pertaining to the potential costs and benefits of attending to the tasks, engage in relatively low rates of inattention/mind wandering, and, over time, as they gain increasing information about the costs and benefits associated with the tasks, they should increasingly value disengagement over engagement; as such, one should observe decreased attentiveness (or increased mind wandering) with time on task.

Importantly, it has recently been posited (Thomson et al., 2015) that the reduced value given to the oft-boring and monotonous tasks employed by researchers of mind wandering might be construed in terms of a reduction in motivation to focus on the task as it unfolds. Thus, given the findings that (a) mind wandering tends to increase over time, and (b) performance tends to deteriorate over time, it is reasonable to suspect that as rates of mind wandering and performance vary with time on task, there ought to be a corresponding change in people's levels of motivation (Thomson et al., 2015). In line with this proposal, several recent studies have reported a link between participants' self-reported levels of motivation and (a) their rates of mind wandering, and (b) task performance. For instance, in Unsworth and McMillan (2013), participants read a passage from a textbook and, while reading, they responded to intermittent thought probes asking them to indicate whether they were "on task" or "mind wandering" just prior to the presentation of each probe. Following the reading task, participants' memory for the text material was tested and, additionally, participants reported their level of motivation to perform well on the task. Results indicated that people who reported lower overall levels of task-based motivation tended to (a) more frequently engage in mind wandering while reading, and (b) perform more poorly on the memory test. Moreover, the researchers found that the association between motivation and test performance was fully mediated by mind wandering: People reporting lower levels of motivation tended to engage in more mind wandering, and this increased propensity to mind-wander was in turn associated with poorer test performance.

Extending the work of Unsworth and McMillan (2013), Seli, Cheyne, Xu, Purdon, and Smilek (2015) sought to determine whether the reported relation between motivation and mind wandering might depend on whether the mind wandering in question occurred with or without intention. In line with an early proposal by Giambra (1995), the authors hypothesized that, because intentional mind wandering appears to be under willful control, it should be negatively associated with participant motivation: Indeed, if an individual is motivated to perform well on a task, it would seem inappropriate to intentionally disengage his thoughts from that task. In terms of the possible link between motivation and unintentional mind wandering, Seli et al. reasoned that, because this type of mind wandering reflects an uncontrolled process, levels of motivation would have little (if any) influence on its rate of occurrence: As they argued, even in the case that an individual were highly motivated to perform well on a focal task, it is reasonable to assume that motivation would have no influence over thoughts that are, by definition, beyond the individual's control. To explore these possibilities, Seli et al. had participants complete a sustained-attention task (the Metronome Response Task; MRT: Seli, Cheyne, & Smilek, 2013), and throughout the task, participants were presented thought probes asking them to indicate whether they were "on task," "intentionally mind wandering," or "unintentionally mind wandering" just prior to the onset of each probe. Additionally, at the end of the study, as in Unsworth and McMillan, participants reported their level of motivation to perform well on the task. As hypothesized, Seli et al. found that, whereas levels of motivation were negatively associated with participants' rates of intentional mind wandering during a sustained-attention task, they were not associated with rates of unintentional mind wandering during the same task (see also, Seli, Wammes, Risko, & Smilek, 2016).

Although the aforementioned studies provide important insights into the relation between motivation and mind wandering, it should be noted that these studies assessed global motivation levels, at the end of the experiments. However, Thomson et al.'s (2015) application of the opportunity-cost model to the mind-wandering literature suggests a more nuanced, tighter coupling of mind wandering, motivation, and performance as they unfold over time. In the present study, we sought to determine whether such temporally dynamic coupling exists by assessing task performance, depth of mind wandering (using thought probes with a continuous response scale; Seli et al., 2014), and participant motivation throughout a sustained-attention task (i.e., the MRT). To index participant motivation over time, we employed a novel probing procedure, which entailed intermittently pausing the task and asking participants to report their current level of task-based motivation. In line with Thomson et al.'s account, we expected to find that fluctuations in inattention (indexed by task performance and depth of mind wandering) would be related to fluctuations in motivation, with a general pattern of decreased motivation over time, coupled with an increase in inattention (i.e., deeper mind wandering and poorer performance).

Moreover, based on work by Unsworth and McMillan (2013), we expected to find that at the within-subjects level, participant motivation would be associated with superior task performance, such that people who report higher levels of motivation should also engage in shallower mind wandering, which should in turn be associated with superior task performance.

Methods

Participants

Participants were 166 individuals who completed a Human Intelligence Task (HIT) posted on the Amazon Mechanical Turk (www.mturk.com). Two participants were removed for not completing the experiment and 15 participants were removed for failing to produce a response to more than 10% of trials, indicating a failure to comply with instructions (see

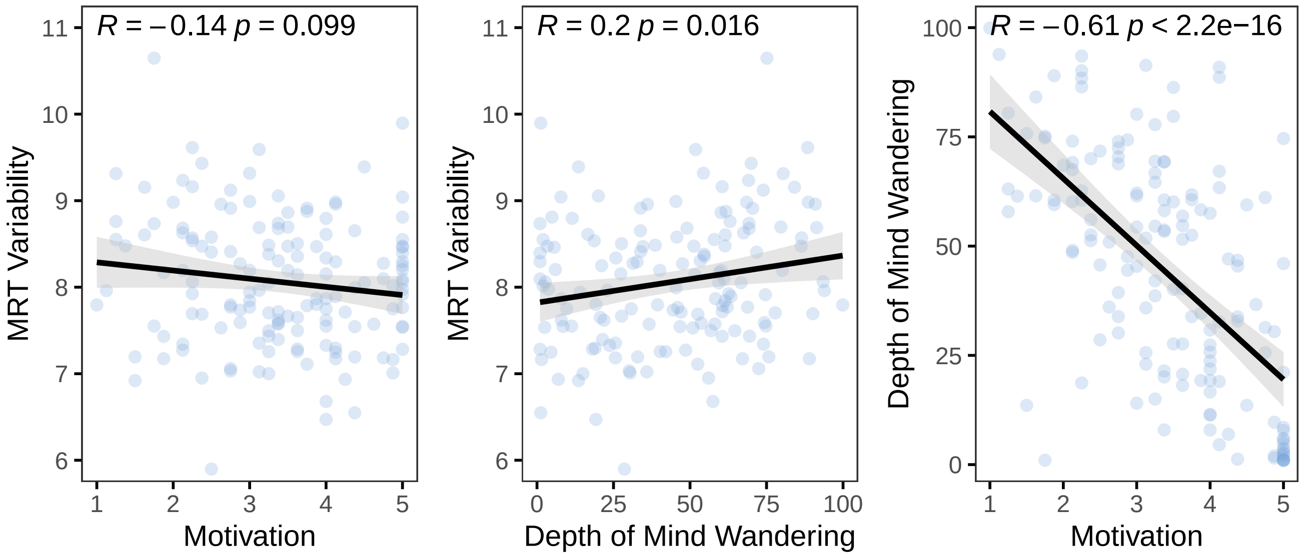

Figure 2. Results showing Pearson correlations between variability in the metronome response task (MRT Variability), motivation, and depth of mind wandering.

Seli, Cheyne, & Smilek, 2013). All participants provided informed consent and were treated in accordance with guidelines approved by the ethics committee at Duke University. Participants were paid $3.00 (U.S. dollars) for completing the HIT, which lasted approximately 20 minutes.

The Metronome Response Task (MRT).

Each MRT trial began with 650 ms of silence followed by the presentation of a tone (lasting 75 ms) and a further 575 ms of silence (total trial duration = 1300 ms). Participants were instructed to "press the spacebar synchronously with the onset of each tone so that your responses are made at the exact time at which each tone is presented." Participants first completed 18 practice trials to familiarize them with the task. Following the practice trials, participants reported their level of motivation to perform well on the task (see below), after which they completed 600 experimental trials.

Participant Motivation

To assess participant motivation, we presented four motivation probes throughout the MRT; this allowed us to assess motivation as the task unfolded. Each motivation probe occurred following the completion of 150 MRT trials. Thus, the first motivation probe was presented after participants completed 150 trials, the second after 300 trials, the third after 450 trials, and the fourth after 600 trials. Upon presentation of each motivation probe, participants saw the following instruction: "We would now like to know about your motivation level over the last few minutes of the task. Please be as HONEST and ACCURATE as possible." The response options were "1, not at all motivated," "2, not very motivated," "3, somewhat motivated," "4, very motivated," or "5, completely motivated."

Thought probes

Throughout the MRT, depth of mind wandering was sampled using intermittently presented thought probes. Four thought probes were randomly presented in each block of 150 trials (for a total of 16 probes). When a thought probe was presented, the task temporarily stopped and the participant was presented with the following question: "To what extent were you mind wandering just before seeing this screen?" Participants were instructed to report their depth of mind wandering by using a sliding scale, the anchors for which were "Not at all Mind Wandering" (which corresponded with a value of 0) and "Fully Mind Wandering" (which corresponded with a value of 100).

Measures

Rhythmic-Response Times (RRTs; Seli, Cheyne, & Smilek, 2013) were calculated on each trial as the difference between the onset of each tone and the associated spacebar press. The mean RRT therefore provides a measure of the extent to which participants approximate the onset of the tone. However, variability in RRTs is the primary measure of interest yielded by the MRT (Seli, Cheyne, & Smilek, 2013). To compute the RRT variability score, we first categorized RRTs in 5-trial moving windows over the task duration. As in Seli, Carriere, et al. (2014), to minimize problems of contamination, we excluded from our computations responses from the first five trials of the MRT, as well as the five responses following each thought probes. Within each 5-trial window, we then computed the variances of the observed RRTs, after which we normalized these scores using a natural logarithm transform (as in Seli, Cheyne, & Smilek, 2013), and then averaged these transformed variance scores for an overall measure of RRT variance (hereafter referred to as "MRT variability"). As we were interested in examining MRT variability as a function of time on task, for each participant, we then calculated MRT variability for each of 4 blocks of 150 trials (which corresponded to the presentation of the motivation probes).

In addition to yielding a measure of response variability, the MRT also yields a measure of omissions, or failures to produce a response on a given trial. Importantly, as in previous work (Seli, Jonker, Cheyne, & Smilek, 2013), we computed omission rates for each participant so that we could remove from our analyses all data from participants whose omission rates were greater than 10%. Omission rates were calculated (as a proportion) by dividing each participant's number of omissions by the total number of MRT trials (600).

Also of interest in the present study were two separate measures of participants' self-reported levels of motivation. First, we were interested in participants' average motivation reports across the entire experimental session (hereafter referred to as "overall motivation"), which was calculated as the mean of the responses to the four motivation probes. Second, we were interested in motivation across each the four blocks of 150 trials: These were simply calculated as the response (1-5) that participants provided upon presentation of each of the four motivation probes at the end of each block.

With respect to measures of mind wandering, of primary interest in the present study was the average depth of participants' mind wandering across the task, which was computed as the sum of their sliding-scale responses (0-100) divided by the total number of thought probes (16). As was the case with MRT variability, because we were interested in examining mind wandering over time, we calculated participants' depth of mind wandering for each of 4 blocks of 150 trials (which corresponded to the four motivation probes that were presented).

Results

This manuscript was prepared using R (R Core Team, 2019). A variety of notable R packages were used for data analysis (Bates, Mächler, Bolker, & Walker, 2015; Fox & Weisberg, 2019; Kuznetsova, Brockhoff, & Christensen, 2017; Singmann, Bolker, Westfall, Aust, & Ben-Shachar, 2019; Wickham et al., 2019; Wickham & Henry, 2019), data visualization (Fox & Weisberg, 2018; Kassambara, 2019; Wickham, 2016; Wilke, 2019), and general manuscript preparation (Aust & Barth, 2018). All data, analysis and manuscript preparation code can be found at osf.io/xxxx.

Overall performance

First, we were interested in examining the between-subjects Pearson product-moment correlation coefficients for overall MRT variability, motivation, and depth of mind wandering across the entire task (i.e., not separated by block). Results indicated that overall MRT variability was significantly associated with overall depth of mind wandering ($r = .20$, 95% CI [.04, .35], $t(147) = 2.43$, $p = .016$) and but not overall motivation ($r = -.14$, 95% CI [−.29, .03], $t(147) = -1.66$, $p = .099$). There was also a significant negative correlation between overall motivation and overall depth of mind wandering ($r = -.61$, 95% CI [−.70, −.50], $t(147) = -9.29$, $p < .001$).

Between Subjects Time-on-task effects

Next, we were interested in examining participants' MRT variability, depth of mind wandering, and motivation levels across the four blocks of 150 trials (see Figure 2). We conducted three separate repeated-measures ANOVAs examining these measures as function of block (4 blocks of 150 trials). Across all three ANOVAs, Mauchly's Tests of Sphericity were significant (all $ps < .001$), and as such, we report the Greenhouse-Geisser corrected values for these analyses. Results of the first ANOVA, which examined MRT variability as a function of block, indicated that there was a significant effect of block, $F(2.6, 385.53) = 33.69$, $MSE = 0.17$, $p < .001$, $\hat{\eta}^2_p = .185$, 90% CI [0.13, 0.24], as well as a significant linear trend, $F(1, 444) = 95.81$, $MSE = 0.15$, $p < .001$, $\hat{\eta}^2_p = .177$, 90% CI [0.13, 0.23]). Thus, as reported in previous work (Thomson et al., 2014), here we found that performance worsens (as indicated by increased MRT variability) over time on task.

Results of the second ANOVA, examining depth of mind wandering as a function of the four blocks, likewise indicated that there was a significant effect of block, $F(2.55, 376.96) = 55.68$, $MSE = 275.07$, $p < .001$, $\hat{\eta}^2_p = .273$, 90% CI [0.21, 0.33], and a significant linear trend, $F(1, 444) = 159.76$, $MSE = 233.54$, $p < .001$, $\hat{\eta}^2_p = .265$, 90% CI [0.21, 0.32]. Consistent with previous work employing dichotomous thought probes (Thomson et al., 2014), this result indicates that the depth of people's engagement in their mind wandering increases as a function of time on task.

Results of the third ANOVA, which examined participant motivation as a function of the four blocks of the MRT, also yielded a significant effect of block, $F(2.13, 315.89) = 52.65$, $MSE = 0.46$, $p < .001$, $\hat{\eta}^2_p = .262$, 90% CI [0.19, 0.32], and a significant linear trend, $F(2.13, 315.89) = 52.65$, $MSE = 0.46$, $p < .001$, $\hat{\eta}^2_p = .262$, 90% CI [0.19, 0.32]. Interestingly, and as predicted by Thomson et al. (2015), this result indicates that people's motivation to perform well on the MRT decreased linearly as the task progressed.

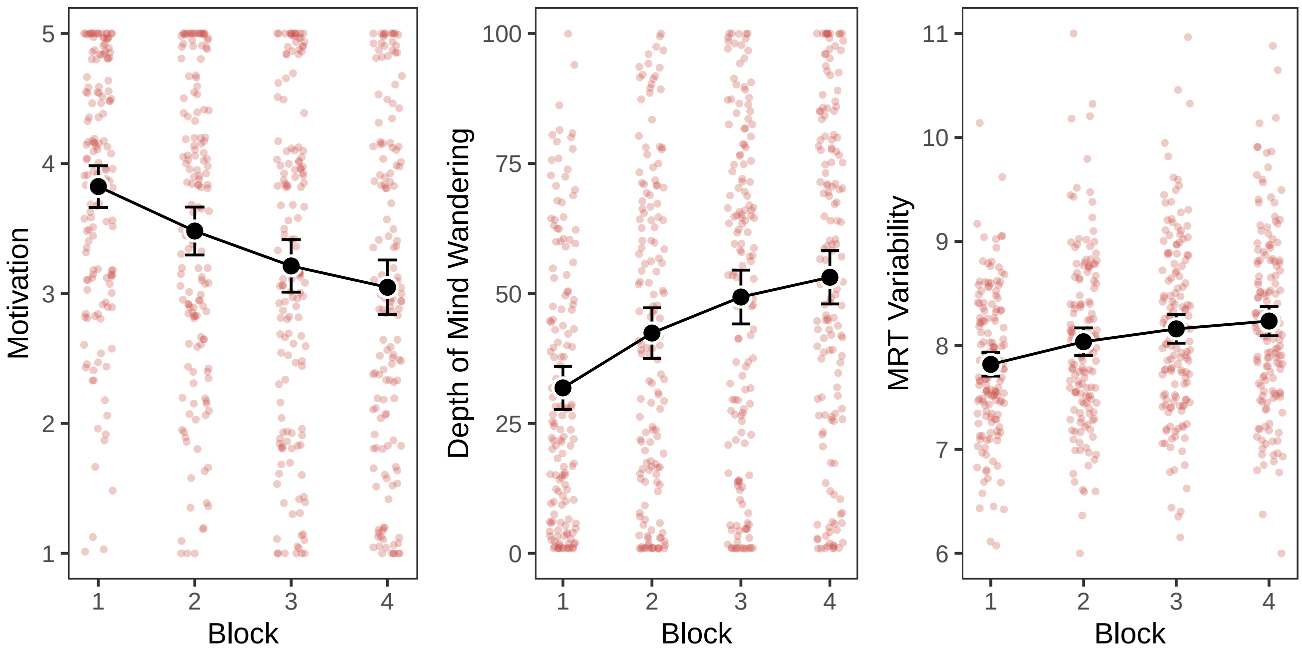

Figure 3. Motivation, depth of mind wandering, and metronome response task (MRT) variability plotted across trial blocks. Means and 95% confidence intervals are plotted over individual data points.

Across-block relationships

To examine the interrelation between motivation and mind wandering and their influence on block-to-block fluctuations in on-task performance, we used mixed-effects models implemented in R (R Core Team, 2019), with MRT variability across blocks as the dependent measure, subjects as random effects, block, depth of mind wandering and motivation as fixed effects. We tested four models (all include block as a fixed factor) with variations of these fixed effects as inputs: (a) mind wandering only; (b) motivation only; (c) both mind wandering and motivation; and (d) mind wandering, motivation, and their interaction.

These analyses could produce several possible outcomes. For example, because overall motivation and mind wandering were correlated across subjects, and because both measures demonstrated similar changes over time, it could be that MRT variability explained by mind wandering and motivation were dependent on shared variance between predictors. In this case both would be significant predictors alone as in models (a) and (b), but neither would be significant in the same model (c and d). Alternatively, mind wandering and motivation could explain some degree of unique variance in MRT variability, such that both are significant predictors (models c or d) or interact (model d).

First, the full model containing both fixed effects as well as the interaction effect (model d) was preferred over both simple models (model a, χ^2 (df = 2) = 12.85, p = 0.002; model b, χ^2 (df = 2) = 25.83, $p < .001$) and over the model with only main effects (model c, χ^2 (df = 1) = 10.71, p = 0.001). Within model d, the fixed effect of mind wandering was significant, $F(1, 541.54) = 22.69$, $MSE = 3.1$, $p < .001$. As was the effect of block, $F(3, 467.25) = 12.85$, $MSE = 1.75$, $p < .001$. The fixed effect of motivation, however, was not, $F(1, 585.18) = 2.23$, $MSE = 0.3$, $p = 0.136$. The main effects were qualified by a significant interaction between motivation and mind wandering, $F(3, 467.25) = 12.85$, $MSE = 1.75$, $p < .001$, demonstrating that the effect of motivation on MRT variability depended on the depth of mind wandering. Specifically, increased motivation was associated in a reduced effect of mind wandering on performance (see Figure 3).

Discussion

In the present experiment, we explored Thomson et al.'s (2015) proposal that time-based variations in mind wandering and task performance might owe to a waning of participant motivation over time (see also Kurzban et al., 2013). Consistent with this proposal, we found that, with increasing time on task, (a) self-reported depth of mind wandering increased, (b) task performance decreased, and (c) motivation waned. These findings provide some initial support for Thomson et al.'s (2015) proposal and suggest that when people have low levels of motivation to perform well on a task they will relinquish control which will in turn result in deeper levels of mind wandering and poorer task performance.

However, we also found an interaction between motivation and mind wandering such that increased rates of motivation

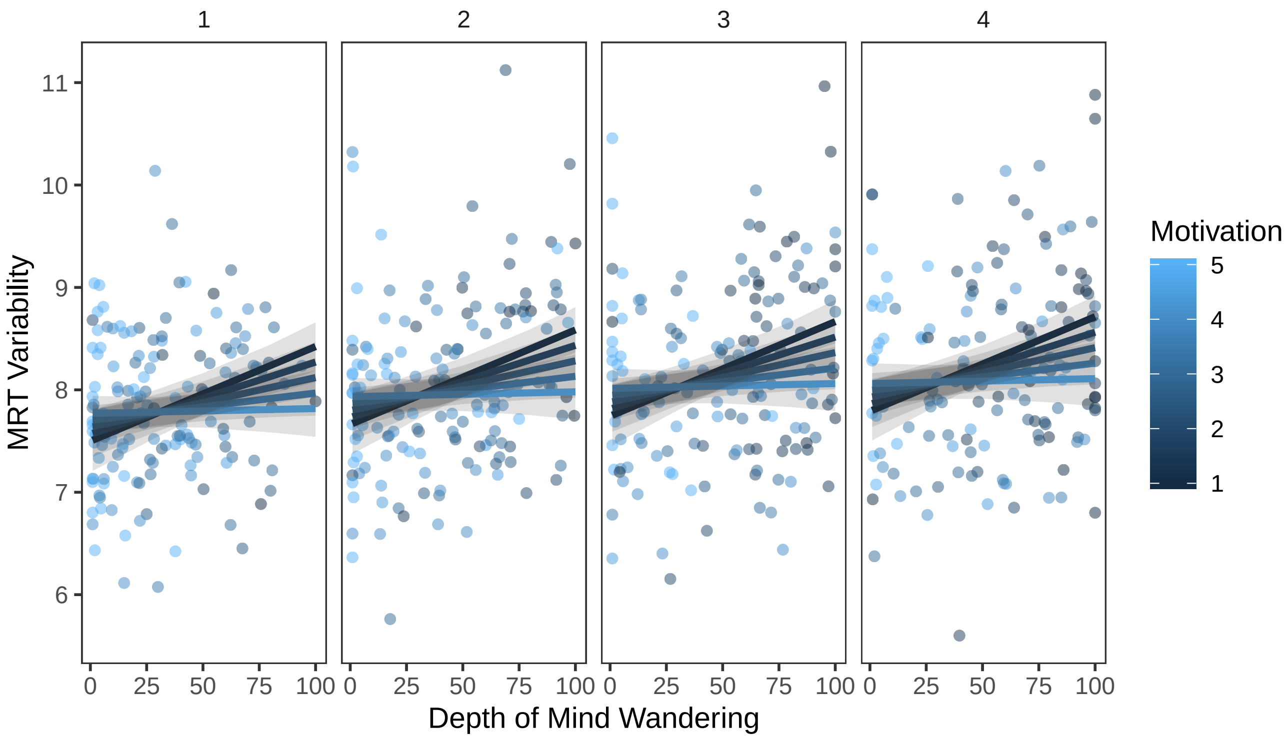

Figure 4. Linear mixed-effect model predictions plotted over participant data; Metronome response task (MRT) variability is plotted as a function of depth of mind wandering and motivation across trial blocks.

were associated with a reduction in the negative effects of mind wandering on performance. Whereas Unsworth and McMillan (2013) found that, at the individual differences level, the influence of motivation on performance was indirect–i.e., mediated by mind wandering–our result suggests a more complex relationship between motivation, mind wandering, and task performance. Although we do find that self-reported motivation is associated with depth of mind wandering, when mind wandering does occur, motivation seems to insulate performance from the negative consequences of inattention. These findings are heartening because they suggest that by manipulating participant motivation, researchers may be able to increase the likelihood that people will value task engagement over disengagement, while also providing insulation from the negative effects of mind wandering, when it does occur.

It is unclear how motivation is able to shield task performance from the negative effects of mind wandering. One possibility is that motivation facilitates participants' automatization of the primary task, freeing up resources for mind wandering, while reducing the negative impact on of mind wandering on performance (Mason et al., 2007; Teasdale et al., 1995; see also, Moors & De Houwer, 2006). Alternatively, motivation may influence cognitive flexibility (Braem & Egner, 2018; Diamond, 2013) and/or task monitoring. If, for instance, we assume that switching between internal and external tasks comes at a cost (e.g., Monsell, 2003), then motivation may enable more flexibility in switching, thereby reducing that cost (Botvinick & Braver, 2015). Motivation may also facilitate on- versus off-task monitoring, such that the influence of mind wandering is reduced because participants become conscious of off-task thoughts quicker and reorient back to the primary task earlier than they would otherwise.

Through the lens of the opportunity cost model, our finding can be interpreted straightforwardly: by incentivizing attentiveness to the task, we shift people's cost-benefit analysis (biasing it toward more benefits than costs), and as such, people are more likely to sustain engagement with the task. As suggested by the present results, this should result in decreased intensity of mind wandering and improved task performance. Given that mind wandering is frequently associated with costly errors (see Mooneyham & Schooler, 2013, for a review), this is particularly encouraging, and suggests a new avenue of research for potential methods of remediation aimed at improving task-attentiveness and performance.

In addition to speaking directly to the literature on mind wandering, the present findings also speak to the resource depletion view of the vigilance decrement. According this view, successful completion of vigilance tasks requires limited attentional resources and as a vigil unfolds over time, the available resources are systematically depleted leading to performance declines over time on task (Helton & Warm, 2008; Smit, Eling, & Coenen, 2004). Along these lines, Helton and Warm (2008 p. 22) note that "observers reported feeling less energetic after the vigil than prior to its start. Decreasing energetic arousal indicates mental fatigue or resource depletion."

From this perspective, our findings could be interpreted such that depleted resources simultaneously causes both lowered motivation and increases in mind wandering. Alternatively, individuals may become less interested in completing the task as it unfolds. The reduction in energetic arousal over time-on-task reported by Helton and Warm (2008) might therefore not reflect resource depletion, but rather increasing levels of boredom that might accompany low levels of motivation. In this case, poor task performance is not caused by a lack of resources, but instead by a reallocation of resources to mind wandering or off-task thoughts.

Two study limitations should be noted. First is the potential ambiguity in participants' interpretation of the motivation probe ("We would now like to know about your motivation level over the last few minutes of the task"). Participants could be answering this as the degree to which they are devoting resources to (i.e., prioritizing) the MRT or to the degree to which they are attempting to overcome their aversion to the task (whether they are successful or unsuccessful). Clarifying the relative contributions of changes in effort to stay on task over time vs. task prioritization over time to performance decrements (e.g., by manipulating reward and/or probe instructions) could have important theoretical implications (Boksem, Meijman, & Lorist, 2006). Another limitation is the smaller number of time points used to calculate the time-on-task effects in motivation compared to mind wandering (motivation: 4 time points, depth of mind wandering: 16 time points). This could have resulted in a noisier measure of the motivation decrement compared to the mind wandering decrement, leading to it predict less variance in block to block performance than mind wandering. Future studies using equal probe rates would be useful to better characterizing the relative contribution of motivation and mind-wandering to time on task performance decreases.

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