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The Role of Mind-Wandering in Measurements of General Aptitude

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Tests of working memory capacity (WMC) and fluid intelligence (gF) are thought to capture variability in a crucial cognitive capacity that is broadly predictive of success, yet pinpointing the exact nature of this capacity is an area of ongoing controversy. We propose that mind-wandering is associated with performance on tests of WMC and gF, thereby partially explaining both the reliable correlations between these tests and their broad predictive utility. Existing evidence indicates that both WMC and gF are correlated with performance on tasks of attention, yet more decisive evidence requires an assessment of the role of attention and, in particular, mind-wandering during performance of these tests. Four studies employing complementary methodological designs embedded thought sampling into tests of general aptitude and determined that mind-wandering was consistently associated with worse performance on these measures. Collectively, these studies implicate the capacity to avoid mind-wandering during demanding tasks as a potentially important source of success on measures of general aptitude, while also raising important questions about whether the previously documented relationship between WMC and mind-wandering can be exclusively attributed to executive failures preceding mind-wandering (McVay & Kane, 2010b).

Keywords: attention, mind-wandering, working memory capacity, fluid intelligence, executive function

The prospect of quantifying an individual's general aptitude with a single variable has been a longstanding aspiration of both academic and commercial research. Motivated as much by practical concerns as scientific parsimony, measures of general aptitude are frequently used when determining access to competitive schools and employment. It is now well documented that performance in a wide variety of contexts can be predicted by measures such as working memory capacity (WMC; Conway, Jarrold, Kane, Miyake, & Towse, 2007; Kane, Hambrick, & Conway, 2005), fluid intelligence (gF; Deary, Strand, Smith, & Fernandes, 2007; Rohde & Thompson, 2007; te Nijenhuis, van Vianen, & van der Flier, 2007), and the Scholastic Aptitude Test (SAT; Frey & Detterman, 2004; Schmitt et al., 2009). However, the underlying reasons for the predictive utility of measures of general aptitude are still under investigation. We propose that mind-wandering—defined as a fluctuation of attention away from a task to unrelated concerns—is associated with impaired performance on these measures of general aptitude, thereby partially explaining the reliable correlations between such measures as well as their broad predictive utility.

This proposal originates from a reassessment of the recently demonstrated link between WMC and mind-wandering. Individuals with high WMC mind-wander less during daily life in circumstances self-rated as challenging or effortful (Kane, Brown, et al., 2007). Furthermore, high-WMC individuals report less mind-wandering and make fewer errors during the sustained attention to response task (McVay & Kane, 2009). These findings have motivated a theoretical account proposing that mind-wandering is a consequence of failures in executive control (McVay & Kane, 2010b; see Smallwood, 2010, for a contrasting perspective). The executive failure account of mind-wandering builds on the view that the complex span tasks used to measure working memory are indicative of an individual's capacity for executive attention: the ability to keep goal-relevant representations in a highly accessible state in the presence of distraction or interference (Engle & Kane, 2003; Kane, Brown, et al., 2007; Kane, Conway, Hambrick, & Engle, 2007). Accordingly, complex span tasks measure executive attention by requiring the recall of stimuli that are presented in alternation with a secondary task that intermittently draws attention away from the to-be-recalled items. Rather than merely testing an individual's capacity to stay focused, complex span tasks create

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a mandatory distraction and examine one's ability to remember items despite it.

On the assumption that complex span tasks measure executive attention, the executive failure view of mind-wandering interprets a negative correlation between performance on complex span tasks and mind-wandering in other contexts as evidence that mind-wandering results from a failure of executive control. However, there is an alternative explanation for why complex span tasks predict mind-wandering. While performance during a complex span task clearly depends on one's ability to appropriately handle the distraction of the unrelated processing task (which serves to briefly divert attention away from the to-be-remembered items), another simple yet unexamined possibility is that task-unrelated thoughts (TUTs) also disrupt performance on the working memory measures themselves. Indeed, mind-wandering is a ubiquitous phenomenon associated with reduced awareness of task stimuli and the external environment (Barron, Riby, Greer, & Smallwood, 2011; Kam et al., 2011; Smallwood, Beach, Schooler, & Handy, 2008), impaired vigilance (Cheyne, Solman, Carriere, & Smilek, 2009; McVay & Kane, 2009; Smallwood et al., 2004, 2008), absent-minded forgetting (Smallwood, Baracaia, Lowe, & Obonsawin, 2003), deficits in random number generation (Teasdale et al., 1995), and poor reading comprehension (Reichle, Reineberg, & Schooler, 2010; Schooler, Reichle, & Halpern, 2004; Smallwood, 2011; Smallwood, McSpadden, & Schooler, 2008). Given that mind-wandering is associated with such a wide range of performance deficits (for a review, see Schooler et al., 2011), it seems likely that mind-wandering that occurs during complex span tasks would also be associated with disruptions to performance.[1] This suggests that the relationship between WMC and mind-wandering on an unrelated task (e.g., McVay & Kane, 2009) may result at least in part from the association between mind-wandering during complex span tasks and the resulting estimation of WMC.

If estimations of WMC are determined not only by one's ability to handle the external distraction of the unrelated processing task but also by the internal distraction of mind-wandering, this would have important implications for the types of evidence that have been used to support the executive failure view of mind-wandering. Linking WMC to mind-wandering in other contexts does not indicate that mind-wandering is a result of executive failure if estimations of WMC are not independent of mind-wandering. Nonetheless, even mind-wandering during complex span tasks could in principle result from executive failures. Rather than falsifying the executive failure view of mind-wandering, evidence that complex span tasks are themselves influenced by mind-wandering would indicate that new lines of evidence would be necessary to determine the precise relationship between these constructs.

If mind-wandering occurs during the measurement of WMC and is associated with worse performance, the same may be true of other measures of general aptitude. This suggests that mind-wandering may contribute to the well-established correlation between WMC and gF (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999). Unsworth and Engle (2005) decomposed a measure of gF (Raven's Advanced Progressive Matrices) and found that the relation between WMC and gF was fairly consistent across items regardless of the level of difficulty, memory load, or rule type (see also Salthouse & Pink, 2008). On the basis of these findings, they suggested that attention may be a possible link between these two measures. Consistent with this proposal, lapses of sustained attention indexed by slow responses during a vigilance task are related to both WMC and gF (Unsworth, Redick, Lakey, & Young, 2010). Additionally, sustained attention and working memory predict overlapping parts of gF (Schweizer & Moosbrugger, 2004). Although gF measures do not include an unrelated processing task and are therefore less obvious measures of executive attention,[2] mind-wandering is an equally applicable source of potential distraction in both types of tasks. Further clarification of the relationship between WMC and gF could therefore come from an investigation of mind-wandering that occurs during the testing of these constructs.

Experimental Overview

Four studies examined the role of mind-wandering during the measurement of general aptitude with the primary aims of establishing whether (a) measures of WMC that have been used to make theoretical claims about mind-wandering are themselves confounded by mind-wandering and (b) whether mind-wandering is correlated with WMC, gF, SAT scores, and the shared variance between these tests. Study 1 measured mind-wandering during three widely used WMC tasks with the hypothesis that mind-wandering during the completion of each measure would be associated with lower WMC. Study 2 examined the trial-by-trial co-occurrence of mind-wandering and impaired WMC performance. This served to establish the relationship between mind-wandering and WMC even within a given individual's performance, while also ruling out a variety of third-variable explanations. To clarify the relationship between mind-wandering and WMC within the context of an experimental paradigm, Study 3 examined whether financial incentives would reduce mind-wandering and thereby improve WMC performance. Finally, Study 4 measured mind-wandering during tests of both WMC and gF with the hypotheses that mind-wandering during these tasks would be associated with SAT scores and with a latent variable capturing the shared variance between multiple measures of general aptitude.

[1] In principle, one could maintain or recover access to task-relevant representations despite the distraction of mind-wandering in much the same way that participants recall to-be-remembered items in complex span tasks despite the distraction of the unrelated processing task. This indicates mind-wandering cannot simply be defined as executive failure because the occurrence of mind-wandering does not guarantee that the representations of to-be-remembered items will be lost. The occurrence of mind-wandering is only an executive failure if the task-relevant representations are lost as a result.

[2] The term *executive control* is used in numerous ways to refer to a varied set of cognitive processes. Existing work indicates that a popular measure of gF—Raven's Progressive Matrices—does recruit a variety of executive control processes, some of which overlap with the *executive attention* that complex span tasks are designed to measure (e.g., resolving proactive interference from prior trials; Unsworth & Engle, 2005).

Study 1

Participants

One hundred fifteen undergraduates (35 male) from the University of California, Santa Barbara (UCSB), participated in exchange for course credit (mean age = 18.98 years, *SD* = 0.99).

Procedure

All participants completed automated versions of the operation span task (OSPAN), reading span task (RSPAN), and symmetry span task (SSPAN) in a counterbalanced order (Unsworth, Heitz, Schrock, & Engle, 2005). These complex span tasks present to-be-remembered stimuli in alternation with an unrelated processing task (i.e., verifying the accuracy of an equation in the OSPAN, the meaningfulness of a sentence in the RSPAN, and the vertical symmetry of an image in the SSPAN). In each of 15 OSPAN and RSPAN trials, the to-be-remembered items were sets of three to seven letters chosen from a pool of 12 and presented for 250 ms. In each of 12 SSPAN trials, participants recalled the location of two to five red squares presented for 650 ms within a 4×4 matrix. The sequence of set sizes was standardized for all participants. At the end of each trial, participants selected the presented items in the serial order in which they appeared. Following standard procedure for these WMC tasks (Conway et al., 2005), eight participants with accuracy rates of less than 85% on the unrelated processing task (including errors caused by failing to respond within a response deadline based on latencies [$M + 2.5$ *SD*s] for 15 practice items) were excluded from the analysis. Span scores were calculated as the total number of items recalled in correct serial order across all trials (Conway et al., 2005). Because the total number of trials and stimuli vary across complex span tasks, a WMC composite for each participant was computed as the *z*-score average (mean) of the three span scores.

At unpredictable intervals during each span task, three trial response screens were replaced with thought-sampling probes which asked participants to indicate to what extent their attention was either on-task or on task-unrelated concerns using a 1–5 Likert-type scale (1 = *completely on-task,* 2 = *mostly on-task,* 3 = *both on the task and unrelated concerns,* 4 = *mostly on unrelated concerns,* 5 = *completely on unrelated concerns*). This thought-sampling procedure provides the opportunity to assess mind-wandering during the crucial moment of task processing. After answering the thought probe, participants were instructed that they would begin a new trial. A mind-wandering score was computed for each task by calculating the mean of the three thought-probe responses. A composite mind-wandering variable for each participant was computed as the mean of the three mind-wandering scores.

Results and Discussion

To examine whether thought sampling affected performance, we compared the OSPAN scores of the participants in this study to those of 97 participants (six excluded based on criteria specified above) who completed an unrelated study during the same period of the academic year. Univariate analysis of variance (ANOVA) revealed no difference in proportion of items recalled between those who completed the OSPAN with experience sampling (M = .651, SD = .228) or without (M = .622, SD = .231), $F(1, 197) = 0.915$, $p = .340$. This indicates that the experience sampling did not significantly impact performance.

We then addressed the role of mind-wandering during the performance of three WMC tasks. Table 1 presents the means, standard deviations, and correlations among measures of mind-wandering and WMC. Significant correlations were found between the three span scores as well as between the three mind-wandering scores. As hypothesized, within each of the three span tasks, those individuals who mind-wandered more during testing had lower WMC scores. The correlation between the composite WMC and composite mind-wandering variables was $-.40$ ($p < .001$). These findings suggest that measures of WMC may predict mind-wandering in other contexts (e.g., McVay & Kane, 2009) at least in part because mind-wandering during these measures is associated with the resulting estimates of WMC.

Both subjective and empirical accounts suggest that mind-wandering is a graded phenomenon. Accordingly, measuring mind-wandering using a 1–5 scale may capture variance that is missed when using a dichotomous measure of on-task versus off-task (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Franklin, Smallwood, & Schooler, 2011; Mrazek et al., 2011). Yet, given the common practice of using dichotomous measures of mind-wandering, we also examined whether our findings would persist after transforming our continuous measurement of mind-

Table 1
Correlations Among Mind-Wandering and Working Memory Capacity Measures

Variable	1	2	3	4	5	6
1. OSPAN	—					
2. RSPAN	.485***	—				
3. SSPAN	.429***	.237*	—			
4. OSPAN TUT	−.269**	−.179	−.255**	—		
5. RSPAN TUT	−.239*	−.359***	−.292**	.501***	—	
6. SSPAN TUT	−.196*	−.123	−.335***	.457***	.552***	—
M	40.39	34.87	16.22	1.54	1.77	1.61
SD	13.58	13.56	6.35	0.59	0.79	0.70

Note. $N = 107$. OSPAN = operation span task; RSPAN = reading span task; SSPAN = symmetry span task; TUT = task-unrelated thought.
* $p < .05$. ** $p < .01$. *** $p < .001$.

wandering into a dichotomous variable of on-task (when respondents reported a 1, indicating they were fully on task) versus off-task (when respondents reported a 2–5, indicating they were to some extent thinking of task-unrelated concerns). This transformation was the most appropriate for this data (as opposed to an extreme split such as 1–2 vs. 4–5) because (a) any degree of off-task thought can be considered mind-wandering and (b) most participants reported being fully on task at the majority of thought probes, making this transformation the equivalent of a median split. Using this approach, performance on each of the complex span tasks was negatively correlated with the number of mind-wandering episodes during that task (OSPAN, $r = -.200$, $p = .039$; RSPAN, $r = -.285$, $p = .003$; SSPAN, $r = -.362$, $p < .001$). The composite complex span score was also negatively correlated with the total number of mind-wandering reports across all three tasks ($r = -.338$, $p < .001$).

Study 2

Although Study 1 demonstrated that individual differences in mind-wandering during testing are associated with lower estimates of WMC, a more comprehensive understanding can be derived from examining whether mind-wandering on a given trial is associated with impaired performance on that trial. Although a trial-by-trial analysis still cannot definitively indicate directionality in the relationship between mind-wandering and WMC, it can rule out a number of possible alternative explanations. For example, if the relationship occurs because people who mind-wander more under any circumstance also have working memory performance detriments, then we would not necessarily expect to observe the co-occurrence of mind-wandering and impaired trial performance even within a given individual. Another possible account for the relationship between mind-wandering and performance is that participants who are having difficulty with the task may struggle to remain engaged. This view predicts that the relationship between mind-wandering and performance should be limited to trials in which task performance is challenging. If mind-wandering and poor performance co-occur even on trials with small set sizes, then it is less tenable that mind-wandering is a consequence of task performance. Finally, to examine the additional possibility that the link between mind-wandering and WMC may be a consequence of task frustration or test anxiety, Study 2 included a retrospective measure of task-related interference (TRI; e.g., thinking about how well you are performing) and a measure of trait test anxiety. If WMC is unrelated to these measures, then we can be reasonably confident that the relationship between mind-wandering and WMC is not the product of task frustration or test anxiety.

Participants

Sixty-seven undergraduates (35 male) from the UCSB participated in exchange for course credit (mean age = 18.64 years, $SD = 1.08$).

Procedure

Participants completed a version of the OSPAN that was the same as in Study 1 except as indicated below. To provide sufficient sampling within each set size, 60 OSPAN trials were divided equally into set sizes of three, five, or seven letters. On 60% of these trials, thought probes using the same Likert-type scale as in Study 1 occurred after the response screen (but before receiving trial feedback), asking participants to indicate their focus throughout the prior trial. In total, 12 thought probes occurred at each set size. Span scores were calculated as in Study 1. One participant was excluded from the analysis for accuracy of less than 85% on the unrelated processing task of the OSPAN. Retrospective reports of TUT and TRI were collected using the thinking and content component of the Dundee State Stress Questionnaire (Matthews, Joyner, Gilliland, Huggins, & Falconer, 1999). Test anxiety was measured using the Reactions to Tests (RTT) scale (Sarason, 1984).

Results and Discussion

In a replication of Study 1, overall mind-wandering was associated with overall WMC ($r = -.426$, $p < .001$). We next addressed the trial-by-trial relationship between these variables. OSPAN data are frequently analyzed using an absolute scoring method in which participants receive credit for a trial only if they recall all of the items (Conway et al., 2005). This allows trials to be binned based on accuracy. A paired-samples *t* test revealed that participants mind-wandered more during inaccurate trials ($M = 2.44$) than accurate trials ($M = 1.76$), $t(65) = 7.48$, $p < .001$.

Because only 21 participants had variation in both accuracy and mind-wandering within each of the three set sizes, we chose to use a trial-by-trial analysis in which each trial was treated as an individual case to test for an interaction between trial accuracy and set size. Each case was associated with a participant's unique identifier to control for differences that existed between participants. Following the statistical procedure described in Bland and Altman (1995), mind-wandering was treated as the continuous outcome variable, accuracy (categorical) and set size (continuous) were included as predictor variables, and participant was treated as a categorical factor using dummy variables (therefore having 66 degrees of freedom). This model was significant, $R^2 = .468$, $F(1, 2342) = 30.18$, $p < .001$. Accurate trials were associated with less mind-wandering ($\beta = -.199$, $p < .001$), whereas set size was not ($\beta = .016$, $p = .374$). As illustrated in Figure 1, there was also an interaction between accuracy and set size such that the impact of set size was only relevant for inaccurate trials ($\beta = .081$, $p = .012$). This interaction suggests that regardless of set size, attention must be relatively focused on the task to achieve complete trial accuracy. By contrast, mind-wandering was greater at small set sizes than at large set sizes for inaccurate trials. This could be because errors at large set sizes may also be a result of the inherent difficulty of these longer trials. Nonetheless, *t* tests revealed that the simple slopes at conditional values corresponding to the three set sizes were all significantly different from zero, indicating that mind-wandering predicted performance at each set size (3: $t = 9.65$, $p < .001$; 5: $t = 16.08$, $p < .001$; 7: $t = 4.81$, $p < .001$).

Mind-wandering may predict performance above and beyond the overall trial accuracy, so we examined the trial-by-trial relationship between mind-wandering and the proportion of items recalled. A multiple regression model was created in which proportion of items recalled was treated as the continuous outcome variable, mind-wandering and set size were included as continuous

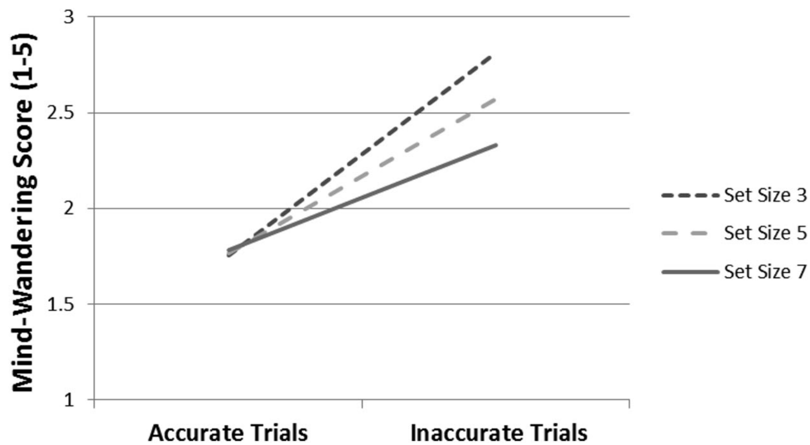

Figure 1. Interaction of set size and trial accuracy on mind-wandering. Accurate trials were those in which all stimuli were recalled in the correct serial position.

predictor variables, and participant was treated as a categorical factor using dummy variables. This model was significant, R^2 = .381, $F(1, 2411) = 20.89$, $p < .001$, with both mind-wandering and set size explaining a significant amount of unique variance in WMC. Impaired trial performance was associated with greater mind-wandering ($\beta = -.263$, $p < .001$) and larger set sizes ($\beta = -.394$, $p < .001$). As illustrated in Figure 2, there was an interaction between mind-wandering and set size such that the impact of mind-wandering on trial performance was greater at larger set sizes ($\beta = -.089$, $p < .001$). Also, *t* tests revealed that the simple slopes at conditional values corresponding to the three set sizes were all significantly different from zero, once again indicating that mind-wandering was associated with impaired performance at each set size (3: $t = 6.40$, $p < .001$; 5: $t = 21.00$, $p < .001$; 7: $t = 12.14$, $p < .001$).

We next conducted a lag analysis to determine whether poor performance on a trial led to more mind-wandering on the subsequent trial. A multiple regression model was created in which mind-wandering was treated as the continuous outcome variable, prior trial accuracy was treated as a categorical predictor variable, and participant was treated as a categorical factor using dummy variables. This overall model was significant, R^2 = .367, $F(1, 2411) = 23.90$, $p < .001$, but prior trial accuracy did not explain a significant amount of unique variance in subsequent mind-wandering ($\beta = -.026$, $p = .130$). A similar model using proportion of items recalled correctly instead of overall trial accuracy was also significant, R^2 = .368, $F(1, 2411) = 24.052$, $p < .001$, and there was a modest association between proportion of items recalled on the prior trial and subsequent mind-wandering ($\beta = -.066$, $p = .006$). The fact that performance on a trial is weakly associated with mind-wandering on the next trial would be expected if there is any consistency in these variables across the task (e.g., mind-wandering on Trial 1 is associated with a greater likelihood of mind-wandering on Trial 2). To disentangle these relationships, a multiple regression model was created in which proportion of items recalled was treated as the continuous outcome variable, both mind-wandering on that trial and mind-wandering on the subsequent trial were treated as continuous predictor variables, and participant was treated as a categorical factor using dummy variables. This overall model was significant, R^2 = .270,

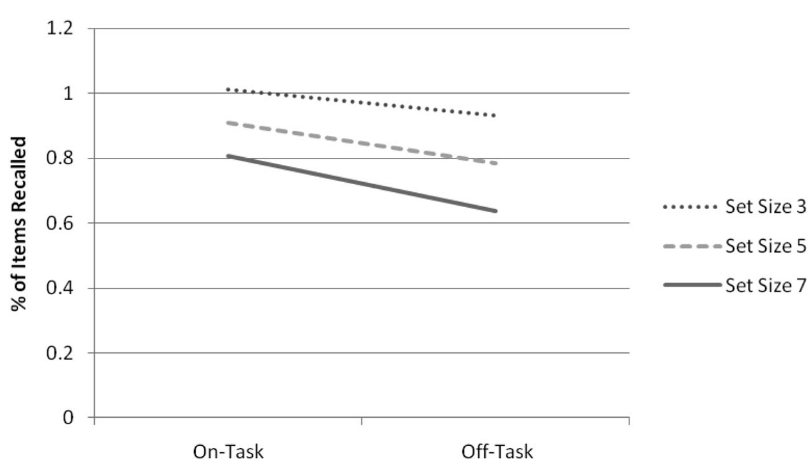

Figure 2. Interaction of mind-wandering and set size on WMC. On-task and off-task are calculated as the 25th and 75th percentiles of mind-wandering reports (such that on-task is ~1 and off-task is ~3 on the 1–5 scale).

$F(1, 2411) = 6.469$, $p < .001$. Whereas mind-wandering during a trial continued to be a strong negative predictor of trial performance ($\beta = -.401$, $p = .000$), mind-wandering on the subsequent trial became a positive predictor of trial performance ($\beta = .126$, $p = .001$). This may indicate that when taking into consideration the consistency of mind-wandering across trials, performing poorly on a trial is associated with slightly reduced mind-wandering on the subsequent trial. This interpretation is consistent with the recent demonstration that correlated activity between a *default mode* region (posterior parietal cortex, thought to underlie off-task thought) and a *task-positive* region (dorsolateral prefrontal cortex, thought to underlie task performance) is associated with worse current trial performance but enhanced performance on the subsequent trial (Prado & Weissman, 2011).

Finally, we examined whether WMC was predicted by test anxiety or retrospective reports of either TRI and TUT (see Table 2). As predicted, retrospective TUT was correlated with both the online measure of mind-wandering ($r = .426$, $p < .001$) and WMC ($r = -.329$, $p = .007$). By contrast, WMC was not significantly related to either TRI ($r = -.191$, $p = .121$) or any of the subscales from the RTT measure of test anxiety (Tension: $r = -.086$, $p = .489$; Worry: $r = -.181$, $p = .143$; TUT: $r = -.104$, $p = .401$; Bodily Sensations: $r = -.067$, $p = .592$).

Study 2 provides further evidence that mind-wandering during complex span tasks is associated with lower estimations of WMC, while also ruling out a variety of possible explanations for the relationship. There was a co-occurrence of poor trial performance and mind-wandering that persisted across set sizes. Given that all participants had the capacity to perform well on trials requiring the recall of only three letters, the association between mind-wandering and WMC is not simply a result of mind-wandering on trials that exceed one's capacity. WMC was also not related to test anxiety or TRI, indicating that the link between mind-wandering and WMC was not merely an artifact of worrying or analyzing one's performance. By contrast, retrospective reports of TUT were correlated with both the experience sampling measure of mind-wandering and overall estimates of WMC. Finally, poor trial performance did not result in more mind-wandering on the subsequent trial, providing further evidence against the explanation that poor WMC performance causes mind-wandering.

Table 2
Correlations Among Thought and Performance Measures

Variable	1	2	3	4	5
1. OSPAN	—				
2. OSPAN TUT	−.426***	—			
3. Retrospective TUT	−.329**	.552***	—		
4. Retrospective TRI	−.191	.186	.333**	—	
5. Test anxiety (RTT)	−.137	.211	.192	.364**	—
M	186.46	1.99	1.98	2.85	2.02
SD	52.99	0.71	0.72	0.64	0.55

Note. $N = 66$. OSPAN = operation span task; OSPAN TUT = mind-wandering during OSPAN; Retrospective TUT = mind-wandering measured after OSPAN; Retrospective TRI = task-related interference measured after OSPAN; RTT = Reaction to Tests scale (all subscales).
** $p < .01$. *** $p < .001$.

Study 3

Although the within-subject correlations between mind-wandering and estimates of WMC suggest that mind-wandering may disrupt performance, the correlational designs of Studies 1 and 2 are limited in their ability to support causal claims. Study 3 aimed to provide stronger evidence regarding the relationship between these constructs by examining whether the effect of financial incentives—an experimental manipulation known to improve complex span task performance (Heitz, Schrock, Payne, & Engle, 2008)—is mediated by a reduction in mind-wandering.

Participants and Procedures

One hundred thirty undergraduates (44 male) from the UCSB participated in this study (mean age = 18.87 years, $SD = 1.00$). All participants completed the OSPAN task as described in Study 1, except as described below. At five unpredictable intervals during the 20-trial OSPAN, a thought-sampling probe occurred using the same procedure described in Study 2.

Half of the participants were randomly assigned to an experimental condition in which they would receive a financial incentive based on their task performance. Following several practice trials, these participants read instructions describing that a typical payment could be as much as $5.00 and that it would be determined equally by both their accuracy on the math problems and their ability to recall the letters. Following completion of the OSPAN task and before payment, all participants were asked whether they had believed that the financial incentive was a genuine offer. Five participants expressed skepticism, with several reporting they had been deceived in other experiments. These participants were dropped from analyses, along with two participants who were excluded for accuracy of less than 85% on the unrelated processing task of the OSPAN. At the end of the experimental session, all participants were paid $5.00.

Results and Discussion

Replicating Studies 1–2, there was a negative correlation between mind-wandering and OSPAN performance ($r = -.211$, $p = .02$). As found by Heitz et al. (2008), participants who received the financial incentive recalled more letters during the OSPAN ($M = 69.61$, $SD = 2.26$) than those who did not ($M = 63.40$, $SD = 2.21$), $F(1, 123) = 3.87$, $p = .05$. There was also significantly less mind-wandering among those who received the financial incentives ($M = 1.55$, $SD = .09$) compared to those who did not ($M = 1.82$, $SD = .09$), $F(1, 123) = 4.63$, $p = .03$. On the basis of the directional effects from Study 2, we examined a mediational model in which financial incentives reduce mind-wandering and thereby improve performance. As illustrated in Figure 3, the effect of the financial incentive on performance was significantly mediated by mind-wandering. When considered in light of Studies 1–2, these results provide converging support that mind-wandering may disrupt WMC performance.

Study 4

An executive attention view of WMC emphasizes the ability to maintain and recover access to task-relevant stimuli that are periodically unattended. Complex span tasks assess this ability by

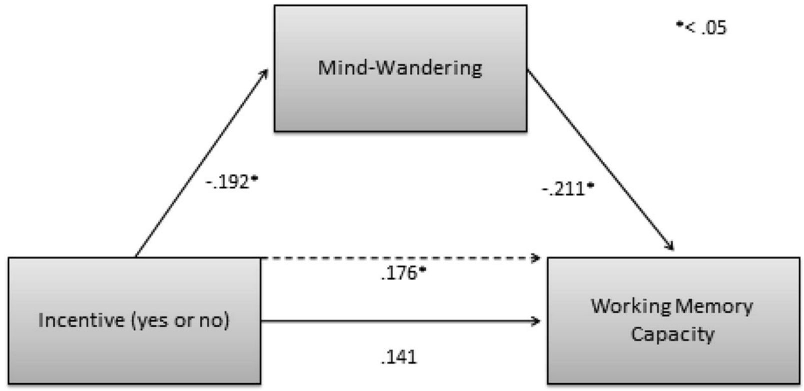

Figure 3. Bootstrapping was used to calculate a confidence interval around the indirect effect. A 95% confidence interval based on 5,000 resamples was [0.01, 4.05]. Zero falls outside this confidence interval, indicating that the mediation effect was significant ($p < .05$).

presenting to-be-recalled items in alternation with a secondary processing task. However, Studies 1–3 suggest that TUTs may serve as an additional source of distraction. Given that mind-wandering could be a source of distraction during any test, TUTs may also be associated with performance on tests of gF. Study 4 therefore embedded thought sampling into tests of both WMC (measured using the OSPAN) and gF (measured using Raven's Progressive Matrices [RPM]) with the hypotheses that mind-wandering would (a) be associated with worse task performance, (b) predict performance on the SAT taken by participants 1–3 years before (thereby providing important ecological validity for the relationship described in this article), and (c) be strongly associated with a latent variable capturing the shared variance between these measures of general aptitude.

Participants

One hundred thirty-nine undergraduates (46 male) from the UCSB participated in exchange for course credit (mean age = 18.75 years, $SD = 1.04$).

Procedure

All participants completed the OSPAN and the final two sets of RPM in a counterbalanced order. The OSPAN was administered as described in Study 1. RPM is a culture-fair measure of abstract reasoning (Raven, 1938). The two most challenging sets (D and E) were used, each consisting of 12 questions presented in ascending order of difficulty. Each question consists of a 3 × 3 matrix of geometric figures with the bottom right figure missing. Following one practice question, participants were given 20 min to answer as many questions as possible by selecting from eight alternatives the figure that completes the overall series of patterns. A final score was computed as the total number of correct solutions.

At eight unpredictable intervals during RPM, a thought-sampling probe asked participants to indicate to what extent their attention was either on task or on task-unrelated concerns using the same procedure described in Study 1.[3] Participants were alerted to answer these questions on the computer by a beep. After answering the thought probe, participants were instructed to resume their paper-and-pencil test. A mind-wandering score was calculated for each task by taking the mean of the eight thought-probe responses. A composite mind-wandering variable for each participant was computed as the mean of the mind-wandering scores in the OSPAN and RPM.

Following these tasks, participants referenced the registrar's website to report the exact SAT scores they submitted when applying to college. A mean score was computed for 15 participants who took the SAT multiple times. Eleven participants had not taken the SAT. Eight participants were excluded from the analysis for accuracy of less than 85% on the unrelated processing task of the OSPAN.

Results and Discussion

Study 4 addressed the role of mind-wandering during the testing of WMC (via the OSPAN) and gF (via RPM). Table 3 presents the means, standard deviations, skew, kurtosis, and correlations among measures. Significant correlations were found between the WMC and gF scores, as well as between the mind-wandering scores across these two tests. In a replication of Studies 1 and 2, mind-wandering during the OSPAN task was negatively correlated with WMC. Similarly, those individuals who mind-wandered more during RPM performed less well on this test of gF. As hypothesized, mind-wandering that occurred during laboratory testing was also predictive of SAT performance. The correlation between the composite mind-wandering variable and SAT scores was −.38 ($p < .001$).

Study 4 provided an additional opportunity to assess whether participants mistakenly responded to thought probes based on their

[3] Although Study 1 found that thought sampling did not influence performance on the OSPAN, 39 separate participants completed the same RPM task either with or without thought sampling to confirm that there was also no issue of reactivity in RPM. A univariate ANOVA revealed no difference in total number of correct solutions between those with thought sampling ($M = 19.32$, $SD = .655$) and those without ($M = 19.80$, $SD = .638$), $F(1, 37) = 0.281$, $p = .600$. Only 19 participants had thought-sampling data, but we observed a nonsignificant negative correlation between mind-wandering and task performance ($r = -.183$, $p = .45$).

Table 3
Correlations Among Mind-Wandering and Performance Measures

Variable	1	2	3	4	5
1. Raven's	—				
2. OSPAN	.241**	—			
3. Raven's TUT	−.370***	−.272**	—		
4. OSPAN TUT	−.241**	−.277**	.558***	—	
5. SAT	.471***	.314***	−.355***	−.317***	—
M	18.23	35.34	1.66	1.59	1,808.92
SD	3.03	12.08	0.60	0.68	181.01
Skew (*SE*)	−0.16 (.21)	−0.31 (.21)	1.04 (.21)	1.04 (.21)	−0.18 (.22)
Kurtosis (*SE*)	−0.58 (.42)	−0.16 (.42)	1.28 (.42)	0.54 (.42)	−0.30 (.44)

Note. $N = 131$, except $N = 120$ for SAT analyses. Raven's = Raven's Progressive Matrices; OSPAN = operation span task; Raven's TUT = mind-wandering during Raven's; OSPAN TUT = mind-wandering during OSPAN; SAT = Scholastic Aptitude Test.
** $p < .01$. *** $p < .001$.

assessment of their task performance (i.e., reporting that they had mind-wandered simply because they had performed poorly rather than because they were actually mind-wandering). If mind-wandering rates predict variance in SAT scores above and beyond WMC and gF task performance, this would be further evidence that mind-wandering reports are not simply indications of participants' appraisal of their task performance. A simultaneous regression model predicting SAT scores from WMC, gF, and composite mind-wandering revealed that the three predictors explained approximately 29% of the variance in SAT scores, $R^2 = .289$, $F(1, 116) = 15.74$, $p < .001$. Those who mind-wandered more during the laboratory tasks scored lower on the SAT ($\beta = -.17$, $p = .05$, $sr^2 = .03$), even when controlling for WMC and gF. This relationship indicates that participants' responses to thought-sampling probes were not merely reflections of their assessments of their task performance.

Having confirmed that fluctuations of attention during testing are associated with WMC, gF, and SAT scores, structural equation modeling was used to test the hypothesis that mind-wandering would be associated with a latent variable capturing the shared variance between these measures of general aptitude. As illustrated in Figure 4, a model with two latent variables was created using Amos statistical software. Data screening indicated that the skew and kurtosis of the mind-wandering variables were within acceptable standards (Kline, 2011) and that all participants had scores within four standard deviations of the mean for each analyzed variable. The mind-wandering latent variable consisted of the mind-wandering scores during the OSPAN and RPM. The general aptitude latent variable consisted of WMC, gF, and SAT scores. The resulting model had an adequate participant-to-parameter ratio of 11:1 (Kline, 2011). Each of the measures loaded significantly on their respective constructs. The path from mind-wandering to general aptitude was $\beta = -.70$, indicating that mind-wandering predicted 49% of the variance in general aptitude. Several statistical tests confirmed that the fit of the model to the data was good, $\chi^2(4, N = 120) = 2.891$, $p = .58$; Hoelter Index = 391; standardized root-mean-square residual = .029; root-mean-square error of approximation = .000, 90% confidence interval [.000, .120]; comparative fit index = 1.000.[4]

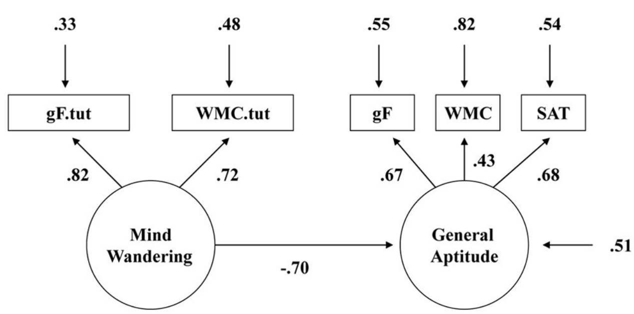

Figure 4. $N = 120$. Structural equation modeling for general aptitude and mind-wandering during testing. The path connecting the two latent variables (circles) reflects the association between the constructs. The numbers from the latent variables to the manifest variables (rectangles) indicate the loadings of each measure onto the latent variable. All error terms represent unexplained variance ($1 - R^2$). gF.tut = task-unrelated thought during Raven's Progressive Matrices; WMC.tut = task-unrelated thought during the operation span task (OSPAN); gF = fluid intelligence assessed via Raven's Progressive Matrices; WMC = working memory capacity assessed via the OSPAN; SAT = Scholastic Aptitude Test scores.

Study 4 confirms that mind-wandering during tests of either WMC or gF is associated with lower estimates of an individual's capabilities as indexed by two widely used and broadly predictive tests. Moreover, the mind-wandering that occurred during laboratory testing was also predictive of scores on the SAT. This indicates that the association between mind-wandering and performance generalizes to an important measure of educational success taken by more than a million students each year. Finally, the role of mind-wandering during tests of general aptitude also suggests that the reliable correlations between these measures may be at least partially explained by the amount of TUT that occurs during testing. Indeed, structural equation modeling suggests that as much as 50% of what is shared across measures of general aptitude can be explained by mind-wandering.

[4] Moderate skew and kurtosis of the mind-wandering variables were within acceptable standards (Kline, 2011), but we nonetheless confirmed that nonparametric path estimates were comparable and that logarithmic transformation of these variables led to equivalent fit statistics.

General Discussion

These studies converge in support of the proposal that mind-wandering during testing is consistently associated with lower estimates of general aptitude. Individuals who mind-wandered more during WMC and gF testing performed less well, and an individual's WMC performance was worse on those trials during which mind-wandering occurred. Furthermore, the performance enhancement among individuals offered a financial incentive was mediated by a reduction in mind-wandering. Finally, mind-wandering during tests of WMC and gF predicted scores on the SAT, a high-stakes test that weighs heavily in undergraduate admissions decisions. In fact, nearly 50% of the shared variance between WMC, gF, and SAT scores was explained by mind-wandering. Future research will be necessary to determine whether other cognitive capacities tested by these measures (e.g., abstract reasoning) have predictive utility even when controlling for the mind-wandering that occurs during testing. It may be that a substantial proportion of what makes tests of general aptitude sufficiently general is that they create a demanding task context in which mind-wandering is highly disruptive.

The present studies also raise important questions regarding the role of executive control in mind-wandering. Prior work has argued that mind-wandering results from executive failure based on several strands of evidence, with perhaps the most central being the association between WMC and mind-wandering (Kane, Brown, et al., 2007; McVay & Kane, 2009, 2010a, 2010b). However, the present work demonstrates that the measurement of executive attention using complex span tasks is confounded with mind-wandering. The claim that mind-wandering results from executive failure can therefore not be made on the basis of the association between complex span tasks and mind-wandering in other contexts.

Nonetheless, the present work does not rule out the possibility that mind-wandering results from executive failure. Even the mind-wandering during complex span tasks could in principle result from executive failures. New lines of evidence that eliminate or control for the occurrence of mind-wandering while measuring executive control will help determine the precise relationship between these constructs. Disentangling the causal relationship between mind-wandering and executive processes will ultimately provide important insight into our understanding of these phenomena. For instance, executive processes may facilitate mind-wandering in contexts when prioritizing TUTs over task focus is adaptive (Baars, 2010). Indeed, recent findings suggest that at least under some circumstances mind-wandering can be functional both by promoting future planning (Baird, Smallwood, & Schooler, 2011) and enhancing creative incubation (Baird et al., 2012). If distracting thoughts can lead to task impairment but also possess some functionality, then an important executive process may be the successful prioritization of mind-wandering over other competing goals. One source of individual variation in mind-wandering may therefore be the number and salience of ongoing task-unrelated goals that require conscious reflection.

Causal data are not necessary when demonstrating that mind-wandering both confounds measurements of executive control and is strongly associated with the shared variance between measures of general aptitude, but further consideration of what constitutes a causal demonstration is warranted given the inherent causal relationship implied by claims that executive failures lead to mind-wandering or that mind-wandering disrupts task performance. Definitive demonstrations of causality are challenging, especially when the variables in question cannot be directly manipulated (as we believe is currently the case for both mind-wandering[5] and executive processes). Yet, even without direct experimental manipulations, evidence of covariation, temporal precedence, and elimination of alternative explanations can converge in support of causal claims (Cook, Thomas, & Campbell, 1979). The present studies have demonstrated covariation between mind-wandering and performance both between and within individuals, presented a variety of arguments supportive of a temporal sequence in which mind-wandering precedes poor performance rather than vice versa, and ruled out alternative explanations such as mind-wandering being a consequence of poor performance, task frustration, or test anxiety. Given the longstanding tendency to ascribe causality to simple correlations between mind-wandering and performance, the current article represents a considerably more rigorous, if not complete, demonstration that mind-wandering may disrupt task performance.

Although general aptitude has traditionally been regarded as unchangeable, recent evidence indicates that intensive training on working memory tasks produces improvements that generalize to tests of gF (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). While the cause of this improvement is unknown, the present studies raise the exciting possibility that performance on tests of general aptitude might be improved by methods that reduce mind-wandering during testing. Consistent with this proposal, Jha, Stanley, Kiyonaga, Wong, and Gelfand (2010) recently demonstrated that decrements in WMC resulting from stressful predeployment military training can be offset by mindfulness exercises. Furthermore, Tang et al. (2007) found that meditation training improved performance on RPM (although only marginally more than a control condition). The conceptual and empirical link between mind-wandering and mindfulness (Mrazek, Smallwood, & Schooler, 2012) suggests that future research should investigate whether the impact of mindfulness training on tests of general aptitude is mediated by a reduction in mind-wandering. Given the apparent costs of mind-wandering, strategies for reducing its occurrence during demanding tasks may significantly improve performance in a broad range of critically important situations.

[5] While our ongoing efforts indicate that mindfulness training may be a particularly effective technique for reducing mind-wandering, mindfulness may also influence a variety of additional cognitive processes (such as metacognitive regulation) and therefore cannot be considered an unpolluted experimental manipulation of mind-wandering.

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