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Working memory capacity and mind-wandering during low-demand cognitive tasks☆

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A B S T R A C T

Individual differences in working memory capacity (WMC) typically predict reduced rates of mind-wandering during laboratory tasks (Randall, Oswald, & Beier, 2014). However, some studies have shown a positive relationship between WMC and mind-wandering during particularly low-demand tasks (Levinson, Smallwood, & Davidson, 2012; Rummel & Boywitt, 2014; Zavagnin, Borella, & De Beni, 2014). More specifically, Baird, Smallwood, and Schooler (2011) found that when individuals with greater WMC do mind-wander, they tend entertain more future-oriented thoughts. This piece of evidence is frequently used to support the context-regulation hypothesis, which states that using spare capacity to think productively (e.g. plan) during relatively simple tasks is indicative of a cognitive system that is functioning in an adaptive manner (Smallwood & Andrews-Hanna, 2013). The present investigation failed to replicate the finding that WMC is positively related to future-oriented off-task thought, which has implications for several theoretical viewpoints.

1. Introduction

Recently, cognitive psychology has experienced a surge of interest into mind-wandering (Callard, Smallwood, Golchert, & Margulies, 2013; Smallwood & Schooler, 2006, 2015). The field has attempted to answer questions about how mind-wandering occurs, for whom and when it most often occurs, and what effects it has on behavior. Several hypotheses have been developed to explain empirical findings. The hypotheses addressed in the present study are the context-regulation hypothesis (Smallwood & Andrews-Hanna, 2013), the cognitive flexibility hypothesis (Rummel & Boywitt, 2014) and the executive failure hypothesis (McVay & Kane, 2009, 2010, 2012a, 2012b). In the present study, we address two unresolved issues within the field. Specifically, how do individual differences in working memory capacity (WMC) relate to tendencies to mind-wander during tasks that make relatively low demands on attention? And, when individuals with high WMC mind-wander, do they tend to use their excess mental capacity to engage in future-oriented thought?

Typically, research has shown that individuals with greater WMC, and thus a greater ability to maintain task goals and to restrict their attention to currently relevant information, show a lower tendency to mind-wander (Kane et al., 2016; McVay & Kane, 2009, 2012a, 2012b; McVay, Unsworth, McMillan, & Kane, 2013; Mrazek et al., 2012; Robison, Gath, & Unsworth, 2017; Robison & Unsworth, 2015; Unsworth & McMillan, 2013, 2014; Unsworth & Robison, 2016). This set of findings is largely consistent with the executive failure hypothesis (McVay & Kane, 2009, 2010, 2012a; McVay & Kane, 2012b), which argues that individuals with

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low WMC experience more frequent failures of goal maintenance, which sometimes manifest as mind-wandering. Individuals with greater WMC maintain task goals in mind, avoid the intrusion of irrelevant internal thoughts, and proceed with the task more consistently. The oft-observed negative correlation between WMC and mind-wandering supports this idea. Indeed a recent meta-analysis of the relationship between cognitive abilities and mind-wandering found that the bulk of existing evidence supported this hypothesis (Randall, Oswald, & Beier, 2014).

Despite this typical finding, some studies have shown null relationships between WMC and mind-wandering during certain tasks. For example, Smeekens and Kane (2016) showed a null relation between WMC and mind-wandering during several versions of a divergent thinking task, as well as the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). McVay and Kane (2012a) also showed a null relation between WMC and mind-wandering during a vigilance version of the SART. So there may be instances in which the general negative relationship does not hold. Furthermore, some studies have shown that when the demands of a task are particularly low, WMC and mind-wandering tendencies actually show a positive relationship (Levinson, Smallwood, & Davidson, 2012; Rummel & Boywitt, 2014). In these situations, it is hypothesized that individuals with high WMC have sufficient mental capacity both to mind-wander and to complete the task successfully. Leveraging the finding that people mind-wander more during tasks with low perceptual load (Forster & Lavie, 2009), Levinson et al. (2012) gave participants a visual search task with two conditions: high and low perceptual load. Under the low-load conditions, WMC positively correlated with mind-wandering rate. Under the high-load conditions, there was a null relationship between WMC and mind-wandering rate. Further, a second experiment asked participants to simply count their breaths and to report both self-caught and probe-caught instances of mind-wandering. During this task, WMC again positively correlated with probe-caught mind-wandering (Levinson et al., 2012). From these findings, Levinson et al. (2012) argue that working memory resources are actually necessary for mind-wandering, and those with greater WMC can actually mind-wander more when their resources are not consumed by external task demands. Additionally, Zavagnin, Borella, and De Beni (2014) gave participants two versions of the SART, the classic perceptual version and a more difficult semantic version. They found that individuals with greater WMC who reported more cognitive failures in their daily lives showed more frequent mind-wandering during the perceptual SART.

In another recent study, Rummel and Boywitt (2014) compared the relationship between WMC and mind-wandering in a relatively non-demanding task (1-back) versus a more demanding version of the task (3-back). They found a negative relationship between WMC and mind-wandering during the 3-back version and a positive relation during the 1-back version. From these findings, Rummel and Boywitt (2014) proposed the cognitive flexibility hypothesis, which argues that the relationship between WMC and mind-wandering depends on task demands. When task demands are low, high-WMC individuals may actually mind-wander more than low-WMC individuals because they have the capacity to do so. But when task demands are high, high-WMC individuals will flexibly adjust their attention to focus on the task, avoiding mind-wandering.

Finally, the context-regulation hypothesis (Smallwood, 2013; Smallwood & Andrews-Hanna, 2013) argues that a high-functioning cognitive system (as is presumably present in high-WMC individuals) regulates the occurrence of self-generated thoughts in a manner that reduces mind-wandering when it can hamper task performance. But during situations in which demands on attention are relatively low, self-generated thoughts play a functional role in planning, creativity, and patience (Baird, Smallwood, & Schooler, 2011; Baird et al., 2012; Smallwood, Ruby, & Singer, 2013). Specifically, Baird et al. (2011) found that when individuals with higher WMC mind-wander, they tend to think about the future, and this form of mind-wandering can be functional autobiographical planning. Baird et al. (2011) had participants complete a choice reaction time task in which participants indicated whether rare target digits (10%) were even or odd. This task had previously been used to study mind-wandering specifically because it made little demands on working memory resources and induces more mind-wandering than tasks that make greater demands on working memory (Smallwood, Nind, & O'Connor, 2009). So at least in some situations, high-WMC individuals may be able to adjust their attention-regulation to meet the external demands of the environment.

Given the evidence addressed above, the bulk of findings that support the executive failure hypothesis may actually mask the complex relationships among WMC, mind-wandering, and task demands because of their exclusive use of highly demanding tasks (Kane & McVay, 2012). These studies have used tasks that make relatively high demands on attention and cognitive processing, such as the Stroop task (Kane et al., 2016; McVay et al., 2013; Robison et al., 2017; Unsworth & McMillan, 2014), the SART (Kane et al., 2016; McVay & Kane, 2009, 2012a; McVay et al., 2013; Unsworth & McMillan, 2014), the antisaccade task (Kane et al., 2016; Robison et al., 2017; Unsworth & McMillan, 2014), flanker tasks (Kane et al., 2016; Unsworth & McMillan, 2014), psychomotor vigilance tasks (Robison et al., 2017; Unsworth & McMillan, 2014), reading comprehension tasks (McVay & Kane, 2012b; Robison & Unsworth, 2015; Unsworth & McMillan, 2013), and working memory tasks (Mrazek et al., 2012; Unsworth & Robison, 2016). All of these tasks can be considered highly demanding, and thus these studies may only find a negative relationship between WMC and mind-wandering because of the conditions under which mind-wandering tendencies were measured. Further, attempts to replicate the finding that high-WMC individuals tend to mind-wander about the future have failed to do so (McVay et al., 2013). However, in both studies analyzed by McVay et al. (2013), mind-wandering was measured during the course of relatively demanding tasks like reading comprehension, Stroop, and SART, which are more demanding than the choice reaction time task employed by Baird et al. (2011). Therefore, their indirect attempt to replicate the WMC-future thought relationship may have been hindered by the exclusive use of attention-demanding measures.

To reconcile these discrepancies, the present study attempted to replicate Baird et al. (2011), both directly and conceptually. To accomplish this, we gave participants three complex span tasks to measure WMC and two low-demand choice reaction time tasks, one of which replicated that used by Baird et al. (2011). The digit reaction time task has previously been used to study mind-wandering because it makes little demand on working memory resources (Smallwood et al., 2009). For this reason we have characterized it as "low-demand." The other low-demand task was a similar choice reaction time task in which few working memory resources are required for successful completion. Finally, we used multiple measures of WMC so we could analyze the relationships at the latent level.

2. Method

2.1. Participants and procedure

Participants were recruited through the University of Oregon undergraduate pool. A total of 140 participants completed all the measures of WMC, the choice reaction time task, and the digit reaction time task. A subset of 16 participants were excluded because they scored below chance on one or both of the two reaction time tasks (presumably due to a mismapping of response keys), leaving a final sample of 124 participants. Participants completed the tasks individually during the course of a two-hour session. The complex span, choice reaction time, and digit reaction time tasks comprised roughly an hour and 15 min of the session. Participants completed other measures of reading comprehension and attention, which were not analyzed in the current study but have been reported previously (Robison & Unsworth, 2015). Specifically, the task order was operation span, symmetry span, reading task, reading test, two psychomotor vigilance tasks, the digit reaction time task, and the choice reaction time task. After the session, participants were debriefed and given partial course credit for participating.

2.2. Tasks

2.2.1. Working memory capacity

2.2.1.1. Operation span. In this task (Unsworth, Heitz, Schrock, & Engle, 2005), participants solved a series of math operations while trying to remember a set of unrelated letters. Participants were required to solve a math operation, and after solving the operation, they were presented with a letter for 1 s. Immediately after the letter was presented the next operation was presented. At recall participants were asked to recall letters from the current set in the correct order by clicking on the appropriate letters. For all of the span measures, items were scored correct if the item was recalled correctly from the current list in the correct serial position. Participants were given practice on the operations and letter recall tasks only, as well as two practice lists of the complex, combined task. List length varied randomly from three to seven items, and there were three lists of each length for a total possible score of 75. The score was total number of correctly recalled items in the correct serial position.

2.2.1.2. Symmetry span. Participants recalled sequences of red squares within a matrix while performing a symmetry-judgment task. In the symmetry-judgment task, participants were shown an 8×8 matrix with some squares filled in black. Participants decided whether the design was symmetrical about its vertical axis. The pattern was symmetrical half of the time. Immediately after determining whether the pattern was symmetrical, participants were presented with a 4×4 matrix with one of the cells filled in red for 650 ms. At recall, participants recalled the sequence of red-square locations by clicking on the cells of an empty matrix. Participants were given practice on the symmetry-judgment and square recall task as well as two practice lists of the combined task. List length varied randomly from two to five items, and there were three lists of each length for a total possible score of 42. We used the same scoring procedure as we used in the operation span task.

2.2.1.3. Reading span. While trying to remember an unrelated set of letters, participants were required to read a sentence and indicated whether or not it made sense. Half of the sentences made sense, while the other half did not. Nonsense sentences were created by changing one word in an otherwise normal sentence. After participants gave their response, they were presented with a letter for 1 s. At recall, participants were asked to recall letters from the current set in the correct order by clicking on the appropriate letters. Participants were given practice on the sentence judgment task and the letter recall task, as well as two practice lists of the combined task. List length varied randomly from three to seven items, and there were three lists of each length for a total possible score of 75. We used the same scoring procedure as we used in the operation span and symmetry span tasks.

2.2.2. Reaction time

2.2.2.1. Choice reaction time. In this task, participants responded as quickly as possible to the appearance of a stimulus in one of four locations on the screen (Unsworth, Redick, Spillers, & Brewer, 2012). The stimulus consisted of a cross presented in white Courier New 32-point font centered at one of four underlined locations. After a random time interval (300–550 ms in 50-ms intervals), the cross appeared randomly in one of the four locations with the exception that the stimulus could not appear in the same location on consecutive trials. During the inter-trial interval, the four possible stimulus locations were marked by four equally-spaced horizontal lines as place holders along the vertical center of the screen. Participants were instructed to be as fast and accurate as possible. They indicated the location of the cross by pressing one of four buttons on the keyboard (F, G, H, J), corresponding to the four possible locations. Participants completed 15 practice trials and 210 scored trials, 15 of which were followed by thought probes.

2.2.2.2. Digit reaction time. This task most directly replicated that used by Baird et al. (2011) and Smallwood et al. (2009). On each trial, a random digit (1–9) appeared in either green or black font. Participants were instructed to only respond to green targets (8% of trials), indicating whether the digit was even or odd with one of two keys as quickly and accurately as possible. Participants completed 30 practice trials and 144 scored trials, 15 of which were followed by thought probes. Trials were separated by a 1250 ms inter-trial interval.

2.2.3. Thought probes

For the choice and digit reaction time tasks, participants were informed that they would be periodically asked to report the contents of their thoughts. During the instructions, they were given the six probe responses and told to be as accurate as possible in describing their thoughts immediately preceding the probe. Probes appeared randomly throughout the two reaction time tasks. Specifically, participants saw:

What were you just thinking about?

1. The current task
2. My performance on the task or how long it is taking
3. A memory from the past
4. Something in the future
5. Current state of being
6. Other

Response 1 was recorded as on-task, response 2 as task-related interference, and responses 3 – 6 as mind-wandering. Response 3 was recorded as past-oriented mind-wandering, response 4 as future-oriented mind-wandering, and response 5 as present-oriented mind-wandering. "Other" responses were recorded as mind-wandering for totals and proportions, but were not given a temporal orientation. If participants were confused about the thought probe categories, the researcher gave some examples for each category. For response 2, an example would be "I wonder how much longer this task is going to take." For response 3, an example would be thinking about a conversation the participant had over the previous weekend. For response 4, an example would be mentally planning a trip for the upcoming weekend. For response 5, an example would be present-related thoughts like "I'm getting kind of hungry." We acknowledged that some thoughts might not fall neatly into one of the five categories, so we encouraged participants to use the Other response for these thoughts.

3. Results

We first analyzed the temporal focus of mind-wandering by summing past-, future-, and present-focused off-task reports, as well as "other" responses and divided these each by the total number of off-task reports. The resulting proportions are depicted in Fig. 1. Overall, mind-wandering rates were lower for the choice reaction time compared to the digit reaction time task (paired-samples $t(123) = 6.95$, $p < 0.001$),[1] which was probably due to the choice reaction time task being slightly more engaging than the digit reaction time task, as it required a response on every trial as opposed to 8% of trials. Present-focused (32%) and future-focused (31%) reports were the most common, followed by past-focused (26%). Within the current data, there was no prospective or retrospective bias to mind-wandering. This was confirmed by a repeated measures ANOVA with temporal focus (past, present, future, and other) as a within-subjects variable. Although there was a main effect of temporal focus ($F(3, 366) = 7.79$, $p < 0.001$, partial $\eta^2 = 0.06$), follow-up Bonferroni-corrected comparisons showed that "other" responses were less frequent than all other responses (all $ps < 0.001$). No other comparisons were significant ($ps > 0.30$).

Next, we examined off-task thought as a function of task and WMC. Correlations among scores on the WMC and reaction time tasks as well as descriptive statistics are shown in Table 1. As can be seen there were moderate correlations across tasks and with reports of mind-wandering, suggesting both convergent and discriminant validity. Notably, the complex span tasks each showed negative correlations with mind-wandering on both reaction time tasks. So at the zero-order level, WMC appears to predict fewer instances of mind-wandering on even these low-demand tasks.

To examine how WMC correlated with future-, past-, and present-oriented mind-wandering, we created a single composite WMC score by averaging each participant's standardized operation span, symmetry span, and reading span scores. Reports of future-, past-, and present-oriented, as well as reports of "other" thoughts were summed across the two reaction time tasks, and correlated with the WMC composite score (Table 2). This analysis allowed us to see how the number of mind-wandering instances of various temporal focus correlated with WMC (i.e., mind-wandering occurrences). Next, we calculated proportions of off-task thought attributable to future-, past-, present-, and other-related thoughts by dividing each of these totals by each participant's total number of off-task thoughts. This analysis allowed us to examine the hypothesis that when high-WMC participants mind-wander, they tend to think about the future, which can be a functional use of off-task thought (i.e., proportions of mind-wandering). The resulting correlations with WMC are shown in Table 3. Baird et al. (2011) showed a null relationship between WMC and total off-task reports, but a positive relationship with the proportion of off-task thought attributed to the future. So we wanted to ensure we examined the correlations from both angles. WMC did not positively correlate with the proportion of mind-wandering attributed to future-oriented thoughts, which is inconsistent with Baird et al. (2011), but is consistent with McVay et al. (2013). So at both the task and composite level, WMC did not show a positive relationship with future-oriented thoughts during relatively low-demand tasks.

Finally, to examine WMC and mind-wandering at the latent level, we performed a confirmatory factor analysis on the three complex span tasks and total mind-wandering reports from the reaction time tasks. Specifically, the three complex span tasks were

[1] Although the mind-wandering rates may seem low (28% and 14% for the digit reaction time and choice reaction time tasks, respectively), they are comparable to the rates observed among the same participants from other tasks in the session (reading comprehension: 18%, Robison & Unsworth, 2015). Further, Smallwood et al. (2009) reported a mind-wandering rate of 32% for the digit reaction time task, which is similar to the 28% observed here.

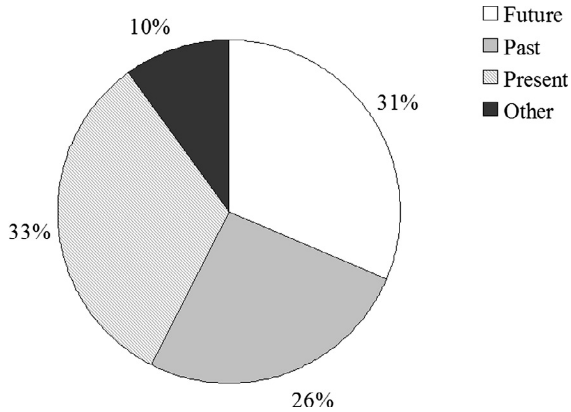

Fig. 1. Proportions of mind-wandering attributed to past-, present-, future-, and non-temporal thoughts.

Table 1
Correlations and descriptive statistics.

	1	2	3	4	5	6	7	8	9
1. Operation span	–								
2. Symmetry span	0.45	–							
3. Reading span	0.69	0.44	–						
4. CRT RT	−0.16	−0.31	−0.20	–					
5. CRT acc	0.09	0.06	0.07	−0.26	–				
6. Digit RT	−0.02	−0.21	−0.05	0.26	−0.12	–			
7. Digit acc	0.23	0.04	0.21	−0.12	0.27	0.08	–		
8. CRT MW	−0.16	−0.14	−0.10	0.20	−0.06	0.09	−0.03	–	
9. Digit MW	−0.24	−0.22	−0.21	.12	−0.04	0.12	−0.09	0.64	–
Mean	59.06	30.12	57.21	451	0.96	853	0.86	0.14	0.28
SD	10.67	7.14	10.90	70	0.02	136	0.14	0.23	0.27
Skewness	−1.05	−0.61	−0.84	1.85	−2.45	0.42	−2.06	1.93	.88
Kurtosis	1.21	−0.23	0.54	6.89	10.32	0.74	6.27	3.22	−0.10

Note. N = 124. CRT RT = mean reaction time for choice reaction time task, CRT acc = mean accuracy for choice reaction time task, Digit RT = mean reaction time for digit task, Digit acc = mean accuracy for digit task, CRT MW = proportion of mind-wandering reports for choice reaction time task, Digit MW = proportion of mind-wandering reports for digit task. SD = standard deviation. Correlations with absolute values ≥ 0.18 are significant at $p < 0.05$.

allowed to load onto a WMC latent variable, reports of mind-wandering (sum of all past, present, future, and “other” thoughts) from the choice and digit reaction time tasks were allowed to load onto a mind-wandering (MW) latent variable, and the two latent variables were allowed to correlate. The resulting model is depicted in Fig. 2. The estimated model fit the data well (N = 124, χ^2 (4) = 1.61, p = 0.80, CFI = 1.00, RMSEA = 0.00, SRMR = 0.02).[2] The WMC and mind-wandering latent variables significantly negatively correlated. Overall, this suggests that participants who had higher WMC reported fewer instances of mind-wandering overall.

4. Discussion

To attempt to reconcile some discrepant findings in the relationship between individual differences in WMC and prospective mind-wandering tendencies (Baird et al., 2011; McVay et al., 2013) the present study gave participants two relatively low-demand tasks during which mind-wandering was measured with thought probes. Although there was not a prospective bias to the mind-wandering reports, future-oriented thought did account for 31% of all off-task reports. Individual differences in WMC were measured with three complex span tasks. Zero-order correlations among the tasks revealed negative correlations between all three span tasks and mind-wandering during the reaction time tasks. We then computed a WMC composite by averaging each participant’s standardized operation span, symmetry span, and reading span scores. This composite score did not positively correlate with any mind-wandering type, and in fact predicted significantly fewer present-oriented thoughts. Our next analysis examined the proportions of off-task thoughts attributed to past, present, and future thoughts. WMC did not significantly correlate with the proportion of mind-wandering reports attributed to any temporal focus. Finally, a latent variable analysis of WMC and mind-

[2] CFI = comparative fit index, values above 0.90 are considered acceptable. RMSEA = root mean square error of approximation, values less than 0.08 are considered acceptable. SRMR = standardized root mean square residual, values less than 0.08 are considered acceptable (Schermelleh-Engel, Moosbrugger, & Müller, 2003). CFA = 1.00 and RMSEA = 0.00 reflect that the chi-square value (1.61) is less than the degrees of freedom in the model (4).

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Table 2
Correlations among WMC, and past, future, and present mind-wandering.

	1	2	3	4
1. WMC	–			
2. Future MW	−0.08	–		
3. Past MW	0.04	0.18*	–	
4. Present MW	−0.29**	−0.01	0.10	–
5. Other	−0.03	0.09	0.06	−0.02

Note. $N = 124$. WMC = composite working memory capacity score, Future MW = sum of all future−oriented mind-wandering reports, Past MW = sum of all past-oriented mind-wandering reports, Present MW = sum of all reports of mind-wandering about current state of being, Other = sum of reports of “other” thoughts.
* $p < 0.05$.
** $p < 0.01$.

Table 3
Correlations among WMC and temporal proportions of mind-wandering.

	1	2	3	4
1. WMC	–			
2. Prop Future MW	−0.03	–		
3. Prop Past MW	0.13	−0.26**	–	
4. Prop Present MW	−0.15	−0.47**	−0.48**	–
5. Prop Other MW	0.09	−0.27**	−0.19*	−0.26**

Note. $N = 124$. WMC = composite working memory capacity score, Prop Future MW = proportion of off-task thoughts attributed to the future, Prop Past MW = proportion of off-task thoughts attributed to the past, Prop Present MW = proportion of off-task thoughts attributed to the present.
* $p < 0.05$.
** $p < 0.01$.

wandering showed a significant negative relationship between the two constructs.

The results are largely inconsistent with the findings of Baird et al. (2011) who found a significant positive correlation between the proportion of off-task thought attributed to future-oriented thoughts and WMC. One of the tasks used in the current study (digit reaction time) was a direct replication of the task used by Baird et al. (2011). Furthermore, one of the three WMC measures in the current study (operation span) was used by Baird et al. (2011) to measure this construct. As an attempt to most directly replicate the findings of Baird et al. (2011), we examined correlations between operation span and proportions of mind-wandering attributable to past-, present-, and future-oriented thoughts. Operation span scores did not correlate with proportions of past- ($r = 0.03$, $p = 0.78$), present- ($r = -0.10$, $p = 0.32$), or future-oriented thoughts ($r = 0.04$, $p = 0.68$). Other attempts to replicate the WMC-future thought relationship (e.g., McVay et al., 2013) have used reading comprehension measures, which are more demanding than the digit reaction time task. Therefore differences in task demands may have made the two findings incomparable. However the results of the

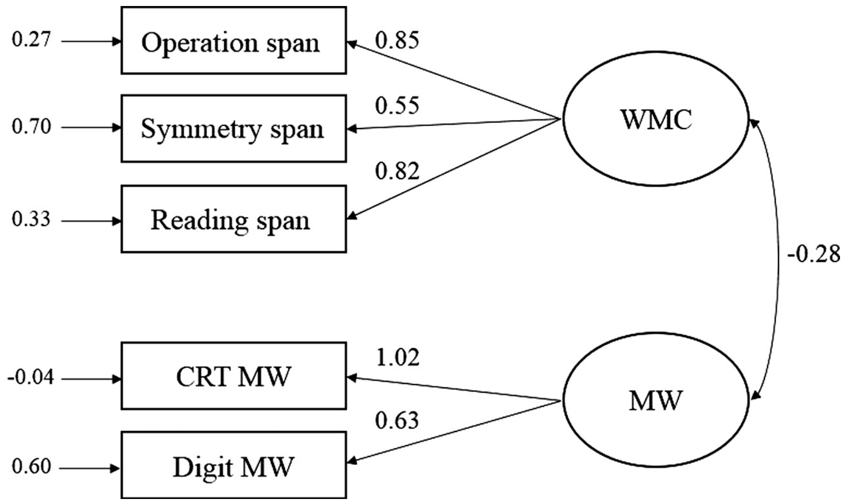

Fig. 2. Confirmatory factor analysis of working memory capacity (WMC) and mind-wandering (MW). The model fit the data well ($N = 124$, $\chi^2 = 1.61$, $p = 0.80$, CFI = 1.00, RMSEA = 0.00, SRMR = 0.02). *Note*: the loading for the CRT MW variable is greater than 1 and the estimated error variance is negative. These parameters are maximum likelihood estimates with standard errors around those estimates, and the theoretical maximum loading and minimum error variance are both within the standard error of these estimates. Fixing the loadings of the path from CRT MW and Digit RT to the MW latent variable did not appreciably change the model fit nor the latent correlation between WMC and MW, so we allowed these parameters to be freely estimated.

current study cannot be attributed to differences in task design. Further, a second relatively low-demand task (choice reaction time) showed the same result as the digit reaction time task. WMC did not correlate with future-oriented mind-wandering, measured both as the total number of future-oriented thoughts and as the proportion of off-task thoughts with a future focus, in either task. We feel our finding is rather robust for several reasons. Compared to Baird et al. (2011; $N = 47$), the present study had a large sample size ($N = 124$). Therefore, even if the effect was rather small, we should have been able to detect it. In addition to measuring WMC with operation span as Baird et al. (2011) did, we included two additional measures of WMC (symmetry span and reading span). Further, we included one additional low-demand task. Therefore, any findings could not have been attributable to task idiosyncrasies.

The current results have implications for several theories of the occurrence of mind-wandering. The context regulation hypothesis posits that cognitive resources (e.g., WMC) are employed to control when mind-wandering occurs. Under conditions of low demand in the external task environment, individuals with greater cognitive resources should actually mind-wander more, since certain types of mind-wandering (e.g., autobiographical planning) can be functional. The findings of Baird et al. (2011) are usually cited as support for this hypothesis. However the present study failed to find such a relationship. One difference between the present study and Baird et al. (2011) is that we used a forced-choice probing technique, whereas Baird et al. allowed participants to report their thoughts in an open-ended manner. These reports were later coded by the experimenters for self-relevance and temporal focus. Although this difference in procedure may account for the discrepancy in the findings, it is not entirely clear why this difference would substantially alter the pattern of correlations. Therefore the present results cast doubt on the idea that an element of greater WMC is the ability to use excess mental capacity to direct thoughts toward the future under conditions of low external demands. The cognitive flexibility hypothesis argues that individuals with greater WMC have greater ability to adaptively adjust their attention to the task demands. Under low-demand conditions, they may split their resources between the task and mind-wandering, which may lead to a positive relationship between WMC and mind-wandering tendencies (Rummel & Boywitt, 2014). The executive failure hypothesis (McVay & Kane, 2009, 2010; McVay & Kane, 2012a, 2012b) makes the prediction that because individuals with greater WMC have a better ability to maintain task goals and to avoid the intrusion of irrelevant information into working memory, they will show less frequent mind-wandering than individuals with lower WMC. Although we have characterized the tasks in the present study as low-demand, there were no high-demand tasks preceding or following these tasks (other than the complex span tasks), so we cannot directly address the cognitive flexibility hypothesis. Participants were unable to exhibit any flexibility as the demands of the tasks did not substantially differ. However the current results are in line with the executive failure hypothesis.

Finally, the latent variable analysis allowed us to compare the correlation between WMC and mind-wandering to other studies that have used more complex, demanding tasks. The latent-level correlation between WMC and mind-wandering is actually quite comparable to other investigations of these two constructs. Previous investigations of WMC and mind-wandering have shown latent correlations of -0.17 (Kane et al., 2016), -0.22 (McVay and Kane (2012a), -0.20 (McVay and Kane, 2012b), -0.41 (Unsworth & McMillan, 2013), -0.30 (Unsworth & McMillan, 2014), and -0.20 (Robison et al., 2017). One commonality among these studies is the use of highly demanding tasks like reading comprehension, antisaccade, Stroop, flankers, psychomotor vigilance, and SART, among others, to measure mind-wandering. However, the use of low-demand tasks in the present study led to quite comparable relationship (latent $r = -0.28$) to these studies. Therefore, we observed no evidence that tasks with low demands on cognitive resources produce an appreciably different relationship between mind-wandering and WMC (see also Randall et al., 2014).

We should note that studies demonstrating a null relationship between WMC and mind-wandering (e.g., Baird et al., 2011; McVay and Kane, 2012a; Smeekens and Kane, 2016), especially at the task-level, need not be summarily dismissed. Rather, these findings can help us further delineate the relationship, identify boundary conditions, and determine the context-specificity of the relationship. Randall et al. (2014) showed that the meta-analytic estimate of the relationship between cognitive ability and mind-wandering is $\rho = 0.14$. So two explanations for null (or significantly positive) relationships between WMC and mind-wandering can take one of two forms: (1) random variation around a small (but true) negative relationship, or (2) a truly positive/null relationship. In the latter case, we should be able to both directly and conceptually replicate the finding, and that was the goal of the present study. However, future research is necessary to enhance our understanding of the dynamic nature of WMC's relationship with mind-wandering in a context-dependent manner, perhaps reflecting an adaptive ability to adjust attention-regulation settings to meet the demands of the environment (Rummel & Boywitt, 2014; Smallwood & Andrews-Hanna, 2013).

5. Conclusion

The present results failed to replicate the finding that individuals with greater WMC employ their considerable mental resources to engage in future-oriented thought during tasks that make relatively few demands on those resources. Although some theories posit that a function of greater WMC is the ability to simultaneously complete simple tasks and engage in functional off-task thought (Smallwood & Andrews-Hanna, 2013), we found no evidence to support this claim. Rather, WMC related to less frequent mind-wandering, even during relatively low-demand external tasks.

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