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Working Memory Capacity Offers Resistance to Mind-Wandering and External Distraction in a Context-Specific Manner

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Summary: The present study examined the impact of mind-wandering and distraction in silent and noisy studying environments and how individual differences in working memory capacity offered resistance to these two distinct forms of attention failure. Two groups of participants read a text in different environments and answered reading comprehension questions. While reading, thought probes asked participants to indicate the current focus of their attention. Results showed that the relationship between working memory capacity and reading comprehension was partially driven by resistance to mind-wandering in the silent condition and by resistance to external distraction in the noise condition. The findings support the distinction between mind-wandering and external distraction, two separate yet related types of attention failure that impact task performance. Further, executive abilities seem to offer resistance to these two types of attention failure differentially depending on the context. Copyright © 2015 John Wiley & Sons, Ltd.

At any point in time, several sources of information compete for an individual's limited focus of attention. Usually, the individual's goals determine how attention is allocated to these sources. However, irrelevant and distracting sources of information sometimes enter the focus of attention, drawing thoughts away from the individual's goals and negatively impacting task completion. Sometimes, the irrelevant source of information is the individual's own internal thought processes that stray from goal-relevant thoughts. This is typically referred to as mind-wandering. Other times, the individual's attention can be drawn to irrelevant external information (e.g., sights, sounds, and physical sensations), which is typically referred to as external distraction. One setting in which mind-wandering and external distraction can be particularly disruptive is studying—attempting to commit information to memory for later recall. Unsworth, McMillan, Brewer, and Spillers (2012) found that, among college students, two of the most common forms of everyday attention failures were mind-wandering and distraction while studying. Depending on the studying environment, mind-wandering and distraction may occur with different frequencies. The present study sought to understand the roles of mind-wandering and distraction in differing studying environments and how the previously mentioned factors work to attenuate task-irrelevant thoughts to maximize performance. More specifically, do mind-wandering and distraction occur in a context-specific manner? Further, do individual differences in executive abilities (e.g., working memory capacity) offer resistance to these two types of attention failure differentially depending on the context?

Testing individuals' comprehension of learned material is a frequent method of evaluating ability and proficiency in a variety of settings, especially education. The ability to read, encode, understand, and recall information is thus used as a metric for success in these settings. Therefore, it is important for individuals to effectively commit themselves to studying material in a manner that maximizes comprehension. A host of factors impacts reading comprehension. These factors include structure, syntax, and context, as well as the reader's cognitive abilities and the environmental conditions. Because of the importance of reading comprehension in various settings, research has focused on how these factors contribute to comprehension. Both individual differences in cognitive abilities (e.g., working memory capacity and attention control; Daneman & Carpenter, 1980; Unsworth & McMillan, 2013; McVay & Kane, 2012) and environmental factors (e.g., music, speech, and traffic noise; Boyle & Coltheart, 1996; Clark et al., 2005; Zeamer & Fox Tree, 2013) have been shown to impact reading comprehension. Therefore, the present study investigated how these internal and external factors contribute to reading comprehension from both individual differences and experimental perspective.

One of the major factors that has been used to explain individual differences in reading comprehension is mind-wandering. Mind-wandering can be defined as entertaining any thoughts that are irrelevant to the task at hand. The actual content of episodes of mind-wandering can vary. For example, individuals may be thinking about something they need to do in the future, or they may be ruminating about a negative past experience, or they may be connecting what they are reading to previously encountered information. Smallwood, Lind, and O'Connor (2009) found that individuals who lack both interest in the reading topic and prior experience with the topic have a tendency to mind-wander about the future (i.e., a prospective bias). On the other hand, individuals who lack interest in the topic yet have experience with the topic tend to mind-wander about events in the past (i.e., a retrospective bias; Smallwood et al., 2009). Schooler, Reichle, and Halpbern (2004) found that when individuals were caught zoning out while reading a fiction passage, they reported thinking about nothing at all (18% of the time), specific things such as school-related topics (27%), fantasies (19%), and themselves (11%). Only 3% of the time did those individuals report thinking about the text when they were zoning out. Sayette, Schooler, and Reichle (2010) found that cigarette smokers who were nicotine deprived and thus craved a cigarette acknowledged more probe-caught mind-wandering than smokers who had recently smoked a

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cigarette. Therefore, physiological sensations like cravings, hunger, thirst, and fatigue can cause an individual's mind to wander.

McVay and Kane (2012) found that the relationships among working memory capacity, attention control, and reading comprehension are partially driven by tendencies to mind-wander. Similarly, Unsworth and McMillan (2013) found that individual differences in working memory capacity predict tendencies to mind-wander in a group of college-aged students studying a political science text. Because working memory capacity reflects an individual's ability to maintain and manipulate information, often in the presence of irrelevant or distracting information (Engle, 2002), individuals with greater working memory capacity are generally able to effectively focus their thoughts on the material they are reading while avoiding irrelevant thoughts. Mind-wandering has the effect of drawing the individual's attention away from information relevant to the task at hand, which causes problems in the development of a situational model of the material (Smallwood, McSpadden, & Schooler, 2008). One major issue with all the studies investigating mind-wandering is that they typically examine reading comprehension in quiet, controlled laboratory settings.

In everyday situations, people must read in conditions that are not completely silent, which introduces a different form of interference: external distraction. Anything that distracts the individual from focusing on the information being learned will impact performance. For example, a student is trying to read in preparation for an upcoming exam, but her roommates are having a loud conversation right outside her door. Or, more subtly, the kicking on and off of the air conditioning system may be sufficient to pull her attention away from the text periodically. While not specific to studying, Zeamer and Fox Tree (2013) investigated the differential effects of various sounds on comprehension of material from a simulated lecture, another important educational environment. First, they investigated what sorts of sounds drew attention away from the lecture. They found that sounds like laughter, construction noise, murmuring, and other people shifting caused distraction and these distractions negatively impacted recall of material presented in the lecture. In a follow-up experiment, Zeamer and Fox Tree (2013) manipulated the timing of these sounds, making them either relevant (e.g., laughter following a joke) or irrelevant (e.g., random laughter). Sounds incongruous with presented information caused greater disruptions to recall than congruous sounds. These distractions seemed to have a general effect on comprehension, rather than being tied to information presented simultaneously with the actual distractor.

Intense noise, such as aircraft traffic, can have a negative impact on reading comprehension as well. Clark et al. (2005) found that children living near airports in the UK, the Netherlands, and Spain all experienced decreased reading comprehension scores as external noise from air traffic increased. The effect remained even after adjusting for socioeconomic variables and individual differences in cognitive functioning (e.g., dyslexia, hearing impairments, and working memory). Whether it acts as a distraction or, more generally, as a hindrance to normal cognitive functioning, noise in this case had significant impact on reading comprehension.

Sörqvist, Marsh, and Nöstl (2013) recently reviewed evidence for the role of working memory capacity in the ability to attenuate auditory distraction. They found that individuals with high working memory capacity resisted being distracted by auditory deviants because of greater task engagement. Therefore, individuals with greater working memory capacity should be more engaged in a reading task and effectively ignore or tune out irrelevant auditory distraction. The present study investigated whether greater working memory capacity would effectively shield individuals from distraction in noisy environments and from mind-wandering in silent environments. It was expected that reports of mind-wandering and distraction would show different patterns in the two conditions, offering evidence that these are two distinct forms of attention failure that occur in a context-specific manner.

To measure the current focus of an individual's thoughts and to catch instances of mind-wandering, prior research has used thought probes that either randomly or systematically ask the participants to report their attentional state (see Smallwood & Schooler, 2006, for a review). In some prior studies, the options are either 'on-task' or 'off-task'. However, off-task reports could be catching two different types of task-unrelated thought—mind-wandering and external distraction. Therefore, Stawarczyk et al. (2011) further delineated the probes to separate mind-wandering and distraction. In their study, Stawarczyk et al. asked participants if they were on-task, if they were experiencing task-related interference (thinking about their own task performance or the nature of the task), if they were distracted by external stimuli (sights and sounds in their environment), or if they were mind-wandering. This technique allows for distinction between external distraction and mind-wandering, both of which would be classified as off-task in a simple on-task or off-task thought probe. Unsworth and McMillan (2014) used this thought probe technique to study mind-wandering, external distraction, attention control, working memory capacity, and fluid intelligence as latent variables. Unsworth and McMillan found that mind-wandering and distraction were two distinct yet correlated factors that both affect important cognitive abilities. In other experimental studies examining the effect of noise on comprehension (Zeamer and Fox Tree, 2013; Boyle & Coltheart, 1996), the researchers must infer that the introduction of noise actually leads to a distracted mental state based on the outcome measure of comprehension. The thought probe method can actually measure rates of attention failure over the course of the task and use this information to predict comprehension. Therefore, the present study sought to understand the distinct roles mind-wandering and distraction play in affecting reading comprehension in two different environments—silence and noise—using this thought probe method.

Other factors that certainly impact reading comprehension are variables specific to the nature of the material and to the reader's disposition—topic interest, topic experience, and motivation. Unsworth and McMillan (2013) found a significant correlation between these three variables, reports of mind-wandering, and reading comprehension. Similarly, in a sample of Norwegian high-school students, motivation independently predicted reading comprehension scores even after controlling for other predicting variables like gender, domain achievement, topic knowledge, and strategic processing (Anmarkrud & Bråten, 2009). Guthrie, Wigfield, Metsala, and Cox (1999) found that reading comprehension was significantly predicted by reading amount when accounting for previous achievement, reading efficacy, and reading motivation. The present study measured these variables, but because they were not the focus of the current investigation, they are only discussed briefly.

THE PRESENT STUDY

The present study investigated how mind-wandering and distraction differentially impact studying in a silent environment and a noisy environment. Both mind-wandering and distraction have been shown to impact reading comprehension. Therefore, it is worth investigating what types of environments cause these two different types of task-unrelated thought. To do so, the present study placed participants alone in a silent room with nothing but a computer on which they read the text. Participants wore headphones to reduce the effects of any other ambient noise (humming of the computer, researchers talking to other subjects outside the room, etc.). In another condition, individuals were in a similar environment, alone in a room with a computer. But in this condition, there was a recording of a busy bar/restaurant playing through the headphones. The recording contained elements of voices, music, the movement and shuffling of furniture, and the clanking of dishes and silverware. This recording was chosen to simulate a typical studying environment that contains additional external stimulation (e.g., a coffee shop, student union building, or residence hall). It is expected that the noisy studying environment will induce distraction, while a silent reading environment will induce mind-wandering. The primary source of task-unrelated thought in the noisy environment should be the irrelevant stream of auditory information. In the silent environment, the primary source of task-unrelated thought should be internally generated information as the mind wanders, which would replicate prior research (McVay & Kane, 2012; Unsworth & McMillan, 2013). Lower rates of mind-wandering and distraction should predict better reading comprehension performance in the silent and noisy environments, respectively. It is also worth investigating how rates of mind-wandering and distraction occur over time. Rates of mind-wandering should increase as the task progresses in the silent condition, following previous research that shows as task length increases, mind-wandering and attention failures also increase (McVay & Kane, 2009). In the noise condition, it is expected that the noise will cause distraction early in the task. Once initially distracted, individuals may mind-wander as the task progresses.

The present study measured several individual differences: working memory capacity, topic interest, topic experience, and motivation. Any time an individual tries to study a text, several factors will affect how well that person will retain information. In addition to environmental factors, the individual brings his or her own cognitive traits and passing dispositional states to the table. All of these will presumably affect performance. Thus, the present study measured these factors. High working memory capacity should predict lower rates of mind-wandering in the silent condition and lower rates of distraction in the noise condition, as well as better reading comprehension in both conditions. Topic interest, topic experience, and motivation should all predict lower rates of mind-wandering and distraction in the two conditions, as well as better reading comprehension. The present study addressed all of these issues in a hope of better understanding the distinction between mind-wandering and external distraction, the relationship between mind-wandering, distraction, and reading comprehension, and how individual differences impact reading comprehension through resistance to mind-wandering and distraction. It is expected that participants will report more mind-wandering in the silent studying environment and more distraction in the noisy studying environment and that the working memory capacity–reading comprehension relationship will be driven by resistance to mind-wandering in silence and resistance to distraction in the presence of noise. This would offer evidence that mind-wandering and distraction are actually two distinct forms of attention failure that occur in a context-specific manner, driven by the nature of the environment.

METHOD

Participants

Participants were 241 students (149 women) from the undergraduate pool at the University of Oregon (120 in noise condition and 121 in silent condition). Our stopping rule for data collection was to reach an adequate sample size ($N = 120$ in each condition) to perform proper individual differences comparisons using confirmatory factor analysis. The average age of the participants was 19.90 years ($SD = 2.89$). All participants were between the ages of 18 and 40 years. Participants were given course credit for participating.

Materials and procedure

After signing informed consent forms and providing demographic information, participants completed two complex span working memory tasks, read a text, answered reading comprehension questions based on the text, and completed a brief questionnaire assessing topic interest, topic experience, motivation, and the nature of their task-unrelated thoughts and sources of distraction. In the same session and after these measures, participants also completed other measures that were not part of the current investigation and are thus unreported here.

Task

Working memory capacity tasks

Upon arrival to the laboratory, participants were randomly assigned to a room, evenly splitting them into a 'silent' condition and a 'noise' condition. All participants first completed two complex span tasks (operation span and reading span). For each task, participants first completed several practice trials to ensure they understand the task demands and then completed scored trials.

Operation span (OSpan). Participants solved a series of math operations while trying to remember a set of unrelated letters (F, H, J, K, L, N, P, Q, R, S, T, and Y). Participants viewed a math operation [i.e., $3 + (6 \times 2)$], then were given a possible answer (i.e., 15), and responded by clicking a box labeled 'TRUE' if the number given solved the operation. If it did not, participants responded by clicking a box labeled 'FALSE'. Three trials of each list length (three to seven) were presented for a total possible score of 75. The order of list length varied randomly. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters (see Unsworth, Heitz, Schrock, & Engle, 2005, for a more detailed description). Participants received three sets of list length two for practice. Items were scored correct if the item was correct and in the correct position. The score was the number of correct items in the correct position.

Reading span (RSpan). Participants were required to read sentences while trying to remember the same set of unrelated letters as in OSpan. For this task, participants read a sentence and determined whether the sense made sense or not (e.g., 'The prosecutor's dish was lost because it was not based on fact'.). Half of the sentences made sense, the other half did not, and these were randomized throughout the task. A sentence was changed to not make sense by replacing one noun with an unrelated noun in an otherwise normal sentence (e.g., replacing 'case' with 'dish'). After giving a response as to whether the sentence made sense or not by clicking on boxes indicating such, participants were presented with a letter for 1 second. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters. There were three trials of each list length, with list length ranging from three to seven for a total possible score of 75 (see Unsworth et al., 2009, for more details). The same scoring procedure as OSpan was used.

Text

Participants read an excerpt from *The Challenge of Democracy* (Janda et al., 2010), a popular introduction to political science text, which is an appropriate text for college students like the current sample. Each paragraph was presented in black font on a white background on the computer screen. When participants finished reading each paragraph, they proceeded to the next paragraph by pressing the space bar. There were 17 paragraphs in all, and participants were given as much time as needed to read the text.

Mind-wandering and distraction probes

At six random points during the reading task, participants were prompted to report their attentional state (Stawarczyk, et al., 2011; Unsworth & McMillan, 2013). When prompted, participants responded by pressing the corresponding number on a keyboard. The optional responses are as follows: (i) I am totally focused on the current task; (ii) I am thinking about my performance on the task or how long it is taking; (iii) I am distracted by sights/sounds or by physical sensations (hungry/thirsty); (iv) I am zoning out/my mind is wandering; and (v) other. Response 1 was scored as being on-task, response 2 was scored as task-related interference, response 3 was scored as distraction, and response 4 was scored as mind-wandering. Because 'other' responses were so rarely reported and nearly impossible to interpret, they were not used in the analyses.

Reading comprehension test

Participants then completed a reading comprehension task based on the text. A total of 10 multiple choice questions comprised the test. Questions were taken directly from the online study guide accompanying the text. For each question, participants were asked about an aspect of the text (i.e., 'What is the oldest objective of government'?) and were required to respond by selecting one of five possible answers. Responses were scored by pressing the corresponding key. Participants were given as much time as needed to answer the questions. Scores were the percentage of questions answered correctly.

Questionnaire

After the reading comprehension test, participants were given a questionnaire to measure their interest in the topic, their experience with the topic, and their overall motivation to perform well. The two questions about topic interest were as follows: (i) 'how interested were you in the topic of the text' and (ii) 'how interested are you in this topic in general'? The two questions measuring motivation asked as follows: (i) 'how motivated were you to do well on the task' and (ii) 'how much did your motivation affect your performance on the task'? The three questions measuring topic experience asked as follows: (i) 'how much background knowledge do you have on the topic of the text'; (ii) 'how much did your prior knowledge influence your performance on the test'; and (iii) 'how many political science or government classes have you taken'? Additionally, participants were asked as follows: 'how similar is this task to how you typically study'? For each question, the anchor ratings were 1 (*not at all*) and 6 (*very much*), except for the question regarding the number of classes taken, for which participants simply typed the appropriate number. Brief descriptions of the ratings were provided, and participants were allowed as much time as needed to answer the questions. Finally, participants were given an open-ended form which asked, 'Did anything distract you while you were reading the political science text? If so, please write a brief description of what distracted you'. These responses were later coded based on condition and types of responses but were used primarily for illustrative purposes and were not statistically analyzed.

RESULTS

Participants in the two conditions did not differ in working memory capacity, topic interest, topic experience, or motivation (all $ps > 0.08$). Reading comprehension scores also did not differ between conditions, with participants in the silent condition ($M = 0.68$, $SD = 0.19$) scoring only a few percentage points higher than participants in the noise condition ($M = 0.66$, $SD = 0.20$). Means and standard deviations for all measures in the silent and noise conditions are listed in

Table 1. Zero-order correlations among all measures are listed in the Appendix.

Mind-wandering and external distraction

Different patterns of mind-wandering and external distraction were expected in the two conditions. Specifically, it was expected that individuals would mind-wander more in the silent condition and report being distracted by external stimuli more in the noise condition. As expected, participants in the noise condition reported higher rates of distraction ($M = 0.38$, $SD = 0.30$) than participants in the silent condition ($M = 0.08$, $SD = 0.14$). But participants in the silent condition reported roughly equal amounts of mind-wandering ($M = 0.18$, $SD = 0.22$) as participants in the noise condition ($M = 0.18$, $SD = 0.23$). These findings were confirmed by an analysis of variance (ANOVA) with report type (mind-wandering versus distraction) as the within-subjects variable and condition (silence versus noise) as the between-subjects variable. The ANOVA revealed a main effect of type [$F(1, 239) = 5.79$, $p < 0.05$, $MSE = 12.91$, partial $\eta^2 = 0.02$] and a main effect of condition [$F(1, 239) = 62.29$, $p < 0.001$, $MSE = 95.39$, partial $\eta^2 = 0.21$], as well as a type by condition interaction [$F(1, 239) = 42.55$, $p < 0.001$, $MSE = 95.31$, partial $\eta^2 = 0.15$], which suggests that rates of mind-wandering and distraction differed across the two conditions. Planned comparisons revealed that participants in the silent condition reported significantly less distraction than participants in the noise condition [$t(239) = -9.81$, $p < 0.001$]. However, reports of mind-wandering were equal across the two conditions [$t(239) = -0.002$, $p > 0.98$]. Adding working memory capacity as a covariate in the model did not reveal an interaction with type [$F(1, 238) = 0.04$, $p > 0.89$], suggesting that this pattern did not change as a function of working memory capacity.

Table 1. Descriptive statistics

Measure	Mean	*SD*	Range	Kurtosis	Skew
		Silence ($N = 121$)			
OSpan	58.62	9.30	21–74	1.61	−0.84
RSpan	57.47	10.48	23–75	0.93	−0.86
Read1	0.74	0.27	0–1	−0.38	−0.70
Read2	0.67	0.25	0–1	−0.93	−0.13
Read3	0.64	0.26	0–1	−0.58	−0.37
MW1	0.16	0.24	0–1	1.51	1.44
MW2	0.19	0.27	0–1	0.83	1.31
ED1	0.07	0.15	0–0.67	3.04	1.95
ED2	0.09	0.21	0–1	6.17	2.52
Int1	2.50	1.22	1–5	−0.73	0.44
Int2	2.81	1.39	1–6	−0.53	0.50
Mot1	3.49	1.28	1–6	−0.44	−0.06
Mot2	4.03	1.14	1–6	−0.56	−0.24
Know1	3.29	1.17	1–6	−0.69	0.21
Know2	3.60	1.24	1–6	−0.51	−0.10
Know3	1.51	1.34	1–5	−0.47	0.61
		Noise ($N = 120$)			
OSpan	58.87	10.85	21–75	1.53	−1.12
RSpan	57.64	11.70	21–75	0.11	−0.90
Read1	0.70	0.29	0–1	−0.27	−0.67
Read2	0.66	0.27	0–1	−0.44	−0.41
Read3	0.62	0.27	0–1	−0.67	−0.24
MW1	0.12	0.22	0–1	2.28	1.76
MW2	0.23	0.31	0–1	−0.02	1.10
ED1	0.43	0.35	0–1	−1.23	0.18
ED2	0.33	0.34	0–1	−0.77	0.68
Int1	2.43	1.28	1–6	0.13	0.79
Int2	2.62	1.30	1–6	−0.32	0.54
Mot1	3.85	1.35	1–6	0.61	−0.30
Mot2	4.06	1.22	1–6	−0.82	−0.11
Know1	3.11	1.29	1–6	−0.27	0.50
Know2	3.27	1.46	1–6	−0.89	0.18
Know3	1.45	1.69	1–10	12.77	3.09

Note: SD = standard deviation. OSpan = operation span, RSpan = reading span, Read = reading comprehension parcels, MW = proportion of probes reporting mind-wandering for first and second half of reading task, ED = proportion of probes reporting distraction for first and second half of reading task, Int = questions concerning topic interest, Mot = questions concerning motivation, Know = questions concerning topic experience.

Time-course analyses of mind-wandering and distraction

The dynamic nature of attentional states over the course of the reading task was also investigated. Because the reading tasks typically took 10.10 minutes in the silent condition ($SD = 3.44$) and 10.21 minutes ($SD = 3.22$) in the noise condition, participants' attentional states may have varied between states of focus, mind-wandering, and distraction. An ANOVA on reports of mind-wandering and distraction revealed a main effect of type [$F(1, 239) = 5.79$, $p < 0.05$, $MSE = 2.15$, partial $\eta^2 = 0.02$], suggesting that reports of mind-wandering and distraction differed, and a type by condition interaction [$F(1, 239) = 42.73$, $p < 0.001$, $MSE = 15.88$, partial $\eta^2 = 0.15$], suggesting that the time series of mind-wandering and distraction differed for the two conditions. The ANOVA also revealed a main effect of time [$F(5, 1195) = 5.73$, $p < 0.001$, $MSE = 0.45$, partial $\eta^2 = 0.02$], suggesting that reports changed over time, a time by condition interaction [$F(5, 1195) = 2.51$, $p < 0.05$, $MSE = 0.20$, partial $\eta^2 = 0.02$], suggesting the rates of change were different in the two conditions, a type by time interaction [$F(5, 1195) = 8.06$, $p < 0.001$, $MSE = 1.81$, partial $\eta^2 = 0.03$], suggesting that mind-wandering and distraction changed at different rates, and a type by time by condition interaction [$F(5, 1195) = 5.60$, $p < 0.001$, $MSE = 0.82$, partial $\eta^2 = 0.02$], suggesting that the difference between the rates of change between mind-wandering and distraction differed as a function of condition. In both conditions, rates of mind-wandering (Figure 1) gradually increased across the duration of the reading task with a short decrease at the end. In the silent condition, rates of distraction (Figure 2) were low during the entire task. However, in the noise condition, rates of distraction were high at the beginning of the task and gradually dropped off.

In a separate analysis, a repeated measures analysis of covariance with type (mind-wandering versus distraction) and time as within-subjects variables, condition (silence versus noise) as a between-subjects variable, and working memory capacity as a covariate did not reveal a significant type by time by working memory capacity interaction ($p > 0.88$). This null result suggests that the dynamic patterns of mind-wandering and distraction in the two conditions do not significantly differ for high and low working memory capacity individuals.

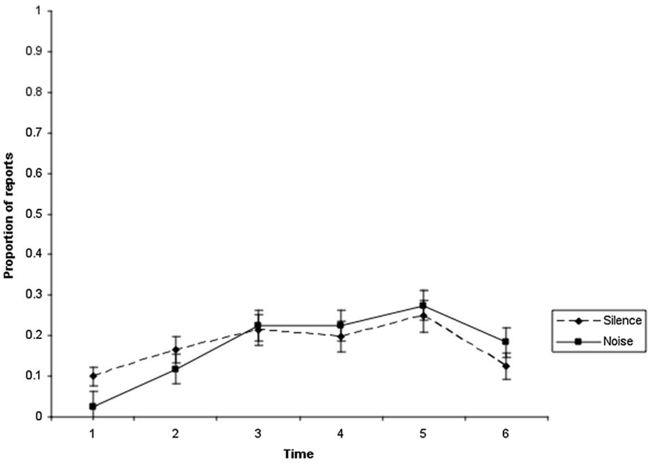

Figure 1. Reports of mind-wandering across time for the silent and noise conditions. Error bars represent one standard error of the mean

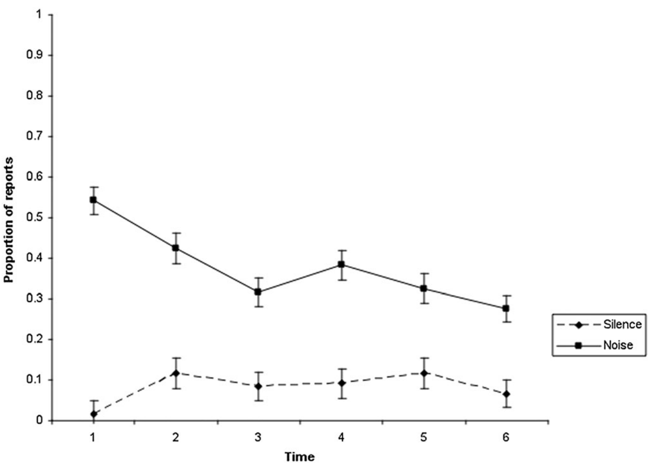

Figure 2. Reports of distraction across time for the silent and noise conditions. Error bars represent one standard error of the mean

Confirmatory factor analysis

To examine the relationships among working memory capacity, reading comprehension, mind-wandering, distraction, topic interest, topic experience, and motivation, a multigroup confirmatory factor analysis was run on these variables, creating latent factors for each construct. The factors were allowed to correlate separately for each condition. To create the factor for reading comprehension, three parcels were created: the first three questions, the second three questions, and the final four questions of the reading comprehension test. Each of these parcels was allowed to load onto a reading comprehension latent factor. Operation span scores and reading span scores were allowed to load into a working memory capacity factor. Responses to the first three mind-wandering probes and responses to the final three mind-wandering probes were allowed to load onto a mind-wandering latent factor, and the same procedure was used to create an external distraction latent factor. The two questions about topic interest were used to create the interest latent factor, the two questions about motivation were used to create the motivation latent factor, and the three questions about experience were used to create the experience latent factor. The overall fit of the model was good, χ^2 (167) = 223.24, $p < .01$, *RMSEA* = 0.05, *NNFI* = 0.92, *CFI* = 0.94. Table 2 shows the correlations among the reading comprehension, working memory capacity, mind-wandering, and external distraction latent variables in each condition.

Several correlations are worth noting. In the noise condition, both mind-wandering and distraction are negatively correlated with reading comprehension. In the silent condition, mind-wandering is negatively correlated with reading comprehension. The correlation between distraction and reading comprehension ($r = -0.39$) is moderate in the silent condition, but because there were so few reports of distraction in this condition, it approached but did not reach traditional levels of significance. It is also probable that, with a larger sample size, this correlation would reach significance.[1] One crucial distinction between the two conditions is that working memory capacity is negatively correlated with distraction, but not mind-wandering, in the noise condition. In the silent condition, the opposite is true; working memory capacity is correlated with mind-wandering but not distraction. We tested the difference between the observed correlations using Williams' *t*-test for differences between dependent correlations. This analysis showed that the correlations between WMC and distraction and WMC and mind-wandering approached significance difference in the silent condition, $t(117) = 1.92$, $p = 0.05$. In the noise condition, the difference between these two correlations was significant, $t(118) = -2.15$, $p < 0.05$. This highlights the finding that mind-wandering and distraction are distinct forms of task-unrelated thought and that working memory capacity offers resistance to these thoughts in a context-specific manner.

To better understand the relations among working memory capacity, mind-wandering, external distraction, and reading comprehension in the two conditions, we conducted variance partitioning analyses to determine unique and shared variance in reading comprehension accounted for by the three predictors (Figure 3). In the silent condition, working memory capacity and mind-wandering accounted for 20.4% of the variance in reading comprehension. Of the variance explained by these two factors, 40% was uniquely accounted for by working memory capacity, 40% was unique to mind-wandering, and 20% was shared. In the noise condition, the three predictors accounted for 12.4% of variance in reading comprehension. Working memory capacity uniquely accounted for 27% of this variance, external distraction uniquely accounted for 53%, and 20% was shared.[2] This analysis reveals that there are both shared and unique components to the relations among these constructs. In silent conditions, some of the variance in reading comprehension is due to executive abilities, some is due to the ability to resist

[1] Although the magnitude of the correlation ($r = -0.39$) is greater than the magnitude of other correlations marked as statistically significant, latent variables each have their own standard errors. In this case, the paucity of reports of external distraction in the silent condition created a large standard error (0.23) around the external distraction latent factor.

[2] Because of the strong negative correlation between external distraction and mind-wandering in the silent condition, we could not analyze working memory capacity, distraction, and mind-wandering together, as this indicated a suppression effect. This is likely due to the forced-choice probe technique.

Table 2. Correlations among latent variables in each condition

Factor	RC	WMC	MW	ED
	Silent condition ($N = 121$)			
RC	—			
WMC	0.35*	—		
MW	−0.35*	−0.25*	—	
ED	−0.39**	0.09	−0.54*	—
	Noise condition ($N = 120$)			
RC	—			
WMC	0.24*	—		
MW	−0.51*	0.06	—	
ED	−0.30*	−0.20*	−0.11	—

Note: RC = reading comprehension, WMC = working memory capacity, MW = mind-wandering, ED = external distraction.
*$p < 0.05$; **$p < 0.10$.

mind-wandering (McVay & Kane, 2012; Unsworth & McMillan, 2013), and some is due to variance shared between these abilities. In noisy conditions, some of the variance in reading comprehension is due to the ability to avoid distraction, some is due to executive abilities, and some is due to a shared component.

The correlations between working memory capacity, reading comprehension, topic experience, interest, and motivation largely replicated the findings of Unsworth and McMillan (2013). But because they are not the focus of the current study, they are not discussed in detail here. See the Appendix for factor loadings for all measures as well as a complete interfactor correlation matrix for each condition.

DISCUSSION

The current study combined experimental and individual differences approaches to understand how working memory capacity offers resistance to mind-wandering and distraction in a context-specific manner. In the silent reading environment, the primary source of task-unrelated thought was mind-wandering. Individual differences in working memory capacity were related to the tendency to mind-wander in a silent reading environment. Higher rates of both mind-wandering and distraction predicted lower reading comprehension scores. These findings replicate previous research on the relationship between these individual differences and reading comprehension (McVay & Kane, 2009; Unsworth & McMillan, 2013). The relationship between working memory capacity and reading comprehension seemed to be at least partially driven by a resistance to mind-wandering.

In the noisy studying environment, individuals seemed vulnerable to both mind-wandering and distraction, as both negatively correlated with reading comprehension. Although we only predicted a correlation between mind-wandering and reading comprehension in silence and distraction and reading comprehension in noise, it seems as if both sources of attention failure negatively impact reading comprehension in both contexts. While trying to read and remember information, the presence of an unrelated stream of audio caused a significant portion of individuals to report being externally distracted. As the task progressed, rates of distraction decreased, and rates of mind-wandering increased. However, rates of distraction stayed above rates of mind-wandering throughout the task. This result could be explained in several ways. It is possible that noise produces an initial distraction, derailing the train of thought, which leads the mind to wander to either irrelevant thoughts or, perhaps, thoughts about the noise itself (e.g., what the people are talking about and what song is playing in the background). It could also be the case that external distraction actually suppressed mind-wandering initially in the noise condition. Participants may have then habituated to the noise, and mind-wandering increased as a function of time just as it did in the silent condition. These possibilities warrant further investigation.

The crucial finding is a distinction between two independent yet related forms of attention failure: mind-wandering and external distraction. Because working memory capacity was uncorrelated with distraction in the silent condition and uncorrelated with mind-wandering in the noise condition, we can conclude that working memory capacity offers resistance to these two forms of attention failure in a context-specific manner. In studies examining mind-wandering in the context of cognitive tasks, participants typically complete the tasks in a controlled laboratory setting, free of any source of distraction other than one's own thoughts. However, in typical studying environments (e.g., coffee shops, student union buildings, and residence halls), individuals must avoid external distraction, as well. The findings bolster those of Stawarczyk et al. (2011) and Unsworth and McMillan (2014) yet expand upon them by adding a noise condition that requires participants to resist an irrelevant stream of auditory information. The results initially seem to indicate that mind-wandering occurs equally across the two environments. While the two groups of participants report similar amounts of mind-wandering and a similar

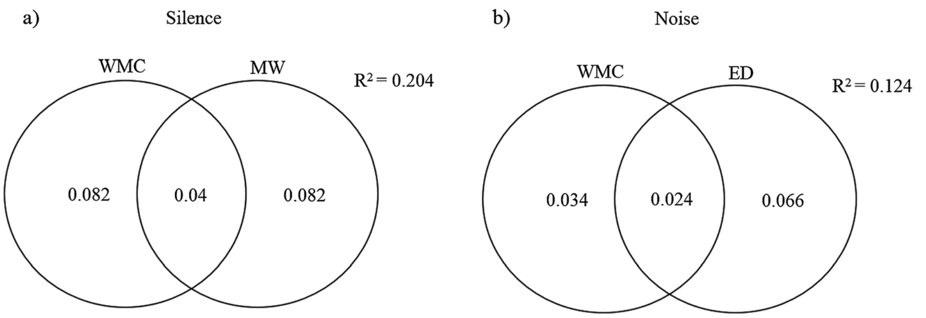

Figure 3. Unique and share variance accounted for by working memory capacity (WMC), mind-wandering (MW), and external distraction (ED) in the (a) silent condition and the (b) noise condition

trajectory with increasing reports of mind-wandering over time, the specific content of those thoughts may be different. In future work, more open-ended attentional sampling techniques may allow for participants to be more specific about the content of their task-unrelated thoughts. Although the present study did allow one open-ended form to report such content, it was difficult to tease apart mind-wandering caused by internal and external information. Also, the questionnaire was given only at the end of the task, so the timing of these thoughts and distractions over the course of the task is impossible to determine.

Because participants reported a significant amount of mind-wandering in addition to external distraction in the noise condition, one interesting finding is that mind-wandering and working memory capacity were no longer significantly correlated, as they were in the silent condition. We interpret this finding to mean that executive abilities, measured here by complex span working memory tasks, offer resistance to separate types of attention failures (i.e., mind-wandering and external distraction) in a context-specific manner. In silent reading environments, the source of 'distraction' is internal: one's own thoughts and personal concerns. The ability to resist this type of attention failure is crucial to encoding and retrieving to-be-remembered information, as indicated by the correlations between working memory capacity, mind-wandering, and reading comprehension in the silent condition. However, in the noisy studying environments, the source of distraction is external: sights and sounds in the environments. In this context, executive abilities offer resistance to this type of attention failure, and this is supported by the correlations between working memory capacity, external distraction, and reading comprehension in the noise condition. Although participants also tended to mind-wander in the noise condition and mind-wandering certainly hurt comprehension, these tendencies did not covary with individual differences in executive abilities.[3] So it seems as though noisy environments lead to more attention failure overall in the form of both mind-wandering and external distraction, but executive abilities offered resistance to the primary source of attention failure amid noise: external distraction.

The results of the variance partitioning analyses suggested that there are both unique and shared components of the executive abilities and the ability to resist mind-wandering and distraction in different contexts. An individual's working memory capacity is necessary to encode information, bind it with existing information, and subsequently retrieve this information. It is also necessary to resist attentional failure. But in each context, attentional failures also make contributions to reading comprehension independently of executive abilities. Together, these results support the context specificity of executive abilities' capacity to resist attention failure.

One surprising finding in the current study is the lack of a discernible difference in reading comprehension performance between individuals who read in a silent environment and those who read in the presence of noise. Presumably, reading and storing information are much more difficult under noisy conditions. However, this result is not entirely unsurprising given the conflicting findings of the effects of music and background noise on reading comprehension. For example, many people listen to music while they read to help them focus or perhaps tune out other sources of distraction. But Perham and Currie (2014) found that even when participants were allowed to choose their own lyrical music, reading comprehension was worse when listening to this music compared with silence or nonlyrical music. Pool, Koolstra, and Van der Voort (2003) found that high-school students who completed homework with soap operas in the background took longer to complete their homework and answered fewer questions correctly. But contrary to those findings, Tucker and Bushman (1991) found no effect of listening to rock and roll music on reading comprehension. Daoussis and McKelvie (1986) found that the effect of music on reading differed as a function of personality (introvert versus extravert). Extroverts were not hampered at all by music, whereas introverts performed significantly better without music. Therefore, it seems as if many factors including studying preferences, personality, and executive abilities account for the effects of background noise and music on performance, which may account for the lack of an effect of noise on reading comprehension in the present study.

Although we did not run any statistical analyses on the qualitative data from the open-ended questionnaire at the end of the reading test, the responses did give us some interesting information about the nature of the mind-wandering episodes and sources of external distraction within the audio recording. In the silent condition, most of the mind-wandering reports were rather mundane responses about personal concerns (e.g., 'Random thoughts about what I need to get done today/what I'm doing after this') or physical sensations (e.g., 'I am hungry, thirsty, and tired. So I was thinking about food and sleep, and I had trouble focusing on the text'). However, the responses in the noise condition were a bit more nuanced. Many participants reported being distracted by the music in the recording (e.g., 'The background music that was playing in the background was heavily distracting for me and made it difficult to focus on the text'.). Another frequently reported source of distraction was the talking in the recording [e.g., 'I couldn't focus on what I was reading due to the noise in the headphones. I found myself listening to their conversations rather then (sic) what I was reading'.]. Another common source was abrupt, unexpected sounds like knocking (e.g., 'Mostly the knocking sounds that happened at random. I was able to block out the music and most of the "crowd" noise'.). Although this information was not critical to the theoretical direction of the current study, the data do open windows into the minds of participants and offer insight for future research.

One limitation of using the audio recording in the present study is the tradeoff between ecological validity and experimental control. In this case, we had an ecologically valid sample of noise that is similar to many popular studying locations among students (e.g., coffee shops and residence halls). However, we could not isolate the effects of rhythmic and constant noise (e.g., the music and unintelligible background

[3] It should be noted that although the magnitude of the correlation between working memory capacity and mind-wandering in the noise condition is small and not significant ($r = 0.06$), a recent review (Randall, Oswald, & Beier, 2014) indicated a point estimate of $\rho = -0.14$ between cognitive abilities and mind-wandering. So the lack of a correlation here is possibly due to low power to detect this small effect.

chatter) and more abrupt noises (e.g., knocking). Prior research suggests that working memory capacity offers resistance to auditory distraction in specific way. In general, it seems as though working memory capacity is either weakly related or unrelated to irrelevant auditory speech effects (Beaman, 2004; Elliott & Cowan, 2005; Hughes et al., 2013). However, it does seem as though working memory does support resistant to auditory oddballs, which allows for a more consistent allocation of attention (Sörqvist et al., 2013). Future research using this type of auditory stream can manipulate the presence and frequency of the constant, rhythmic aspects of the noise and the more deviant, abrupt aspects of the noise to make specific predictions about the role of executive abilities in resisting external distraction while reading. However, the present study suggests that there is in fact a general resistance to auditory distraction offered by higher executive abilities in the presence of noise.

Because reading comprehension is a crucial measure of proficiency and learning in a variety of contexts, being able to maximize this ability has long been a focus of research. Previous research has established a relationship between cognitive abilities (e.g., working memory capacity) and reading comprehension as well as the effect of environmental factors (e.g., external noise). The present study merges these two findings into an analysis of the role of working memory capacity in shielding individuals from mind-wandering and distraction in a context-specific way.

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APPENDIX

Table A1. Latent factor loadings and interfactor correlations in the noise condition

	Factor						
Measure	WMC	RC	MW	ED	Int.	Mot.	Exp.
OSpan	0.69*						
RSpan	0.91*						
Read1		0.46*					
Read2		0.67*					
Read3		0.60*					
MW1			0.78*				
MW2			0.54*				
ED1				0.98*			
ED2				0.43*			
Int1					0.96*		
Int2					0.84*		
Mot1						0.42*	
Mot2						0.29*	
Know1							0.84*
Know2							0.68*
Know3							0.48*
	Interfactor intercorrelations						
WMC	—						
RC	0.24*	—					
MW	−0.06	−0.51*	—				
ED	−0.20*	−0.30*	−0.11	—			
Int.	−0.10	0.45*	−0.38*	−0.31*	—		
Mot.	−0.24	0.06	−0.37	−0.17	0.67*	—	
Exp.	−0.04	0.57*	−0.19	−0.21*	0.40*	0.40*	—

Note: OSpan = operation span, RSpan = reading span, Read = reading comprehension parcels, MW = proportion of probes reporting mind-wandering for first and second half of reading task, ED = proportion of probes reporting external distraction for first and second half of reading task, Int. = self-report questions concerning topic interest, Mot. = self-report questions concerning motivation, Know = self-report questions concerning topic experience. WMC = working memory capacity, RC = reading comprehension, MW = mind-wandering, ED = external distraction, Int. = topic interest, Mot. = motivation, Exp. = topic experience.
*significant at $p < 0.05$.

Table A2. Latent factor loadings and interfactor correlations in the silent condition

	Factor						
Measure	WMC	RC	MW	ED	Int	Mot.	Exp.
OSpan	0.68*						
RSpan	0.92*						
Read1		0.37*					
Read2		0.64*					
Read3		0.56*					
MW1			0.78*				
MW2			0.72*				
ED1				0.42*			
ED2				0.41*			
Int1					0.94*		
Int2					0.90*		
Mot1						0.89*	
Mot2						0.28*	
Know1							0.98*
Know2							0.53*
Know3							0.48*
	Interfactor correlations						
WMC	—						
RC	0.35*	—					
MW	−0.25*	−0.35*	—				
ED	0.09	−0.39	−0.54*	—			
Int.	−0.03	0.71*	−0.39*	−0.21	—		
Mot.	0.10	0.67*	−0.49*	−0.28	0.56*	—	
Exp.	−0.01	0.40*	−0.10	−0.10	0.63*	0.29*	—

Note: OSpan = operation span, RSpan = reading span, Read = reading comprehension parcels, MW = proportion of probes reporting mind-wandering for first and second half of reading task, ED = proportion of probes reporting distraction for first and second half of reading task, Int. = self-report questions concerning topic interest, Mot. = self-report questions concerning motivation, Know = self-report questions concerning topic experience. WMC = working memory capacity, RC = reading comprehension, MW = mind-wandering, ED = external distraction, Int. = topic interest, Mot. = motivation, Exp. = topic experience.
*significant at $p < 0.05$.

Table A3. Zero-order correlations among all measures in silent condition

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. OSpan	—														
2. RSpan	0.64	—													
3. Read1	0.11	0.09	—												
4. Read2	0.19	0.35	0.19	—											
5. Read3	0.05	0.07	0.30	0.35	—										
6. MW1	−0.17	−0.22*	−0.02	−0.16	−0.15	—									
7. MW2	−0.18	−0.10	−0.07	−0.17	−0.23	0.41	—								
8. ED1	−0.03	0.12	−0.08	−0.20	−0.01	−0.22	0.07	—							
9. ED2	−0.01	−0.06	−0.20	−0.11	0.06	−0.19	−0.17	0.17	—						
10. Int1	−0.03	−0.04	0.28	0.36	0.44	−0.27	−0.31	−0.11	−0.08	—					
11. Int2	−0.02	−0.02	0.21	0.34	0.46	−0.20	−0.28	−0.10	−0.01	0.85	—				
12. Mot1	0.12	0.10	0.22	0.35	0.37	−0.33	−0.27	−0.08	−0.13	0.50	0.40	—			
13. Mot2	−0.03	0.02	0.06	0.16	0.21	−0.01	−0.09	−0.08	0.02	0.10	0.09	0.61	—		
14. Know1	−0.09	0.00	0.27	0.19	0.38	−0.11	−0.17	0.02	−0.09	0.64	0.66	0.10	0.07	—	
15. Know2	−0.16	0.01	0.13	0.21	0.34	−0.20	−0.18	0.12	0.01	0.37	0.34	0.10	0.15	0.60	—
16. Know3	−0.10	−0.07	0.13	0.03	0.10	0.01	0.02	0.05	−0.01	0.19	0.15	−0.08	−0.18	0.38	0.15

Note: $N = 121$. OSpan = operation span, RSpan = reading span, Read = reading comprehension parcels, MW = proportion of probes reporting mind-wandering for first and second half of reading task, ED = proportion of probes reporting external distraction for first and second half of reading task, Int = questions regarding topic interest, Mot = questions regarding motivation, Know = questions regarding background knowledge. Correlations with absolute values greater than 0.18 are significant at $p < 0.05$.

Table A4. Zero-order correlations among all measures in noise condition

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. OSpan	—														
2. RSpan	0.63	—													
3. Read1	0.18	0.17	—												
4. Read2	0.00	0.03	0.33	—											
5. Read3	0.04	0.14	0.31	0.37	—										
6. MW1	0.05	0.04	−0.14	−0.30	−0.23	—									
7. MW2	0.00	0.01	−0.15	−0.21	−0.13	0.42	—								
8. ED1	−0.11	−0.19	−0.21	−0.11	−0.30	−0.15	−0.02	—							
9. ED2	−0.10	−0.03	−0.07	−0.05	−0.09	−0.05	−0.37	0.49	—						
10. Int1	−0.08	−0.08	0.11	0.27	0.33	−0.26	−0.28	−0.32	−0.05	—					
11. Int2	−0.18	−0.06	0.13	0.28	0.32	−0.18	−0.28	−0.29	0.03	0.81	—				
12. Mot1	0.11	0.09	0.12	−0.05	0.17	−0.09	−0.25	−0.05	0.06	0.33	0.23	—			
13. Mot2	0.04	0.05	−0.09	−0.08	−0.04	−0.04	−0.03	−0.10	−0.05	0.10	0.07	0.11	—		
14. Know1	−0.10	0.01	0.18	0.32	0.27	−0.14	−0.01	−0.24	−0.15	0.34	0.37	0.08	0.12	—	
15. Know2	−0.08	−0.06	0.07	0.33	0.23	−0.19	−0.05	−0.11	−0.15	−0.19	0.10	0.01	0.31	0.58	—
16. Know3	−0.06	0.01	0.19	0.20	0.23	−0.01	−0.09	−0.13	−0.09	0.21	0 .21	0.21	0.06	0.39	0.30

Note: $N = 120$. OSpan = operation span, RSpan = reading span, Read = reading comprehension parcels, MW = proportion of probes reporting mind-wandering for first and second half of reading task, ED = proportion of probes reporting external distraction for first and second half of reading task, Int = questions regarding topic interest, Mot = questions regarding motivation, Know = questions regarding background knowledge. Correlations with absolute values greater than 0.18 are significant at $p < 0.05$.