MCVAY, JENNIFER C., Ph.D. The Mediating Role of Mind Wandering in the Relationship Between Working Memory Capacity and Reading Comprehension. (2010)
Directed by Dr. Michael J. Kane. 84 pp.

The primary goal of this study was to investigate the mediating role of mind wandering in the relationship between working memory capacity (WMC) and reading comprehension as predicted by the executive-attention theory of WMC (e.g., Kane & Engle, 2003). I used a latent-variable, structural-equation-model approach with three WMC span tasks, seven reading comprehension tasks, and three attention-restraint tasks. Mind wandering was assessed using experimenter-scheduled thought probes during four different tasks. The results support the executive-attention theory of WMC. Mind wandering is a significant mediator in the relationship between WMC and reading comprehension, suggesting that the relationship is driven, in part, by attention control over intruding thoughts. I discuss implications for theories of WMC, attention control, and reading comprehension.

THE MEDIATING ROLE OF MIND WANDERING IN THE RELATIONSHIP BETWEEN WORKING MEMORY CAPACITY AND READING COMPREHENSION

by

Jennifer C. McVay

A Dissertation Submitted to
the Faculty of The Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
2010

Approved by

Michael J. Kane, Ph.D.
Committee Chair

To the members of my family, those who have been around and those who are on their way. Your love and support, your presence even in your absence, and your belief in me have seen me through this journey.

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

Committee Chair ______________________________
Michael J. Kane

Committee Members ______________________________
Arthur Anastopoulos

____
Stuart Marcovitch

____
Paul Silvia

____
Lili Sahakyan

____
Date of Acceptance by Committee

____
Date of Final Oral Examination

ACKNOWLEDGEMENTS

I would like to thank my advisor, Michael J. Kane, and my committee members, Arthur Anastopoulos, Stuart Marcovitch, Paul Silvia, and Lili Sahakyan for their guidance in this process. I received funding for this project through a pre-doctoral Ruth L. Kirschstein National Research Service Award, awarded by the National Institute of Mental Health.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Mind wandering, a universal aspect of human experience, is defined as a shift of attention away from stimuli and mental representations associated with a person's current-task goals to the consideration of task-unrelated thoughts (TUTs). Not all instances of attention to internal stimuli are considered mind wandering. For example, deliberate retrieval from long term memory, or generating imagery as a part of a task, are not mind wandering. In contrast, daydreaming during a class lecture, zoning out while reading, or contemplating evening plans while driving home are all examples of mind wandering, or task-unrelated thought.

The prevalence and pervasiveness of mind wandering makes it important to psychologists attempting to understand the processes that govern human thought and behavior. Previous research indicates that, on average, people spend 30-40% of their time in this mind-wandering state (Kane, Brown, et al., 2007; Klinger & Cox, 1987; Singer, 1975). Furthermore, mind wandering has been implicated in current-task performance deficits (e.g., McVay & Kane, 2009), including deficits in reading comprehension (e.g., Schooler, Reichle, & Halpern, 2004).

The main goal of the current study was to investigate mind wandering as a mediator in the relationship between working memory capacity (WMC) and reading comprehension. WMC, an individual-differences variable reflecting executive aspects of attention, predicts performance on a number of cognitive tasks ranging from simple attention restraint tasks (e.g., antisaccade; Stroop) to complex tasks (e.g., fluid reasoning; reading comprehension). The executive-attention view of WMC posits the control of attention as one important mechanism underlying performance on both WMC tasks and reading comprehension. Furthermore, I predicted that lapses of control over attention (i.e., mind wandering experiences) would be partially responsible for reading-comprehension deficits. That is, individuals with lower WMC have greater deficits in reading comprehension in part because they are unable to keep their thoughts on-task. Task-unrelated thoughts displace the task goal of comprehending the reading material and disrupt a person's ability to process the relevant details of the text for comprehension. I will discuss the relevant literature on mind wandering, WMC, and their connection to reading comprehension before addressing the specific aims and predictions for the current study.

How is mind wandering studied?

The systematic exploration of mind wandering necessitates an objective method for measuring subjective experience. Many studies (e.g., Giambra, 1993; Greenwald & Harder, 1995; Tang & Singer, 1997) have used scales to measure general tendencies to daydream or frequencies of cognitive failures, such as the Imaginal Processes Inventory (Singer & Antrobus, 1970). These global self-report measures are interesting as individual-difference variables but they are not sufficient to isolate cognitive, task, and contextual variables affecting mind wandering in a particular situation. Furthermore, global reports are subject to bias and inaccuracies as a result of their retrospective nature. In-the-moment reports of mind wandering allow researchers to explore the ostensible relationship between TUTs and ongoing task performance. In their seminal paper, Antrobus, Singer, and Greenberg (1966) asked subjects to indicate, at the end of each trial block of a vigilance task, whether they had experienced any mind wandering. This trial-by-trial assessment of TUTs provided a new tool—the “thought probe”—to the field.

When probing subjects for thought content, task interruptions should be minimized to maintain the integrity of both the task and thought content. Unfortunately, some researchers have asked subjects to report the contents of their thoughts out loud at the probe signal, to be transcribed and coded later for relatedness to the ongoing task (Parks, Klinger, & Perlmutter, 1988-89; Smallwood, Obonsawin, & Reid, 2003; Smallwood, Obonsawin, Reid, & Heim, 2002; Smallwood, O’Connor, Sudberry, & Ballantyre, 2004; Teasdale, Lloyd, Proctor, & Baddeley, 1993; Teasdale et al., 1995). This method is problematic in two ways: it interrupts the flow of the task for too long and it forces subjects to verbalize an experience that may not be easily to put into words (Nisbett & Wilson, 1977; see also Ericsson & Simon, 1980). A mind-wandering episode may only contain images or incomplete thoughts, making it necessary for the subject to fill in details for coherence or even to refrain from reporting the thought at all. This type of “verbalization” probe often results in particularly low frequencies of mind wandering.

In contrast, binary responses to probes, which ask subjects some form of the question “*Are you mind wandering?*”’ with a yes or no response choice (Antrobus, 1968; Antrobus, Coleman, & Singer, 1967; Antrobus et al., 1966; Antrobus, Singer, Goldstein,

& Fortgang, 1970; Giambra, 1995; Mason et al., 2007; McKiernan, D'Angelo, Kaufman, & Binder, 2006; Schooler et al., 2004; Shaw & Giambra,1993), do not interrupt the task for more than a few seconds (e.g., *M* = 1555 ms in McKiernan et al., 2006). The cost of using such binary responses, however, is that they do not allow for assessment of other types of cognitive interference during tasks, such as self-evaluative thoughts about task performance (sometimes called "task-related interference"; Smallwood & Schooler, 2006). A simple way around these costs is to use probes that allow subjects to indicate a *category* for their thought, (e.g., "everyday stuff" or "personal worries"; Giambra, Belongie, & Rosenberg, 1994-95; Giambra, Rosenberg, Kasper, Yee, & Sack, 1988-89; McVay & Kane, 2009; Smallwood, McSpadden, & Schooler, 2007). Such categorical probes do not interrupt the task for very long (e.g., *M* = 2300 ms in McVay & Kane, 2009) and provide more information about the subjective experience. In the current study, subjects were asked to categorize their thoughts at the time of the probe based on both task-relatedness and the temporal nature of the thought (past, present, future; e.g., Mason et al., 2007).

Validity of Thought Reports

The use of introspective self-report methods may raise concerns about validity of the measures. First, subjects may not respond honestly to probes if their thoughts are too complex, incomplete, or of a sensitive nature. One way to deal with this problem is to simplify the responses necessary to the probes (i.e., providing multiple-choice questions rather than asking for free descriptions of thoughts) so subjects do not feel pressure to reveal personal details or to generate coherent content from their thoughts. Second, subjects may not recall the contents of their thoughts with clarity. To deal with this issue, researchers should avoid probes that rely heavily on retrospective memory, such as global assessments and questionnaires at the end of a task. Brief interruptions to the task that ask subjects to assess the immediate contents of their thoughts allow for an in-the-moment record of TUTs.

Systematic variations in mind wandering frequency that co-occur with variation in theoretically-motivated task variables indicate that there is validity to self-reports of mind wandering. The frequency of mind wandering *decreases* with increased task complexity (Grodsky & Giambra, 1990; Teasdale et al., 1995), task difficulty (Antrobus et al., 1970; Filler & Giambra, 1973; McGuire, Paulesu, Frackowiak, Frith, 1996; McKiernan et al., 2006; Smallwood et al., 2003; Teasdale et al., 1993), and motivation for high performance (Antrobus et al., 1966); the frequency of mind wandering *increases* with time on task (Antrobus et al., 1967; Antrobus et al., 1966; McVay & Kane, 2009; McVay & Kane, in prep; Smallwood et al., 2004; Smallwood, 2002, Smallwood, Heim, Riby, & Davies, 2005; Teasdale et al., 1995) and alcohol consumption (Finnigan, Schulze, & Smallwood, 2007; Sayette, Reichle, & Schooler, 2009). As well, individual differences in the propensity to mind wander in the laboratory appear to be stable over time and reliable across a variety of tasks (Giambra, 1995; Grodsky & Giambra, 1990; McVay, Kane, & Kwapil, 2009).

The relationship between subjective reports of mind wandering and objective task performance measurements also validate the introspective measure. For example, intra-individual variation in task reaction times is an objective indicator of attention fluctuation that can be used to validate self-report measures. McVay and Kane (2009) found a relationship between the frequency of TUTs and variation in reaction times (r = .40) in a go/no-go, sustained attention task (i.e., SART). It is unlikely that subjects are monitoring and manipulating their overall reaction time variability throughout the task to somehow map onto their probe responses or vice versa. McVay and Kane (in prep) demonstrated a relationship between individuals' longest RTs and their propensity to mind wander. The authors generated an individualized ex-Gaussian distribution (the normal curve with an exponential component) for the RTs of each subjects and isolated the τ parameter (the tail) to represent the degree to which an individual produced exceptionally long RTs (within their own distribution). Individuals with larger estimates of τ mind wandered more often than individuals who did not produce many long RTs (McVay & Kane, in prep). The authors use this finding to help explain the worst performance rule, whereby an individual's longest reaction times are more predictive of their performance than their fastest or overall RTs, in terms of lapses of attention. An individual's longest RTs may represent those trials on which the subject's mind has wandered and thereby represent another example of the negative relationship between mind wandering and performance.

Researchers are searching for additional objective markers of mind wandering, using eye tracking and other physiological measures in addition to observed behavior (Schooler & Smallwood, 2006). For example, Reichle, Reineberg, and Schooler (in press) presented eye-tracking data from reading that suggests that although participants continue to move their eyes in a forward motion across the page when they are mind wandering, they cease to make the specific saccades necessary for comprehension (e.g., making more saccades to infrequent or less-predictable words in a sentence). Moreover, researchers have connected TUTs to activity in certain areas of the brain using neuroimaging technology (e.g., Riby, Smallwood, & Gunn, 2008).

Neuroimaging studies have identified several regions of the brain implicated directly in mind wandering experiences, reinforcing the validity of subjective reports. These areas, labeled the “default mode network” (Raichle et al., 2001), generally show deactivations in activity when subjects shift from a rest state, a time period with no task to complete, to an attention-demanding or goal-driven activity. These deactivations are interpreted to mean that “something” is going on in the brain even when there is no explicit task to complete and that this “something” decreases when attention to a particular task is required. During “rest,” the mind is free to wander, whereas during a task, thoughts must be more constrained. Subjective experience, however, indicates that people do not stay fully tuned in to the task at hand (i.e., their mind wanders) and therefore it is important to look at the activity in these same areas in relation to the subjective experience of mind wandering (Mason et al., 2007; Mason, Bar, & Macrae, 2008; McGuire et al., 1996; McKiernan et al., 2006).

Indeed, several fMRI studies have demonstrated the relationship between rate of TUTs (measured during the task) and changes in activity in the default mode network (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Mason et al., 2007; Mason et al., 2008; McKiernan et al., 2006). Most recently, Christoff and colleagues (2009) directly connected in-the-moment thought reports during a scanning session with the fMRI data. Participants performed a go/no-go task with periodic thought probes while in the fMRI scanner. The researchers measured default network activity in the time interval just prior to each thought probe. They observed greater recruitment of the default network for off-task thought reports than on-task thought reports, confirming the role of the default network in mind-wandering episodes.

Another potential criticism of thought probes is that social desirability and thought monitoring might reactively change the frequency of mind-wandering episodes (or the frequency of their reporting). For example, Filler and Giambra (1973) predicted that the expectation of thought probes would increase estimates of mind wandering during a vigilance task. In the study, Filler and Giambra varied when subjects were first asked about mind-wandering experiences (i.e., after the first, second, or third block of the ongoing task). Contrary to predictions, TUT reports *decreased* when subjects knew earlier about the thought probes. The findings suggested, perhaps, that subjects' awareness of their mind wandering in the first block caused them to exert more executive control during the second block. Alternatively, awareness of their mind wandering in the first block may have caused subjects to monitor for it in the second block, thereby interrupting normal mind-wandering production. Mind-wandering researchers, therefore, should take note of a possible underestimation of TUTs using the probe technique.

Mind Wandering and Performance Errors

Mind wandering has the obvious potential to interfere with ongoing task performance to varying degrees, depending on the task requirements. For example, whereas task-unrelated thought during a lecture is likely to impair learning of the material, the same type of thoughts during a drive would not necessarily affect performance because driving is a largely automatic process. Psychologists are primarily interested in mind wandering during tasks that require focused attention, because errors caused by those mental lapses can range from the bothersome (e.g., brushing one's teeth twice) to the catastrophic (e.g., crashing an airplane). The study of why mind wandering occurs, when it occurs, may shed light on the task and individual-difference variables necessary for optimal task performance. The ability to accomplish a non-automatic task or to fulfill a complex goal fundamentally depends on maintaining attention to that task or goal. Even the most skilled athlete does not expect to perform well if she "can't keep her head in the game."

In fact, mind wandering has been connected to errors on many attention-demanding tasks. The relationship between mind wandering and errors takes two forms: Some studies report a correlation between individual differences in mind wandering rates and performance (McVay & Kane, 2009; Smallwood et al., 2004; Smallwood et al., 2003), whereas others report a within-subjects comparison showing a greater in-the-moment likelihood of an error in conjunction with the report of a TUT than a report of on-task thinking (McVay & Kane, 2009; Schooler et al., 2004; Smallwood et al., 2007). For example, overall recall memory for words is negatively related to TUT rates at study (r = -.25; Ellis, Moore, Varner, Ottaway, & Becker,1997) and subjects who reported one or more TUTs while learning words performed worse than no-TUT subjects on the subsequent memory test (Smallwood et al., 2003).

McVay and Kane (2009) found that mind wandering predicts in-the-moment errors on a Sustained Attention to Response Task (SART; Manly, Robertson, Galloway,

& Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). The SART is a go/no-go task in which stimuli are presented rapidly (250 ms; 900 ms mask) and subject are instructed to respond to all stimuli except infrequent (11%) randomly-occurring target trials that differ on some dimension. Previous work demonstrated that SART performance is related to both global measures of Cognitive Failures (CFQ; Robertson et al., 1997) and end-of-trial thought reports (Smallwood et al., 2004). McVay and Kane (2009) used a version of the SART with word stimuli and thought probes following randomly occurring target trials. Subjects committed more errors on target trials where they reported off-task thinking (M = .58) than when they were on-task (M = .38). The deterioration in performance over time on the SART task paralleled the increase in mind wandering over the same period. Individual differences in subjects' overall accuracy also correlated negatively with their TUT rate (r = -.37). Variation in reaction time to the frequent non-target trials, an index of general fluctuations in attention, shared a relationship with TUTs in this task (r = .40). McVay and Kane (in prep) replicated these findings in the standard SART condition (r = -.30 for TUTs and accuracy; r = .25 for TUTs and RT variability).

McVay and Kane (2009) used evidence from mind wandering in the SART to argue that conscious thought affects performance by interrupting maintenance of the task goal. This claim, if true, should apply to all tasks that require executive control to stay "on-task." Although SART is a useful tool for testing this hypothesis in the lab, it is not a task that people encounter in their daily lives. Reading, on the other hand, is fundamental to learning and communication throughout the lifespan. Starting in the early years of elementary school, textbooks are used to convey information to children; by teenage years, students are required to learn class material almost entirely through reading. Reading is also a task during which most people have had mind wandering experiences, where their eyes continue to move across the page although they are no longer processing the written material (Schooler et al., 2004). Furthermore, reading is usually an integrative task. Whereas SART errors occur on a trial-by-trial basis and do not necessarily affect future trials, missing information during reading can affect overall comprehension of the material. For example, if while reading a scientific article, a reader zones out during the operational definition of one of the variables, she may find it difficult to interpret the results.

Mind Wandering and Reading

Although mind wandering during reading is an experience common to most people, little work has addressed how off-task thoughts affect comprehension of reading material. Giambra and Grodsky (1989, 1990) measured mind wandering during reading and demonstrated a stable propensity to mind wander over vigilance and reading tasks (r = .51). They did not, however, report comprehension measures for the reading tasks and thus, did not demonstrate the effect of mind wandering on reading comprehension. Reichle et al. (submitted; originally presented in Schooler et al., 2004) presented data from the only studies looking directly at the relationship between the performance aspect of reading (i.e., comprehension) and mind wandering. They reported three studies in which subjects read a portion of Tolstoy's *War and Peace* and completed a reading comprehension test. While reading the excerpt on the computer screen, subjects were asked to monitor their mind wandering and report any occurrences by pressing a key (i.e., self- caught mind wandering reports). Some subjects were also probed every 2-4 minutes following either a self-reported mind wandering experience or the last probe. The proportion of probes on which subjects reported mind wandering predicted overall reading comprehension accuracy (r = -.51 in E1; r = -.25 in E2) indicating that more mind wandering predicted of worse comprehension accuracy. In Experiment 2, comprehension questions followed directly after each self-report or probe-caught mind wandering episode. Subjects who reported mind wandering (either self-reported or probe caught) performed worse on comprehension questions directly following the report (*M* accuracy = .59) than did unprobed control subjects (*M* = .80).

One major limitation of the Reichle et al. study is that the authors' focus on meta-awareness (i.e., monitoring the contents of conscious experience) affected their design for thought probes. The probes were contingent on self-reports of mind wandering in that they occurred 2-4 minutes after either the last self-caught report or the last probe. There were, therefore, different numbers of each type of mind wandering report for each subject. This makes the essential comparison of reading comprehension following on-task reports versus following off-task reports difficult. The authors' comparison of accuracy during off-task reports with accuracy of unprobed subjects assumes that the unprobed subjects were not mind wandering and is contrary to the argument that most people mind wander at some point (if not many points) during reading. The current study used only experimenter-scheduled probes, which occurred at certain points in the text or at specific time intervals.

In a third experiment from the same series, Reichle et al. (submitted) compared mind wandering in a vigilance task to mind wandering in a reading task. One potential criticism of their first two experiments is that poor readers mind wander just because they are poor readers and not because task-irrelevant thoughts are actually causal in disrupting reading comprehension. Rather, poor readers mind wander because they are already reading poorly. A relationship between mind wandering in a vigilance task and reading comprehension would strengthen the claim that individual differences in the ability to maintain on-task thinking contributes to comprehension performance. However, while Reichle et al. (submitted) replicated the finding of Grodsky and Giambra (1990), that mind wandering reports in a vigilance task are related to mind wandering reports in reading (r = .36, self-caught reports only), they did not report the crucial relationship between mind wandering in the vigilance task and comprehension performance. Therefore, the current study will provide a more conclusive study of mind wandering and reading comprehension by linking mind wandering during a variety of tasks to reading comprehension.

Mind Wandering and Executive Control

Mind wandering is connected to errors in a variety of tasks, but why? Several researchers have suggested that mind wandering is related to executive function, although there are different views on how TUTs and executive function are related. Smallwood and Schooler (2006) posit that mind wandering requires executive resources, primarily on the basis of two studies by Teasdale and colleagues. Teasdale et al. (1993, 1995) found that subjects reported fewer TUTs during a task than while sitting quietly, during tasks with greater versus lesser memory load, during tasks with faster versus slower stimulus presentation rate, and during more versus less practiced tasks. Finally, subjects were worse at generating random patterns of numbers (an executive function task; Teasdale et al., 1995) when they reported mind wandering than when they reported on-task thoughts (Teasdale et al., 1995). Smallwood and Schooler (2006) view these findings as evidence for resource sharing between the tasks and mind wandering (i.e., fewer resources are available for mind wandering when completing tasks with executive control demands).

An alternative explanation for the Teasdale findings, however, is that the engagement of executive control in the above situations prevented mind wandering in order to facilitate task performance. Mind wandering, by this view, can be conceptualized as reflecting a lapse of executive control, rather than a process that requires executive resources ("*control failures* × *concerns*" view; McVay & Kane, 2009; in press). In fact, mind wandering may be the subjective experience of allowing *automatically* generated thoughts from a continuous stream of thoughts to enter consciousness in an uncontrolled manner. The shared brain areas active during "rest," arguably an unconstrained time period, and mind wandering support this view. Mind wandering that affects performance, therefore, reflects a break in the restraints imposed on the train of thought in order to focus on the task.

Our view is that a failure to control attention underlies the relationship between mind wandering and performance errors (McVay & Kane, 2009; in press). Mind wandering is the subjective experience that accompanies a failure to properly maintain task goals when successful performance relies on goal maintenance. TUTs increase with time on task, suggesting that maintaining on-task thoughts may be subject to fatigue. Other types of control failures, such as expression of stereotype biases (Richeson & Trawalter, 2005), are also subject to fatigue (see also Muraven & Baumeister, 2000; Schmeichel, 2007). More importantly, the propensity to mind wander varies with individual differences in working memory capacity (WMC), a measure of attention control (Engle & Kane, 2004; Kane & Engle, 2003).

The executive-attention view of WMC explains the relationship between WMC span tests and complex cognition, such as language comprehension and reading, through a domain-general attentional-control mechanism – that is, individual differences in the control of attention underlie performance on both WMC span tests and complex cognitive tasks (Engle & Kane, 2004; Kane & Engle, 2003). WMC is measured using complex span tasks requiring subjects to maintain access to items in memory while processing new incoming information. For example, the operation span (Ospan) requires subjects to verify the solution to compound math equations as the processing task. Interpolated with the math problems, subjects see a sequence of letters to learn for an immediate memory test. The reading span (Rspan) shares the same memory task with Ospan (remembering individual letters) but requires subjects to verify whether sentences make sense for the processing task. In addition to complex cognitive tasks like general fluid intelligence, language learning, and scholastic achievement (Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Kane, Hambrick, & Conway, 2005), WMC predicts performance on low-level attention tasks involving minimal memory demands, such as the antisaccade task (Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Scrock, & Engle, 2004). This task requires subjects to resist attentional capture from a flashed stimulus to accurately attend to a target presented in the opposite field of vision. People with high WMC better resist the automatic pull of the flashing distracter stimulus than people with low WMC. Evidence from tasks like these (for review, see Kane, Conway, et al., 2007) suggests that WMC is closely linked to attentional control.

According to Engle and Kane (2004; Kane, Conway, Hambrick, & Engle, 2007) there are two components of executive attention that are related to WMC: goal maintenance and competition resolution. Goal maintenance is sustaining access to task-relevant information in the face of interference from habit, distracters, or competing thoughts (i.e., mind wandering). Competition resolution deals with the interference associated with the particular trial stimulus. That is, even if the goal of the task is sufficiently maintained, there may still be variation in overcoming a stimulus-driven response on a trial-by-trial basis. The dual components of executive attention can also be discussed in terms of "proactive" and "reactive" processes (Braver, Gray, & Burgess, 2007). Proactive processes are initiated prior to the need for control and are sustained until the completion of the task. Reactive processes are initiated on an as-needed basis in response to the conflict on a trial. These two processes are strategically allocated based on the expected demands of the task (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver et al., 2007; Brown & Braver, 2005). If the subject anticipates the need for top-down control in the task, goal maintenance processes will be initiated at the onset of stimuli and maintained throughout the task. Successful performance on many attention-demanding tasks relies on both components of executive attention (for exceptions, see Kane, Poole, Tuholski, & Engle, 2006).

Kane and Engle (2003) provided crucial evidence for the dual-component nature of executive attention. Using a Stroop paradigm, they manipulated the proportion of color-word congruency, such that in some cases the color words and hues matched most of the time and in other they were mostly incongruent. In a mostly incongruent version of the task, the goal of naming the color is reinforced on most trials because reading the word would lead to an incorrect response. In contrast, in a mostly congruent condition, the color naming goal is not reinforced and therefore must be endogenously maintained throughout the task. Two important span differences in the ability to maintain the task goal emerged in the mostly congruent Stroop task. High spans were more accurate than low spans on the infrequent incongruent trials, suggesting they were better maintaining the color naming goal without reinforcement. Furthermore, the low spans responded more quickly than high spans to the congruent trials, suggesting that low spans were reading the words (a faster, more habitual task) rather than naming the color on congruent trials (i.e., they were not maintaining access to the color-naming goal throughout the task). Variation in competition resolution, the second component of executive attention, should produce reaction time differences even in conditions where the goal is easily maintained (mostly incongruent condition). In fact, low spans were slower than high spans to respond accurately on incongruent Stroop trials suggesting that even when they were maintaining the color naming goal, they were having more difficulty resolving the stimulus-based conflict than high spans.

Mind Wandering and WMC

The executive-attention theory of WMC argues that WMC span tasks capture both components of executive attention: goal maintenance and competition resolution. As discussed previously, the experience of mind wandering is the result of TUTs hijacking the task goals, resulting in a goal maintenance failure. Therefore, TUTs should be predicted by individual differences in WMC. Kane et al. (2007) first demonstrated this relationship using a daily-life experience sampling method. One hundred twenty-six subjects, having previously completed WMC screening, carried Palm Pilot PDAs that beeped randomly 8 times a day for 7 days. At the beep, subjects were asked to immediately respond to the phrase “At the time of the beep, my mind had wandered to something other than what I was doing.” Following their binary yes/no response, subject answered additional questions about thought content, perceived control over thought, and context variables (e.g., *What I’m doing right now is related to schoolwork*). Not all everyday tasks require executive-control capabilities that define the types of lab tasks (e.g., Stroop, antisaccade) and more general measures (e.g., SATs; tests of fluid intelligence) that WMC predicts. Therefore, Kane et al. predicted that there would be no overall WMC differences in mind wandering rates but that WMC differences in mind wandering would emerge only at times when subjects were attempting to control their attention.

As predicted, there was no overall relationship between WMC and reports of off-task thinking. There were, however, several important interactions with context factors that support the notion of WMC differences in mind wandering during attention-demanding situations. For example, subjects were asked to rate their level of concentration and the effort demanded by the ongoing task at the time of the beep. At high levels of concentration and effort, higher WMC reported less mind wandering than lower WMC subjects, indicating that lower WMC subjects were having more difficulty maintaining their attention on high-concentration and high-effort tasks. One limitation of this experience sampling method, however, is that we do not get a measure of how well subjects are performing on a daily-life task during which they report mind wandering. McVay et al. (2009) collected (subjective) performance data and TUT reports during daily life in another ESM study. For each probe during daily life, subjects rated their performance of their current activity. Subjects' TUT reports predicted their performance ratings such that when subjects were mind wandering, they were more likely to report poor performance in their daily life activities, compared to when they were on-task. Unfortunately, the sample in McVay et al. (in press) was too small for assessment of individual differences in WMC and their effect on the TUT-performance relationship.

In a related line of studies, researchers have demonstrated a positive relationship between WMC and the ability to suppress or inhibit a particular intrusive thought. Brewin and Beaton (2002) used the "white bear" suppression paradigm (Wegner, Schneider, Carter, & White, 1987) whereby subjects are asked to refrain from thinking about a white bear during a period of time and report intrusions. Subjects with higher WMC (as measured by Ospan) reported fewer intrusions of the forbidden thought (Brewin & Beaton, 2002). Individual differences in WMC also predict suppression of particular real-life events (Brewin & Smart, 2005; Geraerts, Marckelbach, Jelicic, & Habets, 2007). In these studies, subjects identified a particular life event or intrusive thought from their personal experience and attempted to keep it out of their mind for a specified time period. Low WMC subjects experienced more intrusions of the designated thought content than high WMC subjects (Brewin & Smart, 2005; Geraerts et al., 2007). The suppression of particular thoughts may be related to a general ability to maintain on-task thoughts, although the relationship of these two constructs remains to be tested. WMC predicts both thought suppression and the propensity to mind wander, suggesting that thought control may be an important part of goal maintenance and that off-task thoughts should lead to performance errors.

Mind Wandering, WMC, and Performance Errors

The executive-attention theory predicts a mediating role of mind wandering between WMC and errors. WMC span tasks capture individual differences in executive attention, the same resources necessary to keep one's thoughts on task and a prerequisite to accurate performance in attention-demanding tasks. Goal maintenance, one component of executive attention, is disrupted when mind wandering occurs. Therefore, the occurrence of TUTs should explain the same variance as executive-attention driven WMC scores in reading comprehension. In the SART study discussed earlier (McVay & Kane, 2009), subject were screened for their WMC prior to completing the SART with thought probes. WMC variation significantly predicted TUTs (r = -.22), SART accuracy (r = .29) and intra-subject variation in reaction time (r = -.35). Furthermore, mind wandering rate accounted for half WMC's shared variance with performance, indicating that the experience of TUTs partially mediated the relationship between WMC and goal-neglect errors. These findings are in line with the dual-component nature of the executive-attention theory. Goal neglect errors can be the result of either insufficient goal maintenance or competition resolution. The mediating relationship of mind wandering thus most likely indicates instances where maintenance of the task goal is interrupted by TUTs, whereas the remaining, unique variance in goal neglect accounted for by WMC variation is the competition resolution component. The SART promotes the build-up of a strong habitual response on non-target trials, thus making the withholding of the response to target trials difficult even when the task goal is properly maintained. SART is an example of a task where both goal maintenance and competition resolution contribute to task performance and mind wandering mediates the relationship between WMC and performance. Indeed, mind wandering should mediate the WMC-performance relationship in any task that requires goal maintenance for performance. Reading is an activity that requires goal maintenance and shares an established relationship with WMC. Therefore, in the current study, I examine WMC, reading comprehension, and mind wandering.

WMC and Reading Comprehension

Daneman and Merikle’s (1996) meta-analysis on 77 studies of WMC and reading comprehension measures concluded that individual differences in WMC predict comprehension (*rs* =.30 - .52). Furthermore, it is not only the reading version of span tasks (verifying sentences and remembering letters or words) that predicts reading comprehension, but operation span tasks (e.g., verifying math problems and remembering letters) also do, indicating that the verbal processing component in reading span does not entirely drive the relationship. Many of the studies in the meta-analysis used subjects' Verbal Scholastic Aptitude (VSAT) scores as a measure of reading comprehension. In some ways, this dependent measure may underestimate the relationship between WMC and reading because the passages are fairly short and intermixed with vocabulary and analogy sub-tests. Test-takers are also able to look back through the text while answering questions, requiring them to integrate less information from the text as a whole (i.e., they can hunt for the specific answers without an overall understanding of the text). Both of these characteristics of the VSAT may limit the contribution of WMC to performance in that the brevity of the passages may not require sustained attention in the same way as would a longer textbook chapter or journal article. Performance on reading tasks require that subjects to maintain focus on the material for longer periods of time and generate general inferences used to understand the text as a whole should be positively – and strongly – related to WMC.

Current Study

The primary goal of this study was to investigate the mediating role of mind wandering in the relationship between WMC and reading comprehension. As reviewed above, both WMC and mind wandering predict reading comprehension, but this is the first study combining these two individual-difference variables to establish their relationship to one another in predicting comprehension. Using a latent-variable, structural-equation-model approach, I used several measures to derive the variables of interest: WMC, mind wandering, and reading comprehension. The WMC variable was derived from three span tasks to get a good estimate of the domain-general nature. Mind wandering was assessed using experimenter-scheduled thought probes during four different tasks. Two of the tasks were reading for comprehension, in order to look directly at the relationship between TUTs and comprehension. These reading tasks, in addition to five ‘clean’ reading comprehension tasks (i.e., no mind wandering probes) were used to derive a comprehension latent variable. The other two tasks with probes were low-level attention tasks. If individual differences in TUTs on non-reading tasks also predict comprehension, it would provide stronger evidence for mind wandering propensity as a cause of poor reading rather than an effect of poor reading skills.

The two additional attention-restraint tasks were included to help evaluate a mediation claim implicit in the executive-attention theory of WMC. This theory posits that executive attention is the underlying construct connecting WMC to performance on complex cognitive tasks and is supported by the relationship between WMC and low level attention tasks such as Stroop and antisaccade (Kane & Engle, 2003; Engle & Kane, 2004). However, the *mediation* of an executive-attention latent variable in the relationship between WMC and complex cognitive tasks, although implied by the theory, remains untested. The addition of attention restraint tasks with known relationships to WMC (SART, Stroop, and antisaccade; see methods for details) to this design allowed me to test this mediation model using reading comprehension as the complex cognitive task. Furthermore, the measurement of mind wandering during these tasks provided a domain-general estimate of mind-wandering propensity instead of one specific to reading situations.

CHAPTER II

METHODS

Participants

Participants were recruited from the undergraduate participant pool at the University of North Carolina at Greensboro (UNCG) and they participated for course credit. Native English speakers between 18 and 35 years old were invited to participate. Of the 258 participants who gave written informed consent to participate, 248 completed two sessions, and 242 completed all three sessions of the study.

WMC Measures

The tasks used to measure WMC were those recommended by a recent methodological review (Conway et al., 2005). All three measures of WMC required subjects to switch between a processing component and a memory component. Operation span (Ospan) required subjects to verify the answers to compound mathematical equations (e.g., (2+2)/1 = 4) while remembering letters presented after each equation. At the end of 3-6 equation-letter trials, subjects recalled the letters in the order they were presented by clicking boxes (in order) next to 12 possible letters. Reading span (Rspan) used the same memory stimuli but subjects decided whether a sentence made sense or not as the processing task (e.g., "I like to run in the sky"). Spatial span (Sspan), unlike the other two tasks, did not use verbal stimuli. Subjects remembered sequentially-presented locations on a 4×4 grid presented following a decision about whether 16×16 grid patterns were symmetrical along the vertical axis. After each set of grid patterns and 4x4 grid locations, subjects indicated the locations in order by clicking in the boxes in an empty 4x4 grid. All three tasks were automated and presented using E-prime software. Subjects practiced each part of the task (processing task, memory task) separately and then together prior to beginning the test trials. During the practice portion of the processing task alone (15 problems), the program computed the average time it took to complete each trial. During the combined trials, if subjects took longer than two standard deviations above their mean processing time from practice, the computer skipped to the memory component and the trial was designated an error. This way, subjects could not take extra time during the processing task to rehearse the memory items.

Reading Comprehension Measures

The reading tasks in this study were selected to represent a wide range of the types of reading materials that people encounter in daily life. Only two of the reading comprehension measures included thought probes in case the probes somehow affected reading (either by interrupting integration of the test or by alerting subjects when they are off task). For each reading task (other than the VSAT), Flesch-Kincaid scores for ease and grade level are reported below. Flesch-Kincaid (F-K) scores are based on word length and sentence structure as opposed to conceptual content. Higher ease scores indicate less difficult passages (most 13-15 year olds can easily read passages in the range 60-70).

Verbal SATs. The first measure of reading comprehension was the subject's score on the Verbal Scholastic Aptitude Test (VSAT) as recorded by UNCG's admissions office and accessed with subjects' permission.

Inference Verification Test. Materials for this task came directly from Griffin, Wiley, and Thiede (2007) where overall comprehension was related to individual differences in WMC (r = .32). At their own pace, subjects read onscreen (only once and with no additional instructions; see Griffin et al., 2007 for instruction manipulations) two 600-900 word explanatory texts about bacteria and volcanoes, with F-K grade levels of 11-12 and F-K ease scores in the "difficult" range, 31-49. Following each passage, subjects completed a self-paced Inference Verification Test (IVT) on which they responded true or false to statements that tapped comprehension of the text based on drawing inferences from the passage (e.g., Volcanoes occur where oceanic and continental plates converge).

Psychological Journal Articles. The materials for these tasks came from a previous study on feedback and memory, and represented the type of reading material and test format used in higher education (Kang, McDermitt, & Roediger, 2007). Furthermore, a recently-completed dissertation project at UNCG, drawing from the same undergraduate population and using the same materials, provided information about accuracy rates (McConnell, 2009), as the original study population was from a more selective university (Kang et al., 2007). This task comprised 2 articles, of 2000-2500 words, from *Current Directions in Psychological Science*. The two articles, Anastasio, Rose, and Chapman (1999) about media bias and Treiman (2000) about literacy, had F-K ease scores in the range of 40-65 and F-K grade levels of 5.5 and 7.5, respectively (calculated in MS Word). Eight multiple choice questions for each article were taken directly from Kang et al. (2007), with an additional 4 questions created by McConnell (2009), to make 12 per article. Subjects had 15 minutes to read each article on paper followed by a computerized comprehension test. One of the two articles, Treiman (2000), presented auditory thought probes every 2-4 minutes (see mind wandering measures for additional details on thought probes).

Novel Reading Task. The reading material for this task was taken from Schooler et al. (2004), but the comprehension testing was unique for our purposes. Subjects read the first five chapters of Tolstoy's *War and Peace* in a self-paced, paragraph by paragraph format presented on the computer in Times New Roman font size 15. This excerpt was approximately 8000 words and had a F-K grade level of 8.3 and a F-K ease score of 65.5 (calculated in MS Word). Subjects completed true/false comprehension questions at reasonable intervals based on the progression of the story. The questions prompted subjects to verify information from the reading up to that point and were therefore placed at positions in the text where enough new information had been presented to justify a new question. I collected accuracy and RT data on the questions, as well as RT data for reading each screen. Reading comprehension questions were piloted on 95 subjects prior to this project and adjusted based on internal reliability; questions producing close to perfect or close to zero accuracy were replaced. Thought probes appeared throughout the text (see mind wandering section for details) and were each followed by a comprehension question.

Subjects had 50 minutes to read the novel excerpt and answer as many questions and probes as possible (up to 20). In pilot testing, 90 of the 95 subjects completed the chapters within 50 minutes. Subjects who completed the first five chapters and all 20 questions in less than the allotted time continued reading additional chapters until the session was over. We included additional reading material to avoid subjects finishing early and potentially prompting other subjects to skip through in the hopes of finishing early. We did not collect RT data or comprehension information during the additional chapters but the transition from data collection to extra reading was seamless to the subjects.

Short Story Reading Task. Subjects read two short stories, self-paced, presented paragraph by paragraph on the computer in Times New Roman font size 16, *The Coming-Out of Maggie* by O. Henry (*Maggie*) and *Eveline* by James Joyce. The short stories paralleled the journal articles in word length (~2500). *Maggie* had a F-K grade level of 6.2 and a F-K ease score of 73; *Eveline* had a F-K grade level of 4.8 and a F-K ease score of 82.9 (calculated in MS Word). Following each story, subjects completed six true/false questions and six multiple-choice questions to assess whether they comprehended the basic theme and plot of the story. Reading comprehension questions for *Maggie* were piloted on 95 subjects prior to data collection and adjusted based on internal reliability; questions producing close to perfect or close to zero accuracy were replaced.

Attention Restraint Tasks

Stroop Task. Subjects completed a numerical Stroop task where the task goal was to report the number of items presented on each trial. In the classic color-word Stroop, words are presented in different colored inks and subjects are expected to name the ink color. In the numerical variation of the Stroop task, 2, 3, or 4 digits were presented on each trial and subjects were instructed to report the number of items presented (e.g., Windes, 1968; for review, see MacLeod, 1991). Congruent trials were those where the number of digits matched the value of the presented digits (e.g., 333) and incongruent trials presented a mismatch (e.g., 222; correct answer is three). Stroop stimuli were presented in Courier New font size 24. Subjects responded by indicating the number of items presented on each trial by pressing the b key for 2, the n key for 3, and the m key for 4 with their dominant hand. Prior to the start of the Stroop task, subjects completed 36 mapping trials where they used the b, n, and m keys to respond to the number of red boxes onscreen (2, 3, or 4, respectively). Subjects performed 480 experimental trials total, in sets of 60 trials at 75% congruency (without noticeable breaks to the subject). Within each set of 60 trials, 15 congruent and 15 incongruent trials were marked for reaction time and accuracy analysis to equate the number of trials analyzed in each condition (75% congruent = 15 incongruent trials). Mind-wandering probes followed 60% of the incongruent trials in the second half of the task.

Pilot testing (N= 39) revealed RT and accuracy costs on incongruent trials compared to congruent trials (Ms = 10% accuracy difference and 109 ms RT difference). I also looked at whether probes on the second half of the trials affected accuracy or RT; they did not. Furthermore, overall accuracy was significantly correlated with TUTs (r = -.43) and subjects made more errors when they reported a TUT than an on-task thought (M accuracy= .83 vs. M = .93, $t(38) = -2.66$, $p = .01$).

Semantic SART. Subjects completed a 20-minute version of a Sustained Attention to Response Task (SART) with semantic stimuli from McVay and Kane (2009). The SART is a go/no-go task where subjects must respond quickly with a key press to all presented stimuli except infrequent (11%) target trials. In this version of SART, word stimuli were presented in Courier New font size 18 for 300 ms followed by a 900 ms mask. Most of the stimuli (non-targets) were members of one category (animals) and infrequent targets were members of a different category (foods). The SART had 540 trials, 60 targets and 36 probes. Mind wandering probes followed 60% of target trials.

At the end of the SART, subjects completed a short computerized questionnaire asking them to estimate how long it took to complete the SART, how well they did on the task (accuracy estimate, % correct) and how often they were mind wandering (global estimate, % of time mind wandering). They also reported how hard they were concentrating and how much effort they were putting into the task (using 7-point Likert scales).

Antisaccade Task. In this task, a quick flash on one side of the screen reliably predicted the appearance of a target on the opposite side of the screen. Following a key press response to a 'ready' screen, a blank screen lasting unpredictably between 200 ms and 2200 ms preceded the flashing cue. A Courier New font size 24 "=" flashed 100 ms on, 50 ms off, 100 ms on, about 12 cm from the center (randomly but equally often to the left and right), drawing attention to that location (Kane et al., 2001). The target (in Wingdings 3 font size 28), an arrow pointing up, down, right, or left, appeared the same distance from center, on the opposite side, for 150 ms and was then masked by a plus sign for 1500 ms or until the subject responded. Subjects were instructed to press an arrow on the keyboard corresponding to the direction of the target arrow (Roberts, Hager, & Heron, 1994). Subjects performed 10 practice trials where the stimulus appeared in the center of the screen followed by 72 trials experimental trials.

Mind Wandering Probes

Thought probes requiring subjects to classify the contents of their immediately preceding thoughts appeared during four of the tasks in this study. The instructions asked subjects to answer the probe based on their thought content just before the probe appeared and not to try to reconstruct all of their thought content since the last probe. The thought probes were modified slightly to reflect the nature of the ongoing task in the category options, for example (as it appeared during War & Peace):

What were you just thinking about?

1. The text
2. How well I'm understanding the story
3. A memory from the past
4. Something in the future
5. Current state of being
6. Other

Subjects responded by pressing a number on the keyboard corresponding to their thought category. For analysis, the first two categories were coded as task-related, versus task-related interference (TRI), respectively. Responses of 3-6 were coded as task-unrelated thoughts (TUTs).

Stroop Task. During the first 4 sets of 60 trials, there were no thought probes. In the second half of the task, thought probes were attached to 9 of the 15 randomly-occurring incongruent trials within each set of 60 trials for a total of 36 thought probes. The probe appeared as soon as the subject responded to the previous trial and terminated when the subject responded.

Semantic SART. Probes followed directly after 60% of the target trials, randomly distributed throughout the entire task (36 probes).

Journal Article Reading Task. While reading the Treiman (2000) journal article, the computer screen directly in front of them (in their peripheral vision as they read the printed article) flashed red every 2-4 minutes (6 probes in 15 minutes) signaling them to respond to the thought probe that appeared next on the computer screen. After entering their probe response, they resumed reading the article on paper.

Novel Reading Task. While subjects read *War and Peace*, a probe appeared just prior to each comprehension question (20 possible probes).

Procedure

Subjects were tested in groups of 1-6 and completed 4.5 hours of testing broken into three 90-minute sessions. Subjects were informed that participation in all three sessions was necessary to receive their full participation credit prior to signing up for the first session. All three sessions were completed within the same semester (14 weeks of testing), but the interval between sessions varied because subjects scheduled their own appointments for each session (M = 31 days [SD = 19] to complete all three sessions). The order of the tasks is presented in Table 1.

Statistical Procedure

I report non-directional null-hypothesis significance tests with an alpha of .05. I report several fit statistics for confirmatory factor analyses (CFA) and structural equation model (SEM) analyses, as is typically recommended (e.g., Kline, 1998). The chi-square statistic (χ^2) is a "badness-of-fit" test because it reflects whether there is a significant difference between the expected and observed covariance matrixes. Non-significant chi-square tests indicate good model fit. However, chi-square tests are sensitive to sample size and are often significant as a result of a slight difference between the expected and observed covariance matrixes. Informally, then, a chi-square to degrees of freedom ratio of less than 2 may be used to indicate good model fit. I report the confirmatory fit index (CFI) and the root mean square error of approximation (RMSEA), which are less sensitive to sample size. The CFI is a measure of the extent to which the model fits better than an 'independent' model where all covariances are set to zero; values greater than .90 reflect a good fit. RMSEA compares the model to the population covariance matrix; values less than .05 are considered excellent fit. Finally, I report the standardized root-mean square residual (SRMR), which reflects the average squared difference between the observed and reproduced covariances. SRMR values less than .05 indicate excellent model fit (Kline, 1998).

For the SEM models, I report both the direct path coefficients and the indirect effects. The coefficient for the indirect effect is interpreted like a path coefficient. For example, if the path coefficient between WMC and TUT rate is X, then for every 1 SD increase in WMC, TUT should increase by X(SD). Then, if reading comprehension decreases by Y for every 1 SD increase in TUT, the indirect effect of WMC on reading comprehension through TUT is the product of the X (represented by the path coefficient from WMC to TUT) and Y (the path coefficient from TUT to comprehension).

CHAPTER III

RESULTS

The software used for the CFA and SEM analyses, Mplus, deals well with missing data and therefore, data were dropped at a task level instead of a subject level. Subjects who did not complete all tasks were included in analysis using the data from the tasks they completed. The data from subjects with outlier scores on some tasks were left for analysis; only data from the particular task on which they produced an outlier were excluded (see below). An error in the program for data collection during the second journal article task resulted in accurate data for only 166 subjects on that task.

Five subjects completed only the second and third session due to an error in the system for signing up to participate, therefore no data from Session I (Ospan, Stroop, Journal Article 1, and Maggie) are available for those subjects, so the total possible subjects for Session I tasks is 253. All 253 were included for Ospan and Journal Article 1. For Stroop, the data for one subject were lost due to computer malfunction and nine subjects were dropped for failure to follow instructions (i.e., congruent accuracy = 0%, indicating they were not responding with the correct keys). Three subjects were dropped from Maggie because they were outliers on reading time (M < 5000 ms; compared to overall M = 14801 ms) and accuracy (M < .25; less than chance for multiple choice questions), suggesting they were skipping through and not reading the story.

Two hundred forty-eight subjects completed the second session (Sspan, SART, War & Peace). The data from one subject for War & Peace, one subject for SART, and two subjects for Sspan were lost due to computer malfunction (e.g., subject kicking the power cord out of the wall). Data from three subjects were dropped from Sspan for too many errors on the processing task (>15%; see Conway et. al., 2005). The data from 17 SART subjects were corrupted due to a programming error and 5 subjects were dropped for failure to follow instructions (non-target accuracy < .80).

Of the 242 subjects who completed the third session (Rspan, Journal Article 2, IVT, Antisaccade, Eveline), data from one subject in Rspan and six subjects in Antisaccade were dropped as a result of computer or program problems. In addition, data from three subjects were dropped from Rspan for errors (> 15%; see Conway et. al., 2005). One outlier from Antisaccade, whose accuracy was 0%, was dropped. In the IVT, one outlier with fast reading times and low accuracy, most likely indicating a failure to do the task, was dropped. Data from two subjects in the Eveline task were dropped for less than chance accuracy on the comprehension test (17%).

When I ran the CFA analysis, I also tested for multivariate outliers. I isolated three subjects whose Mahalanobis distance exceeded the standard cut-off (χ^2 at $p = .001$ for the number of variables). None of the main SEM findings changed as a result of removing these three subjects. I also isolated seven subjects who were outliers on both Mahalanobis distance and Cook's D (by analyzing a scatterplot of the two variables). None of the main SEM findings changed as a result of removing these seven subjects.

Below I report the statistics for the dataset excluding the seven multivariate outliers on both Mahalanobis distance and Cook's D thereby making n = 251 for the SEM models.

WMC and Reading Comprehension Measures

The descriptive statistics for the three WMC span tasks and the seven reading comprehension measures are presented in Table 2; correlations among these measures are presented in Table 3. The z-score composite for the WMC measures was calculated using a database with over 2000 subjects. Overall, the mean WMC composite z-score (averaging the three span tasks; $M = .17$, $SD = .79$) was slightly higher than the mean z-score in the laboratory database ($M = 0$). The WMC tasks correlate well with each other, Ospan with Rspan ($r = .61$), Ospan with Sspan ($r = .44$), and Sspan with Rspan ($r = .47$). The WMC measures do not yield reliability estimates but the correlations among the tasks indicate a reasonable lower bound for reliability (i.e., the correlation between tasks cannot exceed the reliability of the least reliable task). Regarding the reading measures, some of the reliability estimates were low, but acceptable given the correlations among the tasks (*r*s = .17 to .51 with most in the .35 range).

Verbal SATs. For the VSAT scores, I report the proportion of points the student earned (out of 800) to mirror the accuracy scores on other measures. The mean VSAT score in our sample ($M = .64$, or 510 out of 800) was very close to the national average for 2008 ($M = .63$, or 502 out of 800; College Board http://professionals.collegeboard.com/testing/sat-reasoning/scores/averages; accessed 8/20/2009)

Inference Verification Test. Performance on the IVT (*M* = .67) was similar to performance reported in previous work with the same materials (Griffin et al., 2008; *M* = .69).

Psychological Journal Articles. Subjects were given 15 minutes to read the journal articles. For the first journal article, 36% of subjects finished the whole article in the allotted time and 92% finished reading the second journal article (it was slightly shorter). The two journal articles yielded similar performance rates to McConnell (2008; for the Treiman (2000) article: *M* = .49, *SD* = .15 vs. *M* = .49, *SD* = .14 in McConnell, 2008; for the Anastasio et al. (1999) article: *M* = .62, *SD* = .18 vs. *M* = .60, *SD* = .18 in McConnell, 2008). The two comprehension measures, however, were not significantly correlated with each other (*r* = .12, *p*=.14), most likely due to the low completion rate and low reliability of the first journal article.

Novel Reading Task. Most subjects (82.5%) finished reading the passage from War & Peace in the 50-minute time limit, therefore the mean numbers of questions and probes was 19.23 (range 11-20). The number of questions subjects completed (based on how far they got in the text in the allotted time) did not correlate with accuracy (*r* = -.08) or TUTs (*r* = .07). The mean reading time for each paragraph (*M* = 18 sec, *SD* = 5 sec) did not correlate with accuracy (*r* = .07) or mind wandering (*r* = -.10).

Subjects performed similarly on the true/false comprehension questions as subjects in a previous study using similar materials (.73 versus .69 in Reichle et al., submitted). Subjects were caught mind wandering far more often in our study than in Reichle et al. (submitted; 51% versus 10%-30% of probes). It is unclear how many probes Reichle et al. (submitted) presented because they were dependent on subjects' self-caught reports of mind wandering. These self-caught reports also make it difficult to directly compare mind wandering frequency across studies.

Short Story Reading Tasks. For *Maggie*, the mean reading time for each paragraph (M = 15 sec, SD = 3 sec) did not correlate with comprehension-test accuracy (r = .05). For *Eveline*, the mean reading time for each paragraph (M = 25 sec, SD = 6 sec) did not correlate with accuracy (r = .04).

Attention Restraint Tasks

Table 4 presents descriptive statistics for the attention tasks. In the Stroop task, the interesting trials are the incongruent trials (where the digits mismatch the number of items). The majority of the Stroop effect is seen in slow RTs to the incongruent stimuli. In subsequent analyses of this dataset, we focused on RT from the incongruent trials. I used the incongruent RTs instead of accuracy because accuracy was almost at ceiling. I did not use the RT difference between congruent and incongruent trials (traditional Stroop effect) in the SEM models because Stroop incongruent RT shared higher simple correlations with the other attention restraint measures and loaded significantly on an attention restraint latent factor. In the antisaccade task, unlike the Stroop, all trials are "incongruent," in that they all go against the habitual response. Accuracy was not at ceiling in the antisaccade, so we used it as our primary dependent variable for performance in this task in analyses of the whole dataset from this study.

As in previous work with the SART (McVay & Kane, 2009; McVay & Kane, in prep), we calculated a signal-detection sensitivity score for each subject using the formula for logistic distributions (Snodgrass & Corwin, 1988): $d_L = \ln\{[H(1 – FA)]/[(1 – H)FA]\}$, and a C_L score, representing bias, using: $C_L = 0.5[\ln\{[(1 – FA)(1 – H)]/[(H)(FA)]\}]$, where ln = natural log, H = hit proportion, and FA = false-alarm proportion. We adjusted individual hit or false-alarm rates of 0 and 1 by .01. Negative C_L scores reflect a "go" bias. We also calculated each subjects' individual RT variability (i.e., their RT standard deviation). The d_L score and RT variability have been related to performance, WMC, and TUTs in previous work (McVay & Kane, 2009; McVay & Kane, in prep), but C_L has not been linked to WMC or TUTs. For analyses of the entire dataset, we used the signal-detection sensitivity score (d_L) and RT variability as performance measures from the SART.

Mind wandering within tasks

Table 5 presents descriptive statistics for the mind wandering measures. In all four tasks with probes, mind wandering increased over time. For Stroop, War & Peace, and JA2, I divided the tasks into halves; I divided the SART probes into quarters because there were many more trials and to be consistent with previous work (McVay & Kane, 2009). During the Stroop task, TUT rates increased from Block 1 (M = .24) to Block 2 (M = .36; $t(239) = -5.87$, $p < .001$). Similarly, during War & Peace, TUT rates increased from Block 1 (M = .48) to Block 2 (M = .54, $t(243) = -3.49$, $p < .001$). The same pattern occurred in JA2, TUT rates increased from Block 1 (M = .27) to Block 2 (M = .49, $t(165) = -8.43$, $p < .001$). TUTs also increased over the quarters of SART (Ms = .16, .25, .30, .39; $F(3, 645) = 64.36$, $p < .001$).

Mind wandering predicts performance

Mind wandering rate during the Stroop task was significantly correlated with overall accuracy (r = -.17), incongruent accuracy (r = -.15), and incongruent RT (r = .42). Furthermore, subjects were less accurate on trials when they reported TUTs (M = .84) than on-task thoughts (M = .91; t(225) = -5.49, p < .001). Mind wandering during the SART task did not correlate significantly with accuracy (d_L ; r = -.04), but did correlate with RT variability (r = .27). In contrast, in-the-moment TUT reports predicted errors on target trials (M = .62) when compared to reports of on-task thoughts (M = .42; t(179) = 7.03, p < .001). Mind wandering reported during journal article reading correlated significantly with overall accuracy on the comprehension questions (r = -.31). Conditional probabilities for comprehension during on and off-task thoughts were not calculated because the questions were administered at the end of the reading and were not tied to a specific probe or section of the text. Mind wandering rates during the War & Peace reading task correlated with overall accuracy on the comprehension questions (r = -.41). However, although subjects were numerically more likely to answer comprehension questions correctly when they reported on-task thinking (M = .73) than when they reported TUTs (M = .72), this contrast was not significant (t(197) < 1). This may be the result of a methodological limitation in the War & Peace task. Namely, the questions were all true/false format, allowing a 50% chance of guessing the correct answer regardless of reading comprehension or mind wandering.

WMC, reading comprehension, attention restraint, and mind wandering measures

The simple correlations for WMC, reading comprehension measures, attention restraint tasks, and mind wandering measures are presented in Table 3. I established a measurement model for the various tasks by loading them onto latent factors using confirmatory factor analysis (CFA).

Using CFA, I loaded the observed variables onto four latent variables: WMC, mind wandering, reading comprehension, and attention restraint. *A priori*, I chose to allow certain residual variances in the model to correlate so as best to account for existing relationships between the observed measures. For the latent variable WMC, I allowed Ospan and Rspan to correlate because the storage component of both tasks is recalling letters. For the mind wandering latent variable, I allowed TUTs from the SART and the Stroop task to correlate above and beyond the general variance accounted for by the latent variable because of the similarity of the primary task demands (attention restraint). I also allowed the two TUT measures from reading tasks to correlate, but the correlation was not significant in the CFA and therefore dropped from the model. Finally, for the attention restraint latent variable, I allowed the two performance measures from the SART task, d_L and RT variability to correlate. In subsequent SEM models, I only included significantly correlated residuals from those listed above.

The four-factor CFA model with latent variables for WMC, reading comprehension, attention restraint, and mind wandering fit the data well (χ^2 (126, N = 251) = 194.51, $p < .001$; χ^2:df = 1.54; CFI = .924; RMSEA = .046; SRMR = .060, see Figure 1). The mind wandering measures from four different tasks loaded well onto one latent variable, suggesting that TUT rate is a stable individual difference variable. As expected, WMC and attention restraint both correlated positively and significantly with reading comprehension. Mind wandering, in contrast, was negatively correlated with WMC, attention restraint, and reading comprehension.

Does mind wandering mediate the relationship between WMC and reading comprehension?

Using the latent variables for WMC, reading comprehension, and mind wandering established above, I tested mind wandering as a mediator in the relationship between WMC and reading comprehension. Figure 2 presents a partial mediation model (χ^2 (73, N = 251) = 119.78, p = .001; χ^2:*df* = 1.64; CFI = .938; RMSEA = .051; SRMR = .057), whereby WMC predicts reading comprehension both through mind wandering and independently, and Figure 3 presents the full mediation model (χ^2 (74, N = 251) = 123.74, p < .001; χ^2:*df* = 1.67; CFI = .935; RMSEA = .052; SRMR = .062) whereby all the variance in reading comprehension predicted by WMC is through mind wandering. Both models fit the data well and show significant indirect effects of WMC on reading comprehension through the mind wandering variable. The indirect effect in the partial mediation model (Figure 2) was .112, $p = .022$ and in the full mediation model (Figure 3) was .151, $p = .009$. Because both models fit the data well and show a significant indirect effect, a χ^2 difference test was appropriate to determine which model better fits the data. The χ^2 difference test was significant; that is, the difference between the χ^2 of the full mediation model (123.74) and the partial mediation model (119.78; χ^2 diff = 3.96) was greater than the critical value (3.84) for χ^2 at one degree of freedom (the difference between degrees of freedom in the two models). The significant χ^2 difference test signifies that, as expected, the data support a model with partial mediation of mind wandering in the relationship between WMC and reading comprehension.

Does attention restraint mediate the relationship between WMC and reading comprehension?

The executive-attention view of WMC posits that attention control underlies the relationship between WMC and more complex cognitive tasks. In order to test this view further, I fit a model to the data whereby attention restraint, a form of attention control, mediates the relationship between WMC and reading comprehension. As before, I tested both a partial mediation and a full mediation model. However, in this case, the pathway from WMC to reading comprehension was not significant in the partial mediation model (Figure 4), suggesting that WMC only predicts reading comprehension through its shared variance with attention restraint. Even with the non-significant pathway, the mediation model fit the data well (χ^2 (72, N = 251) = 100.49, p = .0149; χ^2:*df* = 1.39; CFI = .959; RMSEA = .040; SRMR = .052) and the indirect effect of WMC on reading comprehension through attention restraint was marginally significant .381, $p = .056$. The fit improved slightly (χ^2 (73, N = 251) = 100.56, p =.018; χ^2:*df* = 1.38; CFI = .961; RMSEA = .039; SRMR = .052) when I dropped the non-significant pathway (thereby making it a full mediation model) and the indirect effect of WMC on reading comprehension through attention restraint was significant in this model (.267, $p < .001$). This model suggests that only the variance common to WMC and attention restraint tasks predicted reading comprehension and that beyond that shared variance, WMC does not independently predict reading comprehension. These and the other main SEM results remain true even if VSAT (an uncontrolled variable possibly measuring more than reading comprehension, see Daneman & Hannon, 2001) is excluded from the model.

Does mind wandering mediate the relationship between executive attention and reading comprehension?

Based on the executive-attention theory of WMC and the finding above that attention restraint fully mediates the relationship between WMC and reading comprehension, I loaded the WMC tasks and the attention restraint tasks on a common latent variable, labeled executive attention. This variable is meant to capture the common variance, due to a general attention control ability, that determines performance on both WMC and attention restraint tasks. For this model, I allowed the residual variance from the WMC tasks to correlate to account for the contribution of memory (above and beyond attention control) to the performance on the WMC tasks. One component of executive attention, goal maintenance (i.e., keeping the goals of the primary task accessible), is captured by mind wandering measures and therefore I predicted that TUTs would mediate the relationship between executive attention and reading comprehension. The partial mediation model (Figure 5) fit the data well (χ^2 (127, N = 251) = 188.56, p < .001; χ^2:*df* = 1.49; CFI = .932; RMSEA = .044; SRMR = .060) and reflected a significant indirect effect of executive attention on reading comprehension through mind wandering (.172, *p* = .006).

CHAPTER IV

DISCUSSION AND CONCLUSIONS

The current study demonstrated the importance of mind wandering as a mediator in the relationship between WMC and reading comprehension. Latent variable analysis of multiple mind wandering measures, WMC, reading comprehension, and attention restraint tasks provided important information for theories of mind wandering, WMC, and executive control. Mind wandering rates representing failures to maintain on-task thoughts, were stable across both attention restraint and reading tasks, and this propensity for off-task thought was detrimental to performance. WMC, which is thought by some to tap executive control of attention (e.g., Kane, Conway, et al., 2007) significantly loaded with attention restraint tasks onto a forced single latent factor in the final SEM model (Figure 5) and negatively predicted reading comprehension. Finally, TUTs mediated this relationship, suggesting that mind wandering explains part of the relationship between attention control and reading comprehension.

Based on the executive-attention view of WMC, I originally hypothesized that TUT rate would fully mediate the relationship between WMC and reading comprehension. Although both the partial and full mediation model fit the data well, the partial mediation model provided a superior fit, suggesting that WMC predicts reading comprehension above and beyond mind wandering. The original hypothesis stemmed from the contribution of the dual components of executive attention; I expected goal maintenance to solely drive the relationship between WMC and reading comprehension based on the assumption that reading does not require competition resolution in the same way as a Stroop or antisaccade task. The partial mediation reported here, however, provides three alternative hypotheses. Either competition resolution is required for reading comprehension and underlies the additional variance explained by WMC above and beyond mind wandering, or mind wandering does not capture the entirety of fluctuations in goal maintenance during reading comprehension. A third possibility is that WMC contributes to the accrual of vocabulary and grammatical information over a lifetime and it is this factor (i.e., the contribution of prior knowledge) that underlies the additional variance in reading comprehension explained by WMC. Data from the current study refute the third possibility. The variance captured by the attention restraint tasks, tasks without vocabulary or grammar demands, fully mediated the relationship between WMC and reading comprehension. This full mediation suggests that the relationship between WMC and reading comprehension is based on the two components of executive attention, goal maintenance and competition resolution, but does not differentiate their contributions.

Previous research on reading comprehension suggests a role for competition resolution in processing text. Namely, Gernsbacher and colleagues (e.g., Gernsbacher 1993; Gernsbacher & Robertson, 1995) identify several situations where suppression of an inappropriate word meaning is necessary. For example, the meanings of homonyms (turn *left* at the light vs. she *left* the party) and homographs (tied a *bow* vs. *bow* to the emperor) are dependent on context and the inappropriate meaning must be suppressed.

This type of competition resolution, although more subtle and occurring less frequently than competition resolution on a Stroop or antisaccade task, may contribute to variance in reading comprehension accounted for by WMC, beyond its shared variance with mind wandering.

There are several notable limitations to the current study. The mean WMC capacity of subjects in this study was slightly elevated (z-score = .165), but I believe the results generalize to undergraduate populations as the mean VSAT was very close to the national average (510 vs. 502). The second limitation, a methodological change from our previous studies (McVay & Kane, 2009, in prep) is the length of the SART. In previous versions of the SART, lasting 42 minutes or more, overall TUT rate predicted performance. On this shortened version of the SART (approximately 15 minutes), TUTs predicted in-the-moment errors but not SART performance overall. I expect in a longer SART, fatigue contributes to the increase in TUTs and perhaps, more errors are made as a result of mind wandering rather than insufficient behavioral inhibition (i.e., trial-by-trial competition resolution). In general, I did not measure the effect of fatigue across tasks in the current study. Mind wandering did consistently increase over time within a task, but the effect of fatigue across tasks within a session is not reported here. The interaction of fatigue and individual differences in control is an important avenue for future research. It is possible that individuals with high WMC fatigue at a different rate than those with low WMC, but currently, this idea remains untested.

Implications for theories of mind wandering

The current study provides important evidence for the "control failure × concerns" view of mind wandering (McVay & Kane, in press). The control failures × concerns view posits that mind wandering reflects a failure to control attention and maintain task goals, in the face of interference from task-irrelevant, personal-goal related thoughts. An important hypothesis derived from this perspective is that those individuals with fewer attention-control resources at their disposal will more often succumb to interfering thoughts than those with greater attention-control abilities (as will people who have more versus less urgent personal concerns with which to contend). As discussed above, WMC provides a measure of attention-control abilities; therefore, individual differences in WMC should negatively predict mind wandering (as high versus low WMC individuals should not systematically differ in their urgency or extent of personal concerns; see *Future Directions* section below). The resource-demanding view of mind wandering (Smallwood & Schooler, 2006), in contrast, makes the opposite prediction. Namely, those individuals with more executive resources should mind wander more than those with fewer. If mind wandering is resource-demanding, and a trade-off occurs between devoting resources to the current task and to TUTs, then those individual with greater resources should be able to mind wander more often without impacting their task performance. Using a latent variable analysis combining measures of mind wandering across several tasks, this study demonstrates a negative relationship between WMC and TUT rate, in line with the control failures view (see also Kane, Brown, et al., 2007; McVay & Kane, 2009).

The control failures × concerns view of mind wandering addresses TUTs in situations where the current task is demanding and mind wandering results in performance deficits. Smallwood (in press) recently reframed the resource-demanding view as a global workspace view, whereby the resources demanded by mind wandering, originally specified as executive resources (e.g., attention control), are better understood as the limited nature of consciousness. In other words, consciousness of off-task thoughts displaces conscious awareness of task-related thoughts and therefore these two types of thoughts each demand the limited workspace of conscious awareness. Smallwood (in press) argues that this view encompasses a broader understanding of mind wandering than the control failures × concerns perspective. In attention-demanding tasks, the executive attention system interferes in the flow between internal and externally driven thoughts in order to keep thoughts external and task-dependent. In these situations, internally oriented thoughts (i.e., off-task thoughts) create interference on the control system and occasionally failures of control result in the displacement of the task-related thoughts from consciousness (i.e., mind wandering). However, in situations where control over thoughts is unnecessary for successful completion of the task, the control system does not interfere with the flow between internal and external thought content and therefore, off-task thoughts are not in-the-moment failures, per se (Smallwood, in press). The current study does not directly address the global workspace view of mind wandering in that all of the tasks were attention-demanding and therefore, the findings fit comfortably within the control failures × concerns view.

Implications for theories of WMC and attention control

The current results inform functional theories of WMC that seek to identify the underlying factor in the relationship between WMC and higher-order cognition. Various theories posit executive attention (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle et al., 1999; Kane et al., 2004; Cowan et al., 2005), short-term memory (Colom, Rebollo, Abad, & Shih, 2006; Colom, Shih, Flores-Mendoza, & Quiroga, 2006; Krumm et al., 2009), and mental bindings (Oberauer, Süβ, Wilhem, & Sander, 2007; Wilhelm & Oberauer, 2006), as potential mechanisms. Recently, Unsworth and Engle (2007) demonstrated the predictive nature of secondary memory retrieval as well. Retrieval from secondary memory in isolation, however, is not the whole story (but see Mogle, Lovett, Stawski, & Sliwinski, 2008), Unsworth and colleagues argue that WMC relies on a controlled search of memory, emphasizing the need for attention control and not automatic retrieval processes (Unsworth & Engle, 2007; Unsworth, Brewer, & Spillers, in press). By their view, low WMC individuals use a less-constrained search set than high WMC individuals which results in more interference and more intrusions during a deliberate search for low spans. Their view, therefore, opens up a new method for assessing working memory (i.e., secondary memory tasks) but does not conflict with the executive-attention view of WMC. Only WMC theories with an attention component (e.g., executive-attention theory of WMC), however, predict a mediating role of mind wandering in the relationship between WMC and higher-order tasks. Several key findings from this study provide support for the executive-attention view of WMC over other, memory-based, WMC theories.

Using the attention restraint tasks (i.e., Stroop, SART, and antisaccade), I demonstrated the importance of attention control in the relationship between WMC and reading comprehension. In the SEM model (Figure 4), the relationship between WMC and reading comprehension was fully mediated by shared variance with the low-level attention tasks. The executive-attention theory of WMC predicts this mediation in that executive attention underlies performance on all of the tasks and drives the predictive abilities of WMC. The remaining variance from WMC span tasks, presumably accounting for the memory demands of the tasks (i.e., storage) did not predict reading comprehension above the variance shared with the attention-restraint tasks. If simple short-term memory explained the relationship between WMC and reading comprehension (or other complex cognitive tasks; see Colom et al., 2006), then the variance unique to WMC, after accounting for its shared variance with attention-restraint tasks, should drive the relationship with reading comprehension. This is not the case. Furthermore, the WMC tasks and low-level attention restraint tasks loaded significantly onto a common latent factor which significantly predicted reading comprehension (in part through mind wandering).

Mind wandering as a significant mediator, as demonstrated here using SEM, provides evidence for the role of attention control in the relationship between WMC and reading comprehension. Neither storage views (Colom et al., 2006; Krumm et al., 2009) nor the mental-binding view of WMC (Wilhelm & Oberauer, 2006), whereby WMC predicts the ability to generate and sustain mental bindings throughout a task, predict a role for lapses of attention (or mind wandering) in the relationship between WMC and reading comprehension. It is unclear why TUTs would be related to WMC at all based on the binding view of WMC. The executive-attention theory of WMC, in contrast, depends on two components of executive attention, goal maintenance and competition resolution, to explain the WMC-reading comprehension relationship. As TUTs disrupt goal maintenance, the fluctuations in performance as a result of TUTs should vary with WMC, as they do.

Mind wandering as a mediator raises questions about long-term memory activation in reading comprehension. During reading, a person should use their prior knowledge (i.e., secondary memory) to develop situation models and draw inferences about the text (e.g. Singer, 1979; Singer & Kintsch, 2001). These integrative processes promote comprehension. Therefore, information from long-term memory is activated during reading (e.g., Singer & Remillard, 2004). Hasher and Zacks (1988) proposed that individual differences in WMC reflect the ability to successfully filter information cued by the text by inhibiting task-irrelevant thoughts. Unsworth et al. argue that low WMC individuals are less successful than high WMC individuals at constraining their search set during deliberate retrieval to only relevant information. In the case of reading comprehension, the initiation of the task goal (i.e., to understand the material) may also initiate a set of search constraints to filter out automatically activated but task-irrelevant LTM representations. Low spans may activate a greater number of associations as the result of a less-constrained search set and these activations, in turn, could create more interference to task-relevant thoughts. For example, while reading one of the Psychology journal articles, a high span may activate information from their previous classes to aid in understanding the article. A low span, in attempting to do the same, may inadvertently activate a memory of a funny classmate from class using a less-refined search set. The memory of the funny classmate, now activated, may compete for attention with task-relevant information and result in a TUT. Alternatively, high and low spans may activate the same number of LTM activations but differ in the filter between activation and consciousness (Hasher & Zacks, 1988). Additional evidence is needed to determine if the goal of reading for comprehension initiates an active search of LTM, resulting in different LTM activations for high and low span individuals (Unsworth et al., 2007; in press), or if the same LTM representations are activated only to be more easily blocked from awareness by high span individuals (Hasher & Zacks, 1988). The current findings also illuminate the importance of thought control, in addition to action control, in understanding the role of control processes in higher-order cognitive tasks.

Implications for reading comprehension

The role of mind wandering and attention control in reading is consistent with the *Landscape model* of reading comprehension (Linderholm, Virtue, Tzeng, & van den Broek, 2004; Rapp & van den Broek, 2005). This dynamic text comprehension model suggests that concepts fluctuate during reading and that the readily accessible concepts make up a “landscape” for the reader. Concepts are activated from the current text, residual activation from previous text, the memory representation of the text as a whole, and background knowledge activated from long-term memory. Throughout reading the concepts wax and wane as they are displaced, re-activated, and updated. The landscape model posits that reader and text characteristics, the availability of background knowledge, goals and strategies, and (most importantly for our purposes), working memory capacity or attention control determine the activation of concepts and their influence on comprehension. The current study demonstrates the impact of attention control, in part through TUTs, on reading comprehension, as predicted by the landscape model.

Previous research on the relationship between WMC and reading comprehension suggests that WMC impacts several parts of the reading processes, including resolving lexical ambiguity (e.g., Daneman & Carpenter, 1983; Mason & Just, 2007; Miyake, Just & Carpenter, 1994, but see also Waters& Caplan, 2004), drawing inferences (e.g., Cain, Oakhill, & Bryant, 2004; Linderholm, 2002; Singer, Andrusiak, Reisdorf, & Black, 1992), monitoring or meta-awareness (Griffin et al., 2008), and ignoring irrelevant details (Sanchez & Wiley, 2006). Furthermore, as discussed previously, reading requires the activation of background knowledge from long-term memory and high and low span individuals may differ in their control over this search (Unsworth & Engle, 2007; Unsworth et al., in press) or in the ability to inhibit task-irrelevant concepts brought to mind (e.g., Hasher & Zacks, 1988). Which of these processes in reading does mind wandering disrupt? Smallwood, McSpadden, & Schooler (2008) suggest that TUTs disrupt the creation of a situation model for the text. In their study, subjects answered thought probes while reading a Sherlock Holmes story. Subjects were less likely to identify the villain in the story if they reported mind wandering at the beginning of the passage (presumably when they were to be generating their situational model) than at the end of the passage. The authors argue that mind wandering during specific parts of the text interferes with the creation of a situation model and prevents the reader from making the inferences for proper comprehension. They further suggest that the control of attention during critical part of the text is necessary for comprehension of the story. Although the current study does not parse the various processes of reading and the effects of WMC and mind wandering on each, it does emphasize the importance of a role for attention control (and thought control) in theories of reading comprehension.

Reading comprehension is a foundation of both education and job-training. The current study suggests that interventions meant to improve reading comprehension should take into account the impact of mind wandering on comprehending reading material. In other words, thought control, in addition to vocabulary and grammar lessons, should be a focus of reading training. Cromley and Azevedo (2007) conducted a study to analyze the contributions of several aspects of reading comprehension in order to target interventions on the biggest contributing factors. Their factors, background knowledge, inferences, strategies, vocabulary, and word reading accounted for 66% of the variance in reading comprehension. They did not, however, include a measure of mind wandering or any measure reflecting attention control (which may affect the factors they did include and possibly contribute unique variance). Their conclusion, to target reading comprehension interventions on increasing background knowledge and vocabulary (the biggest contributors), does not take into account the possibility that training a more basic attention-control mechanism should improve reading comprehension at a more global level than specific vocabulary or knowledge. In fact, WMC still predicts reading comprehension when prior knowledge about the material is manipulated (e.g., Sanchez & Wiley, 2006).

Training of working memory capacity has proven beneficial to higher-order cognitive tasks (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; McNab et al., 2009) and, based on the current findings, should improve thought control and reading comprehension. Several researchers have demonstrated the benefits of WMC training. Jaeggi et al. (2008) demonstrated an increase in the Ravens Progressive Matrices test, a test of Gf, as result of training over several weeks on a WMC task (*n*-back). Furthermore, McNab et al. (2009) identified a neuroanatomical change as a result of WMC training, potentially underlying long-term changes due to the training. After only 14 hours of WMC training, the density of particular dopamine receptors in regions of the brain associated with WMC performance increased. This suggests that this type of WMC training, over the course of an education program (in terms of years rather than hours) could drastically improve higher-order cognitions like Gf and reading comprehension. According to the executive-attention theory of WMC, the cause of the improvement in Gf and changes in dopamine receptors in the studies above is an increase in attention control abilities. If attention control is increased as a result of WMC training, the training is likely to reduce mind wandering as well, although this connection remains to be tested.

Future Directions

The current study and others from our lab (McVay & Kane, 2009; McVay & Kane, in press; McVay & Kane, in prep) have focused primarily on the “control” contribution of the control failures × concerns view of mind wandering. In the current study, I did not control for or manipulate the presence of current concerns (i.e., the content of TUTs). Instead, differences in the amount or intensity of interfering thoughts between subjects and across task sessions is part of the error variance in these models. The propensity to mind wander was stable across tasks, allowing me to draw conclusions about the effect of individual difference in control on mind wandering. However, future studies should focus on the concerns component of the control failures × concerns view of mind wandering by addressing directly the contribution of varying levels of interfering thoughts. For example, a reading task could be manipulated to present more or less relevant personal-concerns cues within the text. This type of manipulation should reveal variation within subjects in the ability to maintain on-task thoughts as it would impact the level of interference present in the task rather than the availability of control resources.

Conclusion

Mind wandering mediates the relationship between individual differences in attention control and reading comprehension. This finding has important implications for our understanding of reading and its various uses in daily life. For example, education is largely based on the ability to comprehend written text in the form of textbooks, journal articles, and various other sources. This study demonstrates the interference of off-task thoughts on a wide range of reading tasks and furthermore suggests that individual differences in mind wandering is a key factor in understanding failures of reading comprehension. Importantly, educational plans and intervention designed to increase reading comprehension must not only consider language abilities (e.g., vocabulary) but thought control as an important contributor to errors in comprehension.

REFERENCES

Anastasio, P. A., Rose, K. C., & Chapman, J. (1999). Can the media create public opinion? A social-identity approach. *Current Directions in Psychological Science,* 8, 152-155.

Antrobus, J. S. (1968). Information theory and stimulus-independent thought. *British Journal of Psychology, 59,* 423-430.

Antrobus, J. S., Coleman, R., & Singer, J. L. (1967). Signal-detection performance by subjects differing in predisposition to daydreaming. *Journal of Consulting Psychology, 31*, 487-491.

Antrobus, J. S., Singer, J. L., Goldstein, S., & Fortgang, M. (1970). Mind wandering and cognitive structure. *Transactions of the New York Academy of Sciences*, *32*, 242 - 252.

Antrobus, J. S., Singer, J. L., & Greenberg, S. (1966). Studies in the stream of consciousness: Experimental suppression of spontaneous cognitive processes. *Perceptual and Motor Skills, 23,* 399-417.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624-652.

Braver, T. S., Grey, J. R., & Burgess, G. C. (2007). In A. R. A Conway, C. Jarrold, C., M. J. Kane, A. Miyake, J. N. Towse (Eds.) *Variations in Working Memory* (pp. 76-108). New York, NY: Oxford University Press.

Brewin, C. R., & Beaton, A. (2002). Thought suppression and working memory. *Behaviour Research and Therapy,* 40, 923–930.

Brewin, C. R., & Smart, L. (2005). Working memory capacity and suppression of intrusive thoughts. *Journal of Behavior Therapy and Experimental Psychiatry,36,* 61–68.

Brown, J. W., & Braver, T. S. (2005). Learned Predictions of Error Likelihood in the Anterior Cingulate Cortex. *Science, 18*, 1118 – 1121.

Cain, K., Oakhill, J., & Bryant, P. (2004). Children's Reading Comprehension Ability: Concurrent Prediction by Working Memory, Verbal Ability, and Component Skills. *Journal of Educational Psychology, 96*, 31-42.

Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences*, 106, 8719-8724.

Colom, R., Rebollo, I., Abad, F. J., & Shih, P. C. (2006). Complex span tasks, simple span tasks, and cognitive abilities: A re-analysis of key studies. *Memory & Cognition*, *34*, 158-171.

Colom**,** R., Shih, P.C., Flores-Mendoza, C., Quiroga, M.A. (2006). The real relationship between short-term memory and working memory. *Memory, 14*, 804-813

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D., & Minkoff, S. (2002). A latent variable analysis of working memory capacity, short term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*, 163-183.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R.W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*, 769-786.

Cowan, N., Elliot, E.M., Saults, J.S., Morey, C.C., Mattox, S., Hismjatullina, A., & Conway, A.R.A. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*, 42-100.

Daneman, M., & Carpenter, P. A. (1983). Individual differences in integrating information between and within sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 9, 561-583.

Daneman, M. & Hannon, B. (2001). Using working memory theory to investigate the construct validity of multiple-choice reading comprehension tests such as the SAT. *Journal of Experimental Psychology: General,* 130, 208-233.

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension:A meta-analysis. *Psychonomic Bulletin & Review, 3,* 422-433.

Ellis, H. C., Moore, B. A., Varner, L. J., Ottaway, S. A., & Becker, A. S. (1997). Depressed mood, task organization, cognitive interference, and memory: Irrelevant thoughts predict recall performance. *Journal of Social Behavior and Personality, 12*, 453-470.

Engle, R.W., & Kane, M.J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.) *The Psychology of Learning and Motivation* (pp. 145-199). New York: Academic Press.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory and general fluid intelligence: A latent variable approach. *Journal of Experimental Psychology: General, 128,* 309-331.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87*, 215-251.

Filler, M. S., & Giambra, L. M. (1973). Daydreaming as a function of cueing and task difficulty. *Perceptual and Motor Skills, 37*, 503-509.

Finnigan, F., Schulze**,** D., & Smallwood, J. (2007). Alcohol and the wandering mind: A new direction in the study of alcohol on attentional lapses. *International Journal on Disability and Human Developmen*t, *6,* 189-199.

Geraerts, E., Marckelbach, H., Jelicic, M., & Habets, P. (2007). Suppression of intrusive thoughts and working memory capacity in repressive coping. *American Journal of Psychology*, 120, 205-218.

Gernsbacher, M. A. (1993). Less skilled readers have less efficient suppression mechanisms. *Psychological Science,* 4, 294-298.

Gernsbacher, M. A., & Robertson, R. R. W. (1995). Reading skill and suppression revisited. *Psychological Science*, 6, 165-169.

Giambra, L. M. (1993). The influence of aging on spontaneous shifts of attention from external stimuli to the contents of consciousness. *Experimental Gerontology, 28*, 485-492.

Giambra, L. M. (1995). A laboratory method for investigating influences on switching attention to task-unrelated imagery and thought. *Consciousness and Cognition, 4*, 1-21.

Giambra, L. M., & Grodsky, A. (1989). Task-unrelated images and thoughts while reading. In J. Shorr, P. Robin, J. A. Connek and M. Wolpin (Eds.), *Imagery: Current Perspectives.* New York: Plenum Press.

Giambra, L. M, Grodsky, A., Belongie, C., & Rosenberg, E. H. (1994). Depression and thought intrusions, relating thought frequency to activation and arousal. *Imagination, Cognition and Personality, 14(1)*, 19-29.

Giambra, L. M., Rosenberg, E. H., Kasper, S., Yee, W., & Sack, D. A. (1988-89). A circadian rhythm in the frequency of spontaneous task-unrelated images and thoughts. *Imagination, Cognition and Personality, 8,* 309-314.

Greenwald, D. F., & Harder, D. W. (1995). Sustaining fantasies, daydreams, and psychopathology. *Journal of Clinical Psychology, 51,* 719-726.

Griffin, T. D., Wiley, J., & Thiede, K. W. (2008). Individual differences, rereading, and self-explanation: Concurrent processing and cue validity as constraints on \ metacomprehension accuracy. *Memory & Cognition, 36,* 93-103.

Grodsky, A., & Giambra, L. M. (1990). The consistency across vigilance and reading tasks of individual differences in the occurrence of task-unrelated and task-related images and thoughts. *Imagination, Cognition and Personality, 10,* 39-52.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The Psychology of Learning and Motivation: Advances in Research and Theory* (vol. 22, pp. 193-225). San Diego, CA: Academic Press.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences, 105*, 6829–6833

Kane, M. J., Bleckley, M. K., Conway, A. R. A., Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, 130, 169-183.

Kane, M. J., Brown, L. H., McVay, J. C., Silvia, P. J., Myin-Germeys, I., & Kwapil, T. R. (2007). For whom the mind wanders, and when: An experience-sampling study of working memory and executive control in daily life. *Psychological Science, 18,* 614-621.

Kane, M. J., Conway, A. R. A, Hambrick, D. Z., & Engle, R. W. (2007). In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, and J. N. Towse (Eds.), *Variations in Working Memory* (pp. 21-48). New York: Oxford University Press.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General, 132,* 47-70.

Kane, M. J., Hambrick, D. Z., & Conway, A. R. A. (2005). Working Memory Capacity and Fluid Intelligence Are Strongly Related Constructs: Comment on Ackerman, Beier, and Boyle (2005). *Psychological Bulletin, 131,* 66-71.

Kane, M. J., Poole, B. J., Tuholski, S. W., & Engle, R. W. (2006). Working memory capacity and the top-down control of visual search: Exploring the boundaries of "executive attention." *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 32, 749-777.

Kang, S. H. K., McDermott, K. B., & Roediger, H. L. (2007). Test format and corrective feedback modify the effect of testing on long-term retention. *European Journal of Cognitive Psychology, 19,* 528-558.

Kline, R. B. (2005). *Principles and practice of structural equation modeling: Second edition*. New York, NY: The Guilford Press.

Klinger, E., & Cox, W. M. (1987). Dimensions of thought flow in everyday life. *Imagination, Cognition and Personality, 7*, 105-128.

Krumm**,** S., Schmidt-Atzert, L., Buehner, M., Ziegler, M., Michalczyk, K., & Arrow, K. (2009). Storage and non-storage components of working memory predicting reasoning: A simultaneous examination of a wide range of ability factors. *Intelligence,* 37, 347-364.

Linderholm, T. (2002). Predictive inference generation as a function of working memory capacity and casual text constraints. *Discourse Processes*, 34, 259-280.

Linderholm, T., Virtue, S., Tzeng, Y. & van den Broek, P. (2004). Fluctuations in the availability of information during reading: Capturing cognitive processes using the landscape model. *Discourse Processes*, 37, 165-186.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An Integrative Review. *Psychological Bulletin,* 109, 163-203.

Manly, T., Robertson, I. H., Galloway, M., & Hawkins, K. (1999). The absent mind: Further investigations of sustained attention to response. *Neuropsychologia, 37,* 661-670.

Mason, M. F., Bar, M., & Macrae, C. N. (in press). Exploring the past and impending future in the here and now: Mind-wandering in the default state. *Cognitive Sciences.*

Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae. C. N. (2007). Wandering Minds: The Default Network and Stimulus-Independent Thought. *Science, 19,* 393-395.

Mason, R. A., & Just, M. A. (2007). Lexical ambiguity in sentence comprehension. *Brain Research*, 1146, 115-127.

McConnell, M. D. (2009). *Examining the Benefits of Feedback: Are Monitoring Skills Implicated in Successful Performance?* Unpublished doctoral dissertation, University of North Carolina, Greensboro.

McGuire, P. K., Paulesu, E., Frackowiak, R. S. J., & Frith, C. D. (1996). Brain activity during stimulus independent thought. *NeuroReport, 7,* 2095-2099.

McKiernan, K. A., D'Angelo, B. R., Kaufman, J. N., & Binder, J. R. (2006). Interrupting the stream of consciousness: An fMRI investigiation. *NeuroImage, 29,* 1185-1191.

McNab, F., Varrone, A., Jucaite, A., Bystritsky, P., Forssberg, H., & Klingberg**,** T. (2009). Change in cortical dopamine D1 receptor binding associated with cognitive training. *Science, 323*, 800-802.

McVay, J.C., & Kane, M.J. (2009). Conducting the train of thought: Working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*, 196-204.

McVay, J.C., & Kane, M.J. (in press). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychological Bulletin*.

McVay, J.C., & Kane, M.J. (in prep). Drifting from slow to "D'oh!" Working memory capacity and mind wandering predict extreme reaction times and executive-control errors.

McVay, J. C., Kane,M. J., & Kwapil, T. R. (2009). Tracking the train of thought from the laboratory into everyday life: An experience-sampling study of mind-wandering across controlled and ecological contexts. *Psychonomic Bulletin & Review*, 16, 857-863.

Miyake, A., Just, M. A., & Carpenter, P. A. (1994). Working memory constraints on the resolution of lexical ambiguity: Maintaining multiple interpretations in neutral contexts. *Journal of Memory and Language,* 33, 175-202.

Mogle, J.A., Lovett, B.J., Stawski, R.S., & Sliwinski, M.J. (2008). What's so special about working memory? An examination of the relationship among working memory, secondary memory, and fluid intelligence. *Psychological Science, 19,* 1071-1077.

Muraven, M., & Baumeister, R. F (2000). Self-regulation and depletion of limited resources: Does self-control resemble a muscle? *Psychological Bulletin, 126,* 247-259.

Nisbet, R.E., & Wilson, T.D. (1977). Telling more than we can know: Verbal Reports on Mental Processes. *Psychological Review, 84,* 3.

Oberauer, K., Sub, H.-M., Wilhelm, O., & Sander, N. (2007). Individual differences in working memory capacity and reasoning ability. In A.R.A. Conway, C. Jarrold, M.J. Kane, A. Miyake, & J.N. Towse (Eds.), *Variation in working memory* (pp. 21-48). New York: Oxford University Press.

Parks, C. W., Klinger, E., & Perlmutter, M. (1988-89). Dimensions of thought as a function of age, gender and task difficulty. *Imagination, Cognition and Personality, 8*, 49-62.

Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., & Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences, 98,* 676-682.

Rapp, D. N., & van den Broek, P. (2005). Dynamic text comprehension. *Current Directions in Psychological Science*, 14, 276-279.

Reichle, E. D., Morales, F. J., Laurent, P. A., Halpern, D. V., Smallwood, J., Schooler, J. W. (submitted). Mindless reading: The monitoring and consequences of mind-wandering during reading. *Journal of Experimental Psychology: General*

Reichle, E. D., Reineberg, A. E., & Schooler, J. W. (in press). Eye movements during mindless reading. *Psychological Science.*

Riby, L. M., Smallwood, J., & Gunn, V. P. (2008). Mind wandering and retrieval from episodic memory: A pilot event-related potental study. *Psychological Reports,* 102, 805-818.

Richeson, J. A., & Trawalter, S. (2005). Why Do Interracial Interactions Impair Executive Function? A Resource Depletion Account. *Journal of Personality and Social Psychology, 88*, 934-947.

Roberts, R.J., Hager, L. D., & Heron, C. (1994). Prefrontal cognitive processes: Working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General, 123*, 374-393.

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B.T., & Yiend, J. (1997). Oops: Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neurospsychologia, 35,* 747-758.

Sanchez, C. A., & Wiley, J. (2006). An examination of the seductive details effect in terms of working memory capacity. *Memory & Cognition, 34,* 344-355.

Sayette, M. A., Reichle, E. D., Schooler, J. W. (2009). Lost in the sauce: The effects of alcohol on mind-wandering. *Psychological Science*, 20, 747-752.

Schmeichel, B. J. (2007). Attention control, memory updating, and emotion regulation temporarily reduce the capacity for executive control. *Journal of Experimental Psychology: General*, *136*, 241-255.

Schooler, J. W., Reichle, E. D., & Halpern, D. V. (2004). Zoning out while reading: Evidence for dissociations between experience and metaconsciousness. In D. Levin (Ed.), *Thinking and seeing: Visual metacognition in adults and children* (pp. 203-226). Cambridge, MA: MIT Press.

Shaw, G. A., & Giambra, L. M. (1993). Task unrelated thoughts of college students diagnosed as hyperactive in childhood. *Developmental Neuropsychology, 9,* 17-30.

Singer, J. L. (1975). Navigating the stream of consciousness: Research in daydreaming and related inner experience. *American Psychologist, 30*, 727-738.

Singer, J. L., & Antrobus, J. S. (1970). *Manual for the Imaginal Processes Inventory.* Princeton, NJ: Educational Testing Service.

Singer, M. (1979). Processes of inference during sentence encoding. *Memory & Cognition*, 7, 192-200.

Singer, M., Andrusiak, P., Reisdorf, P., & Black, N. L. (1992). Individual differences in bridging inference processes. *Memory & Cognition*, 20, 539-548.

Singer, M., & Kintsch, W. (2001). Text retrieval: A theoretical exploration. *Discourse Processes*, 31, 27-59.

Singer, M., & Remillard, G. (2004). Retrieving text influences: Controlled and automatic influences. *Memory & Cognition*, 32, 1223-1237.

Singer, M., & Ritchot, K. F. M.(1988). The role of working memory capacity and knowledge access in text inference processing. *Memory & Cognition,* 24, 733-743.

Smallwood, J. (in press). Why the global availability of mind wandering necessitates resource competition: Reply to McVay & Kane. *Psychological Bulletin.*

Smallwood, J., Heim, D., Riby L., & Davies, J.D. (2005). Encoding during the attentional lapse: accuracy of encoding during the semantic sart. *Consciousness and cognition, 15,* 218-231.

Smallwood, J., McSpadden, M., & Schooler, J. W. (2007). The lights are on but no one's home: Meta-awareness and the decoupling of attention when the mind wanders. *Psychonomic Bulletin & Review, 14,* 527-533.

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008). When attention matters: The curious incident of the wandering mind. *Memory & Cognition,* 36, 1144-1150.

Smallwood, J., Obonsawin, M.C., & Reid, H. (2003). The effects of block duration and task demands on the experience of task-unrelated-thought. *Imagination, cognition and personality, 22*, 13 -31.

Smallwood, J., Obonsawin, M.C., Reid, H., & Heim, S.D. (2002). An investigation into the role of personality and situation in the maintenance of subjective experience in a laboratory. *Imagination, cognition and personality, 21,* 319-332.

Smallwood, J., O'Connor, R.C., Sudberry, M.V., & Ballantyre, C. (2004). The consequences of encoding information on the maintenance of internally generated images and thoughts: The role of meaning complexes. *Consciousness and cognition, 4,* 789-820.

Smallwood, J., & Schooler, J. W. (2006). The Restless Mind. *Psychological Bulletin, 132*, 946-958.

Snodgrass, J.G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: applications to dementia and amnesia. *Journal of Experimental Psychology: General, 117*, 34–50.

Tang, Z., & Singer, J. L. (1997). Daydreaming styles, emotionality and the Big Five personality dimensions. *Imagination, Cognition and Personality, 16,* 399-414.

Teasdale, J. D., Dritschel, B. H., Taylor, M. J., Proctor, L., Lloyd, C. A., Nimmo-Smith, I., & Baddeley, A. D. (1995). Stimulus-independent thought depends on central executive resources. *Memory and Cognition, 23*, 551-559.

Teasdale, J. D., Lloyd, C. A., Proctor, L., & Baddeley, A. (1993) Working memory and stimulus-independent-thought: Effects of memory load and presentation rate. *European Journal of Psychology, 5*, 417-433.

Treiman, R. (2000). The foundations of literacy. *Current Directions in Psychological Science,* 9, 89-92.

Unsworth, N., Brewer, G.A., & Spillers, G.J. (in press). There's more to the working memory-fluid intelligence relationship than just secondary memory. *Psychonomic Bulletin & Review*.

Unsworth, N., & Engle, R. W. (2006). A temporal-contextual retrieval account of complex span: An analysis of errors. *Journal of Memory and Language, 54*, 346-362.

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 114*, 104-132.

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working Memory Capacity and the Antisaccade Task: Individual Differences in Voluntary Saccade Control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1302-1321.

Waters, G. S., & Caplan, D. (2004). Verbal working memory and on-line syntactic processing: Evidence from self-paced listening. *The Quarterly Journal of Experimental Psychology*, 57, 129-163.

Wegner, D., Schneider, D., Carter, S., & White, T. (1987). Paradoxical effects of thought suppression. *Journal of Personality and Social Psychology, 53*, 5–13.

Wilhelm, O., & Oberauer, K. (2006). Why are reasoning ability and working memory capacity related to mental speed? An investigation of stimulus-response compatibility in choice reaction time tasks. *European Journal of Cognitive Psychology, 18*, 18-50.

Windes, J. D. (1968). Reaction time for numerical coding and naming of numerals. *Journal of Experimental Psychology, 78,* 318-322.

APPENDIX. TABLES AND FIGURES

Table 1.

Order of tasks across sessions.

Session	Tasks
1	Ospan, Journal Article, Stroop, *Maggie.*
2	Sspan, SART, *War & Peace*
3	Rspan, Journal Article with probes, IVT, Antisaccade, *Eveline*

Table 2.

Descriptive statistics for WMC and reading comprehension measures.

Measure	N	Accuracy (SD)	Skew (SE)	Kurtosis (SE)
Ospan	253	.195 (.059)*	-1.213 (.153)	1.416 (.306)
Rspan	238	.223 (.063)*	-.566 (.158)	-.437 (.315)
Sspan	243	.074 (.070)*	-.391 (.156)	-.426 (.312)
VSAT	223	.638 (.102)	.739 (.163)	.209 (.324)
SS1	250	.731 (.148)	-.281 (.154)	-.511 (.307)
SS2	240	.663 (.176)	-.317 (.157)	-.587 (.314)
JA1	253	.487 (.150)	-.057 (.153)	-.054 (.305)
JA2	166	.620 (.182)	-.510 (.188)	-.039 (375)
W&P	247	.723 (.153)	-.164 (.155)	-.740 (.309)
IVT	241	.673 (.116)	.118 (.157)	-.397 (.313)

Note: Ospan = automated operation span task; Rspan = automated reading span task; Sspan = automated spatial span task; VSAT = verbal scholastic achievement test; SS1= first short story; SS2= second short story; JA1 = Treiman (2000); JA2 = Anastasio et al. (1999); W&P = War & Peace (novel); IVT = inference verification test.
**z-score(SE)*

Table 3. *Correlations and reliability for WMC, reading comprehension, attention tasks, and mind wandering measures.*

	OspanZ	SspanZ	RspanZ	VSAT	SS1	SS2	JA1	JA2	WP	IVT	IncRT	SART d	RTsd	AS	Stp	WP	Srt	JA2
SspanZ	.429**																	
RspanZ	.623**	.486**																
VSAT	.114	.141*	.246**															
SS1 ACC	.077	.048	.199**	.442**	*.429*													
SS2 ACC	.049	.056	.099	.355**	.382**	*.599*												
JA1 ACC	.100	.015	.110	.224**	.137*	.156*	*.240*											
JA2 ACC	-.016	.026	.043	.467**	.365**	.409**	.117	*.565*										
WP ACC	.070	.057	.149*	.484**	.408**	.535**	.181**	.444**	*.632*									
IVT ACC	.138*	.174**	.139*	.468**	.309**	.365**	.099	.505**	.335**	*.629*								
StpIncRT	.005	-.143*	-.095	-.161*	-.077	-.082	-.049	-.036	-.104	-.010	*.706*							
Srt d	.142*	.232**	.215**	.159*	.117	.049	.144*	.016	.042	.032	.038	*.872*						
Srt RTsd	-.079	-.275**	-.168*	-.101	-.132	-.188**	-.133	-.173*	-.221**	-.097	.250**	-.262**	*.859*					
AS ACC	.189**	.436**	.322**	.285**	.087	.050	.033	.177*	.093	.199**	-.272**	.169*	-.238**	*.885*				
Stp TUT	.034	-.102	-.033	.069	-.077	-.103	.090	-.046	-.143*	-.036	.129*	-.004	.124	-.100	*.867*			
WP TUT	-.074	-.119	-.139*	-.317**	-.233**	-.218**	-.095	-.250**	-.417**	-.243**	.116	-.097	.206**	-.168*	.346**	*.788*		
Srt TUT	-.132	-.044	-.082	-.002	-.026	-.117	-.010	-.133	-.085	-.096	.210**	-.006	.215**	-.061	.523**	.312**	*.851*	
JA2 TUT	-.063	-.023	-.089	-.044	-.101	-.207**	-.148	-.314**	-.260**	-.171*	.019	.075	.002	-.106	.366**	.392**	.425**	*.670*

Note: Values on the diagonal reflect Cronbach's alpha for each measure as a reliability estimate; alphas were calculated over task blocks for attention tasks and mind wandering measures and over items for the reading comprehension measures. OspanZ = automated operation span task; RspanZ = automated reading span task; SspanZ = automated spatial span task; VSAT = verbal scholastic achievement test; SS1= first short story(Maggie); SS2= second short story(Eveline); JA1 = first journal article (Treiman, 2000); JA2 = second journal article (Anastasio et al., 1999); WP = War & Peace (novel); IVT = inference verification test; Stp = Stroop task; Inc = incongruent trials on the Stroop task; ACC = accuracy; RT = reaction time; Srt = SART (sustained attention to response task); d = signal detection measure of performance; RTsd = non-target reaction time variability; AS = antisaccade task. **p < .05 **p < .01*

Table 4.

Descriptive statistics for attention-restraint tasks.

Variable	*Mean*	*Standard Deviation*
	Stroop (n = 243)	
Overall ACC	.949	.074
Incongruent ACC	.887	.091
Congruent ACC	.967	.075
ACC difference	.082	.058
Incongruent RT	676.924	102.219
Congruent RT	577.280	82.793
RT difference	99.644	48.589
	SART (n = 225)	
d_L	3.385	1.705
C_L	-2.242	.535
Target ACC	.397	.226
Non-target RT	467.842	99.515
Intra-subject RT SD	144.842	44.076
	Antisaccade (n= 235)	
ACC	.742	.212
RT	453.432	108.516

Note: ACC = accuracy; RT = reaction time; SART = sustained attention to response task; d_L *= signal-detection sensitivity score;* C_L *= response bias score; SD = standard deviation*

Table 5.
Descriptive statistics for mind wandering.

Task	*N*	Probes	*M TUTs (SD)*
STROOP	243	36	.319 (.249)
SART	225	36	.273 (.299)
JA2	166	6	.379 (.228)
War & Peace	247	20	.511 (.299)

Note: TUT = proportion of task-unrelated thoughts reported on probes; SART = sustained attention to response task; JA2 =second journal article

Figure Captions

*Figure 1.*Confirmatory factor analysis model for the latent variables working memory capacity, reading comprehension, mind wandering, and attention restraint.

Figure 2. Structural equation model depicting the relationship between working memory capacity and reading comprehension with mind wandering as a partial mediator.

Figure 3. Structural equation model depicting the relationship between working memory capacity and reading comprehension with mind wandering as a full mediator.

Figure 4. Structural equation model depicting the relationship between working memory capacity and reading comprehension with attention restraint as a mediator.

Figure 5. Structural equation model depicting the relationship between executive attention and reading comprehension with mind wandering as a mediator.

Figure 1. Confirmatory factor analysis model for the latent variables working memory capacity, reading comprehension, mind wandering, and attention restraint.

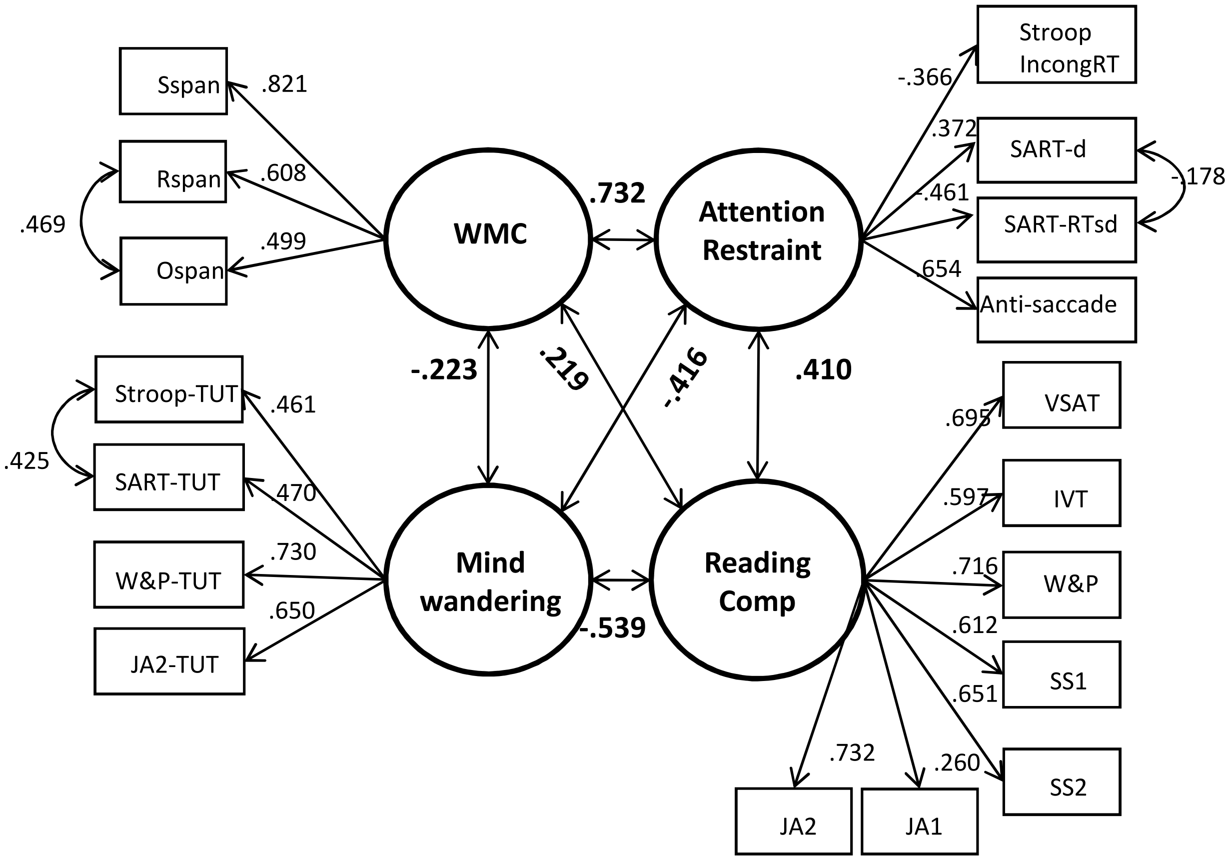

Figure 2. Structural equation model depicting the relationship between working memory capacity and reading comprehension with mind wandering as a partial mediator.

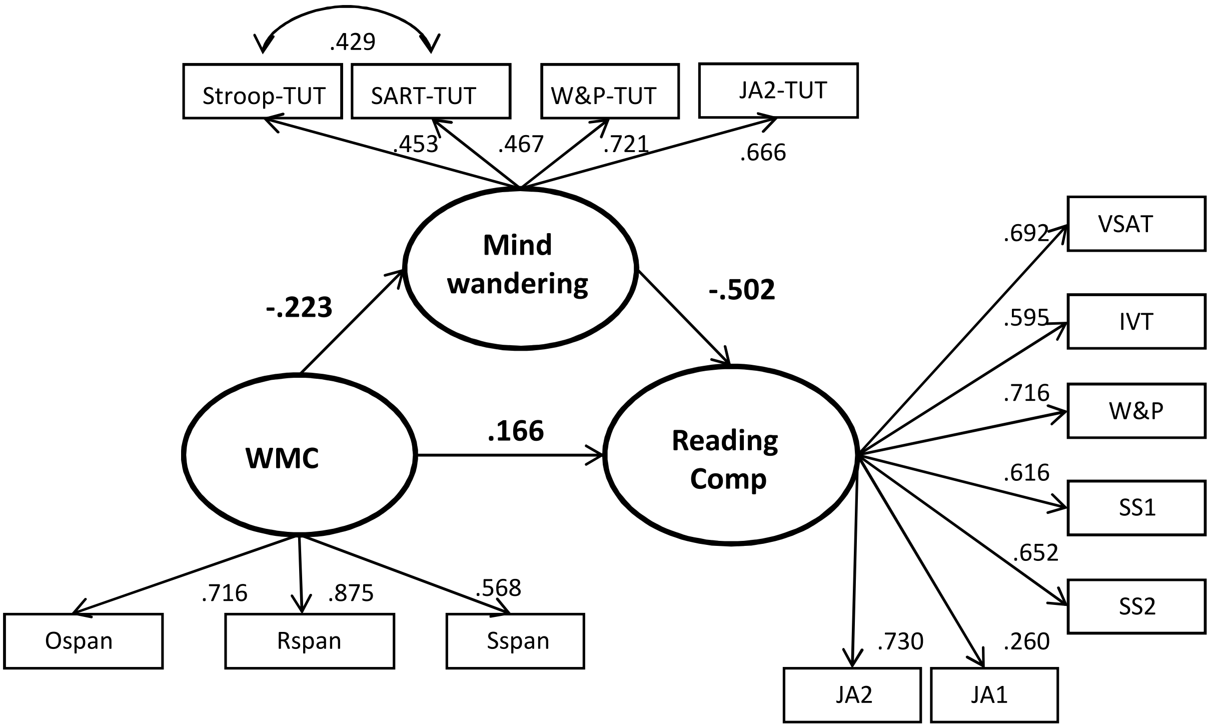

Figure 3. Structural equation model depicting the relationship between working memory capacity and reading comprehension with mind wandering as a full mediator.

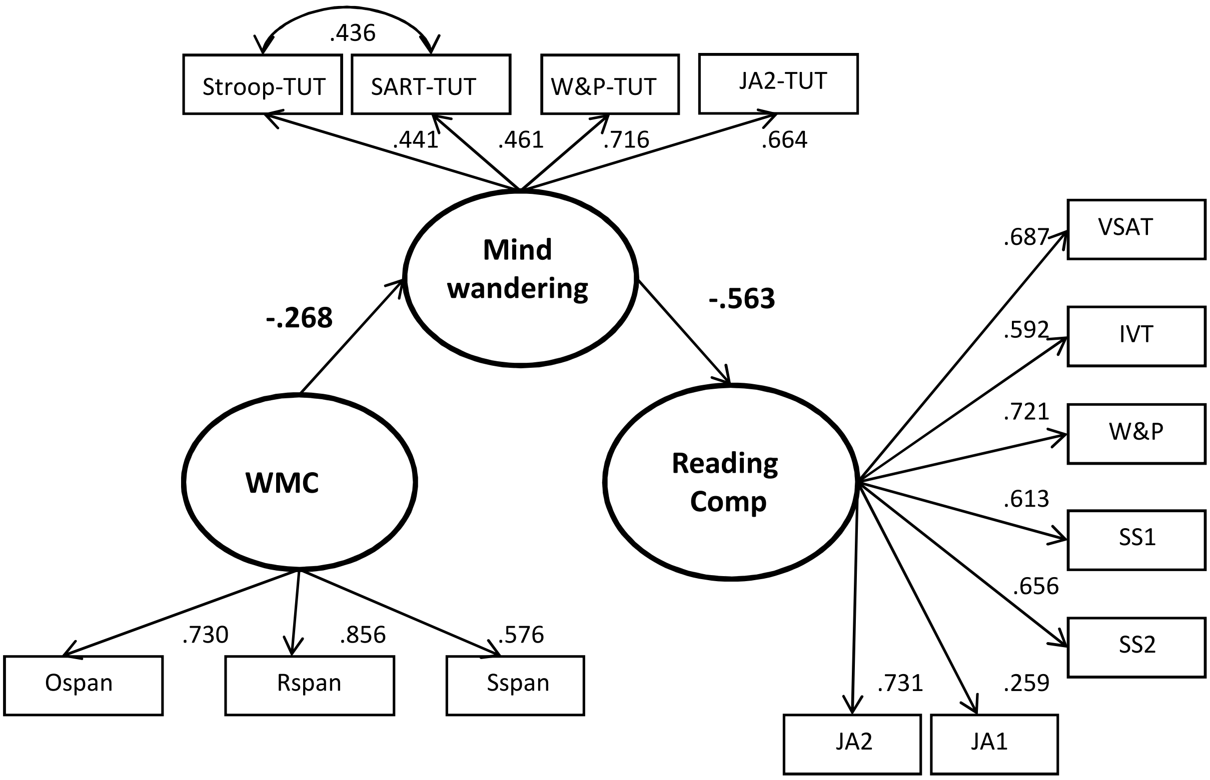

Figure 4. Structural equation model depicting the relationship between working memory capacity and reading comprehension with attention restraint as a mediator.

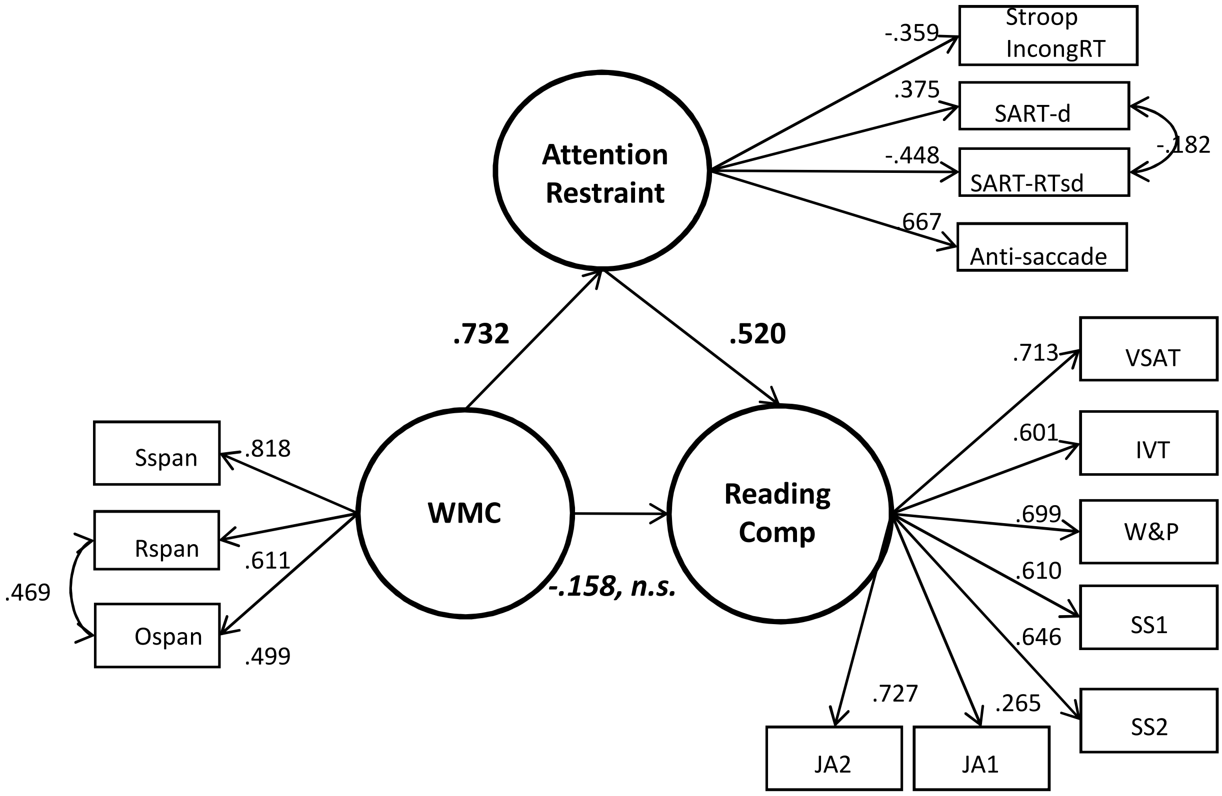

Figure 5. Structural equation model depicting the relationship between executive attention and reading comprehension with mind wandering as a mediator.