Why does working memory capacity predict variation in reading comprehension? On the influence of mind wandering and executive attention.

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Abstract:

Some people are better readers than others, and this variation in comprehension ability is predicted by measures of working memory capacity (WMC). The primary goal of this study was to investigate the mediating role of mind-wandering experiences in the association between WMC and normal individual differences in reading comprehension, as predicted by the executive-attention theory of WMC (e.g., Engle & Kane, 2004). We used a latent-variable, structural-equation-model approach, testing skilled adult readers on 3 WMC span tasks, 7 varied reading-comprehension tasks, and 3 attention-control tasks. Mind wandering was assessed using experimenter-scheduled thought probes during 4 different tasks (2 reading, 2 attention-control). The results support the executive-attention theory of WMC. Mind wandering across the 4 tasks loaded onto a single latent factor, reflecting a stable individual difference. Most important, mind wandering was a significant mediator in the relationship between WMC and reading comprehension, suggesting that the WMC–comprehension correlation is driven, in part, by attention control over intruding thoughts. We discuss implications for theories of WMC, attention control, and reading comprehension.

Keywords: executive control | psychology | experimental psychology | reading comprehension | short term memory | cognitive control | mind wandering | working memory

Article:

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Reading is fundamental to education and job training and is a part of most people's daily life. Yet individual differences in reading comprehension are vast. Comprehension of written material is thus an important ability to explore for cognitive psychologists, in general, and for individual-differences researchers, specifically. Many researchers have approached reading comprehension by examining the properties of text that influence understanding, including grammatical and structural variation within and across reading materials (e.g., Bornkessel & Schlesewsky, 2006; McKoon & Ratcliff, 2003). Others have taken an individual-differences approach to reading comprehension (e.g., Baddeley, Logie, & Nimmo-Smith, 1985; Burton & Daneman, 2007; Daneman & Merikle, 1996), asking the question: Why are some people better readers than others? We adopt the latter approach and provide evidence for an understudied source of individual differences in reading comprehension: normal variation in attention-control capabilities. In the current study, we approached variation in attention control and its impact on reading in the following three ways: (1) by measuring lapses of attention to the ongoing task in the form of task-unrelated thought (TUT), or mind wandering, during both reading and other attention-demanding tasks; (2) by measuring performance on relatively simple attention tasks and assessing their utility in predicting comprehension, and (3) by examining an individual-differences variable known to predict reading comprehension, working memory capacity (WMC), and testing the theoretical claim that attention control underlies this predictive relationship.

Our main goal was to investigate mind wandering as a mediator of WMC's relation to reading comprehension. WMC predicts performance on a range of cognitive tasks, ranging from simple attention-control paradigms (e.g., antisaccade, Stroop) to complex intellectual pursuits (e.g., fluid reasoning, reading comprehension; for reviews, see Heitz, Unsworth, & Engle, 2005; Kane, Conway, Hambrick, & Engle, 2007). The executive-attention view of WMC posits the control of attention as one important mechanism underlying performance on both WMC tasks and reading comprehension and thus of their covariation (Engle & Kane, 2004). We predicted that lapses of control over attention (experienced by subjects as TUTs) would be partially responsible for reading-comprehension differences. That is, individuals with lower WMC should have greater comprehension deficits, in part because they are less able to maintain on-task thought. TUTs should displace the task goal of comprehending the reading material and thus disrupt a person's ability to process relevant details and build a mental model of the text for comprehension (see Smallwood, McSpadden, & Schooler, 2008).

Individual Differences in Reading Comprehension

What makes someone a good reader? Reading-comprehension variation occurs at both a micro level, in processing syntax of textual elements, and a macro level, such as apprehending the text's meaning as a whole (Kintsch & van Dijk, 1978). In other words, readers must first parse the individual words and sentences in the text before they can holistically generate an accurate situation model and appropriate inferences. The variation in comprehension among skilled readers' does not tend to depend as greatly on variation in microlevel functions as it does among unskilled, or novice, readers (Palmer, MacLeod, Hunt, & Davidson, 1985). Novice readers, in contrast, seem to engage more resources on microlevel functions (e.g., identifying words) and are therefore less able to create coherence from the material. With the current study, we focus on skilled readers and therefore on macro-level contributors to comprehension.

Many researchers have adopted a multicomponent approach (e.g., Hannon & Daneman, 2001) to understanding the macro-level influences on reading ability, by exploring the independent and combined roles of components such as vocabulary, world knowledge, reading fluency, reading strategies, and epistemic knowledge (e.g., Aaronson & Ferres, 1986; Baddeley et al., 1985; Burton & Daneman, 2007; Palmer et al., 1985) as predictors of comprehension differences. For example, Cromley and Azevedo (2007) analyzed the contributions of several components in order to target interventions on the strongest factors: Background knowledge, inferences, strategies, vocabulary, and word reading accounted for 66% of the variance on one standardized comprehension measure. Although these contributors accounted for significant and substantial variance, they represented primarily domain-specific influences on comprehension. Domain-general cognitive abilities, such as WMC, also play an important role in skilled reading. Indeed, “complex span” measures of WMC were invented as a means to help predict and understand normal variation in reading comprehension (Daneman & Carpenter, 1980).

Reading Comprehension and WMC

Individual differences in WMC are often assessed with so-called complex span tasks. Whereas a simple span task, such as digit span, might have subjects immediately recall a short series of digits in serial order, a complex span task would require subjects to remember digits while intermittently solving equations (in operation span tasks) or comprehending written or spoken sentences (in reading span and listening span tasks, respectively). In Daneman and Carpenter's (1980) seminal studies using reading and listening span tasks, WMC correlated strongly with three different measures of reading comprehension, including scores on the verbal SAT, and they did so much more strongly than did a simple word span task. These findings set in motion the extensive body of research on the utility of complex WMC span for predicting individual and age-related differences in cognitive abilities (for reviews, see Conway et al., 2007).

Sixteen years and some 70 studies later, Daneman and Merikle's (1996) meta-analysis concluded that individual differences in WMC significantly predict reading comprehension, with correlations in the moderate to strong range (rs = .30–.52). Moreover, WMC does not seem to predict comprehension on the basis of “capacity,” in the sense of short-term storage limits, because the meta-analysis also indicated that simple (storage-only) span tasks did not predict comprehension as well as did complex span (see also, Carretti, Borella, Cornoldi, & De Beni, 2009; Engle, Tuholski, Laughlin, & Conway, 1999). Furthermore, it is not only verbal complex span tasks (reading and listening span) that predict comprehension, but operation span tasks with numerical stimuli also do, indicating that the verbal-processing component in reading span does not fully account for WMC-comprehension associations (Daneman & Merikle, 1996; see also Engle, Cantor, & Carullo, 1992; Kane et al., 2004).

Daneman and colleagues suggested that readers with lower WMC have less capacity to integrate information from the text and from background knowledge into a working mental model (e.g., Daneman & Carpenter, 1980; Daneman & Merikle, 1996; Hannon & Daneman, 2001). Many studies following the 1996 meta-analysis therefore focused on more specific aspects of that “integration” predicted by WMC—for example, WMC correlates with domain-specific integration processes, such as resolving lexical ambiguity (e.g., Daneman & Carpenter, 1983; R. A. Mason & Just, 2007; Miyake, Just, & Carpenter, 1994; but see Waters & Caplan, 2004), drawing inferences (e.g., Cain, Oakhill, & Bryant, 2004; Linderholm, 2002; M. Singer, Andrusiak, Reisdorf, & Black, 1992), and ignoring irrelevant textual details (Sanchez & Wiley, 2006). Although this approach has helped parse the particular aspects of comprehension that rely on WMC, it has not yet offered much specificity regarding the processes or mechanisms that can broadly explain these associations between WMC and comprehension.

We propose that one mechanism responsible for the dynamic memory processes (integration of new and old information) involved in reading is executive attention and, furthermore, that individual differences in attention control are at least partly responsible for the association between WMC and comprehension (e.g., Engle & Kane, 2004). We first review the evidence for the executive-attention theory of WMC and then, with the current study, demonstrate that lapses of attention (in the form of mind-wandering episodes) partially mediate the relationship between WMC and reading comprehension. Our findings thus suggest a domain-general cause—attention-control variation—for comprehension differences among skilled readers.

WMC and Attention Control

The executive-attention view of WMC explains the relationship between WMC span tests and complex cognitive abilities—such as reasoning, language comprehension, and reading—as driven by domain-general attention-control mechanisms. In other words, individual differences in the control of attention underlie performance on both WMC span tests and the complex cognitive tasks with which they correlate (Engle & Kane, 2004; Kane, Conway, et al., 2007; Kane & Engle, 2003; see also Hasher, Lustig, & Zacks, 2007; Unsworth & Spillers, 2010). Indeed, WMC does not only predict normal variation in higher order cognitive indicators—such as inductive reasoning, language learning, and scholastic achievement (Cowan et al., 2005; Kane, Hambrick, & Conway, 2005)—but also in performance of lower level attention tasks involving minimal memory demands, such as the antisaccade task (Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Schrock, & Engle, 2004). This task requires subjects to resist attention capture from a flashed cue stimulus in order to accurately attend to a subsequent target presented in the opposite field of vision. People with higher WMC better resist the automatic pull of the flashing distractor than do people with lower WMC. Evidence from "executive" tasks such as these (for reviews, see Heitz et al., 2005; Kane, Conway, et al., 2007) suggests that WMC is closely linked to attention control.

According to Engle and colleagues (e.g., Engle & Kane, 2004; Kane, Conway, et al., 2007; Kane & Engle, 2003), there are two components of executive attention that are related to WMC: goal maintenance and competition resolution. Goal-maintenance processes allow for the sustained access to task-relevant information in the face of interference from habit, environmental distractors, or irrelevant thoughts (i.e., mind wandering). Competition-resolution mechanisms, in contrast, deal with in-the-moment interference from a stimulus. That is, even on occasions when the goal of the task is actively maintained, there may still be individual-differences variation in the ability to implement control processes to overcome a goal-inappropriate, stimulus-driven response. These dual components of executive attention may therefore be discussed in terms of "proactive" and "reactive" control processes (Braver, Gray, & Burgess, 2007). Proactive processes are initiated prior to the expected need for control, in order to minimize experiences of conflict, and they are sustained until conflict is unlikely. Reactive processes are initiated in-the-moment, on an as-needed basis in response to any experienced conflict. These two executive processes are strategically allocated on the basis of task demands (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver et al., 2007; Brown & Braver, 2005) and subjects' abilities (Braver et al., 2007; Engle & Kane, 2004). Research has indicated that successful performance on many attention-demanding tasks relies on both components of executive attention (Kane et al., 2001; Kane & Engle, 2003; Unsworth et al., 2004; for exceptions, see Kane, Poole, Tuholski, & Engle, 2006). Our subsequent research has suggested that off-task thoughts (i.e., mind wandering) disrupt goal-maintenance processes and result in performance errors in attention-demanding tasks (McVay & Kane, 2009; McVay, Kane, & Kwapil, 2009).

Mind Wandering as a Lapse of Attention Control

Mind wandering, a seemingly universal aspect of human experience, may be defined as a shift of attention away from stimuli and mental representations associated with a person's ongoing activities to the consideration of TUTs (e.g., Antrobus, Singer, & Greenberg, 1966; Giambra, 1995; Smallwood, Obonsawin, & Heim, 2003). We do not consider all instances of attention to internal representations to be a reflection of mind wandering, however. For example, deliberate retrieval from long-term memory (LTM), or generating imagery as a part of an ongoing task, do not qualify as mind wandering because they represent task-relevant cognitions. In contrast, daydreaming during a class lecture, zoning out while reading, or contemplating evening plans while driving home, all constitute mind wandering.

Mind wandering is empirically studied using thought probes, which are brief interruptions to the ongoing task that ask subjects to classify the content of their immediately preceding thoughts as on-task or off-task (for a review, see Smallwood & Schooler, 2006). Self-reported mind-wandering experiences have been validated by their reliable relationship with more objective measures: Systematic variation in TUT frequency co-occurs with variation in theoretically motivated task variables (e.g., Antrobus et al., 1966; Grodsky & Giambra, 1990–1991; McGuire, Paulesu, Frackowiak, Frith, 1996; McKiernan, D'Angelo, Kaufman, & Binder, 2006; Smallwood, Obonsawin, & Heim, 2003; Teasdale et al., 1995; Teasdale, Lloyd, Proctor, & Baddeley, 1993), with several individual-difference constructs (e.g., Kane, Brown, et al., 2007; Shaw & Giambra, 1993; Smallwood et al., 2002), and with particular patterns of neural activity (e.g., Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; M. F. Mason et al., 2007; McKiernan et al., 2006; Smallwood, Beach, Schooler, & Handy, 2008). Previous research has converged on the estimate that, on average, people spend 30%–50% of their time mind wandering (Hurlburt, 1979; Kane, Brown, et al., 2007; Killingsworth & Gilbert, 2010; Klinger & Cox, 1987–1988; McVay et al., 2009; J. L. Singer, 1975). Furthermore, TUTs have been implicated in disruptions to current-task performance (e.g., McVay & Kane, 2009), leading to, in the case of reading, deficits in comprehension (e.g., Schooler, Reichle, & Halpern, 2004), which we discuss in more detail later.

Our Control Failures × Concerns view (McVay & Kane, 2009, 2010a, 2010b) conceptualizes unintended mind wandering as a lapse of attention control. According to this perspective, TUTs are the subjective experiences that accompany failures to properly maintain task goals. These off-task intrusions are automatically generated from a continuous stream of thought on the basis of the current concerns of the individual and cued by the environment (Klinger, 1971, 2009). TUTs that affect performance therefore reflect a break in the restraints imposed on the train of thought used to focus on task goals. Conceived as a failure of attention control, then, it is not surprising that mind wandering is implicated in performance failures in attention-demanding tasks and in WMC variation.

In laboratory investigations, the association between mind wandering and performance errors takes two forms: a significant negative correlation between individual differences in TUT rates and task performance (McVay & Kane, 2009; Smallwood et al., 2003; Smallwood, O'Connor, Sudberry, & Ballantyre, 2004) and a within-subject comparison showing greater in-the-moment likelihood of error following TUT reports than following on-task thinking reports (McVay & Kane, 2009; Schooler et al., 2004; Smallwood et al., 2007). For example, overall recall for word lists is negatively related to TUT rates at study (r = –.25; Ellis, Moore, Varner, Ottaway, & Becker, 1997; see also Smallwood, Baracaia, Lowe, & Obonsawin, 2003), and subjects are less likely to correctly withhold responding to a target in a go/no-go task when they report experiencing a TUT in the moment than when they report an on-task thought (McVay & Kane, 2009).

Furthermore, as predicted by the executive-attention view, WMC variation predicts TUT rates during attention-demanding tasks. Kane, Brown, et al. (2007) first demonstrated the WMC–TUT association using a daily life experience sampling method. During everyday activities with high levels of self-reported concentration, challenge, and effort, higher WMC subjects reported less mind wandering than did lower WMC subjects, indicating that lower WMC subjects had more difficulty maintaining attention on tasks of high cognitive demand. A related line of studies shows WMC to predict the ability to suppress intrusive thoughts (Brewin & Beaton, 2002; Brewin & Smart, 2005; Geraerts, Marckelbach, Jelicic, & Habets, 2007). The suppression of particular thoughts may be related to a general ability to maintain on-task thoughts in the face of conflict, although the relationship between these two constructs remains to be tested. Finally, experimental research has shown that manipulations of working memory load affect TUT rates during ongoing tasks (e.g., Teasdale et al., 1995). WMC clearly predicts both thought suppression and the propensity to mind-wander, suggesting that control over conscious thought may be an important aspect of goal maintenance and executive functioning.

We suggest that the executive-attention theory of WMC predicts a partial mediator role for mind wandering between WMC and task errors, because TUTs should capture only the goal-maintenance, rather than competition-resolution, component of attention control. McVay and Kane (2009) tested this prediction by screening subjects for WMC and having them complete a long go/no-go task (the sustained attention to response task [SART]; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) with thought probes. As hypothesized, WMC variation significantly predicted TUT rate (r = –.22), SART accuracy (r = .29), and within-subject variability in go reaction times (RTs; r = –.35). Furthermore, mind-wandering rate accounted for about half of WMC's shared variance with SART performance (accuracy and RT variability), indicating that the propensity for TUTs partially mediated the relationship between WMC and performance, consistent with the dual-component executive-attention theory (e.g., Engle & Kane, 2004). That is, apparent goal-neglect errors can result from either insufficient goal maintenance or failures in competition resolution. Mind wandering's partial mediation of WMC's effects most likely reflects instances where proactive maintenance of the task goal was interrupted by TUTs. In contrast, the remaining, unique variance in goal neglect accounted for by WMC variation—independent of mind wandering—likely reflects the reactive competition-resolution component of executive control.

By this view, TUT rates should mediate the WMC–performance relationship in any task that requires active goal maintenance for successful performance, including reading comprehension. Hasher and Zacks (1988) first proposed a connection between WMC, attention-control (inhibitory) failure, and comprehension by arguing that lower WMC readers are less able to filter out irrelevant information as it is retrieved from LTM on the basis of cues in the text. This view has been supported by behavioral evidence (for reviews, see Hasher et al., 2007; Hasher, Zacks, & May, 1999) but not yet by direct assessments of TUTs during reading. Therefore, in the current study, we examine individual differences in WMC, comprehension, and mind wandering.

Mind Wandering and Reading Comprehension

Although mind wandering during reading is familiar to most people, little empirical work has addressed how TUTs affect comprehension (see Smallwood, Fishman, & Schooler, 2007). Grodsky and Giambra (1990–1991) measured TUTs during nonfiction reading and during a computerized vigilance task. They demonstrated a stable tendency to mind-wander across both tasks ($r = .51$) but did not report reading-comprehension measures and thus did not demonstrate mind wandering's consequences. The first studies, then, to look directly at the relationship between comprehension and TUTs were reported by Schooler et al. (2004), in several experiments where subjects read selections from War and Peace and completed a comprehension test. While reading on the computer screen, subjects monitored their mind wandering and reported any TUTs via key-press (these were “self-caught” TUTs). Some subjects were also probed unpredictably. The proportion of probed TUT reports predicted overall accuracy ($r = –.51$ in Experiment 1; $r = –.25$ in Experiment 2), indicating that people who mind-wandered more comprehended less.

Smallwood, McSpadden, and Schooler (2008) similarly used experimenter-scheduled probes to demonstrate mind wandering's effects on developing a situation model and drawing inferences. They probed subjects reading a Sherlock Holmes mystery, both randomly and directly following inference-critical episodes (ICEs; sections of the text with information necessary to infer the villain's identity). Overall, subjects who reported more “zone-outs” (reports of TUTs without prior awareness) were less likely to answer questions accurately ($r = –.25$); moreover, subjects who reported one or more zone-outs during ICEs were less likely than those who did not to correctly identify the villain. Finally, those subjects who zoned out during the beginning of the story comprehended less well than did those who zoned out later. Smallwood et al. attributed this temporal effect to disruptions to the initial formation of a situation model, thereby limiting subjects' foregrounding (i.e., reactivating associated information for the purpose of coherence) during critical parts later in the story (see also Smallwood, 2011).

Reichle, Reineberg, and Schooler (2010) further illustrated the effects of mind wandering on comprehension but here using eye-tracking technology. Their analysis of four undergraduates who read a complete novel in the laboratory revealed an effect of TUTs on the top-down processes involved in eye movements during reading. Mindless reading, as indicated by TUT reports, was characterized by subjects continuing to move their eyes across the page but with fewer lexical- and linguistic-driven movements than during mindful reading. In other words, mind-wandering subjects continued to move their gaze forward across the text but were not perceptually processing the text in a normal way (e.g., they showed fewer regressions and fewer words fixated, and their fixations were less sensitive to word length and frequency). Although Reichle et al. did not analyze comprehension accuracy, the reduced perceptual processing during TUTs suggests that subjects did not encode the text as well when they were mind-wandering. Indeed, in a follow-up study (Franklin, Smallwood, & Schooler, 2011), when subjects read computerized text presented word-by-word in response to key-presses, both TUT reports and local comprehension errors tended to be preceded by rapid key-presses that were insensitive to the lexical qualities of the text that otherwise drive RTs when subjects read mindfully.

Despite such considerable advances in the empirical study of mind wandering, it is an inherently correlational enterprise. TUTs occur naturally in some situations and contexts and not in others, and they occur more often in some people than in others. Thus, one potential ambiguity regarding the association between mind wandering and reading comprehension is that poor readers might mind-wander simply because they are poor readers and not because TUTs actually disrupt comprehension. That is, poor readers mind-wander because they are already reading poorly. Studies that assess TUT propensity only during reading tasks cannot disambiguate the causal direction—if any—at work in the TUT–comprehension correlation. However, a relation between comprehension and TUTs in a separate, nonreading task, such as a vigilance task, would strengthen the claim that variation in maintaining on-task thinking contributes to comprehension differences. The current study takes this approach, thus providing a more conclusive test of mind wandering's potential influences on reading comprehension.

The Current Study

Here we investigate the mediating role of mind wandering in the relationship between WMC and reading comprehension. As reviewed earlier, both WMC and mind-wandering vulnerability predict comprehension, but this is the first study combining these individual-difference variables to establish their mutual contributions. Using a latent-variable, structural-equation-model approach, we used multiple measures for each construct of interest: WMC, TUT rate, attention control, and reading comprehension. We measured TUT rate during two types of tasks: attention-control and reading-comprehension tasks. If individual differences in TUTs were consistent across attention and reading tasks, and if this general mind-wandering propensity predicted comprehension, then it would provide stronger evidence for deficient thought control as a cause, rather than a consequence, of poor reading.

Our inclusion of attention-control tasks in this study not only allowed us to assess TUTs across multiple task contexts but, because these attention tasks also correlate with WMC (e.g., Kane et al., 2001; Kane & Engle, 2003; McVay & Kane, 2009), we were able to leverage them to test broader claims about the nature of WMC and its prediction of complex cognitive abilities. If WMC variation, and its covariation with higher order cognition, reflect primarily executive-attention processes (e.g., Engle & Kane, 2004; Kane, Conway, et al., 2007), then the variance shared between WMC and attention-control tasks ought to predict reading comprehension. At the same time, any residual WMC variance (reflecting, in part, memory processes) that is unassociated with attention-control tasks should correlate only weakly with comprehension (for similar logic, see Colom, Rebollo, Abad, & Shih, 2006; Engle et al., 1999). Finally, to the extent that executive-attention abilities predict individual differences in mind-wandering susceptibility, TUT rate should mediate the association between this WMC–attention common variance and comprehension.

In short, we evaluate three novel research questions in the current article: (1) Does TUT rate mediate the relationship between WMC and reading comprehension? (2) Does the variance shared by WMC and attention-control tasks drive the association between WMC and reading comprehension? and (3) Does TUT rate mediate the shared contribution of attention-control and WMC tasks to reading comprehension?

Method

Participants

We recruited native English speakers between 18 and 35 years of age from the undergraduate participant pool of a comprehensive state university, the University of North Carolina at Greensboro (UNCG), who participated for course credit. Of the 258 participants who completed the first session, 248 completed two sessions, and 242 completed all three.

WMC Measures

We used tasks and procedures recommended by a recent methodological review (Conway et al., 2005) to measure WMC. Three WMC tasks required subjects to alternate between a processing and memory component. In operation span (Ospan), subjects verified answers to compound mathematical equations (e.g., [2 + 2]/1 = 4) while remembering individual letters presented after each equation. After three to seven equation–letter trials, subjects recalled the letters in sequence by clicking boxes next to 12 possible letters. Reading span (Rspan) used the same memory stimuli, but subjects judged whether sentences made sense (e.g., “I like to run in the sky”). In spatial span (Sspan), subjects remembered sequentially presented red squares within a 4 × 4 grid presented following a decision about whether black-and-white matrix patterns were vertically symmetrical. After each set of two to five processing-memory pairs, subjects recalled the red-square locations in order by clicking the boxes within an empty grid. All three tasks were automated and presented using E-prime software (Schneider, Eschman, & Zuccolotto, 2002; see http://www.psychology.gatech.edu/renglelab/Eprime1.html). Subjects practiced each part of the task (processing, memory) separately, and then together prior to the test trials. During the combined test trials, if subjects took longer than two standard deviations above their mean practice time on the processing task, the program skipped to the memory stimulus and the trial was designated an error. This way, subjects could not take extra time during processing to rehearse the memory items (Conway et al., 2005).

Mind-Wandering Probes

Thought probes, requiring subjects to classify the contents of their immediately preceding thoughts, appeared during four tasks. The instructions asked subjects to respond on the basis of their thought content just before the probe appeared and not to reconstruct all thoughts since the last probe. We slightly modified probes according to the task in which they appeared, for example (as they appeared during War and Peace):

What were you just thinking about?1. The text2. How well I'm understanding the story3. A memory from the past4. Something in the future5. Current state of being6. Other

Subjects responded by pressing a number on the keyboard corresponding to the thought category (explained at length during instructions). For analysis, the first category was coded as task-related thought and the second as task-related interference (Smallwood, Riby, Heim, & Davies, 2006). The presentation of these two options varied with the task; for example, in the numerical Stroop task, they read: “ 1. The number task; 2. How well I'm performing the number task.” We coded responses of 3–6 as TUTs, and we focus our analyses on this thought category.

Reading Comprehension Measures

The reading tasks in this study were selected to represent the wide range of reading materials encountered in daily life (see Table 1). For each (other than the VSAT), we report Flesch-Kincaid scores for ease and grade level in Table 2 (calculated in Microsoft Word). We piloted (N = 95) comprehension for War and Peace and Maggie (see later) and replaced questions producing near-ceiling or near-floor accuracy.

Tables 1 & 2 are omitted from this formatted document.

VSAT

With permission, we accessed subjects' official scores on the VSAT.

Inference verification test (IVT)

We drew these materials from Griffin, Wiley, and Thiede (2008), where overall comprehension scores correlated with WMC ($r = .32$). At their own pace, subjects read onscreen two 600- to 900-word explanatory texts, one about bacteria and the other about volcanoes. Following each passage, subjects completed a self-paced IVT presenting true/false questions that assessed inferences drawn from the passage.

Psychological journal articles

This task was conducted with materials and test formats used in higher education that came from a previous memory study (Kang, McDermott, & Roediger, 2007; McConnell, 2009). The task comprised two articles (2,000–2,500 words) from Current Directions in Psychological Science:

Journal Article 1 (Treiman, 2000), about literacy, and Journal Article 2 (Anastasio, Rose, & Chapman, 1999), about media bias. Eight multiple-choice questions for each article were drawn from Kang et al. (2007), and an additional four questions were created by McConnell (2009). Subjects had 15 min to read each article on paper, while seated facing a computer workstation, after which they took a computerized comprehension test. During Journal Article 2, we changed the screen color (from gray to blue) to cue the subject to respond to a computerized thought probe every 2–4 min during the reading time.

War and Peace

The reading material for this task was taken from Schooler et al. (2004), but the comprehension testing was unique for our purposes. For 50 min, subjects read the first five chapters of Tolstoy's War and Peace (about 8,000 words) in a self-paced, paragraph-by-paragraph format, presented on the computer in 15-point Times New Roman font and advanced by key-press. Subjects answered true/false questions at reasonable intervals where enough new information had been presented to justify a new question. Thought probes appeared before each question.

Short stories

Subjects read two short stories on-screen, self-paced and presented paragraph-by-paragraph in 16-point Times New Roman font: The Coming-Out of Maggie (Maggie), by O. Henry, and Eveline, by James Joyce. The stories paralleled the journal articles in word length (about 2,500 words). Following each, subjects completed six true/false and six multiple-choice questions to assess theme and plot comprehension.

Attention-Control Tasks

Numerical Stroop

Two, three, or four identical digits were presented in a horizontal row in 24-point Courier New font on each trial, and subjects were instructed to report the number of digits presented (e.g., Windes, 1968). Subjects indicated the number of items by pressing the B key for two, the N key for three, and the M key for four with their dominant hand. Prior to the start of the Stroop task, subjects completed 36 mapping trials in which they used the same keys to respond to the number (two to four) of red boxes on-screen. Subjects performed 480 experimental trials in sets of 60 trials at 75% congruency (without noticeable breaks between blocks). Within each set of 60 trials, 15 congruent and 15 incongruent trials were marked for analysis to equate the number of trials analyzed in each condition (75% congruent = 15 incongruent trials). Thought probes followed 60% of the incongruent trials in the second half of the task.

Semantic SART

Subjects completed a 20-min version of a SART with semantic stimuli, adapted from McVay and Kane (2009). The SART is a go/no-go task in which subjects must respond quickly with a key-press to all presented stimuli except infrequent (11%) targets. This version presented words in 18-point Courier New font for 300 ms followed by a 900-ms mask. Most of the stimuli (nontarget go trials) belonged to one category (Animals) and infrequent no-go targets belonged to another (Foods). The SART presented 540 trials, 60 targets, and 36 probes. Thought probes followed 60% of targets.

Antisaccade task

A quick flash on one side of the screen signaled the appearance of an imperative target on the opposite side. Subjects thus had to avoid capture by the flash in order to direct attention to the target. Following a key-press response to a "ready" screen, a 200-ms to 2,200-ms blank screen preceded the flashing cue. A 24-point Courier New font "=" sign flashed 100 ms on, 50 ms off, and 100 ms on, about 12 cm from the center (randomly but equally often to the left or right), drawing attention to that location (Kane et al., 2001). The target (in 28-point Wingdings 3 font)—an arrow pointing up, down, right, or left—appeared the same distance from the center, on the opposite side from the flashing cue, for 150 ms. A mask ("+") then appeared for 1,500 ms or until response. Subjects pressed an arrow on the keyboard corresponding to the direction of the target (Roberts, Hager, & Heron, 1994). Subjects performed 10 practice trials with the stimulus in the center of the screen, followed by 72 experimental trials.

Procedure

We tested subjects in groups of one to six, and they completed 4.5 hr of testing across three 90-min sessions. Subjects completed all sessions within the same semester, but the intersession interval varied with subjects' scheduling choices ($M = 31$ days [$SD = 19$] to complete all three sessions). The fixed order of tasks is presented in Table 1.

Results

We report nondirectional null-hypothesis significance tests with an alpha of .05; we base conclusions about structural model fits on multiple, commonly used fit indices with cutoffs suggested by Kline (2005): $\chi^2/df < 2$; comparative fit index (CFI) > .90 for reasonably good fit; root-mean-square error of approximation (RMSEA) between .05 and .08 for reasonable approximate fit; standardized root-mean-square residual (SRMR) < .10 for favorable fit (for further discussion, see Hu & Bentler, 1999; Marsh, Hau, & Wen, 2004). Subjects who did not complete all tasks were included in analyses using the data from their completed tasks (using the full information maximum likelihood missing data function in the structural-equation-modeling [SEM] software program Mplus; Muthén & Muthén, 2007). An error in the data-collection program for Journal Article 2 resulted in data for only 156 subjects. For all remaining tasks, data from 0–17 subjects were dropped due to experimenter error, equipment failure, or subjects failing to follow instructions (details available from the authors by request). The SEM models we report exclude seven multivariate outliers on both Mahalanobis distance and Cook's D, thereby leaving $N = 251$ for SEM models.

Performance Measures: WMC, Attention Control, and Reading Comprehension

Table 2 presents descriptive statistics for the WMC and reading-comprehension measures. As shown in Table 3, the WMC tasks correlated well with each other: Ospan × Rspan (r = .61), Ospan × Sspan (r = .44), and Sspan × Rspan (r = .47). These WMC measures do not yield reliability estimates, but their intercorrelations indicate a reasonable lower bound for reliability (i.e., correlations between tasks cannot exceed the reliability of the least reliable task). For the multivariate analyses later, we used z scores for the WMC tasks calculated from our database of over 2,000 UNCG students. Regarding the reading measures, some of the reliability estimates were low (see Table 3) but were deemed acceptable given the significant correlations between the reading-task scores (rs = .17 to .51, with most in the .35 range). We used a proportion score (out of 800) for analyses of the VSAT scores to avoid convergence problems associated with scale differences between variables.

Table 3 is omitted from this formatted document.

Table 4 presents descriptive statistics for the attention tasks. As in previous work with the SART (McVay & Kane, 2009), we calculated a signal-detection sensitivity score (d_L) and response bias score (C_L) for each subject using the formula for logistic distributions (Snodgrass & Corwin, 1988). We also calculated each subjects' RT variability (i.e., their standard deviation for go trials). The d_L score and RT variability have correlated with WMC and TUT rate in previous work, but C_L has not (McVay & Kane, 2009). For analyses, then, we used only d_L and RT variability as performance measures.

Table 4 is omitted from this formatted document.

In the Stroop task, trials of interest were the incongruent trials (e.g., Trial 222). Here we used incongruent RTs in analyses because accuracy was near ceiling. 1 In the antisaccade task, all trials were “incongruent,” in that they all conflicted with the habitual orienting response; accuracy was well below ceiling in the antisaccade, so we used it as our dependent variable (see also Unsworth & Spillers, 2010). Of importance, then, the latent variable for attention control reflected the variance common to both RT (Stroop-incongruent, SART variability) and accuracy (antisaccade, SART signal detection) measures, and so it does not reflect simple processing speed.

Table 3 presents the bivariate correlations between all the WMC, reading-comprehension, attention-control, and TUT measures. Note that these do not correspond to the covariance matrix from the latent-variable models presented later. Rather, they are Pearson's correlations that allow the reader to compare our findings to others in the literature; the *N* for each correlation corresponds to the lesser *N* of the two tasks. (For those who wish to test their own models for our data, we provide the covariance matrix in the associated supplemental materials.)

Mind-Wandering Rates and Task Performance

Table 5 presents descriptive statistics for the TUT measures. Mind-wandering rates within each task correlated negatively and significantly with several aspects of task performance: overall Stroop accuracy (r = –.17), Stroop incongruent-trial accuracy (r = –.15), Stroop incongruent RT (r = .42), SART RT variability (r = .27), accuracy on journal article comprehension (r = –.31), and *War and Peace* comprehension (r = –.41). Furthermore, subjects were significantly less accurate on occasions when they reported TUTs than when they reported on-task thoughts on Stroop incongruent trials (Ms = 0.84 vs. 0.91), $t(225) = –5.49$, and on SART target trials (Ms = 0.42 vs. 0.62), $t(179) = 7.03$. Although subjects were numerically more likely to answer *War and Peace* questions correctly when they had just reported on-task thinking (M = 0.73) versus TUTs (M = 0.72), this contrast was not significant, $t(197) < 1$, perhaps because these true/false questions allowed a 50% chance of guessing the correct answer to a particular question regardless of comprehension or mind wandering.

Table 5 is omitted from this formatted document.

Measurement Model and Construct Correlations

The correlations presented in Table 3 suggest convergent and discriminant validity for our measures: Measures designed to reflect a common construct (e.g., WMC) appeared to correlate strongly with each other and more strongly than with measures of other constructs. To formally assess the fit of our measurement model to the data, we used confirmatory factor analysis (CFA), loading the observed variables onto four latent variables: WMC, TUT rate, reading comprehension, and attention control. A priori, we allowed certain residual variances in the model to correlate to account for shared method variance among observed measures. For WMC, we allowed Ospan and Rspan to correlate, beyond their shared variance with Sspan, because both required letter recall. For mind wandering, we allowed TUTs from the SART and Stroop tasks to correlate because of the similarity of the primary-task demands. We also allowed the two TUT measures from reading tasks to correlate, but the correlation was not significant in the CFA and therefore we dropped it from the model. Finally, for the attention-control factor, we allowed the two SART measures (dL and RT variability) to correlate. The factor loadings of the latent variables for each structural model are presented in Table 6.

Table 6 is omitted from this formatted document.

The CFA model, presented in Figure 1—with latent variables for WMC, reading comprehension, attention control, and TUTs—provided a reasonable fit to the data, $\chi^2(126, N = 251) = 194.51$, $p < .001$; χ^2: df = 1.54; CFI = .924; RMSEA = .046, 90% confidence interval (CI) = [0.033, 0.059]; SRMR = .060. Although, as predicted, the correlation between WMC and attention control was strong, Wald's test of constraint indicated it was significantly less than 1.0, suggesting that a three-factor solution (combining WMC and attention control) would not fit the data as well; indeed, this three-factor model did not converge. Also as expected, WMC and attention control both correlated positively and significantly with comprehension.

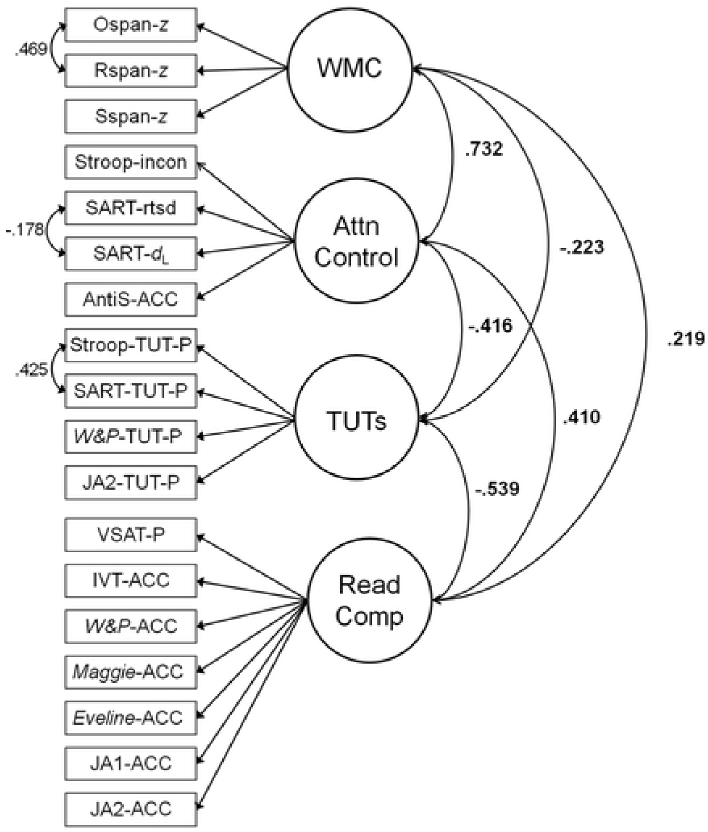

Figure 1. *Confirmatory factor analysis model for the latent variables working memory capacity (WMC), reading comprehension (Read Comp), rates for mind wandering (i.e., task-unrelated thoughts [TUTs]), and attention control (Attn Control), seen in the circles. All paths are statistically significant at p < .05. The boxes represent the observed variables loaded onto each latent factor. The arrows represent the modeled direction of the pathway between variables. For the observed variables (boxes) on the left side of the figure: Ospan- z = z scores for the automated operation span task; Rspan- z = z scores for the automated reading span task; Sspan-z = z scores for the automated spatial span task; Stroop-incon = incongruent trials in the Stroop task; SART-rtsd = nontarget reaction time variability in the sustained attention to response task; SART- dL = signal detection measure of performance in the SART task; AntiS-ACC = accuracy in the antisaccade task; Stroop-TUT-P = proportion of TUTs reported during the Stroop task; SART-TUT-P = proportion of TUTs reported during the SART task; W&P-TUT-P = proportion of TUTs reported during the War and Peace task; JA2-TUT-P = proportion of TUTs reported during the Journal Article 2 task; VSAT-P = proportion score (of 800) on the verbal SAT; IVT-ACC = accuracy on the inference verification test; W&P-ACC = accuracy on the War and Peace comprehension questions; Maggie-ACC = accuracy on comprehension questions for Maggie (Short Story 1); Eveline-ACC= accuracy on comprehension questions for Eveline (Short Story 2); JA1-ACC = accuracy on Journal Article 1 (Treiman, 2000); JA2-ACC = accuracy on JA2 (Anastasio et al., 1999).*

Of note, the mind-wandering measures from four different tasks loaded well onto a single latent variable, suggesting that TUT rate is a stable individual-difference variable, even across such diverse tasks as the SART go/no-go task and reading *War and Peace*. We did not test a model with two separate TUT factors (for reading vs. attention tasks), because it is inadvisable to model latent factors with fewer than three observed measures (Kline, 2005). Here, the TUT factor, reflecting the common variance among mind-wandering rates across four diverse tasks, correlated negatively with WMC, attention control, and reading comprehension.

We began by stepping back from the full measurement model described previously and first taking the simplest approach to our primary theoretical question: Is normal variation in TUT rate at least partially responsible for the well-established association between WMC and reading-comprehension abilities? Figure 2 presents the hypothesized partial-mediation model, in which WMC predicted reading comprehension, both through TUTs and independently, $\chi^2(73, N = 251) = 119.78$, $p = .001$; χ^2: $df = 1.64$; CFI = .938; RMSEA = .050, 90% CI [0.033, 0.066]; SRMR = .057. We also tested a full mediation model, in which all the variance in reading comprehension predicted by WMC was through TUTs, but a significant chi-square difference test (χ^2 diff = 3.96, $df = 1$) indicated that, as expected, the data best supported the partial-mediation model. WMC's indirect effect on comprehension, via TUT rate, was .112 ($p = .022$). We also generated confidence intervals around the indirect effect using 1,000 bias-corrected bootstrapping samples in Mplus: The confidence interval did not include zero (95% CI [0.01, 0.21]), indicating significant mediation. The conservative Sobel test of mediation, which tests the null hypothesis that the pathway (c path) from the predictor (WMC) to the outcome (reading comprehension) is equivalent to the same pathway when the mediator is included in the model (c′ path), approached conventional significance (c path = .28; $b = –0.038$, $SE = 0.016$, $z = 1.81$, $p = .07$).

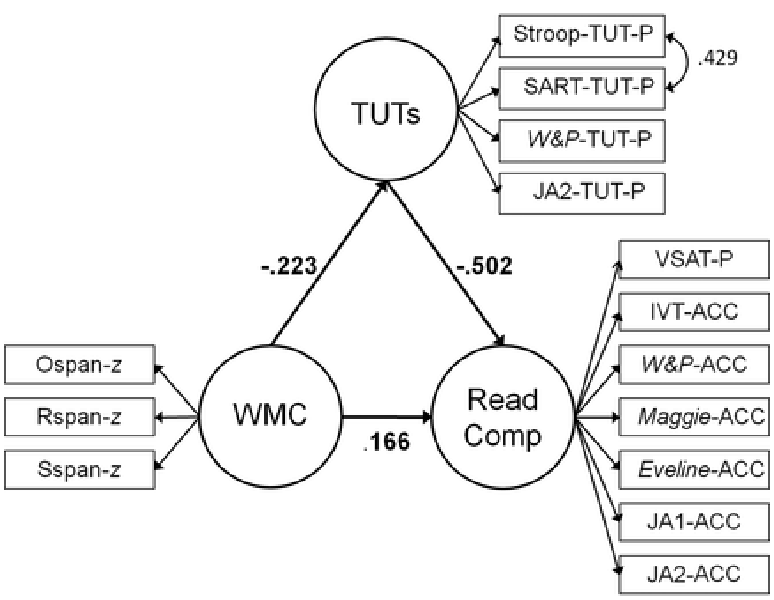

Figure 2. Structural equation model depicting the relationship between working memory capacity (WMC) and reading comprehension (Read Comp) with mind wandering (i.e., task-

unrelated thoughts [TUTs]) as a partial mediator, seen in the circles. All paths are statistically significant at p < .05. The boxes represent the observed variables loaded onto each latent factor. The arrows represent the modeled direction of the pathway between variables. For the observed variables (boxes) on the left side of the figure: Ospan- z = z scores for the automated operation span task; Rspan- z = z scores for the automated reading span task; Sspan- z = z scores for the automated spatial span task. For the observed variables (boxes) on the right side of the figure: Stroop-TUT-P = proportion of TUTs reported during the Stroop task; SART-TUT-P = proportion of TUTs reported during the sustained attention to response task; W&P-TUT-P = proportion of TUTs reported during the War and Peace task; JA2-TUT-P = proportion of TUTs reported during the Journal Article 2 task; VSAT-P = proportion score (of 800) on the verbal SAT; IVT-ACC = accuracy on the inference verification test; W&P-ACC = accuracy on the War and Peace comprehension questions; Maggie-ACC = accuracy on comprehension questions for Maggie (Short Story 1); Eveline-ACC = accuracy on comprehension questions for Eveline (Short Story 2); JA1-ACC = accuracy on Journal Article 1 (Treiman, 2000); JA2-ACC = accuracy on JA2 (Anastasio et al., 1999).

Our second set of models included the attention-control factor to help clarify the nature of WMC's associations with mind wandering and comprehension capability. Based on the executive-attention theory of WMC (e.g., Engle & Kane, 2004), executive-attention processes contribute to performance on WMC tasks, as well as to “lower level” control tasks such as Stroop, SART, and antisaccade, and these executive processes are partly (or largely) responsible for WMC's correlations with higher order cognition. Our next model thus included both WMC and attention-control factors as correlated predictors of TUTs and then of comprehension. Executive-attention theory predicts that WMC should not predict much comprehension variance over and above that accounted for by the attention-control factor; here we also tested whether either would predict comprehension beyond their correlation with TUT rate.

As illustrated in Figure 3, the model indicated significant mediation, $\chi^2(126, N = 251) = 194.51$, $p < .001$; χ^2: $df = 1.54$; CFI = .924; RMSEA = .046, 90% CI [0.033, 0.059]; SRMR = .060, with a strong correlation between WMC and attention control, and an indirect path from only attention control to comprehension, via TUTs. The direct pathways from WMC and attention control to reading comprehension were not significant. We therefore tested a full mediation model by dropping the nonsignificant paths from WMC and attention control to reading comprehension, $\chi^2(128, N = 251) = 197.023$, $p < .001$; χ^2: $df = 1.49$; CFI = .925; RMSEA = .046, 90% CI [0.033, 0.059]; SRMR = .067, which fit the data better than did the partial-mediation model (χ^2 diff = 2.51, $df = 2$). This model indicated a significant indirect effect of attention control on reading comprehension through TUT rate (.343, $p = .015$) but no indirect effect of WMC (–.108, $p = .394$). Bias-corrected bootstrapping on the significant indirect effect yielded a confidence interval that included zero (95% CI [–0.35, 1.03]), whereas the Sobel test approached conventional significance (c path = .424; $b = –0.362$, $SE = 0.023$, $z = 1.85$, $p = .06$). This model thus presents a mixed picture, with an indirect effect of questionable significance but clear evidence against any direct effects, with full mediation fitting the data better than does partial mediation.

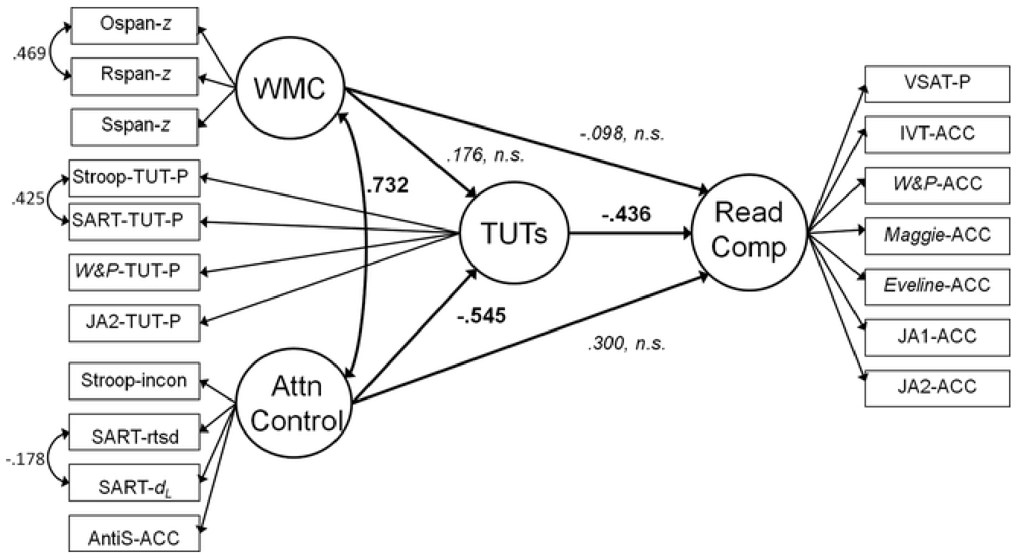

Figure 3. Structural equation model depicting the relationships among the latent variables for working memory capacity (WMC), attention control (Attn Control), and reading comprehension (Read Comp) with mind wandering (i.e., task-unrelated thoughts [TUTs]) as a mediator, seen in the circles. The boxes represent the observed variables loaded onto each latent factor. The arrows represent the modeled direction of the pathway between variables. For the observed variables (boxes) on the left side of the figure: Ospan- z = z scores for the automated operation span task; Rspan- z = z scores for the automated reading span task; Sspan- z = z scores for the automated spatial span task; Stroop-TUT-P = proportion of TUTs reported during the Stroop task; SART-TUT-P = proportion of TUTs reported during the sustained attention to response task; W&P-TUT-P = proportion of TUTs reported during the War and Peace task; JA2-TUT-P = proportion of TUTs reported during the Journal Article 2 task; Stroop-incon = incongruent trials in the Stroop task; SART-rtsd = nontarget reaction time variability in the SART task; SART- dL = signal detection measure of performance in the SART task; AntiS-ACC = accuracy in the antisaccade task. For the observed variables (boxes) on the right side of the figure: VSAT-P = proportion score (of 800) on the verbal SAT; IVT-ACC = accuracy on the inference verification test; W&P-ACC = accuracy on the War and Peace comprehension questions; Maggie-ACC = accuracy on comprehension questions for Maggie (Short Story 1); Eveline-ACC = accuracy on comprehension questions for Eveline (Short Story 2); JA1-ACC = accuracy on Journal Article 1 (Treiman, 2000); JA2-ACC = accuracy on JA2 (Anastasio et al., 1999).

As shown in our next model, another way of testing for TUT's mediation of the WMC/attention prediction of reading comprehension might also better illustrate the key proposal from executive-attention theory—that the variance shared between WMC and attention control is what drives the widely observed correlations between WMC and complex cognition. That is, although WMC and attention control are not identical constructs (see Figure 1), they do share considerable variance.

We propose that this shared variance is critical to their predictive power. Figure 4 presents a structural model that takes the variance common to WMC and attention-control tasks as the predictor of TUTs and, in turn, reading comprehension. To best capture the fact that WMC tasks also share memory-related (and method) variance beyond what they share with attention tasks (e.g., Unsworth & Engle, 2007; Unsworth & Spillers, 2010), we allowed the residuals from the WMC tasks to correlate. We then used this new latent factor, labeled *Executive Attention*, in the causal mediation model with TUTs and comprehension.

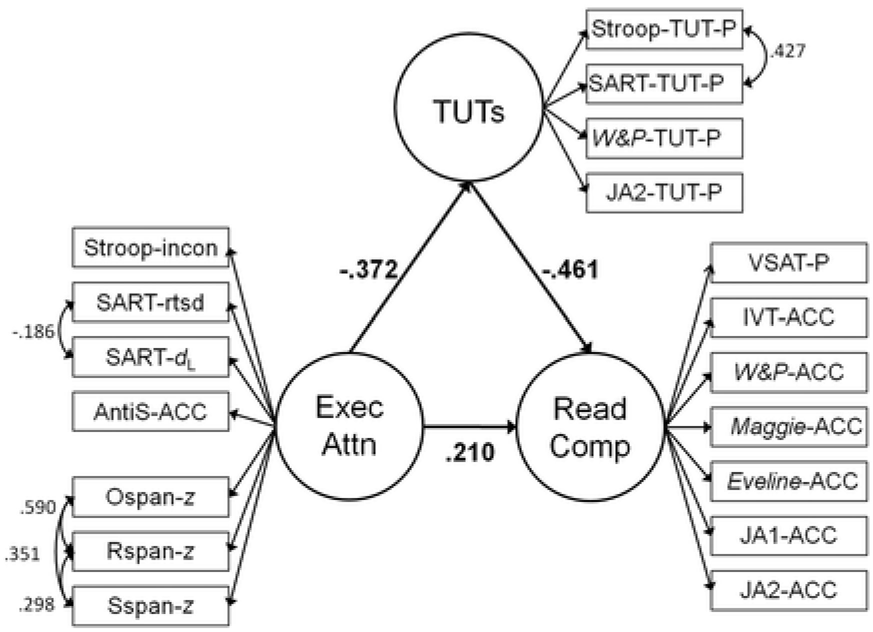

Figure 4. Structural equation model depicting the relationship between the latent variables executive attention (Exec Attn) and reading comprehension (Read Comp) with mind wandering (i.e., task-unrelated thoughts [TUTs]) as a mediator, seen in the circles. All paths are statistically significant at $p < .05$. The boxes represent the observed variables loaded onto each latent factor. The arrows represent the modeled direction of the pathway between variables. For the observed variables (boxes) on the left side of the figure: Stroop-incon = incongruent trials in the Stroop task; SART-rtsd = nontarget reaction time variability in the sustained attention to response task; SART- dL = signal detection measure of performance in the SART task; AntiS-ACC = accuracy in the antisaccade task; Ospan- z = z scores for the automated operation span task; Rspan- z = z scores for the automated reading span task; Sspan- z = z scores for the automated spatial span task. For the observed variables (boxes) on the right side of the figure: Stroop-TUT-P = proportion of TUTs reported during the Stroop task; SART-TUT-P = proportion of TUTs reported during the SART task; W&P-TUT-P = proportion of TUTs reported during the War and Peace task; JA2-TUT-P = proportion of TUTs reported during the Journal Article 2 task; VSAT-P = proportion score (of 800) on the verbal SAT; IVT-ACC = accuracy on the inference verification test; W&P-ACC = accuracy on War and Peace comprehension questions; Maggie-ACC = accuracy on comprehension questions for Maggie (Short Story 1);

Eveline-ACC = accuracy on comprehension questions for Eveline (Short Story 2); JA1-ACC = accuracy on Journal Article 1 (Treiman, 2000); JA2-ACC = accuracy on JA2 (Anastasio et al., 1999).

The model provided a reasonable fit, $\chi^2(127, N = 251) = 188.56$, $p < .001$; χ^2: $df = 1.48$; CFI = .932; RMSEA = .044, 90% CI [0.030, 0.056]; SRMR = .060, and indicated a significant indirect effect of executive attention on reading comprehension through TUT rate (.172, $p = .006$), in addition to the significant direct effect of executive attention on comprehension. Bias-corrected bootstrapping also yielded a confidence interval around the indirect effect that did not include zero (95% CI [0.04, 0.30]); the Sobel test also confirmed significant mediation (c path = .381; $b = –0.075$, $SE = 0.030$, $z = 2.44$, $p = .01$). This partial-mediation model better fit the data than did the full-mediation model (χ^2diff = 4.12, $df = 1$), in which all the variance in reading comprehension predicted by executive attention was through TUTs. Thus, a domain-general vulnerability to mind-wandering experiences is partly responsible for executive attention's substantial correlation with broad reading-comprehension capabilities.

Discussion

The current study demonstrated the importance of individual differences in mind-wandering propensity to the relationship between WMC and reading comprehension. Individuals' TUT rates, representing failures to maintain on-task thoughts, were stable across both attention-control and reading tasks, and this general susceptibility to off-task thought was detrimental to performance. WMC, which taps, in part, executive control of attention (e.g., Engle & Kane, 2004; Kane, Conway, et al., 2007), negatively predicted TUT rates and positively predicted reading comprehension; indeed, the shared variance between WMC and attention-control factors, rather than the memory-related processes exclusive to WMC, appeared to drive the WMC–comprehension correlation. Finally, TUTs mediated the association between WMC/attention control and reading comprehension, suggesting that control over thought content is an important mechanism of successful comprehension (e.g., Smallwood, 2011) and is one of the pathways through which WMC variation influences reading ability.

The fact that the relation between WMC/executive-attention and reading comprehension was only partially mediated by TUT rate suggests that some executive-related processes that are independent of thought control are important to reading. What do these processes reflect? We see three hypotheses worthy of consideration. First, effective competition resolution may be required for comprehension and be tapped by executive-attention variation. Second, the memory-related processes involved in performing WMC tasks (e.g., short-term maintenance or LTM retrieval; Unsworth & Engle, 2007) may be critical to its relationship with comprehension. Third, WMC may contribute to the accrual of vocabulary and grammatical information over a lifetime, and it is this “historical” factor (i.e., the contribution of prior knowledge), rather than dynamic WMC processes acting in the moment, that underlies the non-TUT-related variance in comprehension explained by WMC.

Regarding the first possibility, previous reading-comprehension research does seem to suggest a role for competition resolution in successfully processing text. Specifically, Gernsbacher and colleagues (e.g., Gernsbacher, 1993; Gernsbacher & Robertson, 1995) identified several situations in which suppression of inappropriate word meanings is necessary for accurate comprehension, for example in interpreting homonyms (e.g., turn left at the light vs. she left the party) and homographs (e.g., tied a bow vs. bow to the emperor), according to the surrounding context. Hasher and Zacks (1988) also demonstrated that older adults (a population with lower WMC than younger adults) had more difficulty relinquishing a disconfirmed inference when interpreting new information while reading; for example, older adults were less likely than younger adults to recall a target piece of inferred content from a text when that information was unexpected (on the basis of previous information presented) at the time of its original presentation. This type of competition resolution, although more subtle and less frequent than in a Stroop or antisaccade task, may contribute to the variance in reading comprehension accounted for by WMC, beyond its shared variance with mind-wandering propensity.

Regarding the second and third possibilities mentioned previously (concerning memory-related and knowledge-related accounts of WMC's effects on comprehension), data from the current study seem to undermine the influence of these nonattention components of WMC. The variance in comprehension captured by the WMC factor was always shared with the attention-control factor, which was derived from tasks without memory, vocabulary, or grammar demands. Indeed, when WMC and attention-control factors were modeled together (see Figure 3), the path from WMC to comprehension was not significant after accounting for the indirect pathway through TUT rate and the variance shared with attention control. This finding leads us to tentatively conclude that it is not prior knowledge or memory processes that are driving the independent (beyond TUT) contributions of executive attention to reading comprehension (see the later section Implications for Theories of WMC and Attention Control). We did not, however, include independent tests of grammar, vocabulary, or topic-specific knowledge and therefore cannot conclusively assess their role in reading comprehension. We expect that these types of domain-specific variables may contribute independent variance to reading comprehension, but we do not expect that their shared variance with WMC tasks would predict reading comprehension above and beyond WMC alone, on the basis of the current findings.

Implications for Theories of Mind Wandering

The current study provides additional evidence for the Control Failure × Concerns view of mind wandering (McVay & Kane, 2010a, 2010b), which proposes that unintentional TUTs during an ongoing task reflect failures to control attention, and maintain task goals, in the face of interference from automatically elicited, personal-goal-related thoughts. Moreover, these off-task thoughts have negative consequences for complex-task performance (McVay & Kane, 2010b; Smallwood & Schooler, 2006). An important hypothesis derived from our perspective is that those individuals with weaker attention-control abilities will more often succumb to interfering thoughts than will those with stronger control abilities (as will people who have more vs. less urgent personal concerns with which to contend; see McVay & Kane, 2010b). As discussed earlier, WMC reflects attention-control abilities; therefore, individual differences in WMC should predict mind wandering (e.g., McVay & Kane, 2009), because high versus low WMC individuals should not differ systematically in urgency or extent of personal concerns (see the later section Future Directions).

The resource-demanding view of mind wandering (Smallwood & Schooler, 2006), in contrast, proposes that TUTs consume, specifically, executive resources: “Mind wandering competes with the primary task for the control and coordination of working-memory resources” (p. 950), and “… mind wandering requires the coordination of information using resources under executive control” (p. 949). It thus makes the opposite prediction: People with more resources available should mind-wander more frequently (or more extensively) than those with fewer. That is, if TUTs demand executive resources, and if a trade-off occurs between devoting such resources to the current task and to TUTs, then having more resources in reserve should allow one's mind to wander more often without impacting task performance. Here, by using a latent-variable analysis that combined TUT measures across tasks, we demonstrated a negative relationship between WMC and TUT rate, consistent with the control-failures view (see also Kane, Brown, et al., 2007; McVay & Kane, 2009). 2

With that said, it seems possible to reconcile our findings, and the Control Failure × Concerns view, with Smallwood's (2010) revision of the executive-resources perspective. In his reply to McVay and Kane (2010b), Smallwood recast the “resource” consumed by TUTs as access to the global workspace of consciousness (e.g., Baars, 1988; Dehaene, Kerszberg, & Changeux, 1998; Navon, 1989a, 1989b). By such workspace views, cognitively specialized processing modules may be broadly influenced in a top-down manner by information made globally available to the system via consciousness, defined as verbally reportable experiences. If broadcast access to the global workspace is capacity-limited, and if TUTs gain access to the global workspace by virtue of their being reportable, then, the argument follows, TUTs must consume an executive resource (Smallwood, 2010). On the one hand, one might object that Smallwood has simply moved the theoretical goalposts by defining all conscious experiences as executive, thereby generalizing the concept of executive control too far and limiting its explanatory power. On the other hand, Smallwood's proposal seems consistent with our view that conscious access to goal states (or intermittent and ready access to such states) is important to top-down guidance of behavior and concomitant thought and that automatically cued, concern-related thoughts may overcome control efforts and hijack consciousness in such a way as to further limit the effectiveness of proactive and reactive executive processes. We seem to agree with Smallwood, then, that during cognitive activities such as reading, failures to restrict conscious thought to goal-related representations will frequently result in intrusions of concern-related thought into consciousness, and if the task goal is to comprehend what one is reading, then these intrusions will result in goal neglect and comprehension errors. The present study also demonstrates clearly that individual differences in executive capabilities are partly responsible for individual differences in unintended off-task thinking and in reading-comprehension ability.

Implications for Theories of WMC and Attention Control

The current results inform functional theories of WMC that seek to identify the underlying factor(s) in the relationship between WMC and higher order cognition, and they emphasize the importance of thought control, in addition to action control, in understanding the role of control processes in complex cognitive ability. Current WMC theories posit any of the following—executive-attention processes (e.g., Cowan et al., 2005; Hasher & Zacks, 1988; Kane, Conway, et al., 2007), short-term memory (STM) capacity (Colom, Rebollo, et al., 2006; Colom, Shih, Flores-Mendoza, & Quiroga, 2006; Krumm et al., 2009), the establishment and maintenance of mental bindings (Oberauer, Süß, Wilhelm, & Sander, 2007; Wilhelm & Oberauer, 2006), or retrieval from LTM (Unsworth & Engle, 2006, 2007)—as potential mechanisms of WMC's covariation with complex cognitive ability. Only attention theories of WMC, however, would seem to predict a mediating role of TUTs in the relationship between WMC and higher order cognitive tasks. Several findings from this study thus provide support for an executive-attention view of WMC over memory-based, WMC theories.

First, the variance common to WMC tasks and low-level attention-control tasks significantly predicted reading comprehension (in part through mind wandering). If simple STM explained the WMC–comprehension association, then the variance unique to WMC, after accounting for its shared variance with attention-control tasks, should drive the association with comprehension (e.g., Colom, Abad, Quiroga, Shih, Flores-Mendoza, 2008; Engle et al., 1999). This was not the case. Indeed, in order to explore this issue further, we created a variation of the model in Figure 4 by adding a latent factor to represent the variance shared by the WMC tasks beyond that which it had in common with the attention-control tasks (rather than having the WMC-specific variance represented by correlated error terms, as in Figure 4). This bifactor model (Jensen & Weng, 1994), thus attempted to test whether “residual” WMC variance, representing nonattention processes important to STM or to LTM storage and retrieval, would significantly predict reading comprehension. The model fit the data only modestly well, $\chi^2(129, N = 251) = 227.00$, $p < .001$; χ^2: df = 1.76; CFI = .892; RMSEA = .055; SRMR = .074, probably in large part because the path from the “residual” memory component to comprehension was not significant, and near zero (.008, $p = .99$); as in the Figure 4 model, then, only the variance common to WMC and attention-control tasks predicted comprehension (in part, via TUTs). The predictive power of WMC for comprehension, therefore, did not appear to be driven by the memory-specific abilities that are tapped by WMC tasks (Colom, Shih, et al., 2006; Unsworth & Engle, 2007).

The mediating role of TUT propensity also raises questions about LTM activation and retrieval in comprehension. During reading, one uses prior knowledge (i.e., LTM) to develop situation models and successfully draw inferences about the text (e.g., M. Singer, 1979; M. Singer & Kintsch, 2001; M. Singer & Remillard, 2004). How can this be reconciled with our findings that attentional, rather than memorial, processes were most critical to WMC-related individual differences in reading? Hasher and Zacks (1988) proposed that WMC variation reflects the ability to successfully filter information cued by the text by inhibiting task-irrelevant thoughts. Unsworth and colleagues have argued, in similar fashion, that lower WMC individuals are less successful than are higher WMC individuals at constraining their memory-search set to only relevant information during deliberate retrieval (e.g., Unsworth, 2009; Unsworth & Engle, 2007; Unsworth, Brewer, & Spillers, 2009). In the case of reading comprehension, then, 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. Readers who are lower in WMC 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 with task-relevant thoughts. For example, while reading a journal article, a subject with higher WMC may activate information from previous classes to aid understanding. A reader with lower WMC, in attempting to do the same, may inadvertently activate a memory of a funny classmate using a less-constrained search set. The memory of the classmate, now activated, may compete for attention with task-relevant information and result in TUTs. Alternatively, higher and lower WMC subjects 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 whether the goal of reading for comprehension initiates an active search of LTM, resulting in different LTM activations for higher and lower WMC individuals (Unsworth, 2009; Unsworth & Engle, 2007; Unsworth et al., 2009), or whether the same LTM representations are activated, only to be more easily blocked from awareness by higher WMC individuals (Hasher & Zacks, 1988).

Implications for Training Reading Comprehension

The current study suggests that interventions meant to improve reading should take mind-wandering vulnerability into account: Thought control, in addition to vocabulary and grammar lessons, should be a focus of reading training. Cromley and Azevedo (2007) set out to target interventions for background knowledge, inferences, strategies, vocabulary, and word reading. They did not, however, include measures of TUTs or attention control (which may affect the factors that they did include and possibly contribute unique variance). Their conclusion—to target comprehension interventions on increasing background knowledge and vocabulary (the biggest individual-differences contributors in their study)—does not take into account the possibility that training more basic attention-control capabilities should improve reading comprehension at a more global level than should specific vocabulary or knowledge training. In fact, other data have suggested that WMC continues to predict reading-comprehension variation even when prior knowledge about the material is manipulated (e.g., Engle, Nations, & Cantor, 1990; Sanchez & Wiley, 2006).

Training targeted at particular aspects of reading, such as fluency or word knowledge, is unlikely to yield general improvements in reading comprehension as significant as the training of underlying attention-control mechanisms (e.g., training to maintain on-task thoughts). Swanson and O'Connor (2009) tested the idea that WMC is a secondary contributor to comprehension in children and that increased word fluency would close the comprehension gap between high- and low-WMC readers. In contrast, they found that reading fluency did not mediate the relationship between WMC and comprehension and that fluency practice did not attenuate the relationship. Some researchers have already demonstrated improvements in performance on attention tasks following mindfulness training (e.g., Chambers, Lo, & Allen, 2008; Jha, Krompinger, & Baime, 2007); we suggest that training on thought control during reading deserves further consideration in future studies. Perhaps even more promising is the increase in attention-control capabilities following domain-general WMC training.

A small but rapidly growing body of research has provisionally indicated that WMC training may be beneficial to higher order cognition (e.g., Holmes, Gathercole, & Dunning, 2009; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; McNab et al., 2009; but see Shipstead, Redick, & Engle, 2010), including reading comprehension (Chein & Morrison, 2010). Jaeggi et al. (2008) demonstrated a performance increase on matrix-reasoning tests, which are good markers of general fluid intelligence (Gf), as the result of training over several weeks on a WMC task (the n-back). Furthermore, McNab et al. (2009) identified a training-based neuroanatomical change: After only 14 hr of WMC training, the density of particular dopamine receptors in brain regions associated with WMC performance increased. These findings suggest that, perhaps, some forms of WMC training, over the course of an education program (in terms of years, rather than hours), could significantly improve higher order cognitive abilities such as Gf and reading comprehension. Finally, and most relevant to the present purposes, adult subjects in the Chein and Morrison (2010) study, who completed 4 weeks of training on complex working memory span tasks, showed modest improvement on the Nelson–Denny reading comprehension test compared with no-contact controls. According to the executive-attention theory of WMC, the likely cause of the improvements in Gf and reading comprehension mentioned earlier—if they prove replicable and reliable—is an increase in attention-control capabilities. An increase in attention control, as a result of WMC training, is likely to reduce TUT vulnerability as well, although this connection remains to be tested.

Future Directions

The current study (see also Kane, Brown, et al., 2007; McVay & Kane, 2009; McVay et al., 2009) focused primarily on the control-failures side of the Control Failures × Concerns view. That is, we did not control for, measure, or manipulate the content or cuing of subjects' current personal concerns, which appear to drive and occupy a majority of people's off-task thinking (e.g., Klinger, 1971, 2009). Instead, any individual or contextual differences in the amount or intensity of potentially interfering thoughts between subjects, and across task sessions, represent part of the error variance in our structural models. We found here that the propensity to mind-wander was reasonably stable across tasks (and so, also, across days and sessions; see also McVay et al., 2009), allowing us to draw conclusions about the effect of control-related individual differences on TUTs. Future studies, however, should focus also on the concerns component of our view, by addressing directly the contribution of varying levels of interfering thoughts to individual differences in TUT rate. For example, a reading task could be manipulated to present more- or less-relevant personal-concern cues within the text. This manipulation of the concern-based interference, akin to changing the proportion of incongruent trials and word-based interference in a Stroop task (e.g., Kane & Engle, 2003), should result in differences in the frequency of TUTs between high-cue and low-cue contexts. Furthermore, our view claims that more interference from concern-related cues should increase the need for executive control, making individuals with lower WMC more susceptible than those with higher WMC to in-the-moment TUTs in response to concern-related cues.

Although our studies to date have focused on tasks that were designed to make TUTs detrimental to performance, we recognize the potential benefits of mind wandering and encourage further empirical exploration in this area. We note, in particular, that the task goals, as defined by the experimenter in a controlled laboratory setting, do not necessarily reflect the current concerns and larger life goals of the subject (Baars, 2010; McVay & Kane, 2010a). Thus, the same TUT that detracts attention from processing key details from an article's General Discussion may serve as a problem-solving step in a reader's current conflict with a loved one or even as a cue to an interesting new experiment idea that is more compelling than the arguments made by the article. Indeed, some theorists claim that TUTs can contribute to effective problem solving and creativity quite broadly (e.g., Baars, 2010; Klinger, 2009; J. L. Singer, 1966; Smallwood & Schooler, 2006), and we encourage empirical tests of such claims.

Conclusion

Mind-wandering vulnerability mediates the relationship between individual differences in WMC/attention control and reading comprehension. This finding has important implications for the 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. Our study demonstrates the interfering effects of off-task thoughts on a wide range of reading tasks and, furthermore, suggests that individual differences in TUTs are a key factor in understanding failures of reading comprehension and WMC's prediction thereof. Importantly, educational plans and interventions designed to increase reading comprehension must consider not only language-specific abilities (e.g., vocabulary) but also thought control as an important, and more domain-general, contributor to comprehension skill and ability.

Footnotes

1 We did not use the RT difference between congruent and incongruent trials (à la the traditional Stroop effect) in the SEM models, because Stroop-incongruent RT showed stronger simple correlations with the other attention-control measures and loaded significantly on an attention-control latent factor.

2 As McVay and Kane (2010b) also noted, when higher WMC subjects report TUTs, their task performance is as poor as that of lower WMC subjects who are mind wandering. Thus, having superior WMC, or more “executive resources,” in reserve does not minimize the performance consequences of TUTs or allow for resource sharing between on-task and off-task thought, in apparent contrast to the predictions of the executive-resources view (Smallwood & Schooler, 2006).

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