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On the Relation Between Working Memory Capacity and the Antisaccade Task

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Eight experiments ($N = 2,003$) assessed the relation between working memory capacity (WMC) and performance on the antisaccade task. Experiments 1–5 and 7 examined individual differences in aspects of goal management processes occurring during the preparatory delay of the antisaccade task. WMC tended to interact with delay interval suggesting that high WMC individuals better prepared for the upcoming trial by activating the task goal to a higher level than low WMC individuals (although these effects were generally small). Experiments 3a, 4, and 7 further demonstrated that individual differences in the consistency of attention (i.e., lapses of attention) were partially important for the relation between WMC and antisaccade performance. Experiment 5 demonstrated that knowledge of the likelihood of target location increased overall performance, but did not interact with WMC. Experiment 6 manipulated stimulus onset asynchrony and suggested that speed factors are also likely important for the relation between WMC and antisaccade performance. Finally, structural equation models in Experiment 7 suggested that lapses of attention and speed factors partially accounted for the relation between WMC and antisaccade, but WMC still accounted for unique variance in antisaccade. Collectively, the results suggest that multiple factors (goal activation, consistency of attention, and speed factors) contribute to the relation between variation in WMC and performance on the antisaccade task.

Keywords: working memory, attention control, antisaccade, individual differences


Supplemental materials: <https://doi.org/10.1037/xlm0001060.supp>

Working memory is a core cognitive system that is needed to actively maintain, manipulate, and retrieve task relevant information in a wide variety of tasks. Much prior research has demonstrated that individual differences in working memory capacity (WMC) are associated with performance in a number of cognitive domains including performance on low-level attention and memory tasks as well as higher-level reasoning and comprehension tasks (see Engle & Kane, 2004; Unsworth & Engle, 2007 for reviews). A prominent theory of individual differences in WMC suggests that these individual differences are partially due to normal variation in attention control (or executive attention) abilities (Engle & Kane, 2004; Kane & Engle, 2002; Unsworth & Engle, 2007). By attention control we mean the set of attentional processes that aid in the ability to actively maintain information in the presence of interference and distraction. These attention control abilities are necessary when novel goal-relevant information (i.e., the current task goal/task set) must be maintained in a highly active state in the presence of potent internal and external


distraction (Duncan et al., 1996; Engle & Kane, 2004; Miller & Cohen, 2001). If the task goal is not sufficiently activated or if there is any lapse of attention (or goal neglect, Duncan, 1995) it is likely that the task goal will be lost from working memory resulting in attention being automatically captured by internal (e.g., mind-wandering; Kane et al., 2007; McVay & Kane, 2012b) or external distraction (e.g., Robison & Unsworth, 2015; Unsworth et al., 2014; Unsworth & McMillan, 2014). Thus, a key aspect of attention control is the ability to actively maintain the current goal in a highly active state and prevent attentional capture from internal and external sources. Evidence supporting these notions comes from a variety of studies which have demonstrated relations between WMC and performance on various attention control tasks including the antisaccade task (see Unsworth, 2016 for a review). In the current study we examine various potential reasons for the relation between WMC and performance on the antisaccade task.

Working Memory Capacity and the Antisaccade Task

In the **antisaccade task** (Hallett, 1978; Hallett & Adams, 1980; see Everling & Fischer, 1998; Hutton & Ettinger, 2006; Munoz & Everling, 2004 for reviews) participants are told to fixate on a central cue and after a variable amount of time, a flashing cue appears either to the right or left of fixation, and participants have to shift their attention and gaze to the opposite side of the screen as quickly and accurately as possible. **In the control condition for this task**, participants are instructed to shift their attention and gaze to the same side

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of the screen as the cue (i.e., prosaccade). Typically, participants are more error prone and slower on antisaccade trials compared with prosaccade trials. This has been taken as evidence that antisaccade trials require participants to inhibit reflexive orienting to the cue (i.e., inhibit a prosaccade) and generate a voluntary saccade to the opposite side of the screen. A key aspect of antisaccade trials is that they require not only the ability to generate a correct saccade in the opposite direction once the cue has appeared, but also require the ability to prepare for the upcoming trial by ensuring that the task goal is maintained in working memory (Hutton & Ettinger, 2006; Munoz & Everling, 2004). On prosaccade trials, the task goal and the prepotent response coincide (e.g., look at the flashing box). Relying on either goal maintenance or automatic orienting will result in the correct behavior. On antisaccade trials, however, the task goal and the prepotent response conflict (e.g., if flashing on left—look right). Thus, on antisaccade trials it is critically important to maintain the task goal in working memory in order for accurate responding to occur. If the task goal is not actively maintained, any momentary lapse in attention will result in attentional capture by the cue (Nieuwenhuis et al., 2004; Roberts et al., 1994; Roberts & Pennington, 1996).

The notion that antisaccade performance is partially driven by goal maintenance abilities that occur during the preparatory interval is also supported by neuroimaging studies that have found that several areas are more active for antisaccades than prosaccades during the preparatory interval (e.g., Brown et al., 2007; Curtis & D'Esposito, 2003; Fernandez-Ruiz et al., 2018; Ford et al., 2005; Hakvoort Schwerdtfeger et al., 2012). Furthermore, level of preparatory activation (especially in the dorsolateral prefrontal cortex and anterior cingulate cortex) is related to whether or not a correct or incorrect antisaccade is generated (e.g., Brown et al., 2007; Curtis & D'Esposito, 2003; Ford et al., 2005). That is, when the task goal was not properly maintained during the preparatory interval of an antisaccade trial, an erroneous prosaccade tended to be executed. Additional areas are active during the response generation period that are classically associated with motor control over saccades including the frontal eye field, supplementary eye field, and intraparietal sulcus (Coe & Munoz, 2017). Further, Brown et al. (2007) found that dorsolateral prefrontal cortex and anterior cingulate activity was greater in antisaccades than prosaccades during the preparatory interval but not during actual response generation. This is consistent with the notion that these areas are important for goal maintenance processes, but that other areas are important for the generation of the correct motor response. Collectively, prior research suggests that goal maintenance processes occurring during the preparatory interval are critically important for accurate performance on antisaccade trials (e.g., Hutton & Ettinger, 2006; Hutchison et al., 2020; Munoz & Everling, 2004; Nieuwenhuis et al., 2004; Nieuwenhuis et al., 2000; Roberts et al., 1994; Unsworth et al., 2011).

Given the notion that the antisaccade task places heavy demands on attention control and goal maintenance processes, Kane et al. (2001) used this task to test the theory that individual differences in WMC were partially due to differences in attention control. Kane et al. (2001) had high and low WMC individuals (based on performance on the operation span task) perform blocks of both prosaccade and antisaccade trials and found that high WMC individuals consistently outperformed low WMC individuals on antisaccade trials (higher accuracy and faster reaction times).

Similarly, Unsworth et al. (2004) found that high WMC individuals were more accurate and had faster saccadic reaction times than low WMC individuals in a variety of conditions across three experiments. Similar to Kane et al. (2001), Unsworth et al. (2004) suggested that high WMC individuals had better goal maintenance abilities and were faster to move the focus of attention and generate a voluntary saccade than low WMC individuals. Subsequent research has largely corroborated these results in demonstrating a consistent correlation between WMC and performance on the antisaccade. In particular, the antisaccade task has been used in numerous large-scale factor analytic studies where it has been shown to correlate with measures of WMC and with additional measures of attention control (e.g., Chuderski & Jastrzębski, 2018; Friedman & Miyake, 2004; Kane et al., 2016; Redick et al., 2016; Unsworth & Spillers, 2010; Unsworth et al., 2020a). Indeed, Meier et al. (2018) reported that the antisaccade task typically loads with other attention control measures on an overall attention control factor and this factor is strongly related to a WMC factor. Furthermore, Unsworth (2016) reported that WMC and antisaccade were correlated at $r = .31$ in a sample of 1,038 participants, and Unsworth et al. (2020a) recently reported that WMC was correlated with antisaccade at $r = .25$ in a sample of 3,003 participants (some of that data is included in the present study).

These results suggest that there is a clear relation between individual differences in WMC and performance on the antisaccade task. But, it is not clear exactly why this is the case. As noted previously, the general argument has been that the antisaccade task requires attention control processes to maintain task goals in working memory and low WMC individuals have poorer attention control abilities than high WMC individuals. Thus, low WMC individuals perform more poorly because they cannot maintain the task goal in memory as well as high WMC individuals leading to more attentional capture. While prior results are in line with this notion, it is clear that more work is needed to better understand these relations and better characterize broad goal management processes. For example, based on prior theorizing we have recently begun to better delineate goal management processes and how they are related to variation in WMC (Unsworth & Robison, 2020). Specifically, goal management processes can be broken down into goal selection, goal activation, and goal maintenance (Duncan et al., 1996; Hockey, 1997, 2011, 2013). In typical laboratory tasks, the current task goal must be selected over competing goals that the participant may have. Given that the task goal is likely less important to the participant than other goals, it is necessary that the task goal be sufficiently activated above other competing goals (see also Altmann & Trafton, 2002). It is assumed that this goal activation process takes time (Unsworth et al., 2011; Woodrow, 1914). In some situations it is possible that the task goal is not sufficiently activated when the trial begins, leading to the wrong response or a delayed response. Once the task goal is activated it needs to be actively maintained/sustained in working memory during the course of the trial (or runs of trials) to bias responding to the correct response. If the task goal is not properly maintained throughout the duration of the trial (or runs of trials), the task goal might lose activation allowing for one of the competing goals to gain access to the focus of attention and hijack attention away from the current task (due to external or internal distraction).

In examining performance on the antisaccade task as a function of preparatory delay interval (i.e., the time between the warning stimulus and the flashing cue), Unsworth et al. (2011) suggested

that it takes time to properly activate the task goal in working memory and keep it maintained. When there is little time for preparatory processes to activate the task goal, goal neglect is more likely to occur resulting in more errors at short preparatory delays. As the delay period increases, the likelihood of adequately activating and maintaining the task goal should increase leading to less goal-neglect and fewer errors. In line with this theorizing, Unsworth et al. (2011) found that antisaccade accuracy increased as delay period increased. In another study, Moffitt (2013) examined WMC differences in antisaccade performance across preparatory delays in three experiments. In all three experiments Moffitt found that WMC and antisaccade were correlated (average $r = .25$), but WMC did not interact with the delay interval, suggesting that high and low WMC individuals both prepared to the same extent. Given WMC still correlated with antisaccade performance, Moffitt (2013) suggested that some of the WMC differences were due to conflict resolution processes (suppression) occurring when the distractor stimulus was presented. More recently, Meier et al. (2018) also examined WMC differences as a function of preparatory delay period in two antisaccade tasks. Meier et al. (2018) found that antisaccade accuracy increased across delay period consistent with prior research. Importantly, in one of their antisaccade tasks (letter antisaccade) they found that this increase in accuracy interacted with WMC, such that WMC differences were larger as the delay period increased. Meier et al. (2018) interpreted these results as suggesting that part of the reason that WMC is related to performance on the antisaccade is because high WMC individuals are better able to activate the task goal to a higher level than low WMC individuals. That is, during the preparatory interval, both high and low WMC individuals activate the task goal, but high WMC individuals activate the task goal to a much higher overall level than low WMC individuals resulting in a reduced likelihood of being captured by the cue and better overall performance. Meier et al. (2018) also noted additional possibilities for the relation between WMC and performance on the antisaccade. These included differences in the ability to maintain the goal during the preparatory interval, differences in mind-wandering and fluctuations in attention, and differences in the speed of goal activation. Based on their results, Meier et al. (2018) argued that some of the relation was also due to mind-wandering and attentional fluctuations, but that goal activation processes were critically important for the relation between WMC and performance on the antisaccade. However, Meier et al.'s (2018) results are limited given that the WMC interaction with delay interval did not replicate in another version of the antisaccade. Because of this we cannot draw strong conclusions about the relation between WMC and antisaccade performance from Meier et al.'s (2018) data. Given conflicting findings between Moffitt (2013) and Meier et al. (2018), the current study should provide important clarification on the relation between WMC and antisaccade.

Present Study

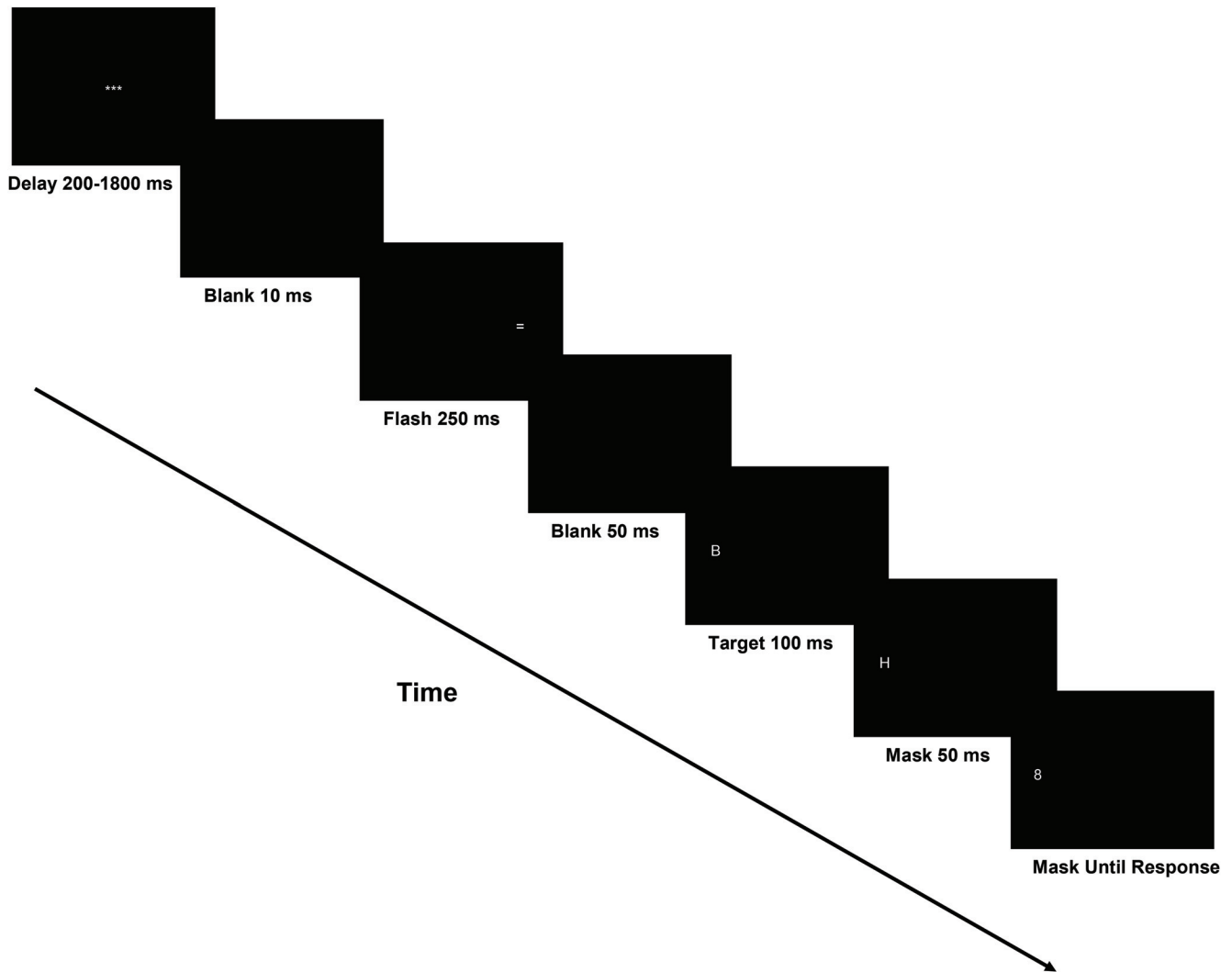
The main goal of the present study was to examine various theoretical reasons for the relation between WMC and antisaccade performance. Shown in Figure 1 is a schematic of the antisaccade task. In this behavioral version of the task (Kane et al., 2001; see also Friedman & Miyake, 2004; Guitton et al., 1985; Hutchison et al., 2020; Nieuwenhuis et al., 2004; Roberts et al., 1994 for

similar button press versions) participants are instructed to focus on a central fixation (***) for a variable delay period. A cue (a flashing “=”) is then presented either left or right of fixation and participants are instructed to move their attention and gaze to the opposite side of the screen to identify a briefly presented target (B, P, or R) which is quickly masked (H and then 8). The primary dependent variable is accuracy of target identification (although correct reaction times are also analyzed).

Similar to Meier et al. (2018) and Moffitt (2013), we were primarily interested in examining how different aspects of goal management processes that occur during the delay interval are potentially related to variation in WMC. Specifically, given conflicting findings from Moffitt (2013) and Meier et al. (2018), in the current study we critically examined different theoretical possibilities for the relation between WMC and antisaccade performance in order to assess more mechanistic accounts of the relation between WMC and antisaccade.¹ The possibilities are shown in Figure 2. Note that the figures illustrate the general possibilities and do not represent precise quantitative predictions. The first possibility is that high and low WMC individuals differ in the ability to energize or activate the task goal over competing goals (*goal activation*). As shown in Figure 2a, high WMC individuals may be better able to activate the task goal to a higher level than low WMC individuals (Meier et al., 2018; Moffitt, 2013; see also Unsworth & Robison, 2020 for a similar possibility for WMC differences in sustained attention). This would result in overall better performance (higher accuracy) on the antisaccade task across most delay periods for high WMC individuals compared with low WMC individuals, given that high WMC individuals are more prepared than low WMC individuals resulting in higher asymptotic accuracy (Meier et al., 2018). That is, general differences in goal activation might predict a main effect across delays (see also Unsworth & Robison, 2020). However, given that it takes time to activate the task goal, it is possible that WMC differences are reduced at short delays (assuming no differences in speed of activation; see below), but are increased with longer delays resulting in an interaction between delay and WMC as shown in Figure 2a. In sum, accuracy should increase across delays, and this increase should be larger for high WMC individuals than for low WMC individuals consistent with Meier et al. (2018). Of course, it is also possible that low WMC individuals simply do not prepare for the upcoming trial and only rely on more reactive control processes (Braver et al., 2007). This would suggest that accuracy increases for high WMC individuals across delay, but does not change for low WMC individuals.

Another possibility is that there are WMC differences in how quickly the task goal can be energized/activated (*speed of activation*). As shown in Figure 2b, high WMC individuals may be able to more quickly activate the task goal than low WMC individuals. This would suggest that when the delay is short that low WMC individuals might not yet have the task goal fully activated

¹ Note that the current experiments were not necessarily designed to examine discrepancies between Moffitt (2013) and Meier et al. (2018) as we began investigating these issues in 2011. Specifically, analyses for Experiment 1 occurred in 2011. Data collection and analyses for Experiments 2 and 6 occurred in 2013. Analyses for Experiments 3a and 3b occurred in 2018. Data collection and analyses for Experiments 4 and 5 occurred in 2018. Data analysis for Experiment 7 occurred in 2021.

Figure 1*Schematic Example of Trials for the Antisaccade Task*

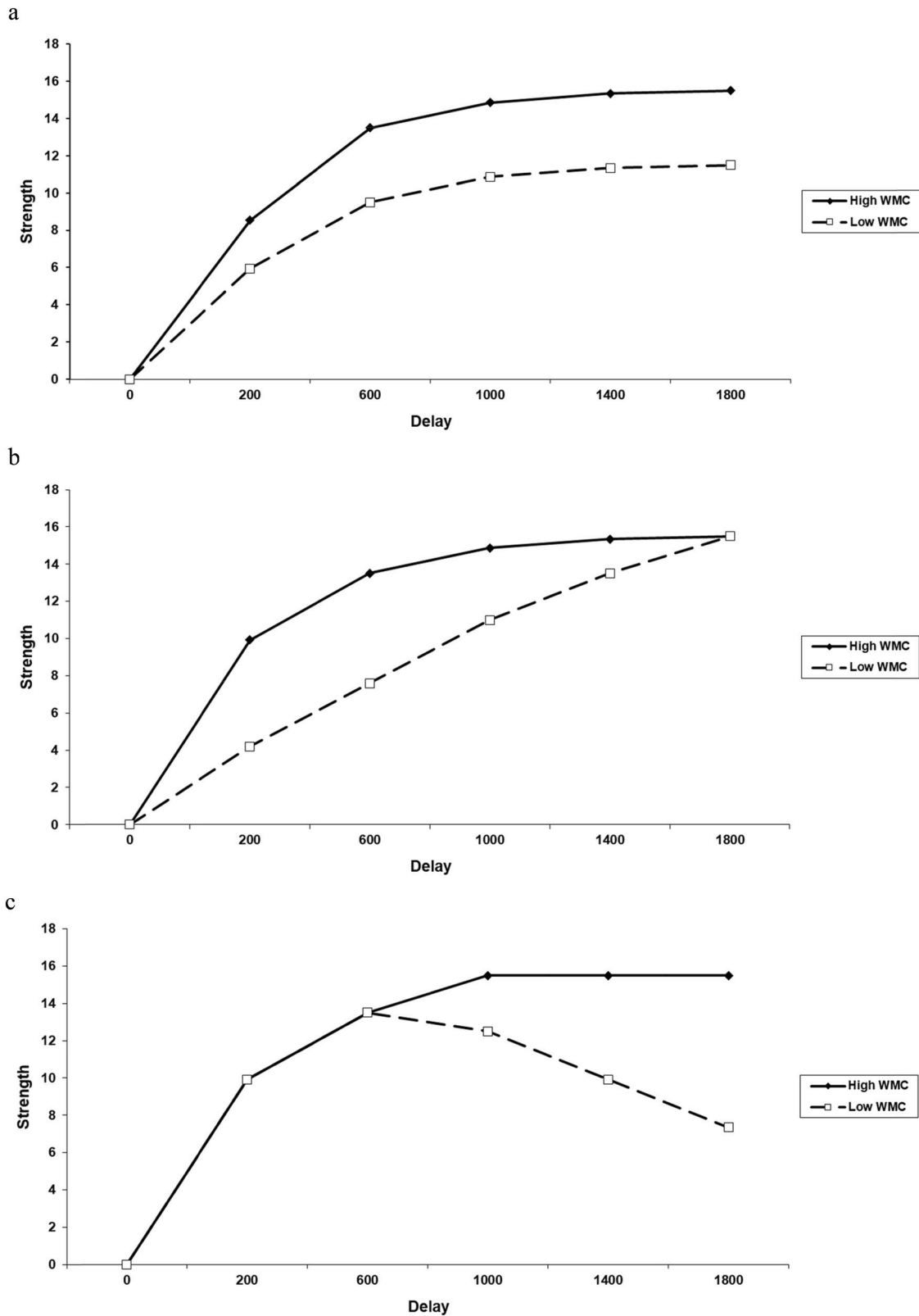
resulting in worse performance compared with high WMC individuals (Meier et al., 2018; Unsworth & Robison, 2020). However, with a sufficiently long delay, low WMC individuals should have plenty of time to activate the task goal to the same level as high WMC individuals. This scenario predicts that high WMC individuals should be more accurate than low WMC individuals overall, but when examining accuracy as a function of delay, these differences should be localized to the shortest delays. Thus, there should be an interaction between WMC and delay.

Conversely, it is possible that WMC differences are due to differences in the ability to actively maintain/sustain the task goal for the duration of the trial (*goal maintenance*). As shown in Figure 2c, high WMC individuals may be better able to actively maintain/sustain the task goal throughout the entire trial, whereas low WMC individuals cannot maintain this high level of activation; hence as the trial proceeds the task goal loses activation until it eventually drops below the competing goals (Meier et al., 2018; Moffitt, 2013; Unsworth & Robison, 2020). This would suggest

that when the delay is long, low WMC individuals are not able to keep the task goal fully activated resulting in worse performance compared with high WMC individuals. This possibility predicts that high WMC individuals should be more accurate than low WMC individuals overall and there should be an interaction between WMC and delay with differences localized to the longest delays, such that performance for low WMC individuals decreases at longer delays.

An additional possibility is that WMC differences arise due to differences in the consistency of attention across trials (*consistency*; (Unsworth, 2015). This possibility suggests that WMC differences on the antisaccade task result from differences in trial-to-trial fluctuations of attention (Meier et al., 2018; Moffitt, 2013; Unsworth & Robison, 2020). Note, the *consistency* account reflects trial-to-trial variability in lapses of attention that could influence goal activation and/or goal maintenance processes. Specifically, it is possible that high and low WMC individuals perform fairly equivalently on most trials, but that low WMC individuals

Figure 2
Possible Patterns of Results



Note. (a) Possible differences between high and low working memory capacity (WMC) individuals in terms of overall goal activation strength (arbitrary units). (b) Possible differences between high and low WMC individuals in terms of how quickly the goal can be activated. (c) Possible differences between high and low WMC individuals in terms of goal maintenance abilities.

experience more lapses of attention (task-unrelated thoughts such as mind-wandering and external distraction) than high WMC individuals in which on a subset of trials the intensity of attention is lower for low WMC individuals. This could result in periodic failures of goal management and potentially poor goal selection, weakened goal activation, or inabilities in goal maintenance. That is, most of the time low WMC individuals can perform just as well as high WMC individuals, but they experience more lapses of attention than high WMC individuals resulting in a larger subset of trials with poor performance. Lapses of attention could also result in temporarily forgetting of stimulus–response associations as well as general slow downs which could result in poorer task performance. This account predicts that high WMC individuals should be more accurate than low WMC individuals, and this relation should be partially accounted for by markers of fluctuations in attention such as self-reports of mind-wandering and/or fluctuations in reaction times. As noted above, Meier et al. (2018; see also Moffitt, 2013) found some evidence for this hypothesis, but suggested that differences in consistency did not fully explain the relation between WMC and antisaccade.

Note that the current hypotheses represent fairly straightforward and simplified accounts of the different possibilities. That is, are differences due to differences in goal activation strength or due to differences in the ability to maintain/sustain the goal during the duration of a trial? Of course, it is also possible that the different accounts are not fully independent. That is, if the goal is not sufficiently activated, it may be more difficult to maintain over time. This would suggest a pattern of results in which low WMC individuals have overall lower accuracy than high WMC individuals, and demonstrate a drop in accuracy at long delays (a combination of Figures 2a and 2b). Additionally, if the task goal is activated only slightly higher than competing goals for low WMC individuals, these low WMC individuals might experience more mind-wandering as potent internal goals (personal concerns) are more likely to break into the focus of attention for these individuals compared with high WMC individuals. Thus, this would suggest an association between the *goal activation* (and potentially *goal maintenance*) and *consistency* accounts. In other words, the different accounts might share variance in accounting for the relation between WMC and antisaccade performance, but they might also account for unique variance.

In addition to goal management processes that are thought to occur during the preparatory delay interval, we also examined potential WMC differences in what occurs during stimulus onset. As noted above, prior research has suggested that WMC differences on the antisaccade task might also be due to differences in various speed factors such as speed of moving the focus of attention and programming a voluntary saccade in the correct direction (e.g., Heitz & Engle, 2007; Unsworth et al., 2004) or speed of conflict resolution processes (Kane & Engle, 2003; Moffitt, 2013). This suggests that part of the reason for WMC differences in the antisaccade are due to differences in how quickly participants can move their attention to the correct location (or resolve conflict) in order to identify the correct target in time.

To examine these issues, we conducted eight individual differences experiments in which participants ($N = 2,003$) performed various versions of the antisaccade task (see Figure 1) along with multiple measures of WMC. Our broad goals were to manipulate aspects of the antisaccade task (delay interval, delay expectancy,

location expectancy, target duration) in order to pinpoint the mechanism(s) responsible for the relation between WMC and antisaccade performance. In each experiment there is sufficient power (power .80, alpha set at .05 two-tailed) to find a correlation of $r = .25$ with N 's > 120 . Furthermore, most experiments have enough power (power .95, alpha set at .05 two-tailed) to detect correlations of $r = .30$ with $N > 134$. In terms of interactions, the experiments are sufficiently powered (.80) to detect medium effects ($\eta_p^2 = .06$), but are underpowered to detect smaller effects ($\eta_p^2 = .01$). Overall, the current experiments extend prior research by more fully examining potential reasons for the relation between WMC and antisaccade performance.

Experiment 1

In our first experiment we examined the relation between WMC and antisaccade by having participants perform a fairly standard version of the antisaccade task along with three complex span measures of WMC. To examine the issues discussed above we specifically examined WMC differences as a function of delay.

Method

Participants

A total of 181 participants were recruited from the subject-pool at the University of Georgia. Data was collected over two full academic semesters. Two participants did not complete the antisaccade task leaving a final sample of 179 participants with full data. Participants were between the ages of 18 and 35 and received course credit for their participation. Each participant was tested individually. None of the participants participated in any of the other experiments. The data is from Unsworth and Spillers (2010).

Materials and Procedure

After signing informed consent, all participants completed Operation span task, Symmetry span task, Reading span task, and the antisaccade task. The four tasks were completed in two 2-hr sessions, during which participants completed other cognitive ability tasks including episodic memory tasks, additional attention control tasks (Stroop, flankers, psychomotor vigilance), and fluid intelligence tasks as part of a larger project which is reported in Unsworth and Spillers (2010).

Tasks

Working Memory Capacity (WMC) Tasks.

Operation Span (Ospan). Participants solved a series of math operations while trying to remember a set of unrelated letters (F, H, J, K, L, N, P, Q, R, S, T, Y). Participants were required to solve a math operation and after solving the operation they were presented with a letter for 1 s. Immediately after the letter was presented the next operation was presented. Three trials of each list-length (3–7) were presented, with the order of list-length varying randomly. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters (see Unsworth et al., 2005 and Redick et al., 2012 for more details). Participants received three sets (of list-length 2) of practice. For all of the span measures, items were scored if the item was correct and in

the correct position. The score was the total number of correct items in the correct position.

Symmetry Span (Symspan). In this task participants were required to recall sequences of red squares within a matrix while performing a symmetry-judgment task. In the symmetry-judgment task participants were shown an 8×8 matrix with some squares filled in black. Participants decided whether the design was symmetrical about its vertical axis. The pattern was symmetrical half of the time. Immediately after determining whether the pattern was symmetrical, participants were presented with a 4×4 matrix with one of the cells filled in red for 650 ms. At recall, participants recalled the sequence of red-square locations in the preceding displays, in the order they appeared by clicking on the cells of an empty matrix. There were three trials of each list-length with list-length ranging from 2–5. The same scoring procedure as Ospan was used (see Unsworth et al., 2009 and Redick et al., 2012 for more task details).

Reading Span (Rspan). Participants were required to read sentences while trying to remember the same set of unrelated letters as Ospan. For this task, participants read a sentence and determined whether the sentence made sense or not (e.g., “The prosecutor’s dish was lost because it was not based on fact?”). Half of the sentences made sense while the other half did not. Nonsense sentences were made by simply changing one word (e.g., “dish” from “case”) from an otherwise normal sentence. Participants were required to read the sentence and to indicate whether it made sense or not. After participants gave their response they were presented with a letter for 1 s. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters. There were three trials of each list-length with list-length ranging from 3–7. The same scoring procedure as Ospan was used (see Unsworth et al., 2009 and Redick et al., 2012 for more task details).

WMC Composite. As the three complex span tasks showed acceptable internal consistency (α ’s ranging from .76-.80) and were correlated with one another, we created a z-score composite for WMC by first z-scoring each WMC measure and then averaging the resulting z-scores. This score is used in all subsequent analyses involving WMC. We decided on a z-score composite to be consistent with Meier et al. (2018) who also used a z-score composite. Overall similar results are found when using a factor composite.

Antisaccade Task. In this task (Kane et al., 2001; see Figure 1) participants were instructed to stare at a fixation point which was onscreen for a variable amount of time (200 ms, 600 ms, 1,000 ms, 1,400 ms, or 1,800 ms). A flashing white “=” was then flashed 12.7 cm either to the left or right of fixation for 100 ms. The target stimulus (a B, P, or R) then appeared onscreen for 100 ms, followed by masking stimuli (an H for 50 ms followed by an 8, which remained onscreen until a response was given). The participants’ task was to identify the target letter by pressing a key for B, P, or R (the keys 4, 5, 6 on the number pad) as quickly and accurately as possible. In the prosaccade condition the flashing cue (=) and the target appeared in the same location. In the antisaccade condition the target appeared in the opposite location as the flashing cue. Participants received, in order, 10 practice trials to learn the response mapping, 15 practice trials of the prosaccade condition, and 60 trials of the antisaccade condition (12 trials per delay). The dependent variable was proportion correct on the antisaccade trials.

Results and Discussion

First, we examined accuracy as a function of delay. Consistent with prior research (Meier et al., 2018; Unsworth et al., 2011) there was an effect of delay, $F(4, 712) = 15.99$, $MSE = .020$, $p < .001$, $\eta_p^2 = .08$, suggesting that accuracy increased as delay increased. Entering WMC as a covariate in an ANCOVA demonstrated a main effect of WMC, $F(1, 177) = 15.76$, $MSE = .089$, $p < .001$, $\eta_p^2 = .12$, suggesting a positive correlation ($r = .29$) between WMC ($M = .01$, $SD = .78$; $\alpha = .74$) and antisaccade accuracy ($M = .52$, $SD = .14$; split-half reliability = .70).² There was also a significant WMC \times Delay interaction, $F(4, 708) = 2.99$, $MSE = .020$, $p = .018$, $\eta_p^2 = .017$.³ As shown in Figure 3, high WMC individuals had higher accuracy than low WMC individuals pretty much across all delays and WMC differences did not seem to be localized to any specific delay. Note, in order to illustrate the effects of interest with WMC, we present quartile splits. For all analyses, WMC was treated as a continuous variable, rather than as arbitrary discrete groups. Thus, although there was a significant interaction, this seemed to be driven by a larger difference at the 1,000 ms delay which does not correspond to any of the possibilities suggested previously and does not replicate Meier et al. (2018).

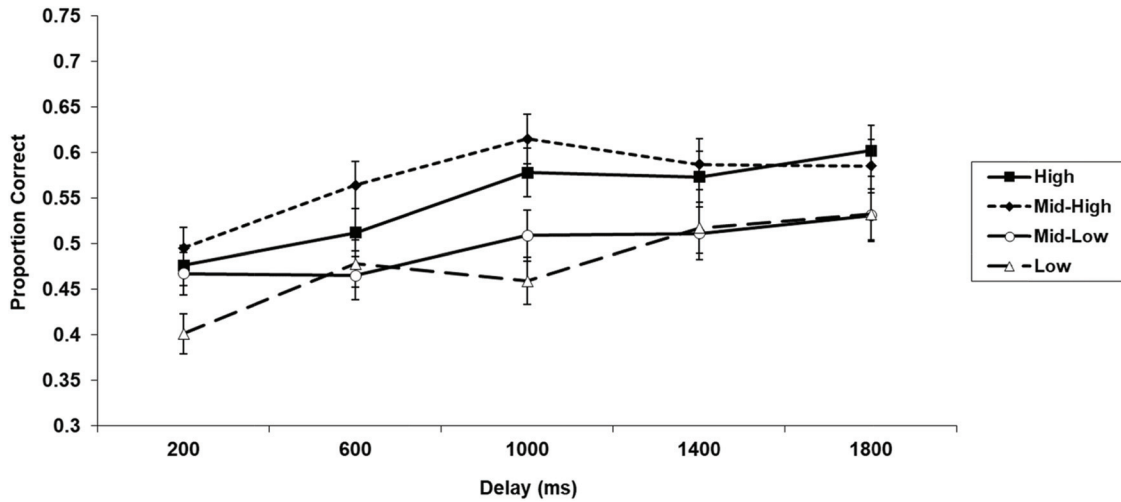
These results suggest that WMC was related to performance on the antisaccade, and that accuracy increased across the delay, suggesting participants were using that time to activate and maintain the task goal in working memory to prepare for the upcoming trial. However, despite a significant interaction between delay and WMC, the pattern of results did not match any of the possibilities suggested previously (see Figure 2) and did not replicate prior research (Meier et al., 2018). As such, these results do not provide evidence for WMC differences in goal management processes occurring during preparatory delay.

Experiment 2

In Experiment 2 we further examined potential relations between WMC and antisaccade as a function of the preparatory delay interval. Specifically, in Experiment 1 the delay interval ranged from 200 ms–1,800 ms similar to prior research. However, it is possible that the reason we did not find evidence consistent with any of the possibilities is because we did not provide a wide enough range of delay intervals. That is, perhaps 1,800 ms was not enough time for low WMC individuals to fully activate the task goal and prepare. Thus, in Experiment 2 we manipulated the delay interval from 50 ms–6,400 ms to better assess differences. Specifically, 50 ms is likely not enough time to activate the task goal and prepare for the upcoming trial. Thus, WMC differences should be reduced here. However, as the delay interval increases up to 6,400 ms there should be plenty of time to activate the task goal and prepare. If WMC differences are due to *goal activation* we should find little to no differences at 50 ms, but larger differences as the delay increases. If WMC differences are due to *speed of activation* we should find little to no differences at 50 ms, but differences should

² Scatter plots for correlations between WMC and antisaccade performance for each experiment can be found in the online supplemental materials.

³ We reanalyzed the data using linear mixed models and found nearly identical results in each experiment.

Figure 3*Antisaccade Accuracy as a Function of Delay and Working Memory Capacity (WMC) in Experiment 1*

Note. Error bars reflect one standard error of the mean.

arise for intermediate delays as high WMC individuals activate the task goal quicker than low WMC individuals. However, with even longer delays, low WMC individuals should be able to activate the task goal resulting in reduced WMC differences. If WMC differences are due to *goal maintenance* abilities, we should see reduced relations at the short delays but increased WMC differences at the longest delays as low WMC individuals are unable to maintain/sustain the goal over the long interval. Thus, we should be able to more fully capture the time course of goal management processes and better examine the possibilities depicted in Figure 2.

Method

Participants

A total of 136 participants were recruited from the subject-pool at the University of Oregon. Data was collected over one full academic quarter. Six participants did not have complete antisaccade or WMC data leaving a final sample of 130 participants with full data. Participants were between the ages of 18 and 35 and received course credit for their participation. Each participant was tested individually. None of the participants participated in any of the other experiments.

Materials and Procedure

After signing informed consent, all participants completed Ospan task, Symspan task, Rspan task, and the antisaccade task. The four tasks were completed in a 2-hr session, during which participants completed other cognitive ability tasks that were not part of the current investigation.

Tasks

WMC Tasks. Same as Experiment 1.

Antisaccade Task. Same as Experiment 1 except that the delay intervals were 50 ms, 200 ms, 400 ms, 800 ms, 1,600 ms, 3,200 ms, or 6,400 ms. There were 12 trials for each delay interval.

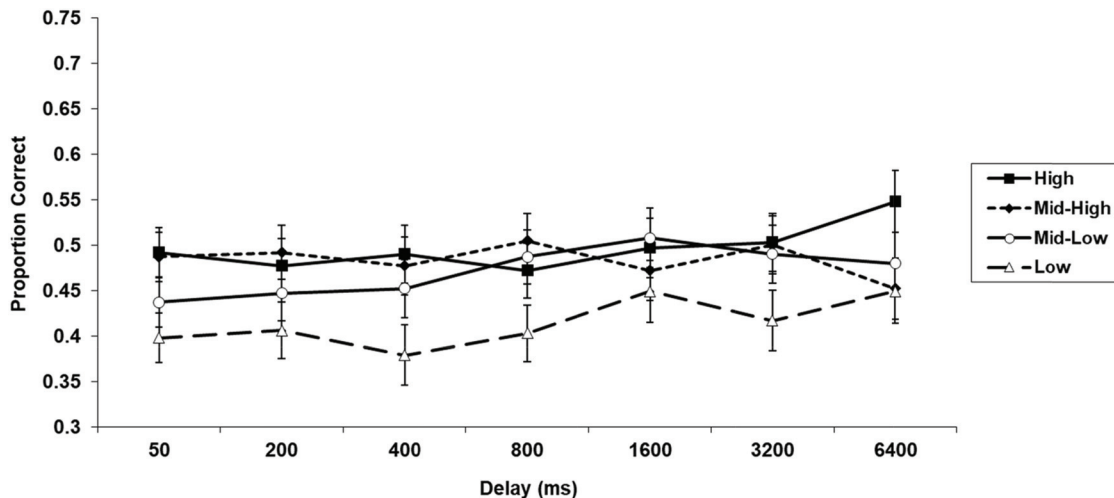
Results and Discussion

Examining accuracy as a function of delay suggested that, unlike Experiment 1, there was not an effect of delay, $F(6, 774) = 1.26$, $MSE = .020$, $p = .274$, $\eta_p^2 = .01$. Entering WMC as a covariate in an ANCOVA demonstrated a main effect of WMC, $F(1, 128) = 9.64$, $MSE = .10$, $p = .002$, $\eta_p^2 = .07$, suggesting a positive correlation ($r = .27$) between WMC ($M = .01$, $SD = .76$; $\alpha = .65$) and antisaccade accuracy ($M = .47$, $SD = .13$; split-half reliability = .82). The WMC \times Delay interaction was not significant, $F(6, 768) = .59$, $MSE = .020$, $p = .74$, $\eta_p^2 = .005$. As shown in Figure 4, high WMC individuals had higher accuracy than low WMC individuals pretty much across all delays and WMC differences did not seem to be localized to any specific delay.

Similar to Experiment 1 and to Moffitt (2013), but inconsistent with Meier et al. (2018), the current results suggested that WMC differences did not seem to change as a function of delay. That is, WMC was correlated with performance on the antisaccade task, but these differences were the same across all delays. Thus, these results are inconsistent with the different possibilities presented in Figure 2. A further interesting finding was that overall there was not an effect of delay on accuracy suggesting that participants may not have used the preparatory interval to adequately prepare. That is, with such a wide range of delay intervals it is possible that participants adopted more of a reactive mode of control (Braver et al., 2007) rather than proactively preparing for the upcoming trial.⁴

Collectively, the results from Experiments 1 and 2 are inconsistent with the results of Meier et al. (2018) suggesting that WMC

⁴To examine this we conducted an exploratory cluster analysis to see if there were distinct groups of participants in the data. The cluster analysis suggested the presence of two groups. The first group composed of 56 participants demonstrated a preparatory effect with an effect of delay, $F(6, 330) = 4.37$, $MSE = .024$, $p < .001$, partial $\eta^2 = .07$. The second group composed of 74 participants did not demonstrate a preparatory effect with no effect of delay, $F(6, 438) = .86$, $MSE = .018$, $p = .53$, partial $\eta^2 = .01$. The first group tended to have higher WMC scores ($M = .24$, $SD = .67$) than the second group ($M = -.11$, $SD = .74$), $t(128) = 2.80$, $p = .006$.

Figure 4*Antisaccade Accuracy as a Function of Delay and Working Memory Capacity (WMC) in Experiment 2*

Note. Error bars reflect one standard error of the mean.

should interact with delay interval consistent with differences in goal activation. So, what's going on? As noted above, Meier et al. (2018) found that WMC interacted with delay in the same antisaccade task with letters as used in the current experiments. However, this effect did not replicate in another antisaccade task (arrow antisaccade) in the same dataset (Meier et al., 2018). Given that Moffitt (2013) also did not find significant interactions between WMC and delay in antisaccade, it is possible that the Meier et al. (2018) results are simply a Type I error. Additionally, because Meier et al. (2018) did not provide estimates of the proportion of variance accounted for by the model parameters, it is possible that the effect is just particularly small. To investigate this further, we reanalyzed the data from Meier et al. (2018) using the same antisaccade task. Specifically, we ran an ANCOVA on accuracy as a function of delay with WMC entered as a continuous covariate. There was a main effect of WMC, $F(1, 460) = 74.48$, $MSE = .093$, $p < .001$, $\eta_p^2 = .14$, in which high WMC individuals were more accurate overall than low WMC individuals ($r = .37$). There was also a significant WMC \times Delay interaction, $F(4, 1840) = 4.33$, $MSE = .014$, $p = .002$, $\eta_p^2 = .009$. Thus, there was a significant interaction, but the effect was very small. These reanalyses suggest that the discrepancy between the current results and those of Meier et al. (2018) might be due to the fact that the interaction between WMC and delay interval is very small and our prior experiments were simply underpowered to detect this small effect. Experiments 3a and 3b were conducted to examine this possibility.

Experiment 3a

In Experiment 3a we reanalyzed data from a large sample ($N = 418$) of participants who completed the same antisaccade task and WMC measures as Experiment 1 and Meier et al. (2018) in order to examine whether the relation between WMC and antisaccade changes as a function of delay interval.

Method

Participants

The data consists of 418 participants who completed the antisaccade task along with three complex span measures of WMC at either the University of Georgia or the University of Oregon. Participants were between the ages of 18 and 35 and received course credit for their participation. Each participant was tested individually. None of the participants participated in any of the other experiments. The data represents participants who had full antisaccade and WMC data from Brewer and Unsworth (2012), Unsworth, Brewer, and Spillers (2012), and Unsworth et al. (2014).

Materials and Procedure

After signing informed consent, all participants completed Ospan task, Symspan task, Rspan task, and the antisaccade task. The four tasks were completed in a 2-hr session, during which participants completed other cognitive ability tasks that were not part of the current investigation.

Tasks

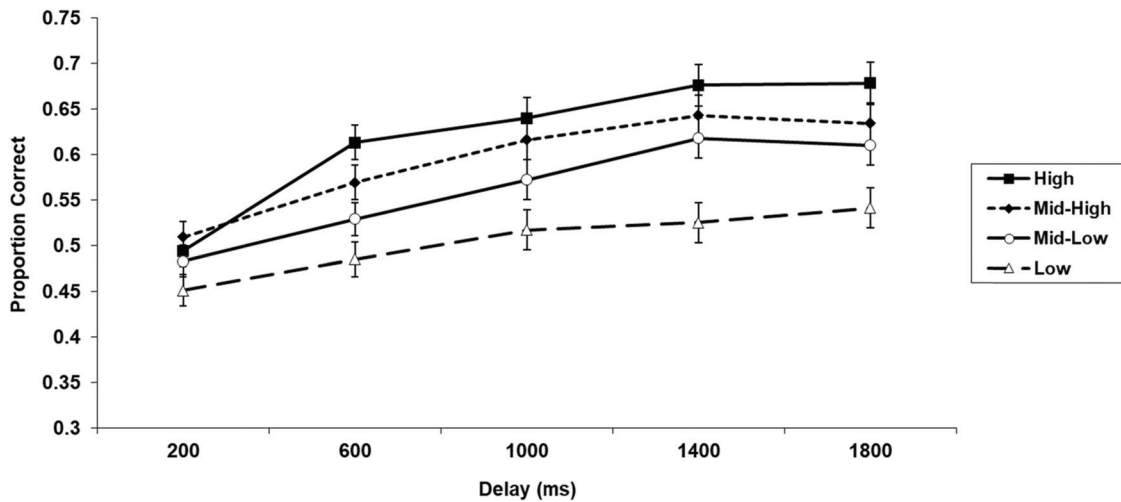
Same as Experiment 1.

Results and Discussion

Examining accuracy as a function of delay suggested that there was an effect of delay, $F(4, 1668) = 48.12$, $MSE = .027$, $p < .001$, $\eta_p^2 = .10$. Entering WMC as a covariate in an ANCOVA demonstrated a main effect of WMC, $F(1, 416) = 37.41$, $MSE = .12$, $p < .001$, $\eta_p^2 = .08$, suggesting a positive correlation ($r = .27$) between WMC ($M = .00$, $SD = .81$; $\alpha = .78$) and antisaccade accuracy ($M = .56$, $SD = .16$; split-half reliability = .80). Importantly, the WMC \times Delay interaction was significant, $F(4, 1664) = 4.45$, $MSE = .026$,

Figure 5

Antisaccade Accuracy as a Function of Delay and Working Memory Capacity (WMC) in Experiment 3a



Note. Error bars reflect one standard error of the mean.

$p = .001$, $\eta_p^2 = .011$.⁵ As shown in Figure 5, high WMC individuals had higher accuracy than low WMC individuals overall, but these effects were reduced for the shortest delay. Indeed, excluding the 200 ms delay from the analysis resulted in a nonsignificant interaction with WMC, $F(3, 1248) = .83$, $MSE = .028$, $p = .48$, $\eta_p^2 = .002$, suggesting that the interaction was driven by smaller WMC differences at the shortest delay.⁶

These results broadly replicate Meier et al. (2018) in demonstrating an interaction between WMC and preparatory delay in the antisaccade such that WMC differences were minimized at the shortest delay. However, the effect was small, suggesting that a large sample is needed to detect this effect. This suggests that other factors are likely important for the relation between WMC and performance on the antisaccade.

Experiment 3b

In Experiment 3b we sought to replicate the results from Experiment 3a by reanalyzing data collected in our laboratory. A large sample of participants completed the antisaccade task along with the three complex span tasks. Additionally, we examined whether variation in *consistency* of attention is important for the relation between WMC and antisaccade. That is, low WMC individuals may experience more lapses of attention due to task-unrelated thoughts (TUTs), resulting in worse performance on a subset of trials than high WMC individuals. To examine this, participants were periodically presented with thought probes asking about their current attentional state during the antisaccade.

Method

Participants

The data consists of 489 participants who completed the antisaccade task along with three complex span measures of WMC at the University of Oregon. Participants were between the ages of 18 and 35 and received course credit for their participation. Each

participant was tested individually. None of the participants participated in any of the other experiments. The data represents participants who had full antisaccade and WMC data from Unsworth and McMillan (2014) and Unsworth and McMillan (2017).

Materials and Procedure

After signing informed consent, all participants completed Ospan task, Symspan task, Rspan task, and the antisaccade task. The four tasks were completed in a 2-hr session, during which participants completed other cognitive ability tasks that were not part of the current investigation

Tasks

WMC Tasks. Same as Experiment 1.

Antisaccade Task. Same as Experiment 1 except that there were 50 total antisaccade trials. Thought probes were randomly presented eight times during the antisaccade task.

Thought Probes. During the antisaccade tasks, participants were periodically presented with thought probes asking them to classify their immediately preceding thoughts. The thought probes asked participants to press one of five keys to indicate what they were thinking just prior to the appearance of the probe. Specifically, participants saw

Please characterize your current conscious experience

1. I am totally focused on the current task

⁵ Using Greenhouse-Geisser corrections for potential violations of sphericity did not change the significance levels of any of the reported results.

⁶ At the request of a reviewer we post-hoc tested for differences in the correlations between the 200 ms and 600 ms delays with WMC in each experiment where a significant interaction was found. The difference was significant in Experiments 3a ($p = .003$), 3b ($p = .042$), and 7 ($p = .027$), but not 4 ($p = .063$). We also examined differences in the correlations between the shortest and longest delays and found significant differences in each experiment where the overall interaction was found. Specifically, Experiments 3a ($p = .004$), 3b ($p = .011$), 4 ($p = .045$), and 7 ($p = .001$).

2. I am thinking about my performance on the task or how long it is taking
3. I am distracted by sights/sounds or by physical sensations (hungry/thirsty)
4. I am zoning out/my mind is wandering
5. Other

These thought probes were based on those used by Stawarczyk et al. (2011) and Unsworth and McMillan (2014). During the instructions participants were given specific instructions regarding the different categories. Responses 3–5 were classified as TUTs.

Results and Discussion

Examining accuracy as a function of delay suggested that there was an effect of delay, $F(4, 1952) = 34.27$, $MSE = .024$, $p < .001$, $\eta_p^2 = .07$. Entering WMC as a covariate in an ANCOVA demonstrated a main effect of WMC, $F(1, 487) = 36.46$, $MSE = .08$, $p < .001$, $\eta_p^2 = .07$, suggesting a positive correlation ($r = .26$) between WMC ($M = .02$, $SD = .78$; $\alpha = .72$) and antisaccade accuracy ($M = .46$, $SD = .14$; split-half reliability = .74). The WMC \times Delay interaction was significant, $F(4, 1948) = 2.44$, $MSE = .024$, $p = .045$, $\eta_p^2 = .005$, but was again a very small effect. As shown in Figure 6, high WMC individuals had higher accuracy than low WMC individuals overall, but these effects were reduced for the shortest delay. Consistent with Experiment 3a, excluding the 200 ms delay from the analysis resulted in a nonsignificant interaction with WMC, $F(3, 1461) = .23$, $MSE = .022$, $p = .88$, $\eta_p^2 = .000$, suggesting that the interaction was driven by smaller WMC differences at the shortest delay.

TUTs were related to both antisaccade accuracy ($r = -.23$, $p < .001$) and WMC ($r = -.14$, $p = .002$). On average participants had 3.27 TUTs ($SD = 3.21$). Next, we examined how WMC and TUTs would account for variation in antisaccade accuracy and whether TUTs would fully account for the relation between WMC and antisaccade. Therefore, we ran a simultaneous regression in which WMC and TUTs predicted antisaccade accuracy. As shown in Table

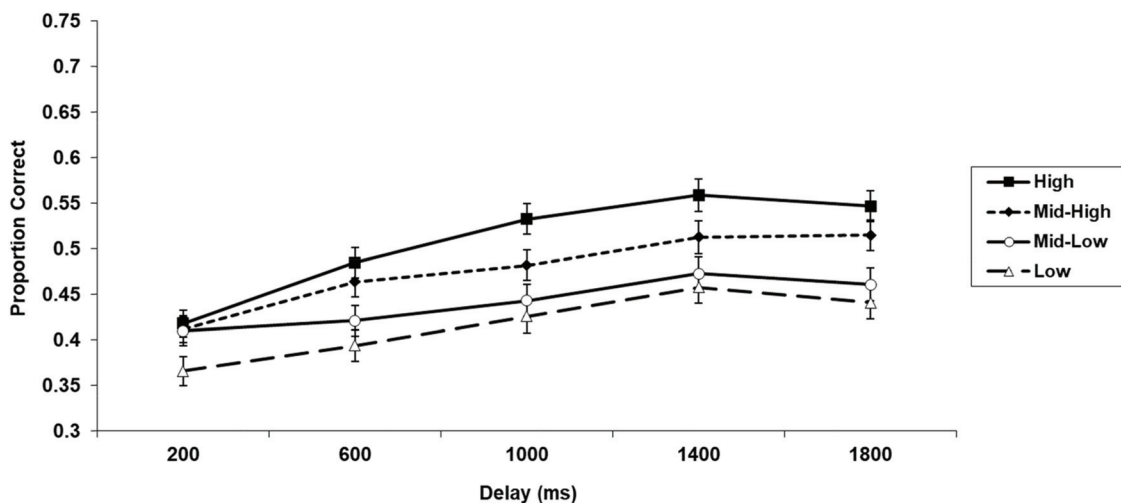
1, the measures accounted for 11% of the variance in antisaccade accuracy. Importantly, both measures accounted for unique variance in antisaccade accuracy. Thus, some of the variance between WMC and antisaccade accuracy was due to shared variance with TUTs, but WMC still accounted for unique variance in antisaccade accuracy even after taking into account TUTs.

The current results replicated both Meier et al. (2018) and Experiment 3a in demonstrating an interaction between WMC and preparatory delay in the antisaccade, such that WMC differences were minimized at the shortest delay. However, as with Meier et al. (2018) and Experiment 3a, this effect was very small. Furthermore, although WMC differences in TUTs accounted for some of the relation between WMC and antisaccade, WMC still accounted for unique variance in antisaccade once TUTs were taken into account. These results suggest that variation in goal activation, lapses of attention/consistency, and additional factors jointly account for the relation between WMC and antisaccade performance.

Experiment 4

The prior experiments suggest some of the relation between WMC and antisaccade is due to variation in *goal activation* and *consistency*. However, there was little evidence for variation in *speed of activation* or *goal maintenance*. The purpose of Experiment 4 was to replicate and extend the prior experiments by further teasing apart the different possibilities. In this experiment participants again performed the three complex span measures of WMC along with two versions of the antisaccade task. Specifically, participants performed the standard antisaccade task with variable preparatory delays along with a version of the antisaccade task in which the delay was always fixed at 1,800 ms. A key aspect of many attention tasks is the uncertainty of when the stimulus will occur (Jennings & van der Molen, 2005; Woodrow, 1914). With a variable delay interval the demands on preparatory attention are high because participants must activate and maintain

Figure 6
Antisaccade Accuracy as a Function of Delay and Working Memory Capacity (WMC) in Experiment 4



Note. Error bars reflect one standard error of the mean.

Table 1
Simultaneous Regression Predicting Antisaccade Accuracy in Experiment 3b

Variable	B	<i>t</i>	<i>sr</i> ²	<i>R</i> ²	<i>F</i>
WMC	.24	5.51**	.056		
TUTs	-.20	-4.51**	.037	.11	29.32**

** $p < .01$.

the task goal at a high level in order to rapidly shift attention to the correct location to identify the target. A fixed temporal structure in which the stimulus always occurs at the same time, however, requires less focused attention and typically results in better overall performance (particularly on sustained attention tasks; Langner & Eickhoff, 2013; Shaw et al., 2012; Unsworth & Robison, 2020; Unsworth et al., 2018). Rather than needing to maintain preparatory attention throughout the entire delay interval, participants can ramp up attention in line with the occurrence of the stimulus. Thus, the antisaccade task with a fixed delay should be less attention demanding, resulting in reduced WMC differences compared with the more standard antisaccade task. However, if WMC differences are due to high WMC individuals' ability to maintain the task goal over the entire long interval compared with low WMC individuals, then when the delay is fixed at 1,800 ms WMC differences should be larger as low WMC individuals cannot maintain the task goal over the delay. Thus, the *goal maintenance* account makes different predictions depending on whether the task goal needs to be maintained throughout the entire delay or whether it can be activated just prior to stimulus onset. If it can be activated just prior to stimulus onset, demands on goal maintenance should be reduced resulting in reduction in WMC differences (see also Unsworth & Robison, 2020). If the task goal needs to be maintained during the entire delay, then demands on goal maintenance should be increased, resulting in an increase in WMC differences. Another possibility, however, is that WMC differences are due to differences in how quickly participants can activate the task goal. If this is the case, then we should see a reduced WMC differences as all participants should now have adequate time to activate the task goal. Finally, if differences are due to variation in goal activation strength, then regardless of the particular delay we should still see WMC differences (and of a similar magnitude as those found in the varied delay condition) if low WMC individuals cannot activate the task goal to the same level as high WMC individuals. Similar to Experiment 3b, thought probes were embedded in each antisaccade task to examine whether variation in lapses of attention accounted for the relation between WMC and antisaccade. Thus, Experiment 4 provides a means of not only replicating the basic findings from the prior experiments, but also adjudicating between the various possible reasons for the relation with WMC.

Method

Participants

A total of 157 participants were recruited from the subject-pool at the University of Oregon. Data was collected over one full academic quarter. Seven participants did not have complete antisaccade data for both antisaccade tasks leaving a final sample of 150 participants with full data. Participants were between the ages of

18 and 35 and received course credit for their participation. Each participant was tested individually. None of the participants participated in any of the other experiments.

Materials and Procedure

After signing informed consent, all participants completed Ospan task, Symspan task, Rspan task, the standard antisaccade task, and the fixed at 1,800 ms antisaccade task. Order of the two antisaccade tasks was counterbalanced across participants. The five tasks were completed in a 2-hr session, during which participants completed other cognitive ability tasks that were not part of the current investigation.

Tasks

Ospan. Participants completed a shortened version of the task from Experiment 1 in which there were two trials per set size for a total score of 50.

Symspan. Participants completed a shortened version of the task from Experiment 1 in which there were two trials per set size for a total score of 28.

Rspan. Participants completed a shortened version of the task from Experiment 1 in which there were two trials per set size for a total score of 50.

WMC Composite. Same as Experiment 1.

Antisaccade Task. The standard antisaccade task was the same as Experiment 3b. The fixed at 1,800 ms antisaccade task was identical to the standard antisaccade differing only in that the delay was always 1,800 ms.

Thought Probes. Same as Experiment 3b except that there were 11 total probes.

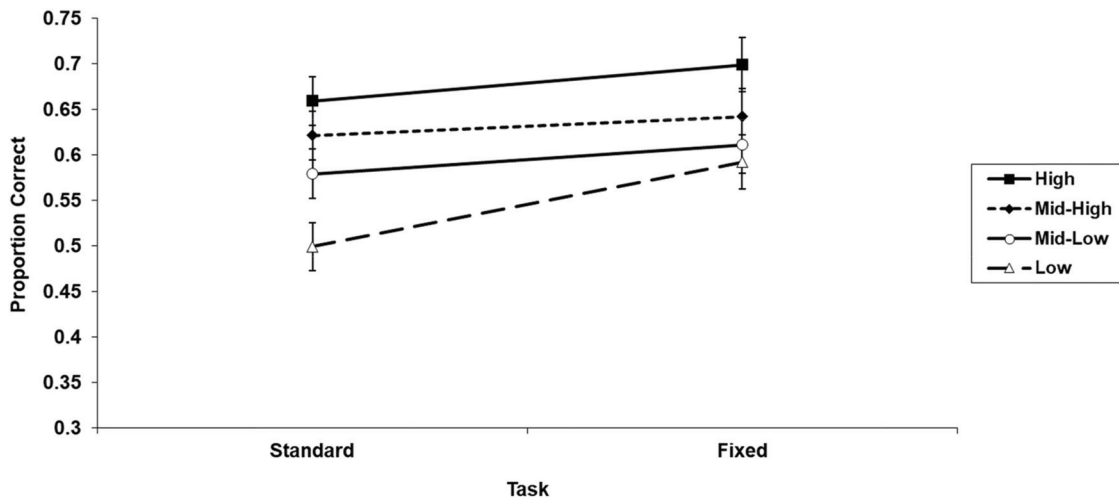
Results and Discussion

Examining accuracy as a function of task suggested that there was an effect of task, $F(1, 149) = 16.58$, $MSE = .010$, $p < .001$, $\eta_p^2 = .10$, in which accuracy was higher in the fixed at 1,800 ms task ($M = .64$, $SD = .19$; split-half reliability = .86) than in the standard task ($M = .59$, $SD = .17$; split-half reliability = .82). Entering WMC as a covariate in an ANCOVA demonstrated a main effect of WMC, $F(1, 148) = 20.19$, $MSE = .05$, $p < .001$, $\eta_p^2 = .12$, suggesting a positive correlation ($r = .35$) between WMC ($M = .00$, $SD = .81$; $\alpha = .75$) and antisaccade. The WMC \times Task interaction was not significant, $F(1, 148) = 2.03$, $MSE = .010$, $p = .16$, $\eta_p^2 = .01$, suggesting similar relations in the fixed delay antisaccade. As shown in Figure 7, WMC differences were generally similar in the two tasks.

Examining the thought probe responses in each task suggested that there were similar rates of TUTs in each task, $F(1, 149) = .001$, $MSE = 2.44$, $p = .97$, $\eta_p^2 = .000$. Entering WMC as a covariate in an ANCOVA suggested a main effect of WMC, $F(1, 148) = 3.92$,

Figure 7

Antisaccade Accuracy as a Function of Task and Working Memory Capacity (WMC) in Experiment 4



Note. Error bars reflect one standard error of the mean.

$MSE = 18.89$, $p = .05$, $\eta_p^2 = .026$, in which high WMC individuals reported fewer TUTs than low WMC individuals ($r = -.16$). The $WMC \times Task$ interaction was not significant, $F(1, 148) = .13$, $MSE = 2.454$, $p = .72$, $\eta_p^2 = .001$, suggesting similar relations between WMC and TUTs across the two antisaccade tasks.

We also examined accuracy as a function of delay in the standard antisaccade task to see if we could replicate the prior experiments. There was an effect of delay, $F(4, 596) = 18.60$, $MSE = .023$, $p < .001$, $\eta_p^2 = .11$. The $WMC \times Delay$ interaction was also significant, $F(4, 592) = 2.95$, $MSE = .021$, $p = .020$, $\eta_p^2 = .020$, consistent with some of the prior experiments.

Given that WMC was related to antisaccade performance and TUTs, and because these relations did not change as a function of task, we combined the data (accuracy and TUTs) across the two tasks and examined the overall relations. As seen above, WMC was related to antisaccade ($r = .35$, $p < .001$). TUTs were related to both antisaccade ($r = -.36$, $p < .001$) and WMC ($r = -.16$, $p = .05$). Similar to Experiment 3b we ran a simultaneous regression in which WMC and TUTs predicted antisaccade accuracy. As shown in Table 2, the measures accounted for 21% of the variance in antisaccade accuracy. Similar to Experiment 3b, both measures accounted for unique variance in antisaccade accuracy, suggesting that WMC still accounted for unique variance in antisaccade accuracy even after taking into account TUTs.

The current results suggest that fixing the delay interval in the antisaccade to 1,800 ms resulted in higher accuracy than when the delay interval was varied, but this did not interact with WMC. A *goal maintenance* account would predict that WMC differences

should be either smaller or larger with a fixed long delay. A *speed of activation* account would predict that WMC differences should be smaller with a fixed long delay as low WMC individuals would have ample time to activate the task goal to the same level as the high WMC individuals. Although WMC differences were numerically smaller in the fixed antisaccade task, the interaction with WMC was not significant. Thus, these results are most in line with a *goal activation* account which suggests that low WMC individuals do not activate the task goal to the same level as high WMC individuals regardless of the particular delay interval. Similarly, TUTs were related to WMC, suggesting that differences in lapses of attention (*consistency*) were partially responsible for the relation.

Experiment 5

In Experiment 4 we found that reducing temporal uncertainty of when the target would appear resulted in higher accuracy, but this did not interact with WMC. Within the antisaccade people need to not only maintain a high level of preparatory attention because they do not know when the target will occur, but they also do not know where it will occur. Thus, both temporal expectancy and location expectancy are placing demands on preparatory attention. In Experiment 5 we examined whether increasing location expectancy would increase accuracy and reduce correlations with WMC. That is, knowing where the target is likely to appear should result in overall higher accuracy and could potentially reduce correlations with WMC as demands on preparatory attention are reduced.

Table 2

Simultaneous Regression Predicting Antisaccade Accuracy in Experiment 4

Variable	B	<i>t</i>	<i>sr</i> ²	<i>R</i> ²	<i>F</i>
WMC	.30	4.01**	.086		
TUTs	-.31	-4.15**	.092	.21	19.81**

** $p < .01$.

To examine this, participants performed both the standard antisaccade task in which the targets appeared equally on the right or left side of the screen and an antisaccade task in which 80% of targets appeared on one side of the screen (and 20% on the other side of the screen).

Method

Participants

A total of 140 participants were recruited from the subject-pool at the University of Oregon. Data was collected over one full academic quarter. Three participants did not have complete antisaccade data for both antisaccade tasks leaving a final sample of 137 participants with full data. Participants were between the ages of 18 and 35 and received course credit for their participation. Each participant was tested individually. None of the participants participated in any of the other experiments.

Materials and Procedure

After signing informed consent, all participants completed Ospan task, Symspan task, Rspan task, the standard antisaccade task, and the 8020 antisaccade task. Order of the two antisaccade tasks was counterbalanced across participants. The five tasks were completed in a two-hour session, during which participants completed other cognitive ability tasks that were not part of the current investigation.

Tasks

WMC Tasks. Same as Experiment 4.

Antisaccade Task. The standard antisaccade task was the same as Experiment 3b except that there were no thought probes. The 8020 antisaccade task was identical to the standard antisaccade differing only in that 80% of the time the target always appeared on the same side of the screen (e.g., 80% of the time on

the right). For half the participants 80% of targets appeared on the right, and for the other half 80% of targets appeared on the left.

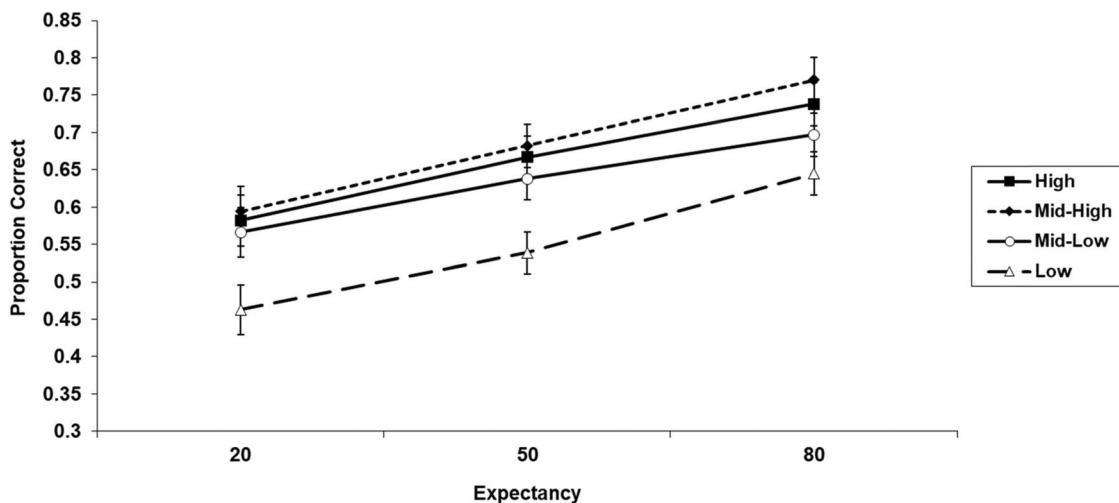
Results and Discussion

Examining accuracy as a function of location expectancy (20%, 50%, or 80%) suggested a main effect of condition, $F(2, 272) = 62.84$, $MSE = .014$, $p < .001$, $\eta_p^2 = .32$, in which accuracy increased as location expectancy increased (20% $M = .55$, $SD = .20$, split-half reliability = .49; 50% $M = .63$, $SD = .17$, split-half reliability = .82; 80% $M = .71$, $SD = .18$, split-half reliability = .81). Entering WMC as a covariate in an ANCOVA demonstrated a main effect of WMC, $F(1, 135) = 16.06$, $MSE = .07$, $p < .001$, $\eta_p^2 = .11$, suggesting a positive correlation ($r = .33$) between WMC ($M = .00$, $SD = .80$; $\alpha = .72$) and antisaccade. The $WMC \times Task$ interaction was not significant, $F(2, 270) = .98$, $MSE = .014$, $p = .38$, $\eta_p^2 = .007$, suggesting similar relations in the 20% ($r = .29$), 50% ($r = .32$), and 80% ($r = .22$) conditions. As shown in Figure 8, WMC differences were largely the same across the different location expectancy conditions.

We also examined accuracy as a function of delay in the standard antisaccade task. There was an effect of delay, $F(4, 544) = 11.79$, $MSE = .024$, $p < .001$, $\eta_p^2 = .08$. The $WMC \times Delay$ interaction was not significant, $F(4, 540) = 1.14$, $MSE = .024$, $p = .23$, $\eta_p^2 = .010$. Although, this could be due to a lack of power as several of the prior experiments suggested that a large sample size is needed to detect this effect.

The current results suggest that manipulating location expectancy so that targets appeared frequently in the same location resulted in higher accuracy than when location expectancy was more uncertain, but this did not interact with WMC. Similar to Experiment 4, it was thought that reducing expectancy (here location expectancy) would lower demands on preparatory attention, resulting in weaker relations with WMC. This was not the case. WMC relations were similar in all three location expectancy conditions. Thus, all participants benefited similarly from knowing where targets were likely to occur.

Figure 8
Antisaccade Accuracy as a Function of Location Expectancy and Working Memory Capacity (WMC) in Experiment 5



Note. Error bars reflect one standard error of the mean.

Experiment 6

In the prior experiments we were primarily concerned with examining processes occurring during the preparatory interval to examine the influence of goal management processes and overall preparatory attention on the relation between WMC and antisaccade performance. In Experiment 6, rather than examining preparatory factors, we focus on factors that occur when the target is presented. Specifically, it has been suggested that part of the relation between WMC and performance on the antisaccade could be due to speed differences that occur when the target stimulus appears. For example, Unsworth et al. (2004) suggested that high and low WMC individuals likely differ in how quickly they can move the focus of attention to the correct location. Additionally, it is possible high and low WMC individuals differ in conflict resolution processes, such that low WMC individuals are slower to resolve conflict than high WMC individuals, resulting in poorer task performance (Engle & Kane, 2004; Kane & Engle, 2003). For example, Heitz and Engle (2007) suggested that low WMC individuals might be slower to refocus attention to the target location after being captured by the cue than high WMC individuals (see also Fukuda & Vogel, 2011; Unsworth et al., 2014). Because the target is only presented for 100 ms before being masked in the current task, this would result in low WMC individuals demonstrating lower accuracy than high WMC individuals. Heitz and Engle (2007) suggested that a time-course analysis could be useful in examining these issues. Therefore, in Experiment 6 we had participants perform a variant of the antisaccade task in which we manipulated the stimulus onset asynchrony (SOA) between the cue and the mask (i.e., target duration) from 50 ms up to 2,000 ms. It was expected that accuracy should increase as SOA increases leading to asymptotic levels of accuracy. Importantly, low WMC individuals should reach the same level of asymptotic accuracy as high WMC individuals, but should reach asymptote at slower rate than high WMC individuals. That is, the 2,000 ms SOA should allow for plenty of time to resolve the conflict between the cue and the target location or correct any saccade errors and redirect attention to the correct location resulting in high accuracy for all participants. Thus, by manipulating SOA, we should be able to pinpoint time differences in speed (speed of moving focus, speed of conflict resolution) between high and low WMC individuals.

Method

Participants

A total of 142 participants were recruited from the subject-pool at the University of Oregon. Data was collected over one full academic quarter. Participants were between the ages of 18 and 35 and received course credit for their participation. Each participant was tested individually. None of the participants participated in any of the other experiments.

Materials and Procedure

After signing informed consent, all participants completed Ospan task, Symspan task, Rspan task, and the antisaccade task. The four tasks were completed in a 2-hr session, during which participants completed other cognitive ability tasks that were not part of the current investigation.

Tasks

WMC Tasks. Same as Experiment 1.

Antisaccade Task. The antisaccade task was the same as Experiment 1 except that SOA between the cue and the first mask varied across trials. That is, rather than the target appearing for 100 ms as in the prior experiments, the target now appeared for a variable amount of time across trials. The SOAs were 50 ms, 100 ms, 200 ms, 400 ms, 800 ms, 1,200 ms, 1,600 ms, and 2000 ms. There were 96 total trials with 12 trials per SOA.

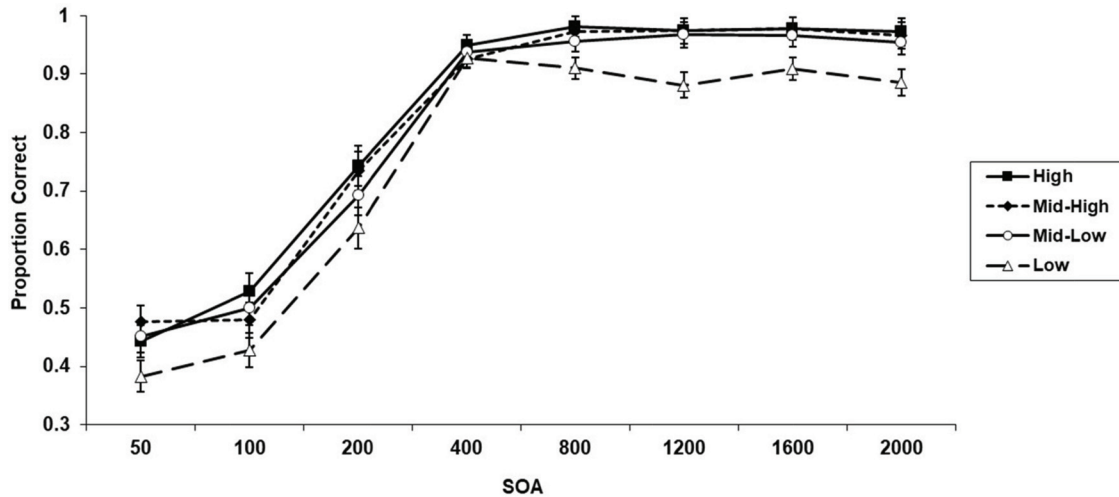
Results and Discussion

Examining accuracy as a function of SOA suggested a main effect of SOA, $F(7, 987) = 477.57$, $MSE = .015$, $p < .001$, $\eta_p^2 = .77$, in which accuracy increased as SOA increased. Entering WMC as a covariate in an ANCOVA demonstrated a main effect of WMC, $F(1, 140) = 15.40$, $MSE = .06$, $p < .001$, $\eta_p^2 = .10$, suggesting a positive correlation ($r = .32$) between WMC ($M = .02$, $SD = .79$; $\alpha = .71$) and antisaccade accuracy ($M = .79$, $SD = .09$; split-half reliability = .78). The WMC \times Task interaction was not significant, $F(7, 980) = .74$, $MSE = .015$, $p = .64$, $\eta_p^2 = .005$, suggesting similar WMC differences across SOA. Indeed, as shown in Figure 9, WMC differences occurred at basically all SOAs, even the very longest SOAs when the target remained onscreen for 2,000 ms.

These results were surprising to us, as we expected that at some point high and low WMC individuals' performance would come together and reach the same overall accuracy levels. However, as seen in Figure 9, even when the SOA was 2,000 ms, low WMC individuals still performed worse than high WMC individuals. To examine these results further, we conducted an exploratory factor analysis on accuracy across the different SOAs to see if potentially different factors are contributing to performance at the short and long SOAs. That is, perhaps some low WMC individuals are having problems at the short SOAs, whereas other low WMC individuals are having problems at the long SOAs. We submitted the eight SOAs to a principal axis factor analysis with promax rotation (oblique rotation). As a criterion for factor extraction we used eigenvalues greater than one and examined the scree plot. As shown in Table 3, the factor analysis yielded two factors (Factor 1 eigenvalue = 4.00, Factor 2 eigenvalue = 1.88) accounting for 57.78% of the variance. The first factor consisted of the longest SOAs, whereas the second factor consisted of the shortest SOAs. The two factors were correlated with each other ($r = .37$) and both were correlated with WMC (longest SOA factor $r = .26$; shortest SOA factor $r = .27$). Next, we examined how these two factors would account for both unique and shared variance in WMC. To examine this, we ran a simultaneous regression in which the longest SOA factor and the shortest SOA factor both predicted WMC. As shown in Table 4, both factors accounted for 10% of the variance in WMC. Importantly, both factors accounted for some unique variance in WMC. These results suggest that part of the relation between WMC and antisaccade is due to unique variance present in the longest SOAs, some of the relation is due to unique variance present in the shortest SOAs, and some of the relation is due to shared variance across all SOAs (likely due to variation in goal-management processes). We speculate that the unique variance in the shortest SOAs primarily reflects differences in speed (speed of moving the focus, speed in conflict resolution) such that low WMC individuals are slower than high WMC individuals

Figure 9

Antisaccade Accuracy as a Function of Stimulus Onset Asynchrony (SOA) and Working Memory Capacity (WMC) in Experiment 6



Note. Error bars reflect one standard error of the mean.

resulting in lower accuracy at particularly short SOAs. At longer SOAs, there should be plenty of time for low WMC individuals to correct any erroneous saccades and still identify the target letter. Thus, we speculate that the unique variance at the longest SOAs could reflect more specific goal neglect problems, whereby some low WMC individuals do not correct their errors even when given sufficient time. Indeed, prior research has suggested that some participants fail to correct their erroneous saccades, and it has been suggested that this occurs due to goal neglect (e.g., Bowling et al., 2012; Ethridge et al., 2009; Fischer et al., 2000; Nieuwenhuis et al., 2004). For example, Nieuwenhuis et al. (2004) manipulated SOA in a version of the antisaccade task and found that older adults did not reach the same level of asymptotic accuracy as younger adults. In a second experiment, Nieuwenhuis et al. (2004) found that schizophrenic patients also did not reach the same asymptotic levels of accuracy as control participants. Nieuwenhuis et al. (2004) suggested that both older adults and schizophrenic patients frequently failed to redirect their attention and correct their errors due to

periodic failures in goal maintenance. Consistent with prior research, the current results suggest that some low WMC individuals may not consistently correct their errors even when given ample time to do so. These periodic failures could result from deficits in goal management processes or susceptibility to lapses of attention. It is also possible that WMC differences at the longest SOAs reflect motivational issues, whereby some low WMC individuals are simply not as motivated to correct their errors. Finally, it is also possible that WMC differences at the longest SOAs reflect response mapping errors whereby low WMC individuals are less able to set-up and temporarily maintain stimulus-response mappings than high WMC individuals (e.g., Wilhelm & Oberauer, 2006; Wilhelm et al., 2013). Future research is needed to better examine these potential issues.

Experiment 7

In the prior experiments we suggested that a number of factors seemed to be responsible for the relation between WMC and

Table 3

Exploratory Factor Analysis for All Stimulus Onset Asynchronies

Measure	Factor		h^2
	1	2	
SOA50		.53	.29
SOA100		.69	.45
SOA200	.21	.46	.31
SOA400	.52		.30
SOA800	.84		.75
SOA1200	.93		.90
SOA1600	.91		.76
SOA2000	.94		.87

Note. Factor loadings less than .20 have been omitted. SOA = stimulus onset asynchrony; h^2 = communality estimate.

Table 4
Simultaneous Regression Predicting Working Memory Capacity (WMC) in Experiment 6

Variable	B	<i>t</i>	<i>sr</i> ²	<i>R</i> ²	<i>F</i>
Short SOA	.20	2.15*	.035		
Long SOA	.19	2.32*	.029	.10	7.89**

* $p < .05$. ** $p < .01$.

antisaccade performance. For example, there was some evidence that goal activation processes during the preparatory interval were important as well as variation in lapses of attention (*consistency*) as measured by TUTs. These notions are consistent with Meier et al. (2018) who similarly suggested in a structural equation model that variation in fluctuations of attention (measured by TUTs and reaction time (RT) coefficient of variation) partially accounted for the relation between WMC and antisaccade. Furthermore, in Experiment 6 we suggested that speed factors might also be important. However, we did not directly measure speed of processing/baseline differences in RT in that experiment. Examining correlations between correct reaction times on the antisaccade task and WMC in each prior experiment suggests mixed results. Specifically, only in Experiment 6 was WMC related to correct antisaccade reaction times (Experiment [E1] $r = -.03$, $p = .66$; E2 $r = .11$, $p = .22$; E3a $r = .03$, $p = .54$; E3b $r = -.03$, $p = .52$; E4 $r = -.07$, $p = .72$; E5 $r = -.10$, $p = .22$; E6 $r = -.20$, $p = .02$).⁷ Thus, it is not clear to what extent that speed partially mediates the relation between WMC and antisaccade. Therefore, in Experiment 7, we more formally test the notion that lapses of attention (*consistency*) and speed factors partially account for the relation between WMC and antisaccade by reanalyzing data from a recent large-scale investigation of individual differences in lapses of attention (Unsworth et al., 2020). In this study, participants performed a number of tasks including the same WMC and antisaccade measures used in the prior studies. Additionally, we measured lapses of attention both behaviorally and with self-reports of TUTs in multiple tasks. We also examined speed factors by examining reaction times in several measures. Thus, it should be possible to examine how various factors (lapses of attention, speed) partially or fully account for the relation between WMC and antisaccade.

Method

Participants

A total of 358 participants were recruited from the subject-pool at the University of Oregon. Each participant was tested individually in a laboratory session lasting approximately 2 hr. None of the participants participated in any of the other experiments.

Materials and Procedure

After signing informed consent, all participants completed Ospan, Symspan, Rspan, antisaccade, cued visual search, psychomotor vigilance task, Stroop, SART, choice RT, continuous tracking, and whole report visual working memory. All tasks were administered in the order listed above. Following the tasks participants completed a set of questionnaires.

Tasks

WMC Tasks. Same as Experiment 4.

Antisaccade. Same as Experiment 1.

Psychomotor Vigilance Task. The psychomotor vigilance task (PVT; Dinges & Powell, 1985) was used as the primary measure of sustained attention. Participants were presented with a row of zeros on screen. After a variable amount of time the zeros began to count up in 17-ms intervals from 0 ms (as determined by the 60 Hz monitor refresh rate). The participants' task was to press the spacebar as quickly as possible once the numbers started counting up. After pressing the space bar the response time was left on screen for 1 s to provide feedback to the participants. Interstimulus intervals were randomly distributed and ranged from 2 s to 10 s. The entire task lasted for 10 min for each individual (roughly 75 total trials). The dependent variable was the number of trials with RTs ≥ 500 ms (Dinges & Powell, 1985). Thought probes were randomly presented after 20% of trials. Additionally, in order to examine possible influences of speed of processing we rank ordered all of the RTs from fastest to slowest, and used the fastest 20% of RTs as a measure of processing speed.

Sustained Attention to Response Task. Participants completed a version of the sustained attention to response task (SART) with semantic stimuli adapted from McVay and Kane (2012a). 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 18-point font for 300 ms followed by a 900 ms mask. Most of the stimuli (nontargets) were members of one category (animals) and infrequent targets were members of a different category (foods). There were 315 experimental trials, 35 of which were targets. The dependent variables were number of omissions on go trials, number of anticipatory RTs (RTs < 100 ms), and coefficient of variation for correct go RTs > 200 ms (Cheyne et al., 2009). Thought probes followed 60% of target trials.

Choice Reaction Time. In this task, participants responded as quickly as possible to the appearance of a stimulus in one of four locations on the screen (Unsworth, Redick, et al., 2012). The stimulus consisted of a cross presented in white Courier New 32-point font centered at one of four underlined locations. After a random time interval (300 ms–550 ms in 50-ms intervals), the cross

⁷ We also examined correct reaction time as a function of delay and WMC in each relevant experiment. In each experiment (except Experiment 3a) there was a main effect of delay such that reaction times were generally longest for the shortest delays (p 's $< .001$) consistent with prior research (Unsworth et al., 2011). However, there were no interactions involving WMC in any experiment (all p 's $> .15$). Although we note that these results should be interpreted cautiously given the low numbers of correct reaction times at each delay. Prior research (Unsworth et al., 2011) that has examined correct reaction times across delays utilized many more trials (70) per delay than the current study.

appeared randomly in one of the four locations with the exception that the stimulus could not appear in the same location on consecutive trials. During the intertrial interval, the four possible stimulus locations were marked by four equally-spaced horizontal lines as place holders along the vertical center of the screen. Participants were instructed to be as fast and accurate as possible. They indicated the location of the cross by pressing one of four buttons on the keyboard (F, G, H, J), corresponding to the four possible locations. Participants completed 15 practice trials and 210 experimental trials. The main dependent variable was the number of “blocks” defined as reaction times that are twice as long each individual’s mean RT (Bills, 1931). Additionally, in order to examine possible influences of speed of processing we rank ordered all of the correct RTs from fastest to slowest, and used the fastest 20% of RTs as a measure of processing speed.

Continuous Tracking. Participants were presented with a small black circle on a gray background. The participants’ task was to track the black circle as closely as possible with the cursor of the mouse. Each trial began with a 3-s screen saying, “Please focus on the black dot.” The text then disappeared and the dot remained on-screen for 5 s. The screen then told participants, “Click the dot to begin the trial.” The black circle then began to move around the screen. The circle moved in a pseudorandom fashion within a 400×440 pixel region centered on the screen (the borders of which were invisible). The circle moved at a constant speed in vertical, horizontal, and diagonal directions. Trials lasted for 30 s, 60 s, 90 s, or 120 s. Participants first completed one 30-s trial as practice, after which they were encouraged to seek clarification from the experimenter if necessary. Participants then completed one 30 s and one 120 trial and two 60 and two 90 s trials, which occurred in a random order for each participant. The main dependent measure was the number of flat spots—periods in which tracking completely stopped for a period of at least 1.5 s. The measurement of flat spots as a stoppage of at least 1.5 s was based on prior research using tracking tasks (Peiris et al., 2006).

Whole Report Visual Working Memory. The participants’ task was to remember the colors of squares over brief delays and to report the colors of these squares on a testing screen (Adam et al., 2015; Robison & Unsworth, 2019). Each trial began with a 1-s fixation screen on which a black fixation cross appeared on a gray background, followed by a 100-ms blank screen. Then, a pattern of six colored squares appeared and remained on screen for 250 ms. The squares (60×60 pixels; 3° visual angle) appeared within a 540×402 -pixel region centered on the screen. The locations were random with the restriction that no items appeared within a 100-pixel vector distance of each other (measured from each item’s top-left starting point). Colors were randomly sampled from a set of nine discrete colors (white, black, red, blue, lime green, magenta, green, cyan, and yellow). Colors did not repeat within a trial (i.e., all six items were different colors). After a 1,000-ms blank delay screen, the color response grids appeared in the locations where the six items had appeared previously. The participants’ task was to report the color of the square in each location by clicking the appropriate color in the grid. After the participant responded to all six items, the next trial immediately started. Participants first read through a series of instruction screens followed by five practice trials. If participants were confused during the practice trials, they were encouraged to seek clarification from the experimenter. They then completed 68 experimental trials. The

main dependent variable was the number of trials where participants recalled only zero or one items correctly (Adam et al., 2015). Thought probes were randomly presented after eight trials.

Stroop. Participants were presented with a color word (red, green, or blue) presented in one of three different font colors (red, green, or blue; Stroop, 1935). The participants’ task was to indicate the font color via key press (red = 1, green = 2, blue = 3). Participants were told to press the corresponding key as quickly and accurately as possible. Participants received 15 trials of response mapping practice and six trials of practice with the real task. Participants then received 100 experimental trials. Of these trials, 67% were congruent such that the word and the font color matched (i.e., red printed in red) and the other 33% were incongruent (i.e., red printed in green). Twelve thought probes were randomly presented after incongruent trials. Additionally, in order to examine possible influences of speed of processing we rank ordered all of the correct congruent RTs from fastest to slowest, and used the fastest 20% of RTs as a measure of processing speed.

Thought Probes

During the psychomotor vigilance, whole report working memory, Stroop, and sustained attention to response tasks participants were periodically presented with thought probes asking them to classify their immediately preceding thoughts. Probes asked participants to report the current contents of their consciousness. Specifically, they saw a screen that said,

Please characterize your current conscious experience.

- 1) I am totally focused on the current task
- 2) I am thinking about my performance on the task
- 3) I am distracted by sights/sounds/physical sensations
- 4) I am daydreaming/my mind is wandering about things unrelated to the task
- 5) My mind is blank.

Responses 3–5 were taken as the measure of TUTs in each task.

Results and Discussion

First, examining accuracy as a function of delay suggested that there was an effect of delay, $F(4, 1392) = 61.51$, $MSE = .02$, $p < .001$, $\eta_p^2 = .15$. Entering WMC as a covariate in an ANCOVA demonstrated a main effect of WMC, $F(1, 346) = 19.97$, $MSE = .11$, $p < .001$, $\eta_p^2 = .06$, suggesting a positive correlation ($r = .23$) between WMC and antisaccade. The $WMC \times Delay$ interaction was significant, $F(4, 1384) = 3.36$, $MSE = .02$, $p = .010$, $\eta_p^2 = .01$, but was very small. Consistent with the prior experiments, excluding the 200-ms delay from the analysis resulted in a nonsignificant interaction with WMC, $F(3, 1038) = .54$, $MSE = .02$, $p = .65$, $\eta_p^2 = .002$, suggesting that the interaction was driven by smaller WMC differences at the shortest delay.

Confirmatory Factor Analysis and Structural Equation Model

Next, we used latent variable techniques to test our main questions of interest. Descriptive statistics and correlations for all measures for Experiment 7 are shown in the Appendix A and Appendix B. These are reproduced from Unsworth et al. (2020) with the addition of the antisaccade reaction times. In our first analysis, we specified a confirmatory factor analysis to examine relations

between latent factors for WMC, behavioral lapses, TUTs, speed, and the antisaccade manifest variable. Therefore, we specified a confirmatory factor analysis with the three WMC tasks loading onto the WMC factor, the seven behavioral indicators of lapses loading onto a lapse factor, the four TUT measures loading onto the TUT factor, and the four speed measures loading onto the Speed factor. Given that three measures come from the SART task, we allowed the residuals for those three measures to correlate. Additionally, we allowed residual variances for psychomotor vigilance lapses and psychomotor vigilance fastest 20% of RTs to correlate and residual variances for Ospan and Rspan to correlate given that they rely on the same stimulus set. Loading for the antisaccade was set equal to one. To fit the models, we used the sample correlation matrix using all available data (pairwise correlations). For all model testing (using Lisrel 8.80; similar results were found when using the lavaan package in R), we report several fit statistics. Nonsignificant chi-square tests indicate adequate model fit; with large samples like ours, however, they are nearly always significant. Comparative fit indices (CFI) and non-normed fit index (NNFI) of $\geq .90$ indicate adequate fit, whereas the root mean square error of approximation (RMSEA) and standardized root mean square residual (SRMR) values of $\leq .08$ indicate adequate fit (e.g., Schermelleh-Engel et al., 2003). The overall fit of the model was adequate, $\chi^2(138) = 452.62, p < .001$,

RMSEA = .08, 90% CI [.072, .088], NNFI = .89, CFI = .91, SRMR = .07. Factor loadings and factor correlations are shown in Table 5. As can be seen, all of the measures loaded significantly on their respective factors and all of the factors were correlated. In particular, WMC, behavioral markers of lapses, and speed all demonstrated moderate relations with antisaccade, and TUTs demonstrated a much weaker relation. These results are consistent with the prior experiments in suggesting that these factors are related to performance on the antisaccade.

Next, we utilized structural equation modeling to examine the extent to which these factors accounted for unique variance in antisaccade and whether WMC would still predict antisaccade performance after taking into account the other factors. Therefore, we specified a model in which the WMC, Lapses, TUTs, and speed factors all predicted variation in antisaccade. The exogenous factors were all allowed to correlate with one another and the same residuals as in the confirmatory factor analyses were freed. The overall fit of the model was adequate, $\chi^2(138) = 452.62, p < .001$, RMSEA = .08, 90% CI [.072, .088], NNFI = .89, CFI = .91, SRMR = .07. Overall, 24% of the variance in antisaccade was accounted for by the different predictors. Shown in Figure 10a is the resulting model. As can be seen, WMC, lapses, and speed all accounted for unique variance in antisaccade, suggesting that each was an important contributor to variation in antisaccade.

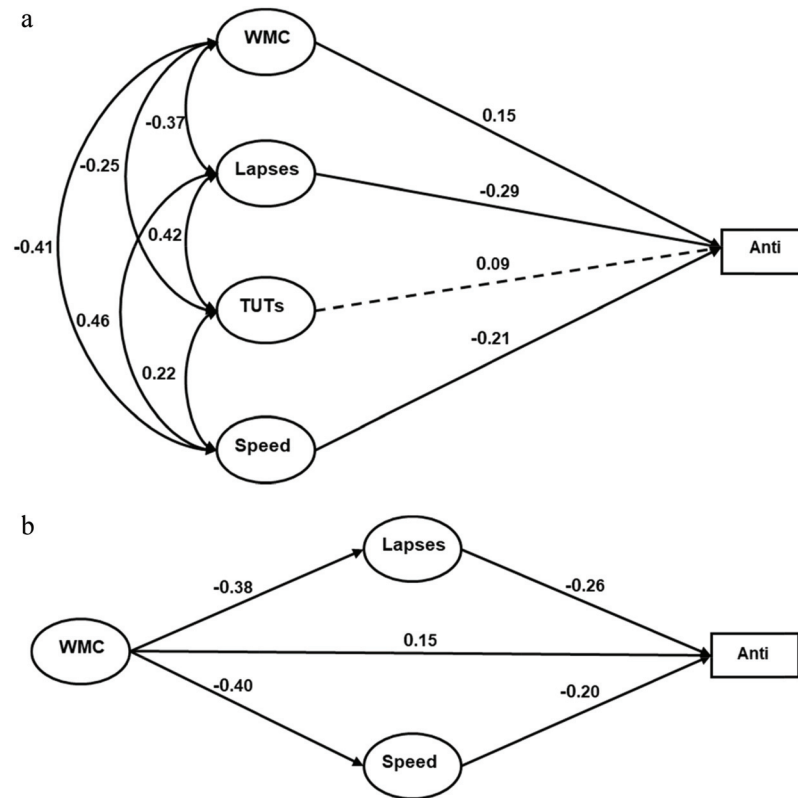
Table 5
Confirmatory Factor Analysis for WMC, Lapses, TUTs, Speed, and Antisaccade

Measure	Latent factor			
	WMC	Lapses	TUTs	Speed
Ospan	.53*			
Symspan	.76*			
Rspan	.46*			
PVTLap		.68*		
FlatSpot		.57*		
WRLap		.51*		
Blocks		.53*		
SaCoV		.48*		
SaAntic		.29*		
SaOm		.48*		
WRTUT			.65*	
PVTTUT			.63*	
StTUT			.67*	
SaTUT			.76*	
PVTRT1				.50*
CRTRT1				.65*
StRT1				.80*
AntiRT				.33*
Interfactor correlations				
WMC				
Lapses	-.37*			
TUTs	-.25*	.42*		
Speed	-.40*	.46*	.22*	
Anti	.32*	-.41*	-.12*	-.39*

Note. Ospan = operation span; Symspan = symmetry span; Rspan = reading span; Anti = antisaccade; PVTLap = lapses in psychomotor vigilance task; FlatSpot = flat spots in continuous tracking; WRLap = lapses in whole report working memory; Blocks = blocks in choice reaction time; SaCoV = coefficient of variation in sustained attention to response task; SaAntic = anticipations in sustained attention to response task; SaOm = omission errors in sustained attention to response task; WRTUT = task-unrelated thoughts in whole report working memory; PVTTUT = task-unrelated thoughts in psychomotor vigilance task; StTUT = task-unrelated thoughts in Stroop; SaTUT = task-unrelated thoughts in sustained attention to response task; PVTRT1 = fastest 20% of reaction times in the psychomotor vigilance task; CRTRT1 = fastest 20% of reaction times in choice reaction time; StRT1 = fastest 20% of reaction times on congruent trials in the Stroop; AntiRT = correct reaction times in antisaccade.

* $p < .05$.

Figure 10
Structural Equation Models for Experiment 7



Note. (a) Structural equation model in which working memory capacity (WMC), behavioral lapses of attention, task-unrelated thoughts (TUTs), and speed predict antisaccade. (b) Structural equation model in which working memory capacity (WMC) predicts behavioral lapses of attention, speed, and antisaccade, and both lapses and speed predict antisaccade. Single-headed arrows connecting variables to each other represent standardized path coefficients, indicating the unique contribution of the variable. Solid lines are significant at the $p < .05$ level.

Importantly, these results suggest that part of the variance shared between WMC and antisaccade was due to shared influences with lapses and speed, but WMC still predicted antisaccade performance after taking into account the other factors. To further test the notion that WMC had both direct and indirect (via lapses and speed) on antisaccade, we specified another model in which WMC had direct effects on lapses, speed, and antisaccade, and indirect effects on antisaccade through Lapses and Speed. The overall fit of the model was adequate, $\chi^2(80) = 254.24$, $p < .000$, RMSEA = .08, 90% CI [.067, .089], NNFI = .90, CFI = .92, SRMR = .07. Shown in Figure 10b is the resulting model. Consistent with the prior model, WMC, lapses, and speed all had direct effects on antisaccade accuracy. Importantly, WMC demonstrated indirect effects through both lapses (indirect effect = .09, $p = .005$) and speed (indirect effect = .09, $p = .014$). Thus, these results suggest that the total effect (.33) of WMC on antisaccade was due to at least three sources of variance: (a) a direct effect possibly due to variation in preparation and goal activation processes; (b) variation in lapses of attention (*consistency*); and (c) variation in speed factors. These results suggest that multiple factors contribute to the relation between WMC and antisaccade performance.

General Discussion

In eight experiments we investigated WMC differences in antisaccade performance. In all experiments, participants performed multiple measures of WMC and variants of the antisaccade task. Our main set of analyses focused on examining WMC-antisaccade relations as a function of the preparatory delay interval. Shown in Table 6 is a summary of the results across the experiments. As can be seen, there was a main effect of WMC in each experiment suggesting that WMC was positively correlated with antisaccade performance. However, WMC only interacted with some of the critical manipulations, suggesting that some factors were more important than others in driving the WMC-antisaccade relation. In particular, in Experiment 1, WMC interacted with delay, but the results were ambiguous. In Experiment 2 we examined a wider range of delay intervals and found that although WMC was correlated with antisaccade performance, there was not an interaction with delay. These results were consistent with prior research by Moffitt (2013) who also found no interaction between WMC and delay, but were inconsistent with prior research by Meier et al. (2018) who found an interaction with delay (at least in the letter

Table 6*Summary of Results for All Experiments*

Experiment	Manipulation	Main effect of WMC	Manipulation \times WMC interaction
E1	Delay (200 ms–1,800 ms)	Yes ($\eta_p^2 = .12, p < .001$)	Yes ($\eta_p^2 = .02, p = .018$)
E2	Delay (50 ms–6,400 ms)	Yes ($\eta_p^2 = .07, p = .002$)	No ($\eta_p^2 = .005, p = .74$)
E3a	Delay (200 ms–1,800 ms)	Yes ($\eta_p^2 = .08, p < .001$)	Yes ($\eta_p^2 = .01, p = .001$)
E3b	Delay (200 ms–1,800 ms)	Yes ($\eta_p^2 = .07, p < .001$)	Yes ($\eta_p^2 = .005, p = .05$)
E4	Delay expectancy	Yes ($\eta_p^2 = .12, p < .001$)	No ($\eta_p^2 = .01, p = .16$)
E5	Location expectancy	Yes ($\eta_p^2 = .11, p < .001$)	No ($\eta_p^2 = .007, p = .38$)
E6	Stimulus onset asynchrony	Yes ($\eta_p^2 = .10, p < .001$)	No ($\eta_p^2 = .005, p = .64$)
E7	Delay (200 ms–1,800 ms)	Yes ($\eta_p^2 = .06, p < .001$)	Yes ($\eta_p^2 = .01, p = .01$)

antisaccade task). To better understand these discrepant results we reanalyzed Meier et al.'s (2018) results and found that the WMC \times Delay interaction (for the letter antisaccade) was fairly weak accounting for only roughly 1% of the variance. In Experiments 3a and 3b we utilized larger sample sizes to see if we could replicate Meier et al. (2018). In both experiments WMC correlated with antisaccade performance and there was an interaction with delay interval. In particular, high WMC individuals had higher accuracy than low WMC individuals at all delays, except for the shortest delay. In Experiment 4 we manipulated whether the delay interval varied as in the other experiments or whether it was fixed at a long delay. Both tasks were related to WMC and there was no interaction with WMC, suggesting that fixing the delay interval did not influence the relation with WMC. Similar to Experiment 3b, TUTs correlated with both overall antisaccade performance and WMC. Examining the task in which the delay interval varied suggested that the delay interval interacted with WMC similar to Experiments 3a and 3b. In Experiment 5 we compared a standard antisaccade task in which location expectancy was 50% for each side of the screen to a task in which location expectancy was 80% for a specific side of the screen (and 20% for the other side of the screen). WMC correlated with all three conditions and there was no interaction with WMC, suggesting that even when participants had more knowledge of where the target would appear WMC differences remained. In Experiment 6 we varied SOA and found consistent WMC differences across all SOAs, suggesting that WMC differences were present both when participants had very little time (50 ms) and substantial time (2,000 ms) to identify the target. Interestingly, variation at short and long SOAs was partially separable with short and long SOAs both accounting for unique variance in the WMC. Finally, Experiment 7 demonstrated that latent factors for WMC, TUTs, behavioral lapses, and speed were all correlated with antisaccade performance. Structural equation models suggested that WMC, behavioral lapses, and speed accounted for unique variance in antisaccade, and part of the relation between WMC and antisaccade was due to variation in lapses of attention and speed.

Collectively, these results suggest there is a robust relation between WMC and performance on the antisaccade task. In each experiment WMC and antisaccade performance were related. Furthermore, the correlation remained even in conditions where we hypothesized that the correlation should be substantially reduced or eliminated (e.g., when the delay interval was fixed; when the probability of the target location was high; when the SOA was long). That is, we were generally unsuccessful in our attempts to

eliminate the correlation. Additionally, the results suggested that part of the relation was due to preparatory factors occurring during the delay interval prior to stimulus presentation. Our results further clarified discrepant results between prior studies in suggesting that variation in preparatory processes are important, but that these effects are small and require large sample sizes and adequate power to detect them.

Multiple Factors Contribute to the Relation Between WMC and Antisaccade

Previously we suggested four possibilities in terms of how variation in goal-management processes could influence the relation between WMC and antisaccade. First, the *goal activation* possibility suggests that high WMC individuals are better able to activate the task goal to a higher level than low WMC individuals. Within the current task, this possibility predicts an interaction between WMC and preparatory delay such that differences in WMC should increase with delay as high WMC individuals should better prepare than low WMC individuals. Evidence consistent with this possibility was found in Experiments 3a, 3b, 4, and 7 which all demonstrated an interaction between WMC and delay interval. These results are broadly consistent with Meier et al.'s (2018) results. At the same time, some of the results were inconsistent with this hypothesis in that the interaction in Experiment 1 did not correspond to the predicted results and when we varied the preparatory delay over a larger range in Experiment 2 the interaction was not significant (see also Moffitt, 2013). Overall, the current results suggest the presence of WMC differences in *goal activation*, which partially account for the relation between WMC and antisaccade performance. However, WMC differences in *goal activation* are fairly small accounting for only approximately 1% of the variance in the interaction. Thus, these results clarify the discrepant results between Moffitt (2013) and Meier et al. (2018) in demonstrating the presence of a WMC \times Delay interaction with a sufficiently large sample size detect this small effect.

Second, the *speed of activation* possibility suggests that high WMC individuals activate the task goal quicker than low WMC individuals. This possibility also predicts an interaction between WMC and preparatory delay, but critically predicts that WMC differences should decrease with delay as low WMC individuals should be able to activate the task goal to the same level as high WMC individuals when given sufficient time. Unfortunately, there was little evidence for this hypothesis in any of the experiments. Although there was a WMC \times Delay interaction in several

experiments, the pattern never corresponded to predicted pattern where WMC differences should be reduced at long delays. In particular, in Experiment 2 the delay was increased to 6,400 ms and low WMC individuals still did not reach the same level of performance as high WMC individuals. Furthermore, in Experiment 4 where the delay interval was fixed at 1,800 ms, WMC differences were still present. The only evidence consistent with this hypothesis was the finding that there were WMC differences even at very short delays (50 ms–200 ms), suggesting that some of the variance at these short delays could be due to high WMC individuals activating the task goal faster than low WMC individuals. Thus, overall there was little evidence to suggest that the WMC–antisaccade relation was due to differences in the speed of goal activation.

Third, the *goal maintenance* possibility suggests that high WMC individuals are better able to maintain the task goal over a delay than low WMC individuals. This possibility predicts an interaction between WMC and delay interval such that low WMC individuals' accuracy should decrease with increasing delay as they cannot actively maintain the task goal. Similar to the *speed of activation* hypothesis, there was little evidence for the goal maintenance hypothesis in any of the experiments. In particular, in none of the experiments did low WMC individuals demonstrate a decrease in accuracy with increasing delay. Furthermore, in Experiment 4 where the delay interval was fixed at 1,800 ms, the *goal maintenance* possibility predicts that WMC differences should either increase or decrease compared with the more standard antisaccade task. However, there was no interaction between WMC and task in this experiment. As such, across all experiments, there was little evidence to suggest that differences in *goal maintenance* influenced the relation between WMC and antisaccade.

Finally, the *consistency* possibility suggests that high WMC individuals are better able to consistently maintain attention on task than low WMC individuals. That is, low WMC individuals experience more lapses of attention than high WMC individuals which results in lowered performance on a subset of trials. This possibility predicts that measures of lapses of attention such as self-reports of TUTs during the antisaccade task should be correlated with WMC and should mediate the relation between WMC and antisaccade. This possibility was examined in Experiments 3b and 4 in which thought-probes were embedded in the antisaccade task and it was found that self-reports of TUTs correlated with both antisaccade performance and WMC. However, correlations between WMC and TUTs were generally small (r 's of $-.14$ and $-.16$). Furthermore, regression analyses suggested that WMC still accounted for performance in antisaccade even after taking TUTs into account. Experiment 7 more fully examined these relations by examining latent factors for TUTs and behavioral markers of lapses and demonstrated that both were correlated with antisaccade performance. Importantly, the relation between WMC and antisaccade was partially due to variation shared with lapses of attention.

Collectively, the current results provide some evidence that both *goal activation* and *consistency* of attention partially account for the relation between WMC and antisaccade. There was little evidence suggesting that *speed of activation* or *goal maintenance* influence the relation between WMC and antisaccade. There was also evidence that speed factors occurring during stimulus presentation are important. Specifically, in Experiment 6 we found that variation at

short SOAs were uniquely related to WMC, suggesting that high WMC individuals have higher accuracy than low WMC individuals even when the target is only presented for 50 ms. These results suggest that speed factors such as speed of moving the focus of attention or speed of conflict resolution processes are important for the relation between WMC and antisaccade. Experiment 7 further demonstrated that a latent factor for speed was related to antisaccade and partially accounted for the relation between WMC and antisaccade performance. Thus, these results suggest that not only are *goal activation* and *consistency* important for the relation between WMC and antisaccade, but speed factors are important as well. Although we note that the latent speed factor in Experiment 7 was composed of measures of speed of responding and not necessarily speed of discriminating the targets. Future research is needed to examine the importance of stimulus discrimination speed to individual differences in antisaccade performance. Overall, these results broadly suggest that multiple factors contribute to the relation between WMC and antisaccade. The fact that multiple factors are important is a likely reason why the correlation is so robust and difficult to eliminate. That is, controlling for variation in *goal activation* might reduce the correlation a bit, but will likely not eliminate it as variation in *consistency*, speed, and potentially other factors will still remain. Thus, the current results provide important evidence suggesting that the relation between WMC and antisaccade is multifaceted and future research will need to attempt to examine these different factors. As such, the current results extend prior research by providing a more comprehensive examination of possible theoretical mechanisms for the relation between WMC and performance on the antisaccade task and suggest that multiple factors are important. Furthermore, as noted previously, antisaccade tends to correlate with many other tasks and loads highly on a broad attention control factor. These results further suggest that a likely reason for these extensive relations is because the antisaccade taps into multiple aspect of attention control (e.g., goal activation, consistency, and conflict resolution) making it a particularly salient measure of attention control abilities. Collectively, the current results suggest that individual differences in antisaccade performance are multifaceted and in order to understand this variation we will need to examine the many potential factors that influence performance on this task.

Limitations, Alternative Explanations, and Future Directions

We would be remiss not to address several limitations of the current study. For example, much of the current study was focused on examining preparatory goal management processes that are thought to occur during the delay interval prior to target presentation. However, we didn't actually measure goal activation processes during the delay interval, but rather examined accuracy as a function of delay interval. Thus, we are making inferences related to preparatory goal management processes via changes in accuracy. In order to better examine variation in goal management processes during the delay, we will need to actually try and measure these processes. One potential way of examining these issues is to use pupillary responses that occur during the delay interval as an index of preparatory attention allocated to goal management processes. In prior research we found that preparatory pupillary responses tended to increase during the delay interval in a sustained attention task, and the magnitude of the pupillary response

was related to performance on the task as well as to WMC (Unsworth et al., 2020b), such that individuals who demonstrated a larger ramp up in the pupil during the delay tended to perform better than individuals who demonstrated only a slight (or no) ramp up during the delay. Similarly, Hutchison et al. (2020) found that pupillary responses during the delay interval were larger for antisaccade than prosaccade trials (see also Wang et al., 2015) and that individual differences in the pupillary responses were related to overall accuracy and TUTs. Thus, measuring pupillary responses during the delay interval should provide a means of better examining variation in preparatory attention to goal management processes during the delay in the antisaccade and how they are related to WMC.

In several of the experiments with sufficient power, we found an interaction between WMC and delay interval such that WMC differences were reduced at the shortest delay compared with the other delays. This was interpreted as being consistent with the *goal activation* possibility. However, an alternative possibility is that there are processing limits in this extreme condition that preclude finding any differences. That is, this condition is data-limited rather than resource limited (Norman & Bobrow, 1975). While this alternative seems plausible there is some evidence to suggest against it. First, in Experiments 1, 2, and 5 WMC significantly correlated with accuracy at the shortest delay intervals, suggesting that in some situations there is a relation with WMC. Second, as seen in the online supplemental materials, in each experiment accuracy in the shortest delay ranged from very low (near zero) to very high (near 1.0) suggesting that performance was not necessarily on floor for this condition. Future research is needed to examine whether processing limits at the shortest delay limit finding systematic individual differences in performance.

Another limitation of the current study is that perhaps we were underpowered to detect some of the critical effects. That is, we based our sample sizes and power estimates on the finding that correlations between WMC and antisaccade are around $r = .25$ based on prior research. But, relations between WMC and some of the critical measures were much smaller than this with r 's around .15. Furthermore, as noted previously we had sufficient power to detect medium effects ($\eta_p^2 = .06$), but were underpowered to detect smaller effects ($\eta_p^2 = .01$). Given these smaller relations and given the notion that multiple factors contribute to the relation between WMC and antisaccade, it is likely that we are underpowered to detect these much smaller effects. Likewise, it is possible that there are individual differences in *speed of activation* and *goal maintenance*, but these relations are so small that we did not have sufficient power to detect them. Future research utilizing larger sample sizes is needed to better examine these potentially small relations.

An additional limitation of the current study is that we did not fully examine variation in conflict resolution/suppression abilities. A fairly standard explanation of the correlation between WMC and antisaccade is that high WMC individuals are better at resolving the conflict between the goal and habit via suppression than low WMC individuals (e.g., Kane et al., 2001; Unsworth et al., 2004). That is, high WMC individuals are better at suppressing an eye movement toward the flashing cue than low WMC individuals. However, in the current study we primarily focused on examining goal management processes during the delay rather than examining conflict resolution processes during target presentation. Thus, the fact that

WMC consistently correlates with antisaccade even after taking into account other variables suggests that much of the relation between WMC and antisaccade is simply due to differences in conflict resolution/suppression. Future research is needed to more fully assess the role of conflict resolution/suppression processes in accounting for the relation between WMC and antisaccade.

An additional alternative explanation for our data is that perhaps WMC differences are not really about goal management processes per se, but rather reflect variation in the ability to setup and maintain temporary stimulus-response bindings (Oberauer et al., 2007; Wilhelm & Oberauer, 2006; Wilhelm et al., 2013). In the current antisaccade task, targets (B, P, or R) are arbitrarily mapped to three different responses on the keyboard (here 4, 5, 6 on the number pad). Prior research has suggested that relations between WMC and performance on choice RT tasks is partially due to whether the task relies on arbitrary stimulus-response bindings (Wilhelm & Oberauer, 2006). Thus, it is possible that low WMC individuals make more errors on the current antisaccade task than high WMC individuals, because low WMC individuals cannot setup and maintain the arbitrary bindings as well as high WMC individuals. As noted previously, this is one possible reason for why low WMC individuals demonstrated poorer performance even when at very long SOA conditions in Experiment 6. It is also a possible reason for why the speed factor in Experiment 7 partially accounted for the relation between WMC and antisaccade. While this account might partially explain some of the shared variance between WMC and antisaccade, we do not think it explains the whole relation. As noted throughout, the results suggest that multiple factors likely account for the relation between WMC and antisaccade and it is unclear how differences in maintaining bindings would account for the finding that lapses of attention (TUTs and behavioral lapses) partially account for the relation (see also McVay & Kane, 2012a). Additionally, prior research has also used a version of the antisaccade in which the targets are arrows which are mapped to the arrow keys (e.g., Chuderski & Jastrzębski, 2018; Chuderski et al., 2012; Friedman & Miyake, 2004; Kane et al., 2016; McVay & Kane, 2012b; Miyake et al., 2000) and this more compatible stimulus-response mapping version is correlated with the current antisaccade task (Meier et al., 2018) and both are related to WMC (McVay & Kane, 2012b; Meier et al., 2018). Finally, if the relation is entirely due to arbitrary stimulus-response mappings, then we would expect that a prosaccade task with the same mappings should correlate with WMC at the same magnitude as the antisaccade version. However, some prior research suggests that is not the case (Kane et al., 2001). Thus, while it is possible that some of the shared variance between WMC and antisaccade is due to stimulus-response mapping features, it is unlikely that this is the sole reason for the relation.

Given the notion that multiple factors contribute to the relation between WMC and antisaccade performance, a final limitation of the current study is that we did not fully assess multiple factors simultaneously (e.g., preparation, TUTs, speed, suppression, etc.). In Experiment 7 we examined speed and lapses (TUTs and behavioral lapses), but we did not have any measures of preparation or potential suppression abilities. Thus, future research is needed to further examine how multiple factors jointly account for the relation between WMC and antisaccade.

Conclusions

In the current study we clarified the relation between WMC and antisaccade. In seven experiments it was found that WMC was consistently related to performance on the antisaccade. Results across several experiments suggested part of this relation was due to differences in *goal activation* processes whereby high WMC individuals are better able to activate the task goal during the delay interval than low WMC individuals resulting in better performance. Results across two experiments also suggested that part of the relation was due to variation in the *consistency* of attention whereby low WMC individuals experience more lapses of attention and task-unrelated thoughts than high WMC individuals resulting in worse performance. Other possible reasons for the relation between WMC and antisaccade such as differences in *speed of activation* or *goal maintenance* during a trial were associated with little to no evidence. Finally, there was evidence that part of the relation was due to other speed factors whereby high WMC individuals were faster at target identification than low WMC individuals resulting in better performance. Collectively, the current results suggest that the robust relation between WMC and antisaccade is due to multiple factors.

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(Appendices follow)

Appendix A

Information for Experiment 7

Table A1*Descriptive Statistics for All Measures in Experiment 7*

Measure	<i>M</i>	<i>SD</i>	Skew	Kurtosis	Reliability	<i>N</i>
Ospan	37.93	8.08	−.69	.09	.72	357
Symspan	18.82	5.21	−.48	−.10	.64	358
Rspan	37.25	8.60	−1.05	1.36	.76	358
Anti	.60	.15	.04	−.62	.83	349
PVTLap	4.71	6.59	3.21	14.14	.83	351
FlatSpot	1.43	4.28	4.60	25.41	.81	335
WRLap	11.06	8.58	1.54	2.13	.91	290
Blocks	2.01	2.59	2.61	10.22	.77	349
SaCoV	.32	.11	1.04	1.36	.79	338
SaAntic	5.30	10.21	3.56	15.67	.88	337
SaOm	19.79	16.44	1.75	4.13	.98	338
WRTUT	.55	.38	−.18	−1.45	.64	311
PVTTUT	.44	.30	.24	−.95	.60	353
StTUT	.22	.29	1.39	.87	.71	354
SaTUT	.45	.33	.23	−1.24	.89	354
PVTRT1	283.10	26.07	1.23	3.45	.97	351
CRTRT1	293.60	39.86	.33	4.72	.96	347
StRT1	439.49	67.73	1.19	2.38	.97	354
AntiRT	880.52	261.81	1.22	2.52	.92	349

Note. Ospan = operation span; Symspan = symmetry span; Rspan = reading span; anti = antisaccade; PVTLap = lapses in psychomotor vigilance task; FlatSpot = flat spots in continuous tracking; WRLap = lapses in whole report working memory; Blocks = blocks in choice reaction time; SaCoV = coefficient of variation in sustained attention to response task; SaAntic = anticipations in sustained attention to response task; SaOm = omission errors in sustained attention to response task; WRTUT = task-unrelated thoughts in whole report working memory; PVTTUT = task-unrelated thoughts in psychomotor vigilance task; StTUT = task-unrelated thoughts in Stroop; SaTUT = task-unrelated thoughts in sustained attention to response task; PVTRT1 = fastest 20% of reaction times in the psychomotor vigilance task; CRTRT1 = fastest 20% of reaction times in choice reaction time; StRT1 = fastest 20% of reaction times on congruent trials in the Stroop; AntiRT = correct reaction times in antisaccade.

(Appendices continue)

Appendix B

Information for Experiment 7

Table B1*Correlations Among the Measures for Experiment 7*

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Ospan	—																		
2. Symspan	0.41	—																	
3. Rspan	0.51	0.35	—																
4. Anti	0.18	0.24	0.14	—															
5. PVTLap	-0.06	-0.15	-0.17	-0.32	—														
6. FlatSpot	-0.06	-0.15	0.02	-0.16	0.45	—													
7. WRLap	-0.23	-0.31	-0.26	-0.16	0.33	0.29	—												
8. Blocks	-0.06	-0.09	-0.08	-0.24	0.43	0.28	0.21	—											
9. SaCoV	-0.15	-0.16	-0.2	-0.3	0.33	0.25	0.34	0.27	—										
10. SaAnti	-0.07	-0.1	-0.16	-0.12	0.18	0.13	0.31	0.14	0.76	—									
11. SaOm	-0.16	-0.14	-0.18	-0.23	0.3	0.3	0.25	0.27	0.6	0.46	—								
12. WRTUT	-0.03	-0.07	-0.11	0	0.14	0.13	0.19	0.03	0.09	0.14	0.07	—							
13. PVTUT	-0.07	-0.14	-0.08	-0.13	0.33	0.22	0.11	0.14	0.02	-0.04	-0.01	0.38	—						
14. StTUT	-0.11	-0.17	-0.08	-0.11	0.28	0.28	0.23	0.22	0.08	0.02	0.04	0.35	0.53	—					
15. SaTUT	-0.05	-0.16	-0.04	-0.08	0.16	0.26	0.14	0.16	0.22	0.17	0.22	0.59	0.42	0.48	—				
16. PVTRT1	-0.06	-0.17	-0.1	-0.29	0.6	0.18	0.12	0.23	0.13	0	0.08	0.09	0.35	0.16	0.03	—			
17. CRTRT1	-0.07	-0.18	-0.05	-0.18	0.15	0.09	0.04	0.17	-0.08	-0.15	0.11	0.07	0.09	0.13	0.01	0.32	—		
18. StRT1	-0.19	-0.23	-0.2	-0.28	0.33	0.13	0.3	0.21	0.07	-0.03	0.16	0.06	0.15	0.25	0.05	0.44	0.55	—	
19. AntiRT	-0.17	-0.19	-0.03	-0.35	0.03	-0.04	0.02	0.04	0.1	0	0.02	-0.03	-0.01	0.03	-0.01	0.1	0.27	0.22	—

Note. Ospan = operation span; Symspan = symmetry span; Rspan = reading span; Anti = antisaccade; PVTLap = lapses in psychomotor vigilance task; FlatSpot = flat spots in continuous tracking; WRLap = lapses in whole report working memory; Blocks = blocks in choice reaction time; SaCoV = coefficient of variation in sustained attention to response task; SaAnti = anticipations in sustained attention to response task; SaOm = omission errors in sustained attention to response task; WRTUT = task-unrelated thoughts in whole report working memory; PVTUT = task-unrelated thoughts in psychomotor vigilance task; StTUT = task-unrelated thoughts in Stroop; SaTUT = task-unrelated thoughts in sustained attention to response task; PVTRT1 = fastest 20% of reaction times in the psychomotor vigilance task; CRTRT1 = fastest 20% of reaction times in choice reaction time; StRT1 = fastest 20% of reaction times on congruent trials in the Stroop; AntiRT = correct reaction times in antisaccade.

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