WORKING MEMORY CAPACITY AND SACCADE PERFORMANCE ACROSS FIXATION DELAY: ATTENTIONAL PREPARATION OR GOAL NEGLECT?

by

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ABSTRACT

Correctly performing an antisaccade requires the ability to inhibit an automatic response (*look away from a flashing cue)* as well as maintain the task goal to look opposite the cue. Past research has shown that this ability relates to Working Memory Capacity (WMC). Goal maintenance is assumed to occur before trial onset, during presentation of the fixation stimulus. Yet, there has been little research investigating whether there is an optimal time for preparing to execute the goal of inhibiting the automatic response. Furthermore, little has been done to discover how mind wandering might interfere with goal maintenance and saccade performance across the delay period. Three experiments tested the prediction that increasing the fixation duration during saccade tasks will differentially impact performance between individuals higher and lower in WMC. In Experiment 1, correlations between antisaccade accuracy and WMC increased across fixation duration, with high-span participants' performance increasing across the delay, but no effect of delay for low-spans participants. In Experiment 2, prosaccade accuracy plateaued for high-span individuals from medium to long delays, but decreased for low-spans individuals. In Experiment 3, reports of mind wandering were correlated with WMC and antisaccade accuracy, yet impacted high-span participants more than low-span participants. The results are interpreted in terms of the required preparatory and maintenance processes mentioned above.

INTRODUCTION

The world is filled with sources of potential distraction. Walk down any crowed urban environment and you will likely experience a cacophony of car horns, car engines, construction work, and noisy pedestrians. You might also experience visual commotion in the form of flashing lights, rapidly moving vehicles, and oncoming pedestrians. Yet, while these distractions are external, other sources of distraction are internal, in the sense that they generate from within the mind or body. It is not difficult to think of times when unwanted thoughts entered consciousness while reading an article, thus compromising reading comprehension and memory for the material. Examples of internal distraction include daydreaming, anxiety, or fatigue, which can involve removing attention from task-relevant processing to focus on task-irrelevant information.

This brings up the interesting, yet seemingly obvious, point that distraction interferes with attention. Thus, behaviors that involve a high probability of distraction require mechanisms to control attention (Norman & Shallace, 1986). Such attentional control involves keeping attention focused on a goal that will result in successful task completion (Kane & Engle, 2003). For example, a visiting basketball player at a foul-line preparing to shoot a free-throw may experience potential distraction in the form of a noisy home crowd and noisy visual displays directly behind the basketball hoop. To successfully maximize performance and execute the free-throw, the basketball player will need to direct his or her attention toward the goal of making a basket and away from the noisy crowd and visual displays.

Perhaps the greatest form of distraction is overcoming a habitual response in favor of a novel, yet task appropriate response. One classic paradigm for investigating how attention operates under such response conflict involves making an eye movement away from a flashing cue, and instead looking in the opposite direction (Kane, Bleckley, Conway & Engle, 2001). Looking away from the abrupt onset of a distractor cue is referred to as an antisaccade. This task requires one to suppress the relatively automatic response of looking at stimuli that rapidly appear in the periphery (Unsworth, Schrock and Engle, 2004). The rapid onset of such stimuli is said to capture attention. When people notice a flash in their periphery, the natural tendency is to look toward the flash, perhaps to identify its source.

Antisaccade tasks thus require a great deal of attentional control for successful performance. Not surprising, performance on such tasks is related to working memory capacity (WMC, Engle, 2002; Kane et al., 2001). WMC is typically measured by complex span tasks that involve the ability to keep information (e.g. a word) accessible online while simultaneously engaging in effortful cognition (e.g., solving math problems). Individuals who score high (high-WMC individuals) on complex span tasks tend to be more accurate on antisaccade trials, compared to individuals who score low (low-WMC individuals) on complex span tasks (Kane et al., 2001). Explanations for this difference in antisaccade performance often rest on the relation between WMC and attentional control; namely, the ability to maintain task goals in working memory in the face of distraction, and to inhibit habitual, task-irrelevant information (Engle, 2002; Kane et al., 2001; Kane & Engle, 2003; Braver, Gray & Burgess, 2007). In target identification paradigms, when making an antisaccade, an individual must maintain the goal of looking away from a distractor cue in order inhibit the pre-potent response generated by the onset of the flashing cue. In general, high-WMC individuals (high spans) tend to be better than low-WMC individuals (low spans) at maintaining task goals in the presence of distraction and overriding automatic responses in favor of achieving task goals (Conway, Cowan, & Bunting, 2001; Engle, 2002).   Conway, Cowan, and Bunting (2001) demonstrated this in a dichotomous-listening task, in which participants repeated out loud words presented in one ear while ignoring words presented in the other ear. Critically, a participant's name was included with the to-be-ignored words to increase distractibility by hearing one's own name being said. In short, high-span participants were less likely than low-span participants to report hearing their name, indicating that they were able to block the distracting information coming from the unattended ear. Therefore, in a similar fashion, during an antisaccade task high-span individuals use attentional control to maintain the task goal and inhibit the automatic response captured by the flashing cue.

One assumption inherent in theories of attentional control is that it takes time to engage in such control. For example, in the realm of task-switching paradigms, giving participants adequate time to prepare prior to an upcoming trial leads to a reduction in reaction time and errors when switching between cognitive tasks (Rogers & Monsell, 1995; Monsell, 2003). Ruge et al. (2005) examined the blood-oxygenation level-dependent (BOLD) activation of participants when engaged in such cue-based preparation for task-switch and task-repeat trials. Participants were required to identify the location of a small square that appeared in one of four locations in a quadrant. The square could either appear in the left or right quadrants on the top, or the left and right quadrants on the bottom. Thus, participants randomly switched between indicating if the square appeared on the top versus bottom, and if the square appeared on the left versus right. The task cue was comprised of two arrows appearing on either the sides of the quadrant (left- and right-pointing arrows), or on the top and bottom of the quadrant (up- and down-pointing arrows). If participants saw the left and right arrows, they were to indicate which side of the quadrant the square appeared on (left or right). Alternatively, if participants saw the up and down arrows, they were to indicate if the square was in a top or bottom quadrant. Thus, the square was associated with bivalent responses (up/right, up/left, down/right, and down/left). The arrow cues remained on screen for either 100 ms, or 2000 ms.

Overall, Ruge et al. (2005) found more errors and longer reaction times for the 100 compared to the 2000 ms condition. In addition, networks of prefrontal and parietal cortex, including the left inferior frontal junction (IFJ), anterior fronto-median cortex (aFMC), left/right posterior superior parietal lobules (pSPL), and left/right anterior and posterior intraparietal sulci (IPS), displayed larger activation for switch trials compared to repeat trials. However, an interesting finding was that activations within the prefrontal area IFJ and parietal areas pSPL and IPS were found when activation was cue-locked and target-locked in the 2000 ms Cue-Target Interval (CTI) condition, as well as the 100 ms CTI condition. Yet, the activation was greater in these areas on switch trials involving 100 versus 2000 ms CTIs. Ruge et al. suggest that the greater activation on switch trials when CTIs are short reflects a greater activation of task-implementation processes in parietal cortex that have not had adequate time to implement the relevant “action-schema.” This often results in either an error or a longer reaction time. The logic is that cue presentation initiates preparatory task processing in prefrontal cortex (IFJ), which involves activation of the appropriate, abstract task rules and goals that have become associated with the cue. This activation, in turn, initiates activations within parietal cortex (IPS and SPL) involved with basic task-implementation processes (i.e. using visual information to implement the correct action). In this model, a longer CTI allows the task-implementation processes to settle into a preparatory state, which allows for a faster application of task rules at target onset, similar to the release of a spring after being compressed, thus reducing switch costs. Ruge et al. imply that this is a feed-forward process, in that the flow of information begins in prefrontal cortex and is directed to parietal cortex. Therefore, preparatory attention in this case involves allowing task-implementation processes to initiate representations necessary for the execution of task-relevant behavior.

Time-related effects of control have also been demonstrated in task-switching paradigms that involve switching between prosaccade and antisaccade responses. For example, Mueller, Swainson and Jackson (2009) used event-related potentials (ERPs) from electroencephalograph (EEG) recordings to find neural signatures of brain activity prior to and during switch and repeat trials that followed either short (300 ms) or long (1000 ms) CTIs. Participants completed trials in which they were presented with either a red or a green fixation cross that instructed participants to make an eye movement away from or toward a target box, respectively. The fixation cross (the cue) remained on screen for either 300 ms or 1000 ms, followed by the presentation of a target box on either the left or right side of the screen. One finding of interest was a cue-locked late frontal negativity (LFN) during the long CTIs for switch trials. Crucially, this LFN was only present for CTIs prior to switches to prosaccade trials. This fits with past research linking LFNs to overcoming suppression of previous, task-irrelevant responses that are now relevant (Matthews, Flohr, & Everling, 2002). The implication is that during long CTIs, participants engaged in attentional preparation that took the form of overcoming, or re-activating, previously suppressed responses. Because prosaccades are pre-potent, habitual responses, they must be suppressed during antisaccade trials. Thus, when it comes time to switch to a prosaccade, the suppression must be successfully overcome, and this process requires sufficiently long CTIs.

Another crucial finding of Mueller, et al. (2009) was a stimulus-locked negativity (N2) in parietal regions when the target box appeared on screen. However, this was only present for antisaccade trials, and largest following short CTIs. Research has linked such parietal N2 negativity to ongoing response suppression during Go/Nogo tasks (e.g., Eimer, 1993). Mueller et al. claimed that the N2 during antisaccade trials following short CTIs reflected the current suppression of prosaccades in favor of antisaccade responding. Further support for this view was the finding that response latencies were also greater when switching to antisaccade trials following short CTIs, suggesting that attentional control was working during those latencies to suppress prosaccade responding.

The implication from the Mueller et al. (2009) study is that there are separate proactive and reactive (see Braver et al., 2007) neural signatures of attentional control in the form of proactively overcoming the suppression of stimuli and reactively inhibiting pre-potent responses. The overall importance of these findings to the current set of experiments is that attentional control is critical during both preparation for and execution of a conflicting non-habitual response.

A neuroimaging study using event-related fMRI, conducted by Brown, Vilis and Everling (2007) found additional evidence for an effect of preparation on antisaccade performance in blocks of prosaccade and antisaccade trials. Specifically, these researchers found that, for antisaccade trials, areas of prefrontal cortex, including left dorsolateral prefrontal cortex (DLPFC), exhibited significant activation during a preparatory period lasting one second prior to the onset of the distractor. Areas responsible for making eye movements (i.e. Frontal and Supplementary Eye Fields) displayed no activation during the preparatory period, yet were activated during target responding (i.e. at distractor onset). Antisaccade trials in which no prefrontal activation was found were associated with more errors. On the other hand, greater prefrontal activation was associated with faster reaction times and less response-related activation in frontal and supplementary eye fields, suggesting that areas responsible for eye movements had to work less at suppressing the response of looking toward the distractor. This is evidence that activation of prefrontal cortex prior to target onset enhances target-appropriate responding at target onset, thus facilitating performance.

The results discussed above suggest that, if given enough time, individuals can engage attentional control processes to access goal-relevant information in Working Memory in anticipation of cognitively challenging tasks to aide performance (Braver et al., 2007). However, the above-mentioned studies did not investigate individual differences in WMC and attentional control during attention preparation periods. Other research has demonstrated a link between working memory and prefrontal connectivity in primates (Goldman-Rakic, 1987), and activation of prefrontal cortex and individual differences in WMC in humans (Kane & Engle, 2002). Such work suggests that prefrontal activation is more likely to occur for high-span individuals compared to low-span individuals (Kane & Engle, 2002).

For antisaccade tasks, the amount of time required for the engagement of control processes and how this preparation time interacts with individual differences in WMC has yet to be specifically investigated. This is interesting, given the fact that a common procedure of saccade experiments is to vary the amount of time that an initial fixation stimulus stays on the screen before each distractor cue is presented. This is usually done to prevent participants from guessing when the cue will appear. For example, Unsworth, Schrock and Engle (2004) varied the fixation between 600 and 2200 ms in 100-ms increments. Thus, on some trials participants were required to make antisaccades relatively quickly after the initial presentation of the fixation point, whereas on other trials antisaccades were made after a longer period of time. Yet, while Unsworth et al. (2004) did show that high-span individuals were more accurate than low-span individuals on antisaccade trials, these researchers did not examine how fixation delay might have influenced accuracy, and how the effect of delay on performance might have interacted with WMC, such that the difference in performance might only appear in trials that came after the shorter or longer fixation periods. Consistent with the neuroimaging studies on preparatory attention, one might predict that high-span participants may experience a greater improvement in antisaccade accuracy over low-span participants as the fixation delay increases.

Yet it is also possible that high-WMC individuals are better not only at attentional preparation and execution of task goals in the presence of distraction, but also at maintaining task goals over longer periods of time during cognitively demanding tasks. This possibility is consistent with research investigating individual differences in WMC and mind wandering (Kane & Engle, 2003). Generally, mind wandering is referred to as the spontaneous engagement of internally directed cognitions unrelated to specific task-dependent constraints (Smallwood & Schooler, 2006). Mind wandering thus seems to begin rather spontaneously, independent of the stimuli of the task that an individual is engaged in. Smallwood and Schooler argue that in order for the individual to engage in mind wandering, resources must be freed up from other attentional sources, which may hamper the ability to pay attention to the current task. In this vein, it is most likely to occur during well-practiced tasks that have become nearly automatic (Smallwood, Beach, Schooler, & Handy, 2008; Smallwood, Nind, & O'Connor, 2009). A well-practiced task, in theory, would require little attentional resources, thus mind wandering is likely to spontaneously occur during such tasks.

In the realm of attentional control, mind wandering is often used synonymously with the term goal neglect (Duncan, 1995). This is because goal neglect involves a momentary loss of the currently relevant task goal, due to the spontaneous engagement of internally directed thought unrelated to the specific task at hand (Kane & Engle, 2003; McVay & Kane, 2009). The likelihood for spontaneous goal neglect is often used as an explanation for the relation between individual differences in WMC and performance. For example, McVay and Kane (2009) demonstrated that low-span participants mind wandered (as measured by the rate of Task-Unrelated Thoughts, or TUTs) more than high-span participants during a sustained attention to response task (SART Go/Nogo task), and these WMC-related variations in mind wandering predicted error rates in the task. The implication is that mind wandering reflects a WMC-related failure to maintain task-relevant goals. Thus, in terms of saccade performance, low-span individuals may demonstrate a decrease in accuracy with an increase in fixation delay, as they would be more susceptible to the occurrence goal neglect over time.

Kane and Engle (2003) conducted a series of Stroop experiments investigating the role of goal neglect in individual differences in WMC and attentional control. In a typical Stroop task, participants are presented a word on a computer screen and required to name the font color in which the word is presented, rather than saying the word itself. The word is often a color name (e.g. the word BLUE) that is presented in one of four font colors (e.g. red, blue, green, yellow). Incongruent trials are those in which the font color and the word do not match (e.g., BLUE in red font), whereas congruent trials are those in which the font color and word do match (e.g., BLUE in blue font). Incongruent trials are relatively more challenging than congruent trials, due to the fact that reading the word (a well-learned task) must be overcome in favor of naming the font color (a novel task). Congruent trials, on the other hand, can be successfully completed by simply reading the word as it comes on the screen, thus requiring little attentional control. Therefore, Stroop effects are referred to as the committal of errors and/or longer reaction times on incongruent trials relative to congruent trials. In one of Kane and Engle's experiments (Experiment 4), participants completed blocks of trials that were 80% congruent and 20% incongruent, as well as blocks that were 80% incongruent and 20% congruent. Because incongruent trials were rare in the former blocks, participants did not have much experience with them, thus the goal of responding to the font color rather than the word was not strongly reinforced. As a consequence, participants were likely to commit errors on the rare incongruent trials, reflecting that they had succumbed to goal neglect. More importantly, individuals with low WMC were significantly more likely to commit such errors on incongruent trials compared to individuals high in WMC. Thus, high-WMC individuals were attributed with the ability to resist goal neglect, particularly as it pertains to tasks involving response conflict.

Such an inability to maintain the goal of a task, thereby succumbing to goal neglect, is the dominant account for WMC-based differences in antisaccade performance (De Jong, Berendsen & Cools, 1999; Kane et al., 2001; Unsworth et al., 2004). Kane et al., (2001) had participants perform blocks of antisaccade trials in which a distractor cue abruptly appeared on one side of the screen followed by a target letter on the opposite side of the screen. Participants were instructed to look away from the cue to identify the target. An eye tracker was used in their Experiment 2 to measure eye movement. Across the two experiments, the results consistently revealed that low-span individuals were slower and committed more errors (both target identification and eye movement) than high-span individuals during the antisaccade task. Kane et al. concluded that what differentiates high- from low-span participants in this regard is that low-span individuals have a lower attentional capacity to keep goal states active, particularly in situations involving a high degree of distraction or interference. In essence, inability to inhibit the distractor cue is a direct result of a decreased maintenance of goal states (i.e. goal neglect). As a result of goal neglect, the antisaccade goal cannot be accessed quickly enough at the time the distractor cue appears.

Similarly, Unsworth et al. (2004) conducted experiments in which participants made voluntary and involuntary antisaccades and prosaccades. In the involuntary conditions, a box flashed on either side of the fixation point to cue participants where to direct their eye movement; for prosaccades, participants were to look toward the location of the flashing box, whereas for antisaccades, participants were to look away from the location of the flashing box. In the voluntary conditions, the flashing boxes were replaced by arrows that appeared in the center of the screen pointing either left or right; for prosaccades, participants were to look in the direction indicated by the arrow, whereas for antisaccades, participants were to look in the opposite direction indicated by the arrow. Consistent with Kane et al. (2001), low-span participants were slower and less accurate overall on antisaccade trials. However, the difference between low- and high-span participants' performance was greatest on trials that involved the voluntary generation of saccades, which included both prosaccades and antisaccades. Unsworth et al. claimed that by intermixing prosaccade with antisaccade trials increased the need for goal maintenance, in a similar fashion as the Stroop experiments by Kane and Engle (2003). As Unsworth et al. point out: "In these situations of increased interference, the need to actively maintain the task goal is of critical importance… that low-span participants made more errors on both prosaccades and antisaccades suggests that they were deficient in their ability to keep the task goal actively maintained and thus were more susceptible to goal neglect than were high-span participants" (p.1312). However, rather than simply impeding the ability to inhibit habitual responses, as is the case for involuntary antisaccades, goal neglect impairs a more general ability to allocate attention to the generation of the saccade, regardless of whether the goal is to make an antisaccade or prosaccade. Yet, while Kane et al. and Unsworth et al. do not deny that the ability for response inhibition is also important in separating the performance of high- and low-span individuals, they argue that it is the incapacity to keep the goal active that is responsible for the lack of response inhibition which results in antisaccade errors. In short, differential saccade performance between high- and low-span individuals reflects a greater susceptibility of goal neglect in low-span participants.

In addition to predictions regarding attentional preparation and goal neglect, a final consideration of WMC-related differences in saccade performance consists of the possibility of differences in response suppression in service of conflict resolution. As mentioned above, Kane and Engle (2003) conducted a series of Stroop experiments investigating WMC and attentional control. While they support the notion of goal neglect as a contributor of performance-compromising interference, they also found evidence for competition resolution as a significant contributor. A crucial factor was that participants completed blocks of trials that were 80% congruent, as well as blocks that were 80% incongruent. In the later block of trials, incongruent trials were common, while congruent trials were rare. Thus, in theory, participants should have become relatively familiar with performing incongruent trials. Yet, Stroop effects were still observed. However, the effect was found in reaction times, rather than error rates. While increases in error rates are indicative of goal neglect, Kane and Engle (2003) argued that increases in reaction time are indicative of overcoming response competition inherent in incongruent trials. In other words, participants did not lose the goal, but had to exercise attentional control nonetheless to overcome the conflicting word naming response, which is present on every incongruent trial. This is similar to the N2 ERP signatures found by Mueller et al. (2009) during antisaccade trials, discussed previously, which were also associated with longer response latencies. Such findings suggest that trials involving response competition inherently evoke the need for cognitive control, and that the resolution (or suppression) of this competition takes time. In addition, Kane and Engle found that individuals low in WMC had particularly longer reaction times to the commonly occurring incongruent trials compared to high-span individuals. This finding points out a relationship between WMC and the suppression of response competition. In essence, high-span individuals were superior to low-span individuals in overcoming response competition; low-span participantss could still successfully complete the task, it just took them a bit longer to do it compared to high-span individuals. Thus, one might predict that high-span individuals would be more successful at an antisaccade task compared to low-span individuals, due to the idea that they are better at resolving response competition.

An interesting consideration is that this response-suppression deficit could be reflected in error rates in some antisaccade paradigms (Hutchison, 2007; Payne, 2005). For example, in target-identification paradigms, participants see a distractor cue briefly presented on either the left or right side of the screen, followed by a target that briefly appears on the opposite side of the screen as where the distractor appeared. Participants are thus instructed that when they notice the distractor cue appear, they should immediately look toward the opposite side of the screen (i.e., to make an antisaccade) and try to identify a target (e.g., a letter) that will appear there. The catch is that the target usually remains on screen for such a brief time (e.g., 100 ms) before it is removed or hidden by a different pattern that, if participants cannot initially suppress the tendency to look toward the distractor cue when it flashes and instead look to the opposite side of the screen, they will not have enough time to identify the target. An antisaccade error in this instance (i.e., not making an antisaccade fast enough to correctly identify the target) would be a direct result of not successfully engaging in response-competition suppression. Therefore, one might still expect to find WMC-related differences in antisaccade performance in target-identification paradigms in the form of task-irrelevant response suppression; high-span individuals should still outperform low-span individuals because they have been shown to be faster at resolving response completion (e.g., Kane & Engle, 2003). Thus, they could overcome the tendency to look at the distractor cue in time to make the antisaccade required to identify the target appearing opposite the distractor cue. Based on the findings of Mueller et al. (2009), one could further predict greater N2 ERPs for high-span participants during the onset of the distractor cue compared to low-span participants.

This literature review points out three primary predictions for individual differences in attentional control that might be important in saccade experiments. The first prediction concerns attentional preparation. As mentioned above, a period of time that allows for attentional preparation can enhance performance on some tasks. Of further importance is the idea that high-span individuals might benefit more from attentional preparation than low-span individuals. To the extent that high-span individuals can use top-down attentional control in a proactive manner (e.g. Braver et al., 2007), it is logical that separation in antisaccade performance based on individual differences in WMC could be increased as fixation delay increases. However, this has yet to be investigated. The second prediction, which might seem contradictory to the first, is that of goal neglect, or mind wandering. From the literature reviewed above, there is evidence that an individual's attention can wax and wane as they engage in cognitive tasks. As individuals begin to mind wander, they begin to neglect the relevant goals of the current task, which typically manifests in error rates. To the extent that individuals lower in WMC are more susceptible to goal neglect than high-span individuals, one might expect that increasing the fixation delay before antisaccade trials would create goal neglect for low-span participants. This would result in more errors on antisaccade trials at longer delays for low- compared to high-span individuals.

However, as high-span participants would not be as susceptible to goal neglect, their error rate would not be affected by longer fixation delays; their error rate would remain low and stable regardless of the delay. This also has yet to be investigated in antisaccade paradigms using long vs. short delays and individual differences in WMC. Finally, the third prediction involves response-conflict resolution. As already mentioned, attentional control involves the ability to engage in the resolution of completion between possible responses. In the antisaccade task, the need for this ability is increased, due to the fact that the competing, incorrect response is a pre-potent, habitual response. To the extent that high-span individuals are better at overcoming and suppressing conflicting responses than low-span individuals, they should have fewer errors overall on antisaccade trials compared to low-span individuals. Yet, while this has been demonstrated in the past, it is unclear at this point whether varying the fixation delay in antisaccade tasks will differentially affect individuals high and low in WMC in regard to suppression of task-irrelevant responses. It could be that antisaccade tasks mainly involve response suppression. If that were the case, one would expect high-span participants to be better than low-span participants on antisaccade trials, but neither group of individuals to be affected by increasing fixation delays. Again, this possibility has yet to be directly tested.

Therefore, the primary objective of the current set of experiments is to investigate whether differences in WMC interact with fixation delays in affecting saccade performance, and in turn, whether mind wandering differentially affects the saccade performance of high- and low-span participants. To accomplish this objective, participants completed tasks designed to measure WMC (an operation span task) followed by saccade tasks that randomly varied the length of fixation before saccade trials. Finally, for Experiment 3, thought probes were inserted on 25% of saccade trials as an index of mind wandering, a process critical to explanations of individual differences in saccade performance involving goal neglect.

Experiment 1

In Experiment 1, participants completed three blocks of antisaccade trials that varied fixation delays prior to the onset of distractor cues. One of six fixation periods randomly occurred before presentation of the distractor cue for each antisaccade response. The six fixation periods were 250 ms, 500 ms, 1000 ms, 2000 ms, 4000 ms, and 8000 ms. Prior to the antisaccade task, participants completed an automated version of the operation span task (OSPAN task, Unsworth, Heitz, Schrock, & Engle, 2005). Based on the literature reviewed above, this experiment contains predictions based on several possible outcomes. Overall, it was predicted that antisaccade accuracy would be greater for high-span individuals compared to low-span individuals. This is supported by previous findings suggesting that high-span participants are more accurate when successful completion of trials involves conflict resolution and response suppression.

In terms of the effect of fixation delay, three potential patterns are predicted. First, antisaccade accuracy for high-span individuals should increase as fixation delay increases, consistent with attentional preparation research described above. However, for low-span participants, antisaccade accuracy should either remain stable across delays, or improve at a smaller rate than high-span participants (see Figure 1a). A second possible outcome is that antisaccade accuracy of low-span participants should be similar to that of high-span participants at the short fixation delays, but greatly decrease as fixation delay increases, consistent with goal neglect accounts of low span performance. Accuracy for high-span participants, however, will remain high and relatively stable across fixation delays (see Figure 1b). It is important to point out that both the attentional preparation and goal neglect hypotheses predict WMC differences in performance to increase as fixation delays increase, yet for different reasons. Attentional preparation predicts that the difference should be due to high-span participants increasing in accuracy across the fixation delays, whereas the goal neglect hypothesis predicts that low-span participants should decrease in accuracy across delays. Finally, it is possible that no effect of delay will be found, such that differences in performance related to individual differences in WMC will simply reflect a general advantage among high-span participants to resolve competition between responses (see Figure 1c).

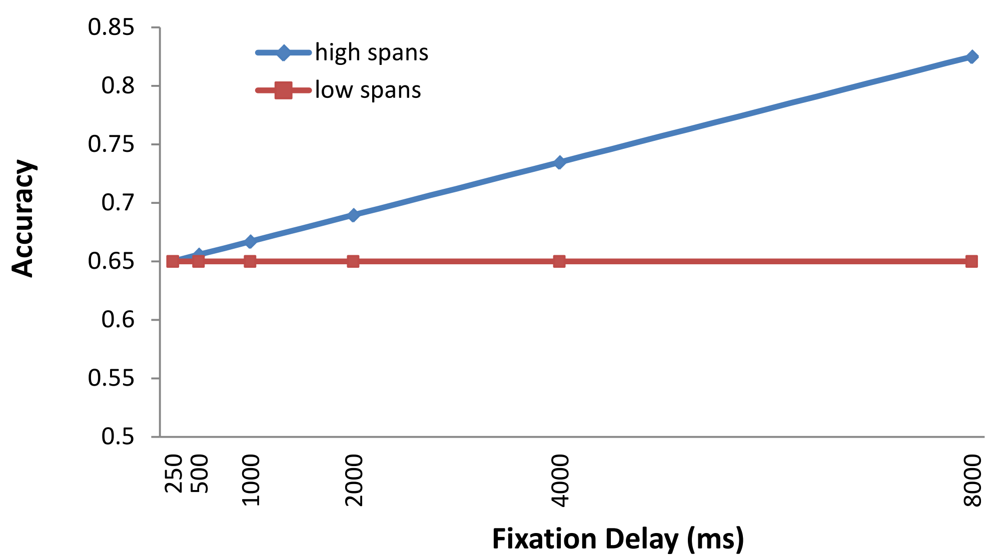

Figure 1a: Attentional Preparation Hypothesis.

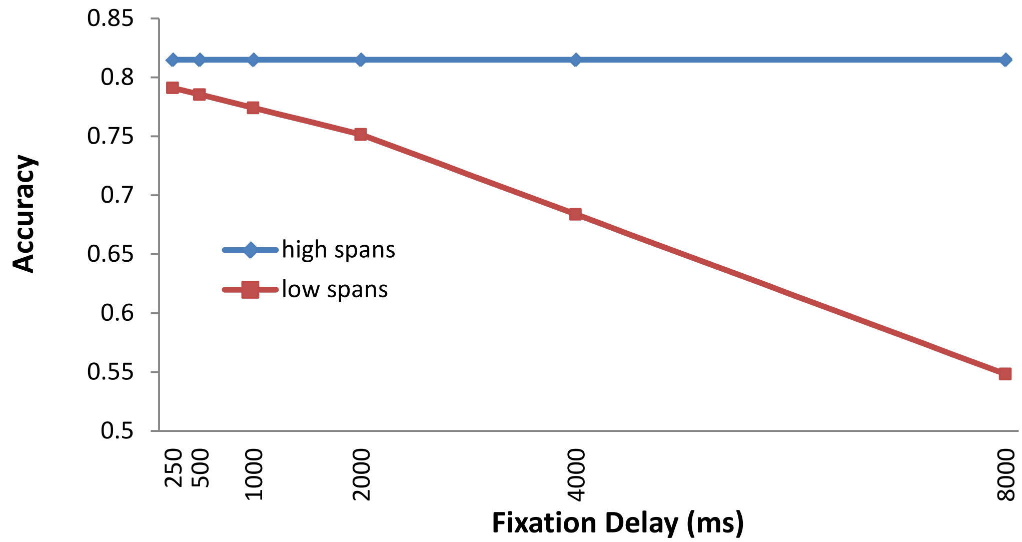

Figure 1b: Goal Neglect Hypothesis.

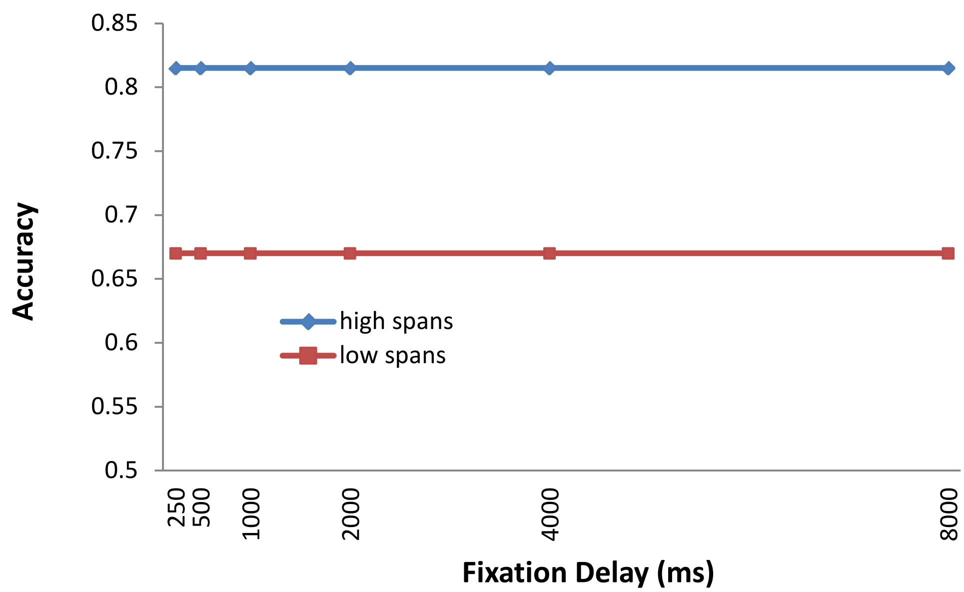

Figure 1c: Response Suppression Hypothesis.

METHOD

Participants and Design

One-hundred twenty-eight male and female undergraduate students, between the ages of 18 and 35 years, from Montana State University were recruited from a subject pool to participate for partial credit as part of an introductory psychology course. Each participant was tested individually in a laboratory session lasting approximately one hour. Six fixation delays (250, 500, 1000, 2000, 4000, and 8000 ms) varied within subjects. The effects of fixation delay on antisaccade accuracy were examined both across the entire range of WMC scores and between extreme groups (high-WMC vs. low-WMC). The primary dependent variable was the proportion of correct target identification trials during the antisaccade task.

Apparatus and Stimuli

A Dell Optiplex Gx270 computer, with an Intel Pentium 4 2.40 GHz processing unit with 1.5 GB of RAM, was used to run the experiment. The antisaccade task was programed and executed using E-studio (version 2.0.8.90) E-prime software from Psychology Software Tools. Stimuli were displayed on a 16-inch Dell monitor, with 1024 x 768 screen resolution and 75 Hz refresh rate. The fixation cross that appeared in the center of the screen during the fixation period was in white Courier New, 14-point bold font. The distractor stimulus was a white asterisk presented in Courier New, 30-point bold font. The ‘O’ and ‘Q’ targets were presented in black Courier New, 14-point bold font. Finally, the ‘##’ pattern that served as a mask covering the target was in black Courier New, 16-point bold font. The distractor, targets, and mask appeared in the same location approximately 12.5 cm horizontally from the center of the fixation cross. This resulted in approximately 11.89° visual angle between fixation cross and distractor, targets, and mask.

Procedure

Prior to engaging in the experiment, participants were given a consent form to read and sign, explaining the potential risks and benefits involved of the experiment. Following completion of the consent form, participants began the experiment by performing the automated operation span task (OSPAN task) designed to index WMC. In this task, participants were presented with a math problem (e.g. $4 \times 5 + 2 = 22$) on the computer screen and were asked to solve the problem using a mouse to click on a box marked “true” or a box marked “false” located below the math problem. A letter then appeared on the screen for one second for participants to hold in memory. After three to seven sets of math problems and letters, participants were presented with a 3×4 matrix of letters and asked to click on the presented letters in the order in which they were shown. A participant’s operation span score was the total number of recalled letters for sets in which all letters were recalled in the correct order.

Following the OSPAN task, participants completed an antisaccade task. Participants were seated at a computer and given instructions for how to complete the task. At the start of each trial, participants were presented with a light grey screen containing the fixation point on the center of the screen. The length of time that the fixation point remained on the screen (i.e., the fixation delay conditions) varied between 250, 500, 1000, 2000, 4000 and 8000 ms. The fixation point disappeared and then the distractor immediately appeared on either the left or right side of the computer screen, disappearing after 300 ms. The target (either an ‘O’ or a ‘Q’) then appeared on the opposite side of the screen as the distractor and remained for 100 ms and was then replaced (masked) by the two ‘##’ symbols. Participants were instructed to identify the target on the screen by pressing either the ‘O’ or ‘Q’ button on the keyboard if an ‘O’ or a Q’ was identified, respectively. Following a participant’s response, there was a two-second interval, and then the next trial began with onset of the fixation point. Participants completed a practice block of 24 trials, followed by three experimental blocks, each containing 48 trials (144 total trials). Each block contained eight trials of each fixation delay, and all trials were randomized within each block. On completion of the antisaccade task, participants were debriefed about the purpose of the experiment, given credit for participating, and sent on their way.

RESULTS

Working Memory Capacity

A quartile-split was calculated on the range of OSPAN scores (0-75) to determine extreme WMC groups. Ten participants were excluded from analyses due to math accuracy below 80% during the OSPAN. Overall mean OSPAN score was 44.36 (*SD* = 17.32). Participants scoring in the upper quartile (score above 55) were deemed as high-span participants, whereas those scoring in the lower quartile (score below 33) were considered low-span participants. This resulted in 29 high-span individuals and 28 low-span individuals.

Antisaccade Accuracy, Fixation Delay, and Working Memory Capacity

To test for an overall effect of fixation delay on antisaccade accuracy, a general linear model was used, with Fixation Delay (250, 500, 1000, 2000, 4000, and 8000 ms) as a within-subject factor. The results revealed a main linear effect of Delay, $F(1,117) = 6.001$, $p = .016$, such that antisaccade accuracy increased across the delay conditions.

To examine the effect of WMC and fixation delay, accuracy was subjected to a general linear mixed-model with Fixation Delay as a within-subject factor and OSPAN (WMC) as a continuous between-subject factor. The analysis yielded a main effect of WMC, $F(1, 116) = 8.44$, $p = .004$, such that overall antisaccade accuracy increased as WMC increased ($r = +.26$). Of particular interest, a linear trend analysis revealed a marginal Fixation Delay × WMC linear interaction, $F(1, 116) = 2.78$, $p = .098$, such that correlations between antisaccade accuracy and WMC tended to increase across Fixation Delay.

Extreme-Groups Analysis

To illustrate the marginal interaction between fixation delay and WMC on antisaccade accuracy, the quartile-split described above was used to separate extreme WMC groups into high- (upper quartile) and low-span (lower quartile) participants. These data are shown in Figure 2. As indicated, high-span participants were significantly more accurate than low-span participants ($F(1,55) = 6.04$, $p = .017$). Pairwise comparisons suggested that the difference in performance between high- and low-span participants was largest at the 2000 ms (*mean difference* = .107, $p = .01$) and 8000 ms (*mean difference* = .112, $p = .015$) fixation delays, and marginal at the 500 ms, 1000 ms, and 4000 ms fixation delays (all ps $\leq .10$). However, the WMC × Fixation Delay linear interaction was not significant, $F(1,55) = 2.119$, $p = .15$.

Given the marginal linear interaction between fixation delay and WMC when the entire distribution of OSPAN scores was used, it was reasonable to examine linear trend analyses separately for high- and low-span participants. For high-span participants, there was a linear increase in antisaccade accuracy across Delay that approached significance, $F(1,28) = 3.72$, $p = .06$, whereas there was no effect of Delay for low-span participants ($F < 1$).

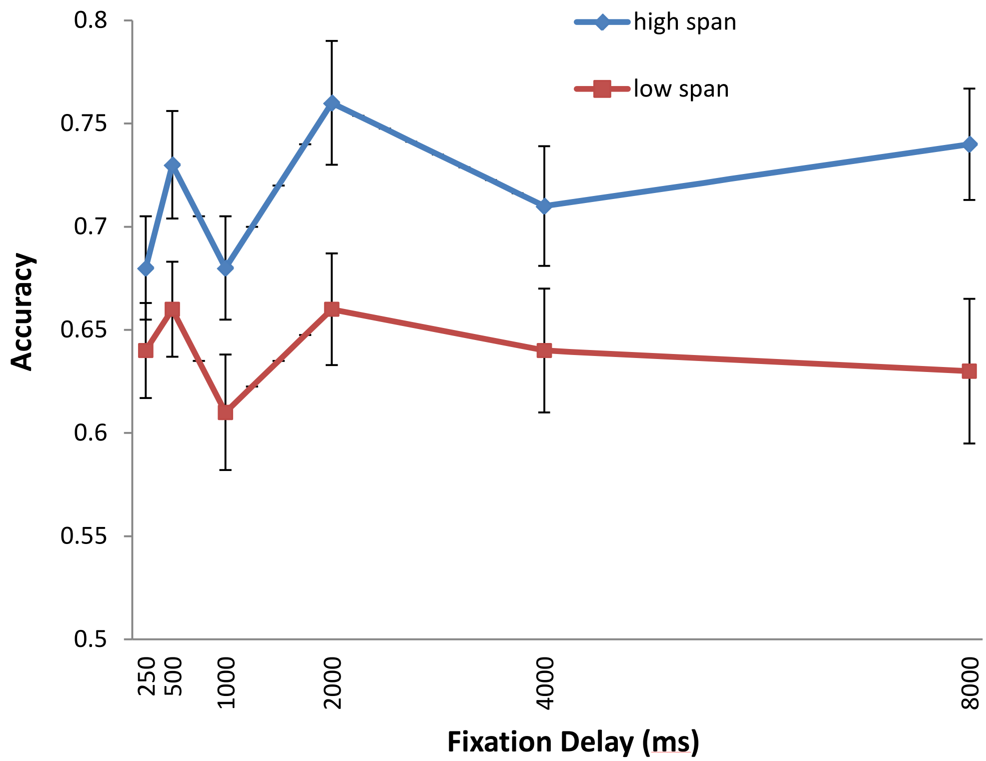

Figure 2: The effect of Fixation Delay on Accuracy for High and Low Spans.

DISCUSSION

The finding that accuracy increased across delay supports the attentional preparation hypothesis that increasing the amount of time before executing an antisaccade can be utilized to increase performance. Further support for this was provided by the finding that high-span participants' accuracy tended to increase across delay, while low-span participants' did not. This suggests that increasing the fixation delay can benefit performance, and it is those individuals high in WMC that can best utilize this preparatory opportunity. Furthermore, rather than experiencing a decrease in accuracy as fixation delay increased, low-span participants' performance was relatively stable. This finding does little to support the notion that individuals low in WMC are neglecting the goal of executing an antisaccade, thus being negatively impacted by the amount of time that passes prior to engaging in the task.

Instead of applying a goal neglect account of control to explain differential performance between high- and low-WMC individuals on attention-demanding tasks, it makes more sense, based on the results of the current experiment, to suggest that differential performance results from the opportunity to prepare oneself to execute the task. Braver et al. (2007) refer to this as proactive control, arguing that high-WMC individuals are more likely to utilize this form of control. The finding of the current study that high-span participants were more accurate than low-span participants, even at the short delays, also suggests that the process that high-span individuals can better prepare for involves response suppression, particularly with responses that involve conflict. By extension, high-span individuals may be more likely to utilize a period to prepare their attention for later execution of conflict resolution. This is counter to the dominant explanation for the effect of WMC on antisaccade performance. As described above, differences in antisaccade performance between high- and low-span participants is said to result primarily from goal neglect (De Jong et al., 1999; Kane et al., 2001; Unsworth et al., 2004); that is, low-span individuals lack the attentional capacity to maintain goals in the face of distraction, which results in a decrease in accuracy. Thus, the difference should come from a decrease in the accuracy of low-span participants over time, rather than in increase in accuracy of high-span participants.

A potential explanation for why there was no evidence of goal neglect is that the paradigm of the current experiment did not allow for goal neglect, as participants completed blocks composed entirely of antisaccade trials. In other words, participants might constantly be reminded of the task goal simply because of the fact that they were engaging in the relevant task 100% of the time. This idea is analogous to the Stroop experiment mentioned above that was conducted by Kane and Engle (2003). To recount, on the rare incongruent trials, low-span participants committed significantly more errors than high-span participants. The authors theorized that increasing the percentage of congruent trials allowed goal neglect to occur, which in turn affected low-span individuals more than high-span individuals. Crucial to the current experiment, Kane and Engle further suggest that paradigms that alter the proportion of congruent to incongruent trials alter the sensitivity of goal neglect. In essence, because the current experiment was composed of 100% incongruent blocks of trials, the paradigm was not sensitive enough to measure goal neglect. Experiment 2 investigated this possibility.

Experiment 2

In Experiment 2, prosaccade trials were included in along with antisaccade trials. Having blocks with randomized prosaccade and antisaccade trials should increase the sensitivity of finding goal neglect, in a similar fashion that having a higher proportion of incongruent to congruent trials can increase the sensitivity of goal neglect in Stroop experiments. Prior to the saccade task, participants completed the same OSPAN task used in Experiment 1. It was predicted that antisaccade trials should yield more errors than prosaccade trials overall, regardless of fixation delay and individual differences in WMC. In addition, consistent with Unsworth et al.'s (2004) finding, individuals with high WMC should outperform individuals low in WMC on antisaccade and prosaccade trials, although to a greater extent on antisaccade trials. However, the main prediction of interest is similar to the goal neglect prediction of Experiment 1 that antisaccade accuracy of low-span participants should greatly decrease as fixation delay increases. This would be due, in part, to temporal uncertainty induced by randomizing prosaccade and antisaccade trials with the occurrence of short and long delays (Neill, Valdes, Terry, & Gorfein, 1992). In essence, if a switch trial following a long fixation delay is preceded by a trial that had a short fixation delay, then the previous response should be relatively fresh in memory. This would result in a brief impairment in discriminating between the previous, yet currently inappropriate response, and the current, appropriate response, thus inducing goal neglect. Furthermore, the previous trial would no longer predict the current trial. Therefore, as fixation delays increase, maintaining the appropriate task goal becomes exceedingly crucial, thus impacting low-span participants more negatively on antisaccade trials than high-span participants. Antisaccade accuracy for high-span participants, however, should remain high and relatively stable across fixation delay.

METHOD

Participants and Design

One-hundred fifty-two male and female undergraduate students, between the ages of 18 and 35 years, from Montana State University were recruited from a subject pool to participate for partial credit as part of an introductory psychology course. Each participant was tested individually in a laboratory session lasting approximately one hour. Six fixation delays (250, 500, 1000, 2000, 4000, and 8000 ms) and two saccade tasks (prosaccade and antisaccade) varied within subjects. The effects of fixation delay and task were examined across the entire range of OSPAN scores. For illustrative purposes, the effect of fixation delay on prosaccade and antisaccade accuracy was also examined between extreme groups (high- vs. low-span participants). The primary dependent variable was the proportion of correct target identification trials during the prosaccade and antisaccade tasks.

Apparatus and Stimuli

The same computer, experiment software, stimuli and specifications used in Experiment 1 were used in Experiment 2. The only exception was the inclusion of word cues that instructed participants about the upcoming saccade task. Word cues were presented in Courier New, 18-point bold font, the ink color changing based on whether participants were required to make a prosaccade or antisaccade. The word cues appeared in the same location as the fixation cross.

Procedure

The procedure was nearly identical to that of Experiment 1, which the exception that the saccade task involved 50% prosaccades and 50% antisaccades and included word cues to instruct participants as to which task to perform. Specifically, at the start of each saccade trial, participants saw either the word "toward" in blue ink for 500 ms, instructing participants to look toward the distractor to catch the target (prosaccade trial), or the word "away" in red ink for 500 ms, instructing participants to look away from the distractor to catch the target (antisaccade trial). After a short delay of 1500 ms, a light grey screen appeared, containing the fixation point (a small, white plus sign) on the center of the screen.. The length of time that the fixation point remained on the screen randomly varied between 250 ms, 500 ms, 1000 ms, 2000 ms, 4000 ms, and 8000 ms. The fixation point then disappeared and the distractor (a white asterisk) immediately flashed on either the left or right side of the computer screen. The target (either an 'O' or a 'Q') then appeared on either the same side of the screen as the distractor (prosaccade condition), or the opposite side as the distractor (antisaccade condition), as per pre-trial instructions. The target remained on screen for 100 ms and was then masked by the two '##' symbols. Participants were instructed to identify the target on the screen by pressing either the 'O' or 'Q' button on the keyboard if an 'O' or a Q' was identified, respectively. After a participant responded, there was a 1.5 second interval followed by the presentation of the word cue for 500 ms. Thus, the inter-trial interval included the word cue and was equated to that of Experiment 1 (i.e., two seconds).

Participants began the task by completing three practice blocks containing 12 trials each (36 total). The first practice block contained only prosaccade trials and was designed to familiarize participants to the ‘toward’ word cues and the required prosaccade responses. The next practice block contained only antisaccade trials and was designed to familiarize participants to the ‘away’ word cues and the required antisaccade responses. The final block contained six prosaccade trials and six antisaccade trials, presented in random order, designed to familiarize participants with how the actual experiment would run. Following the practice blocks, participants completed three experimental blocks, each containing 24 prosaccade trials and 24 antisaccade trials (48 trials per block), resulting in 144 total trials. The prosaccade and antisaccade trials were presented in random order. The amount of fixation delay conditions remained equal across blocks and saccade type, such that each fixation delay randomly occurred four times for each saccade type per block.

RESULTS

Working Memory Capacity

Similar to Experiment 1, a quartile-split was calculated on the range of OSPAN scores (0-75) to determine extreme WMC groups. Ten participants were excluded from analyses due to math accuracy below 80% during the OSPAN task. The overall mean OSPAN score was 42.75 (*SD* = 16.33). Participants scoring in the upper quartile (score above 54) were deemed as high-span participants, whereas those scoring in the lower quartile (score below 31) were considered low-span participants. This resulted in 36 high-span individuals and 35 low-span individuals.

Saccade Accuracy and Fixation Delay

As mentioned above, saccade accuracy is the proportion of correct target identification responses to total trials. Overall saccade accuracy was analyzed using a general linear model with Fixation Delay (250,500, 1000, 2000, 4000, and 8000 ms) and Saccade Type (prosaccade and antisaccade) as within-subjects factors. As predicted, the analysis yielded a linear main effect of Delay ($F(1,141) = 23.03$, $p < .001$), and a main effect Saccade Type ($F(1,141) = 799.77$, $p < .001$), such that accuracy increased as Fixation Delay increased and prosaccade trials were more accurate than antisaccade trials. In addition, there was a significant interaction between Delay and Saccade Type, $F(1, 141) = 4.31$, $p = .04$, indicating that antisaccade accuracy increased at a greater rate across Delay compared to prosaccade accuracy.

Saccade Accuracy, Fixation Delay, and Working Memory Capacity

Saccade accuracy was also analyzed using a general linear mixed model with Fixation Delay and Saccade Type as within-subjects factors and OSPAN (WMC) as a continuous between-subject factor. As predicted, the analysis revealed a significant linear main effect of WMC, $F(1, 140) = 14.49$, $p < .001$, such that overall saccade accuracy increased as WMC increased ($r = +.31$). However, neither the WMC × Saccade Type, the WMC × Delay, nor the three-way interaction was significant (all Fs < 1).

Given the significant overall linear interaction between saccade type and delay, and the main effect of WMC, general linear mixed models were used to examine the effect of Fixation Delay separately for antisaccade accuracy and prosaccade accuracy using the entire range of OSPAN scores as a between-subjects variable. Regarding antisaccade accuracy, the only significant result was a main effect of WMC, $F(1, 140) = 10.65$, $p = .001$, such that accuracy increased as WMC increased ($r = +.27$). For prosaccade accuracy, there was also a main effect of WMC, $F(1, 140) = 8.73$, $p = .004$, such that accuracy increased as WMC increased ($r = +.24$). However, as with antisaccade accuracy, there was no main effect of Delay ($p = .17$), nor a WMC × Delay interaction ($F < 1$).

Extreme-Groups Analysis

To illustrate the main effect of WMC on saccade accuracy and the effect of saccade type and delay on accuracy as a function of WMC, a mixed linear trend analysis was conducted with extreme WMC groups (high- vs. low-span participants) as a dichotomous between-subjects variable, and Delay and Saccade Type as within-subjects variables. As shown in Figure 3, high-span participants were significantly more accurate than low-span participants regardless of Saccade Type ($F(1, 69) = 11.39$, $p = .001$), and prosaccade trials were more accurate than antisaccade trials ($F(1, 69) = 384.06$, $p < .001$). Furthermore, accuracy increased across Delay regardless of saccade type ($F(1, 69) = 4.58$, $p = .04$). However, the Delay x WMC, Type x WMC, and the three-way interaction were not significant (all *F*s < 1).

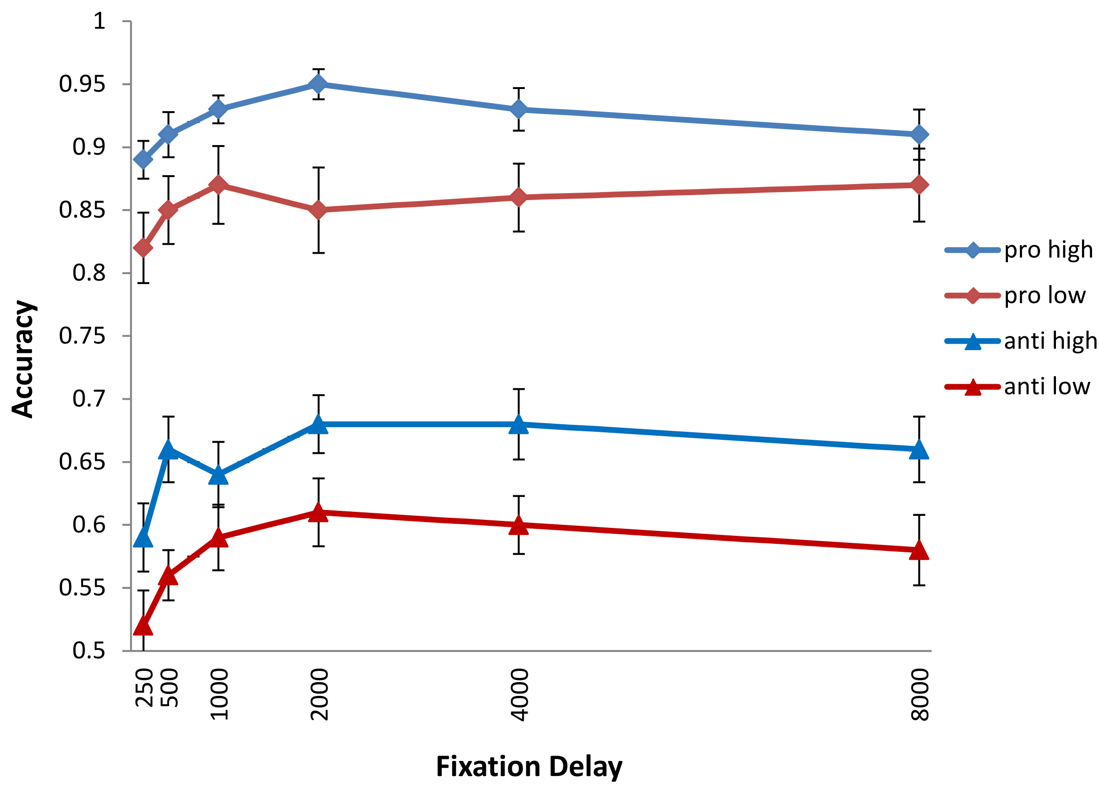

Figure 3: The effect of Fixation Delay by Type and Span. (Note: pro = prosaccade; anti = antisaccade; high = high spans; low = low spans)

DISCUSSION

The results of Experiment 2 were consistent with the prediction that prosaccade accuracy would be greater than antisaccade accuracy overall, and that high-span participants would outperform low-span participants. This supports past research demonstrating that antisaccade trials are more difficult than prosaccade trials, due to the requirement of attentional control inherent on antisaccade trials. Surprisingly, however, while high-span participants had higher saccade accuracy overall compared to low-span participants, the difference in performance between the two groups was constant across prosaccades and antisaccades. This suggests that high-span individuals are superior at engaging in response suppression, yet are still affected by the conflict involved in antisaccade trials.

Also surprising regarding the predictions of Experiment 2 was that there was a benefit of delay on antisaccade accuracy for both high- and low-span participants. This suggests, and seems somewhat contradictory to the goal neglect literature, that mind wandering was not influencing the ability to successfully execute antisaccades. If this were the case, antisaccade accuracy for low-span participants would have *decreased* across delay. This is especially interesting, given the fact that prosaccade trials were included in the task particularly to increase the likelihood of succumbing to goal neglect at the long delays. As the delays increased, the ability to discriminate between the previous, yet inappropriate response and current, appropriate response should have decreased (e.g., Neill et al., 1992). Furthermore, the ability to use the previous trial to predict the current trail was eliminated. Therefore, a susceptibility of goal neglect should have increased for low-span participants. However, the inclusion of prosaccade trials seemed to have the opposite effect.

Also interesting was the lack of an effect of delay on prosaccade accuracy. Of greater interest was that neither high- nor low-span participants were affected by delay. Unsworth et al. (2004) argued that what differentiated the performance of high- and low-span participants in their experiment was the actual voluntary generation and execution of saccades, regardless of whether they were antisaccades or prosaccades. One crucial finding was that low-span participants had larger response latencies for both prosaccades and antisaccades. In other words, low-span participants were slower to generate and execute saccades compared to high-span participants, even on prosaccades trials, which should be more automatic. Unsworth et al's argument, however, was that it was succumbing to goal neglect (which low-span individuals are more prone to) that was responsible for compromising the ability to generate and execute saccades. However, the results of the current Experiment do not support that view. If so, then low-span participants should *decrease* in prosaccade accuracy as the fixation delay increased.

A potential issue with the current Experiment, however, is the built in assumption that long fixation delays will increase the instance of mind wandering, thereby increasing goal neglect. While logical, this assumption was not directly examined in Experiment 1 or 2. Therefore, Experiment 3 will investigate this assumption more fully by asking participants to report what they were thinking about during antisaccade and prosaccade trials. This would not only shed light on the assumption of fixation delays increasing the likelihood of mind wandering, but perhaps conclusively rule out goal neglect as being solely responsible for differentiating high- and low-span participants' performance on antisaccade tasks.

Experiment 3

For Experiment 3, thought-probes similar to those used by McVay and Kane (2009) were used to index task-unrelated thoughts (i.e., mind wandering) during the fixation delays prior to being required to make prosaccades and antisaccades. Each saccade trial began in a similar manner as that of Experiment 2, with the exception that on 25% of trials, following the saccade response participants responded to a question that asked what they were thinking about during that trial. The predictions of Experiment 3 were the same as those of Experiment 2, with the addition of expected outcomes for the thought-probes. Specifically, low-span individuals should have a higher rate of mind wandering overall compared to high-span individuals. In addition, the rate of mind wandering should increase as the length of the fixation delay increases. Furthermore, the rate of mind wandering should be positively related to saccade errors. This rests partly on the finding of Unsworth et al. (2004) regarding the presumed effect of goal neglect on the voluntary generation and execution of both antisaccades and prosaccades. Yet, it still might be the case that the rate of mind wandering is more positively related to antisaccade errors than prosaccade errors, because antisaccades involve both the suppression of a pre-potent response and the generation of a voluntary response. Finally, if goal neglect is crucial to producing a separation in performance between high- and low-span participants, then it is predicted that the rate of mind wandering will mediate the effect of WMC on saccade accuracy.

However, if attentional preparation is what accounts for differential WMC-based saccade performance, then saccade accuracy, particularly antisaccade accuracy, for high-span participants should increase as fixation delay increases. On the other hand, for low-span participants, saccade accuracy should either remain stable across delays, or improve at a smaller rate than that of high-span participants. Furthermore, the rate of mind wandering will not be a mediating factor of saccade accuracy above and beyond WMC.

METHOD

Participants and Design

One-hundred thirty-five male and female undergraduate students, between the ages of 18 and 35 years, from Montana State University were recruited from a subject pool to participate for partial credit as part of an introductory psychology course. Data from seventeen participants were removed from analyses because of incomplete data due to technical issues or participants choosing not to complete the experiment. This resulted in usable data from 118 participants. Each participant was tested individually in a laboratory session lasting approximately one hour. Four fixation delays (500 ms, 2000 ms, 4000 ms, and 8000 ms) and two saccade tasks (prosaccade and antisaccade) varied within subjects. The reduction in the amount of fixation delays for Experiment 3 was due to the need for an increase in the amount of overall saccade trials so that enough thought probes (25% of trials) could be utilized. Thus, the proportion of though probes remained constant within and between subjects. The effect of fixation delay and mind wandering on saccade accuracy was examined across the entire range of OSPAN scores. The effect of fixation delay and mind wandering on prosaccade and antisaccade accuracy was also examined between extreme groups (high-WMC vs. low-WMC). The primary dependent variables were the proportion of correct target identification trials during the prosaccade and antisaccade tasks.

Apparatus and Stimuli

E-studio (version 2.0.8.90) E-prime software from Psychology Software Tools was used to program and present the saccade stimuli. The experiment was run on a Panasonic CF-50 ToughBook laptop, with a Mobile Intel Pentium 4-M 2.00 GHz processor, 768 MB of RAM, and an AT Mobility Radeon 7500 Display Adapter. Task stimuli were presented on a 17-inch NEC Multisync LCD 1760v monitor, with a 60 Hz refresh rate, attached to the laptop via an RS232 USB serial port.

The word 'toward' that instructed a prosaccade trial was presented in blue Courier New, 18-point bold font; the word 'away' indicating an antisaccade trial appeared in red Courier New, 18-point bold font. The fixation cross that appeared in the center of the screen during the fixation period was in white Courier New, 22-point bold font. The distractor stimulus was a white asterisk presented in Courier New, 36-point bold font. The 'O' and 'Q' targets were presented in black Courier New, 20-point bold font. Finally, the '##' pattern that served as a mask covering the target was in black Courier New, 25-point bold font. The distractor, targets, and mask appeared in the same location approximately 13-cm horizontally from the center of the fixation cross. This resulted in approximately 12.4° visual angle between fixation cross and distractor, targets, and mask.

Procedure

The procedure was similar to that of Experiment 2, which the exception that a shorter version of the OSPAN task was used to minimize the length of the experiment, thought probes occurred on 25% of prosaccade and antisaccade trials, and there were four fixation delays. The shorter version of the OSPAN task was taken from Hutchison (2007). Participants were presented with a simple math problem on the screen, along with a word that followed the math problem (e.g. “Is 9/3 + 2 = 4? bottle”). Participants were instructed to say the math problem out loud, indicate whether it was correct by saying “yes” or “no,” and then say the word aloud. Series of math problems and words varied from two to six math problem/word sequences. Participants were instructed to remember each word in each series. After each series of math problem/word sequences, participants were presented with three question marks (???) and instructed to repeat out loud each word they saw in that series to the experimenter. OSPAN scores were the total amount of words the participant recalled for each series in which all the words were recalled in the correct order, which ranged from 0-50.

Following the OSPAN task, participants began the saccade task. At the start of each saccade trial, participants saw either the word “toward” in blue ink for 500 ms, instructing participants to look toward the cue to catch the target (prosaccade trial), or the word “away” in red ink for 500 ms, instructing participants to look away from the cue to catch the target (antisaccade trial). After a short delay of 1500 ms, a light grey screen appeared, containing a fixation point (a small, white plus sign) on the center of the screen. The length of time that the fixation point remained on the screen randomly varied between 500 ms, 2000 ms, 4000 ms, and 8000 ms. The fixation point then disappeared and a cue (a white asterisk) immediately flashed on either the left or right side of the computer screen. A target (either an ‘O’ or a ‘Q’) then appeared on either the same side of the screen as the cue (prosaccade condition), or the opposite side of the screen as the cue (antisaccade condition), as per pre-trial instructions. The target remained on screen for 100 ms and was then masked by two '##' symbols. Participants were instructed to identify the target on the screen by pressing either the 'O' or 'Q' button on the keyboard if an 'O' or a Q' was identified, respectively. Following a participant's response, the next trial began. The inter-trial interval was the same as the saccade tasks in Experiment 1 and 2 (i.e., two seconds).

As previously mentioned, 25% of the saccade trials (36 prosaccade and 36 antisaccade, totaling 72) were immediately followed by a thought-probe screen assessing task-unrelated thoughts (TUTs). The thought-probe instructions were taken from McVay and Kane (2009), which were explained to participants prior to beginning the saccade task. Specifically, on thought-probe trials, participants saw the question "What were you thinking about during the trial you just completed?" appear on the screen, along with seven response options: (1) *task* (i.e., thinking about the stimuli and the appropriate response); (2) *task performance* (i.e., evaluating one's own performance); (3) *everyday stuff* (i.e., thinking about recent or impending life events or tasks); (4) *current state of being* (i.e., thinking about conditions such as hunger or sleepiness); (5) *personal worries* (i.e., thinking about concerns, troubles, or fears); (6) *daydreams* (i.e., having fantasies disconnected from reality); or (7) *other* (i.e., other thought types). Participants were instructed to respond by pressing the corresponding number on the keyboard. Following a participant's response, the next trial began.

Participants began the task by completing three practice blocks containing 12 trials each (36 total). The first practice block contained only prosaccade trials and was designed to familiarize participants to the ‘toward’ word cues and the required prosaccade responses. The next practice block contained only antisaccade trials and was designed to familiarize participants to the ‘away’ word cues and the required antisaccade responses. The final block contained six prosaccade trials and six antisaccade trials, presented in random order, designed to familiarize participants with how the actual experiment would run. Participants were then instructed about the thought probes. Following the practice blocks, participants completed three experimental blocks, each containing 48 prosaccade trials and 48 antisaccade trials (96 trials per block), resulting in 288 total experimental trials. The prosaccade and antisaccade trials were presented in random order. The amount of fixation delay conditions and percentage of thought probes remained equal across blocks and saccade type, such that each fixation delay occurred 12 times for each saccade type per block, and each fixation delay per block contained three thought probes. Fixation delay and thought probes were presented in random order. Following the saccade task, participants were debriefed about the purpose of the experiment, given credit for participating, and sent on their way.

RESULTS

Working Memory Capacity

To determine our extreme WMC groups, a quartile-split was calculated on the range of OSPAN scores (0-50). Two participants were excluded from analyses due to math accuracy below 80% during the OSPAN task, resulting in the analysis of 116 participants. The overall mean OSPAN score was 10.53 (SD = 7.5). Participants scoring in the upper quartile (score above 14) were deemed high-span participants, whereas those scoring in the lower quartile (score below 6) were considered as low-span participants. This resulted in 28 high-span individuals and 35 low-span individuals.

Saccade Accuracy and Fixation Delay

Overall saccade accuracy was analyzed using a general linear model with Fixation Delay (500, 2000, 4000, and 8000 ms) and Saccade Type (prosaccade and antisaccade) as within-subjects factors. As predicted, there was a main effect of Saccade Type ($F(1,115) = 1100.55$, $p < .001$), and a main linear effect of Delay ($F(1,115) = 51.01$, $p < .001$), such that prosaccade trials were more accurate than antisaccade trials and accuracy increased as Fixation Delay increased. However, the linear interaction between Delay and Saccade Type failed to reach significance, $F(1, 115) = 2.50$, $p = .12$.

Saccade Accuracy, Fixation Delay, and Working Memory Capacity

Saccade accuracy was also analyzed using a general linear mixed model with Fixation Delay and Saccade Type as within-subjects factors and OSPAN (WMC) as a continuous between-subject factor. As predicted, the analysis revealed a significant main effect of WMC, $F(1, 114) = 7.02$, $p = .009$, such that overall accuracy increased as WMC increased ($r = .24$). In addition, the WMC × Saccade Type interaction was marginally significant, $F(1, 114) = 3.44$, $p = .07$. However, the WMC × Delay interaction and the three-way interaction were not significant (all Fs < 1).

General linear mixed models were used to illustrate the effect of fixation delay separately for antisaccade and prosaccade accuracy using the entire range of OSPAN scores as a continuous between-subjects variable. Regarding antisaccade accuracy, there was a main effect of Delay, $F(1, 114) = 4.09$, $p = .046$, such that accuracy increased across Delay. In addition, there was a linear main effect of WMC, $F(1,114) = 6.60$, $p = .012$, revealing that accuracy increased as WMC increased ($r = .24$). However, the WMC × Delay interaction did not reach significance ($F(1,114) = 1.22$, $p = .27$). For prosaccade accuracy, the only effect that was statistically significant was a main effect of delay, $F(1, 114) = 6.3$, $p = .013$, such that accuracy increased across delay. Neither the main effect of WMC ($F(1,114) = 1.27$, $p = .26$), nor the WMC × Delay interaction, $F(1,114) = 1.40$, $p = .24$, were significant.

Mind Wandering and Fixation Delay

Task-unrelated thoughts (TUTs) were considered as any response from three to seven on the thought-probes. Thus, responses three through seven were collapsed into a single score and used as an indicator of a TUT. TUT rate was calculated by dividing the amount of TUTs by the number of trials that had thought probes (25% of total trials). Overall TUT rate was subjected to a general linear model with Saccade Type (prosaccade and antisaccade) and Fixation Delay (500, 2000, 4000, and 8000) as within-subjects variables. The linear main effect of Delay was not significant ($F < 1$). However, the results yielded a significant main effect of Saccade Type, $F(1,115) = 7.20$, $p = .008$, such that TUT rate was higher for antisaccade compared to prosaccade trials. In addition, there was a significant Saccade Type × Delay linear interaction, $F(1,115) = 5.28$, $p = .02$, indicating that TUT rate increased across Delay for prosaccade trials, but not antisaccade trials.

Given the Saccade Type × Delay linear interaction, general linear mixed models were used to illustrate the effect of fixation delay on TUT rate separately for antisaccade and prosaccade trials. Regarding antisaccade trials, the main effect of Delay failed to reach significance ($F < 1$). However, for prosaccade trials, there was a linear main effect of Delay, $F(1, 115) = 4.86$, $p = .03$, such that TUT rate increased across delay.

Mind Wandering, Fixation Delay, and Working Memory Capacity

TUT rate was also analyzed using a general linear mixed model with Fixation Delay and Saccade Type as within-subjects factors and OSPAN (WMC) as a continuous between-subject factor. As predicted, the analysis revealed a significant linear main effect of WMC, $F(1, 114) = 4.60$, $p = .03$, such that overall TUT rate decreased as WMC increased ($r = -.20$). However, all other interactions involving WMC were not significant (all Fs < 1), and thus are not reported here.

Mind Wandering, Working Memory Capacity, and Saccade Accuracy across Delay

Correlations were used to examine possible relations between saccade accuracy, TUT rate, and WMC. As shown in Tables 1a and 1b, OSPAN (WMC) was negatively correlated with overall TUT rate, indicating that as WMC increased, TUT rate decreased. In addition, both WMC and TUT rate were significantly correlated with overall antisaccade accuracy, demonstrating that accuracy increased as WMC increased (r = .23), and accuracy decreased as TUT rate increased ($r = -.19$). Table 1a displays correlations between antisaccade accuracy, TUT rate and WMC at each fixation delay. Regarding prosaccade accuracy, neither WMC nor TUT rate was significantly correlated with overall prosaccade accuracy (Table 1b).

Partial correlations were used to test for the contribution of TUTs and WMC separately on overall antisaccade accuracy. When controlling for the effect of TUT rate, significant correlations between WMC and antisaccade accuracy remain ($r = .20$). However, when controlling for the effect of WMC, correlations between TUT rate and antisaccade accuracy fail to reach significance ($r = -.15$, $p = .11$). These results suggest that mind wandering does not significantly contribute to the effect of WMC on antisaccade accuracy beyond what WMC contributes. A 2 (Saccade Type) x 4 (Fixation

Delay) repeated-measures linear model ANCOVA was also conducted on overall accuracy, with TUT rate as a covariate to examine whether TUT rate mediated the effects of saccade type and delay. The main effects of Saccade Type and Fixation Delay remained, whereas none of the interactions with TUT rate reached significance (all Fs < 1). Finally, stepwise regression analyses were conducted on overall saccade accuracy to model the effects of TUT rate and WMC. When WMC was entered into the model first, the change in R^2 was not significant ($\Delta = .025$, $p = .082$). However, when TUT rate was entered first, the change in R^2 was significant ($\Delta = .042$, $p = .025$).

In sum, antisaccade performance is positively correlated with WMC and negatively correlated to TUT rate. However, the relation between WMC and accuracy is not mediated by TUTs, such that the relation remains strong even without the contribution of TUTs. Similarly, the effects of delay and saccade type on accuracy were not mediated by TUT rate. Finally, TUT rate has no predictive value above and beyond what WMC predicts, whereas WMC has predictive value beyond TUT rate.

Extreme-Groups Analysis

To illustrate the effect of WMC on saccade accuracy and the relation between TUT rate and overall performance on saccade trials, a quartile split on the range of OSPAN scores was used to separate WMC into high (upper quartile) and low (lower quartile) WMC groups. A mixed linear trend analysis was conducted on saccade accuracy with WMC as a dichotomous between-subjects variable (high- vs. low-span participants), and Fixation Delay (500, 2000, 4000, and 8000 ms) and Saccade Type (prosaccade and antisaccade) as within-subjects variables. Although the main effect of

WMC failed to reach significance ($F(1,61) = 2.52$, $p = .12$), there was a significant WMC × Saccade Type interaction, $F(1,61) = 4.43$, $p = .04$, such that high-span participants were more accurate than low-span participants on antisaccade trials, but not prosaccade trials (see Figure 4). However, the three-way WMC × Saccade Type × Delay interaction was not significant ($F < 1$).

Overall, high-span participants reported having less TUTs ($m = .33$) than low-span participants ($m = .45$), with the difference approaching significance, $t(61) = 1.93$, $p = .058$. To examine the effects of WMC, TUT rate, and saccade type, overall saccade accuracy was subjected to a 2 (high- vs. low-span participants) × 2 (Saccade Type) × 2 (thought-probe report: TUT vs. Task-Related Thoughts, TRTs) mixed-model linear ANOVA, with WMC as a dichotomous between-subjects variable and Saccade Type and Thought-Probe report as within-subjects variables. Some individuals reported having no TUTs in some of the delay conditions. Thus, saccade accuracy as a function of TUT rate could not be calculated in those conditions. Therefore, thought-probe report was collapsed across delay due to missing cells in some of the delay conditions (the data from one participant was not used, due to no reports of a TUT in any of the delay conditions). The results yielded a main effect of Saccade Type ($F(1,60) = 348.69$, $p < .001$) and Thought-Response Type ($F(1,60) = 7.42$, $p = .008$), such that prosaccades were more accurate than antisaccades and accuracy was higher under TRTs than TUTs, respectively. Interestingly, as shown in Table 2a, high-span participants' overall accuracy appears more negatively impacted by TUTs than that of low-span particpants. High-span participants experienced an 11% decrease in accuracy when reporting that they had a

TUT, whereas low spans experienced only a 4% decrease in accuracy. Furthermore, the difference in performance was even larger during antisaccade trials, in which high spans experienced a 21% decrease under TUTs, whereas low spans experienced only a 7% decrease (Table 2b). However, neither the main effect of span, nor the span x saccade type or span x saccade type x thought type was significant (all *F*s < 1).

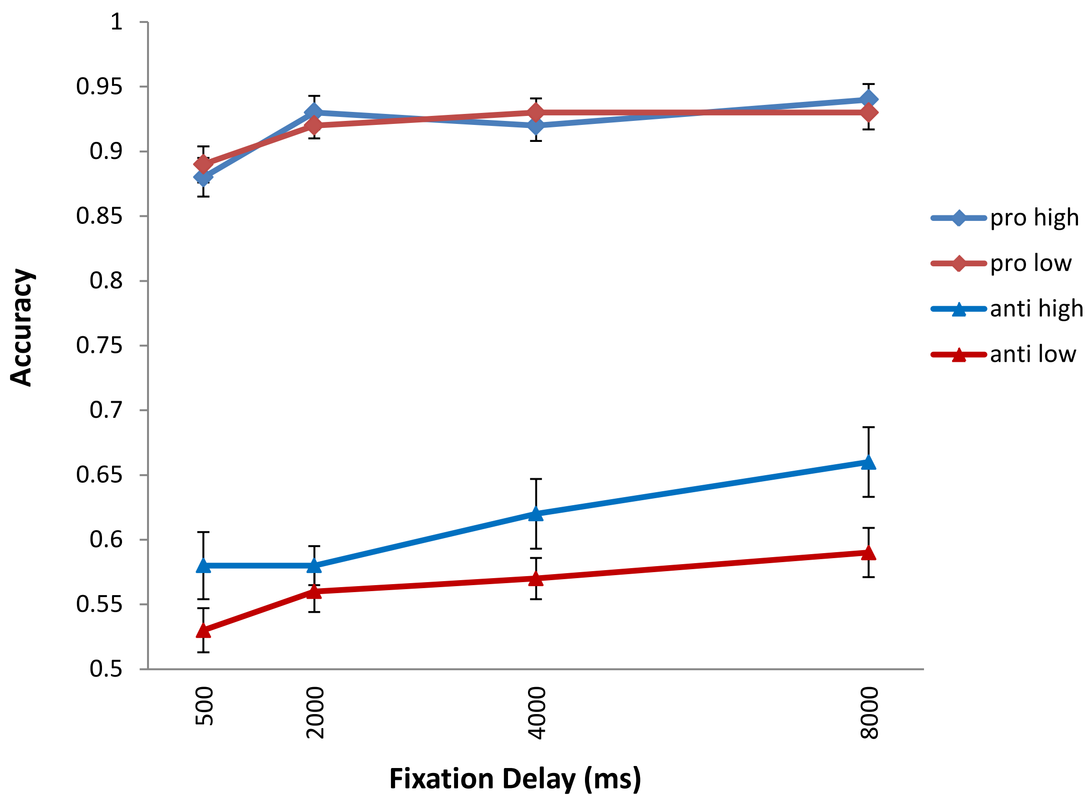

Figure 4: The effect of Fixation Delay by Type and Span. (Note: pro = prosaccade; anti = antisaccade; high = high spans; low = low spans).

Table 1a. Correlations between WMC, TUTs, and antisaccade accuracy at each fixation delay.

	TUTs	Overall	Anti500	Anti2000	Anti4000	Anti8000
WMC	-.197*	.234*	.208*	.117	.230*	.230*
TUTs		-.191*	-.073	-.173	-.236*	-.166
Anti500				.666**	.503**	.544**
Anti2000					.699**	.657**
Anti4000						.749**

Table 1b. Correlations between WMC, TUTs, and prosaccade accuracy at each fixation delay.

	TUTs	Overall	Pro500	Pro2000	Pro4000	Pro8000
WMC	-.197*	.105	.013	.156	.026	.166
TUTs		-.099	-.086	-.046	-.004	-.175
Pro500				.578**	.509**	.533**
Pro2000					.623**	.537**
Pro4000						.559**

Table 2a. Overall saccade accuracy as a function of TRTs and TUTs by WMC

WMC	TRTs	TUTs
	M (SE)	*M (SE)*
High Span	.79 (.03)	.68 (.02)
Low Span	.75 (.02)	.71 (.02)

Table 2b. Prosaccade and antisaccade accuracy as a function of TRTs and TUTs by WMC.

	Prosaccade		Antisaccade	
WMC	TRT	TUT	TRT	TRT
	M (SE)	*M (SE)*	*M (SE)*	*M (SE)*
High Span	.94 (.01)	.90 (.04)	.64 (.03)	.50 (.04)
Low Span	.94 (.02)	.91 (.02)	.55 (.03)	.52 (.03)

DISCUSSION

The antisaccade results, overall, are consistent with past research (Unsworth et al., 2004; Kane et al., 2001) in that high-span participants outperformed low-span participants. This confirms that WMC captures a fundamental aspect of attention control; namely the capacity to use goal information in the face of distraction to successfully complete interference-rich tasks. That antisaccades require attentional control for successful completion was also supported by the finding that antisaccades were far more inaccurate than prosaccades, in which participants can simply rely on the automatic reflex of looking toward the distractor to identify the target. However, somewhat inconsistent with past research is a lack of a WMC difference on prosaccade trials. Unsworth et al. (2004) found that high-span participants outperformed low-span participants even on prosaccade trials. However, this difference was contributed to the voluntary execution of the prosaccade using an endogenous control arrow cue, at which high-span indivduals were faster and more accurate. Under involuntary conditions, high- and low-span participants did not differ in prosaccade performance. The results of the current Experiment suggest that the prosaccade trials did not require voluntary saccade execution, thus high- and low-span participants did not differ.

In terms of goal neglect, the overall results are consistent with past research (McVay & Kane, 2009) demonstrating that low spans tended to mind wander more than high spans. However, this did not seem to cause WMC differences in saccade performance. In fact, WMC differences in antisaccade accuracy occurred only when both groups reported being on task (see Table 2). In other words, goal neglect, as measured by

TUT rate, did not contribute to correlations between WMC and antisaccade accuracy above and beyond with WMC accounts for. Similarly, when used as a covariate, TUT rate did not mediate the effects of delay and saccade type on accuracy. In essence, though low spans are more susceptible to mind wandering, mind wandering was not a factor in accounting for span differences in saccade performance. This is further supported by a significant benefit of delay on accuracy. Rather than low spans decreasing in antisaccade accuracy across delay, as would be predicted from a goal neglect account, low spans increased in accuracy across delay, albeit at a smaller rate than high spans.

However, the validity of the thought probes as a measure of mind wandering in this task can be called into question. Recall that there was an effect of saccade type on TUT rate. Specifically, TUTs were higher during fixation delays for antisaccade compared to prosaccade trials. If thought probes were truly measuring mind wandering, there is no logical reason for this to happen. Mind wandering should occur at least as strongly during the fixation delays for prosaccade as antisaccade trials. If anything, the knowledge that it is an antisaccade trial should reduce mind wandering, as participants know antisaccades are more effortful, requiring vigilant attention. Therefore, attentional vigilance during the fixation delay should reduce mind wandering, especially compared to prosaccade trials in which participants can simply rely on the distractor cue for successful task completion. Paradoxically, on the other hand, there was an interaction between saccade type and delay on TUT rate. In particular, mind wandering increased across delay for prosaccade but not antisaccade trials. This could support the view that thought probes were capturing mind wandering. To the extent that prosaccades are relatively automatic, and that effortless attention increases the probability of mind wandering, it is logical to expect that mind wandering would increase as the delay increases. Therefore, mind wandering should increase across delay to a larger extent for prosaccade versus antisaccade trials.

These variations in TUT rates suggest that either seeing the instructional words prior to saccade trials somehow differentially induced mind wandering, that participants are not capable of introspecting back to the delay period, or that participants were using their responses on thought probes to justify their errors. That participants would use the probes to justify their errors could explain why saccade accuracy was lower for TUTs than task-related thoughts; on making an error, participants could have simply reported that they were off task to justify their error. However, that high-span participants' saccade accuracy was more negatively impacted for TUTs than that of low-span participants provides an intriguing suggestion. It could suggest that high-span individuals are more able than low-span individuals to self-reflect back to the delay period about the type of thoughts they were experiencing. In other words, high-span individuals may be more likely to notice when they are off task. Thus the negative correlation between antisaccade accuracy and TUT rate truly reflects that mind wandering, while less than that of low-span participants, negatively impacted performance. Alternatively, high-span individuals might also be the ones who experience anxiety about making an error, and thus more likely than low-span individuals to feel the need to justify their errors, which occurred more for antisaccade trials. It is unclear at this point exactly how accurately participants introspected in response to thought probes. More research should be done to understand these issues.

The increase in antisaccade accuracy across delay for both high- and low-span participants suggests that what differentiates performance is not necessarily goal neglect, as emphasized by past research (Kane et al., 2001; Unsworth et al., 2004). Rather, it is more consistent with attentional preparation and overall response suppression. As the delay increased, more time was provided to prepare attention for the difficult task of inhibiting the distractor cue and generating the correct saccade. Both high- and low-span participants benefitted from the delay, yet high-span participants' antisaccade accuracy was still higher than that of low span participants. This suggests that, although low-span individuals use the delay period to prepare their attention, high-span individuals can utilize the preparatory opportunity to a greater degree. It further suggests that the separation in performance between extreme WMC groups hinges on a capacity to prepare attention for response suppression, rather than general goal neglect interfering with performance. These possibilities could be substantiated by further research.

GENERAL DISCUSSION

In three experiments, the effects of fixation delay and WMC on saccade accuracy was examined, thereby testing several possible hypotheses about why span differences exist in antisaccade tasks. In general, the results do not provide support for goal neglect as the mechanism responsible for WMC differences in antisaccade performance. The results are more consistent with the hypothesis that differences result from a greater capacity of high-span individuals to utilize attentional preparation. In Experiment 1, it was demonstrated that antisaccade accuracy increased across delay overall, and that high-span participants tended to increase in accuracy whereas low-span participants' accuracy remained low but stable. These results suggest that the OSPAN is tapping an attentional preparation construct that emerges in interference-rich antisaccade tasks. If it were the case that goal neglect was primarily responsible, low-span individuals would be negatively impacted by their susceptibility for goal neglect, thereby decreasing in accuracy as the fixation delay increased. Therefore, the findings suggest that there is separation in antisaccade performance between high- and low-span individuals. Yet, the reason for it appears inconsistent with the current goal neglect explanation (see Kane et al., 2001; Unsworth et al., 2004). Instead, it might be that low-span individuals lack the capacity to engage in attentional preparation to the extent that high-span individuals can.

There was also little evidence for goal neglect in Experiment 2. Specifically, there was an overall benefit of delay for both high- and low-span participants, demonstrating that accuracy increased across delay. These results suggest that mind wandering was not hampering antisaccade performance. If so, accuracy for low-span participants would have decreased across delay, especially due to the fact that the blocks were mixed with both prosaccade and antisaccade trials. Recall that prosaccade trials were intermixed with antisaccade trials to increase the need for goal maintenance across the fixation delays, thereby increasing susceptibility in low-span participants for goal neglect as the delays increased (Unsworth, et al., 2004). This is due, in part, to a diminished temporal discriminability induced by the previous trial not predicting the current trial. Such a reduction in temporal discriminability would be greatest at the longer delays (Neill et al., 1992). In such situations, low-span individuals should perform more poorly on antisaccade trials. Yet, both high- and low-span participants improved at the same rate on antisaccade and prosaccade trials across delay conditions. There was a main effect of WMC, indicating that high-span participants were better than low-span participants on both antisaccade and prosaccade trials. Again, considering the WMC-based difference in antisaccade performance, the result suggests that high-span individuals have a stronger capacity for successfully performing antisaccade tasks. However, as with Experiment 2, there is little to suggest that this difference in performance reflects general goal neglect.

Both Experiments 1 and 2 yielded results inconsistent with a goal neglect argument, instead suggesting that attentional preparation may be a contributing factor. In Experiment 3, a goal neglect account was further weakened by the demonstration that mind wandering did not contribute to the relation between WMC and antisaccade performance above and beyond what WMC contributes. Specifically, it was shown that when TUT rate was controlled for, the correlation between antisaccade accuracy and

WMC remained strong. Similarly, as a covariate, mind wandering did not influence the effect of delay and saccade type on accuracy. Furthermore, mind wandering had no predictive value over WMC, whereas WMC had predictive value beyond mind wandering. Such results run against research suggesting that goal neglect is responsible for the WMC-based difference in antisaccade performance. However, it was demonstrated that there is some link between mind wandering and WMC, as low-span participants mind wandered more and were less accurate than high-span participants overall. Yet, based on the results of Experiment 3, there is little support that this link is critical in producing antisaccade errors in low-span individuals. If so, mind wandering would have influenced the relation between WMC and accuracy, as well as mediated the effect of delay and saccade type.

An additional inconsistency with goal neglect literature (e.g., Unsworth et al., 2004; Kane et al., 2001; De Jong et al., 1999) is that high-span participants appeared more negatively impacted by mind wandering than low-span participants. Recall that high-span participants experienced a decrease in accuracy under mind wandering conditions, whereas low-span participants did not. Rather than reflecting goal neglect, this implies that either low-span individuals have difficulty distinguishing between on-task and off-task states, or that thought probes are being used as a way to justify errors. The effect of saccade type on the rate of mind wandering provides support for the latter view. If mind wandering was truly occurring, it should occur for both saccade types. There is no reason at this point to assume that the word cues instructing which task to perform somehow induced mind wandering when participants saw the word ‘away’ versus ‘toward.’ This leads to the conclusion that either mind wandering was not occurring, or the thought probes used in this Experiment were not valid indices of mind wandering.

Goal Neglect, Attentional Preparation or Response Suppression?

In Experiments 1-3, there is little evidence for goal neglect. This is supported by 2 consistent findings across the three experiments. First, in none of the Experiments did low-span participants experience a delay-related decrease in accuracy, and in some cases even significantly improved across delay (Experiment 3). A goal neglect account would argue that, as low-span individuals are more susceptible to goal neglect than are high-span individuals, their accuracy should be substantially lower in situations that increase susceptibility for goal neglect. In other words, differences in accuracy should reflect decreases in accuracy of low-span participants across delay. Second, high-span participants generally increased in antisaccade accuracy across delay, even to a larger extent than low-span participants in Experiment 3. These findings demonstrate that in almost every instance, high-span participants outperformed low-span participants due to an increase in accuracy across delay conditions. Again, this gives no implication that WMC differences reflect goal neglect on the part of low-span individuals.

Instead, an increase in accuracy across delay is more indicative of attentional preparation enhancing response suppression. This finding reinforces the view that a brief delay period can be utilized to enhance performance on certain tasks. Yet, high-span participants still had consistently higher accuracy than low spans, which seems to substantiate the idea that WMC differences in antisaccade accuracy reflect a general response-suppression benefit for high-span individuals. As demonstrated by Kane and Engle (2003) high-span individuals have a stronger capacity for response suppression, as indicated by shorter reaction times compared to low-span individuals on commonly occurring incongruent Stroop trials. These findings are consistent with the current findings that high-span participants were significantly more accurate than low-span participants on antisaccade trials, which require response suppression. Therefore, it appears that high-span individuals outperform low-span individuals simply because they have a stronger ability to suppress distracting, habitual information.

However, such a response-suppression account does not eliminate the claim that response suppression acts on attentional preparation. Previous research has demonstrated benefits that occur due to increasing the time between cues and response-conflict trials. This has been demonstrated in behavioral and neuroimaging studies of task-switching (Monsell, 2003; Ruge et al., 2005), studies of antisaccade performance (Brown et al., 2007; Matthews et al., 2002), and studies in which prosaccade trials are intermixed with antisaccade trials (Mueller, 2009). Similar to the results of the current Experiments, the results of these studies suggest a link between a capacity for attentional control and response suppression, and the ability to prepare attention. Ruge et al (2005) demonstrated several key prefrontal areas (e.g., IFJ and aFMC) that are implicated in successfully preparing attention to switch between tasks that involve a high potential for interference. In addition, Ruge et al. implicated areas of parietal cortex (pSPL and IPS) as being responsible for executing the action-schemas activated by IFJ and aFMC.

Crucially, longer reaction times and greater activation in pSPL and IPS were found on switch trials involving short CTIs, suggesting that the mechanism involved with current response suppression did not have sufficient time to prepare. Similarly, Mueller et al. (2009) demonstrated that late frontal negativity (LFNs) was greater for long CTIs prior to antisaccade trials, which have been correlated with the ability to activate action-schemas during periods of attentional preparation. Of greater importance, neural correlates of performance also involved greater N2 parietal activity, particularly during antisaccade trials following short CTIs, reflecting a response suppression mechanism that occurs at the onset of the distractor cue, particularly when parietal regions have not had adequate time to fully implement action-schemas.

In light of the findings of Ruge et al (2005) and Mueller et al (2009) the results of the current study are consistent with the idea that two mechanisms are responsible for WMC differences in antisaccade performance; namely, response suppression and attentional preparation. First, the overall finding that high-span participants were more accurate than low-span participants on antisaccade trials reflects a general response suppression benefit, similar to the response suppression benefit of high-span individuals found by Kane and Engle (2003). Such a benefit could involve the same mechanisms and parietal regions suggested by Ruge et al. that act to implement goal appropriate representations activated by prefrontal regions. Thus, high-span individuals may utilize these mechanisms more quickly than low-span individuals. In addition, low-span indivdulas should have larger N2s in parietal regions for antisaccede trials compared to high-span individuals, indicating that they must use a greater level of attentional effort for response suppression. Second, the overall positive effect of delay reflects an attentional preparation benefit, similar to the attentional preparation benefit found by Ruge et al. and Mueller et al. Thus, similar mechanisms and cortical areas may be involved during the fixation delays of the current Experiments. Specifically, the onset of the fixation point could cue prefrontal regions to focus attention on antisaccade task-appropriate representations, which are then implemented by parietal regions responsible for task execution. Thus, increases in fixation delays are likely to give the representation implementation process time to “get set” prior to the onset of the distractor cue, hence attentional preparation resulting in greater accuracy. That high-span participants tended to increase in accuracy across delay to a greater extent than low-span participants (Experiment 1 and 3) suggests that such an attentional preparation mechanism is related to WMC. High-span individuals could have a larger capacity to use activated antisaccade goal representations in prefrontal cortical regions to bias antisaccade response-schemas in parietal cortex. In essence, with a longer time to prepare, the goal activation and implementation process is enhanced in high-span individuals. The finding in Experiment 3 that low-span participants increased in antisaccade accuracy across delay suggests that low-span individuals also have the capacity for attentional preparation. However, even though low-span participants increased in accuracy, their accuracy in the longest delay condition was only slightly greater than the accuracy of high-span participants in the shortest delay condition (see Figure 5). In addition, they tended to increase in accuracy as a smaller rate than high-span participants. This reiterates a possible connection between WMC and attentional preparation in antisaccade tasks, as other studies have related individual differences in WMC with prefrontal cortex function (Kane & Engle, 2002) and proactive cognitive control (Braver et al., 2003).

Therefore, the findings of the current Experiment are consistent with a two-process model of WMC-based differences in antisaccade performance, one involving attentional preparation, and another involving response suppression. Furthermore, rather than goal neglect being responsible for antisaccade deficits in low-span individuals, it's likely that differences reflect a greater capacity of high-span individuals to activate goal states during periods of attentional preparation to facilitate response suppression. Thus, high-span individuals outperform low-span individuals not because of goal neglect interfering with response suppression, but because attentional preparation enhances a process at which they are already effective.

Limitations and Future Directions

A critical assumption of the current Experiments is that increasing the fixation delay will induce mind wandering, thereby inferring that a lack of an effect of fixation delay is equated with a lack of mind wandering. Thought probes were used in Experiment 3 in an attempt to alleviate this issue. However, the thought probes, or at least the manner in which they were used, may not have been a valid measure of mind wandering. The content of the thought probes were taken from McVay and Kane (2009), who demonstrated that TUTs were a significant predictor of errors and WMC-based differences in performance on cognitively challenging tasks. However, it is unclear from the results of our Experiment 3 that participants were responding to the thought probes in the way they were intended. The implication is that thought probes, as an after-the-fact report, are not direct measures of mind wandering

In a similar vein, it is speculative at this point to infer that what separates high-span individuals from low-span indivduals on antisaccade tasks is a capacity for attentional preparation. Although logical, there was no direct measure of attentional preparation, just as there was no direct measure of mind wandering. Therefore, to conclusively rule out one or the other account, direct measures of both mind wandering and attentional preparation would be required. As such, the results of the current Experiments remain somewhat inconclusive.

An additional constraint is that saccade accuracy was confounded with target identification. Previous research on antisaccade performance and individual differences in WMC often use eye trackers to measure and define saccade accuracy. This has two benefits. First, it eliminates possible explanations of differences in saccade performance that rest on the idea of secondary-task load. In essence, successfully executing an antisaccade involves two tasks: looking away from the distractor cue, and identifying the target before it is hidden. Thus, using eye movement as accuracy would eliminate this potential problem. Second, it allows for a more sensitive measure of reaction time. Reaction times could provide crucial, additional information about how fixation delays affect saccade accuracy, in terms of the generation and speed of correct saccades, and the recovery and self-correction of erroneous saccades.

Eye tracking data could also serve as a crucial leap from relying on indirect measures of constructs such as mind wandering, which would be highly beneficial in investigating the effects of fixation delay and mind wandering on saccade accuracy. It could be the case that as the mind wanders, the eyes begin to wander, thus impairing performance. Therefore, eye movement during the fixation delay could be a beneficial variable in measuring mind wandering, thereby conclusively ruling it out as a factor in antisaccade performance. Similarly, it might be possible to find correlates of eye movement and/or pupil dilation and attentional preparation. This could be an area of future research, which in turn could add to our understanding of why it is that certain individuals are better than others at overcoming distraction in the service of successful performance.

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