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Oculometric Indicators of Individual Differences in Preparatory Control During the Antisaccade Task

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Individual differences in preparatory control in the antisaccade task were examined in two experiments via an examination of pupillary responses and fixation stability during the preparatory delay. In both experiments, high attention control individuals (high-antisaccade performers) demonstrated larger pupillary responses during the preparatory delay than low attention control individuals (low-antisaccade performers). These results suggest that variation in antisaccade performance were partially due to individual differences in the ability to ramp up and regulate the intensity of attention allocated to preparatory control processes. Additionally, fixation stability, working memory capacity, susceptibility to off-task thinking, and task-specific motivation were found to correlate with antisaccade performance. Furthermore, both preparatory control and off-task thinking accounted for much of the relation between working memory capacity and antisaccade. These results provide evidence that individual differences in antisaccade performance are multifaceted and that variation in preparatory control (along with other factors) are critically important.

Public Significance Statement

Our ability to ramp up attention and properly prepare for goal-directed action is important for several everyday tasks. In the current study we demonstrate that individual differences in preparatory control are related to individual differences in performance on the antisaccade task. Individuals who are better able to ramp up and regulate their intensity of attention and more fully engage preparatory control perform better than individuals who are less able to ramp up and regulate their intensity of attention for preparatory control. These results further our understanding of how variation in preparatory control is critical for successful goal-directed action.

Keywords: antisaccade, intensity of attention, preparatory control, individual differences, pupillary responses

Supplemental materials: https://doi.org/10.1037/xhp0001070.supp

The ability to control attention in order to focus on critical information and block distractors is a core aspect of our cognitive system that is needed in several everyday circumstances. Attention control refers to the set of processes that allow us to focus attention, regulate the intensity of attention, and resist attentional capture in order to guide thought and action in the presence of internally or externally distracting information. Critically, there is a great deal of variation in attention control (AC) abilities, such that some individuals are better at regulating their attention and preventing interference or distraction than others. In the current study, we further examined the nature of individual differences in AC by examining variation in preparatory control processes in the antisaccade task.

Variation in Attention Control and Antisaccade Performance

Prior latent factor studies suggest there are large and important individual differences in AC abilities (e.g., Friedman & Miyake, 2004; Kane et al., 2016; Miyake et al., 2000; Redick et al., 2016; Unsworth & Spillers, 2010; Unsworth et al., 2021; although see Rey-Mermet et al., 2019). In addition to examining broad AC latent factors, research has also focused on examining variation in AC abilities in individual tasks such as the antisaccade (e.g., Hutchison et al., 2020; Kane et al., 2001; Meier et al., 2018; Unsworth et al., 2004; Unsworth et al., 2021b). In the antisaccade task (Hallet, 1978; Hallet & Adams, 1980; see Everling & Fischer, 1998; Hutton & Ettinger, 2006; Munoz & Everling, 2004 for reviews) participants are told to fixate on a central cue and after a variable amount of time (preparatory delay), a flashing cue appears either to the right or left of fixation, and participants have to shift their attention

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and gaze to the opposite side of the screen as quickly as possible (to detect a briefly presented target in some versions). In the control condition for this task, participants are instructed to shift their attention and gaze to the same side of the screen as the cue (i.e., prosaccade). Typically, participants are more error prone and slower on antisaccade trials compared to prosaccade trials (Everling & Fischer, 1998; Hutton & Ettinger, 2006; Munoz & Everling, 2004). Thus, antisaccade trials require AC in order to prevent a prepotent response (i.e., reflexive orienting to the cue) and execute a novel goal-directed saccade to the opposite side of the screen.

Given that there is a great deal of variability in antisaccade performance (Evdokimidis et al., 2002; Hutton & Ettinger, 2006; Unsworth et al., 2021) a number of studies have attempted to discern the nature of individual differences in antisaccade by examining different factors that might account for variation in performance. For example, a number of prior studies have demonstrated a consistent positive correlation between variation in working memory capacity (WMC) and antisaccade performance (Kane et al., 2001; Meier et al., 2018; Unsworth et al., 2004; Unsworth et al., 2021; Unsworth et al., 2021b). These results have been interpreted as suggesting the importance of maintaining the current task goal in working memory to ensure accurate responding on antisaccade trials (Kane et al., 2001; Meier et al., 2018; Roberts et al., 1994; Unsworth et al., 2004; Unsworth et al., 2021b). Additionally, if the task goal is not actively maintained in working memory, then any momentary lapse in attention should result in attentional capture by the flashing cue (Nieuwenhuis et al., 2004; Roberts et al., 1994; Roberts & Pennington, 1996). Recent research has provided evidence for this notion by demonstrating that variation in lapses of attention (e.g., off-task thinking) is also important for variation in antisaccade performance (Hutchison et al., 2020; Meier et al., 2018; Unsworth et al., 2012; Unsworth et al., 2021b). That is, those individuals who experience more frequent lapses of attention and mind-wandering typically perform worse on the antisaccade (and other tasks) than individuals who consistently maintain attention on-task. Furthermore, prior research has suggested that at least some of variation in antisaccade performance is due to speed factors such that some individuals are faster at moving the focus of attention than others resulting in better performance (e.g., Unsworth et al., 2004; Unsworth et al., 2021b) on versions of the antisaccade task that require the detection of briefly presented targets (e.g., Kane et al., 2001; Meier et al., 2018; Miyake et al., 2000; Roberts et al., 1994; Unsworth et al., 2021; Unsworth et al., 2021b). For example, Unsworth et al. (2021b) found that WMC, lapses of attention, and speed all accounted for unique variance in antisaccade performance, suggesting that all three factors are important for variation in antisaccade. Collectively, prior research suggests that several factors seem to be important for variation in antisaccade performance.

Preparatory Control in the Antisaccade

A key aspect of antisaccade trials (compared to prosaccade trials) is that they require not only the ability to generate a correct saccade in the opposite direction once the cue has appeared, but also require the ability to prepare for the upcoming trial by ensuring that the current task goal (look away from the flash) is selected, activated, and maintained throughout the preparatory interval to ensure that the correct response is generated (Hutton & Ettinger, 2006; Meier et al., 2018; Hutchison et al., 2020; Munoz & Everling, 2004; Unsworth et al., 2011; Unsworth et al., 2021b). Error monitoring processes are also critically important in order to correct possible errors (e.g., Crawford et al., 2011). Evidence for the importance of preparatory control on antisaccade performance comes from a number of neuroimaging studies that have found that several areas are more active for antisaccades than prosaccades during the preparatory interval (e.g., Brown et al., 2007; Connolly et al., 2002; Curtis & D'Esposito, 2003; Fernandez-Ruiz et al., 2018; Ford et al., 2005; Hakvoort Schwerdtfeger et al., 2012). Thus, a critical factor in antisaccade performance is the extent to which preparatory control is utilized throughout the task (e.g., Hutton & Ettinger, 2006; Hutchison et al., 2020; Munoz & Everling, 2004; Nieuwenhuis et al., 2004; Roberts et al., 1994; Unsworth et al., 2011).

The extent to which preparatory control processes are engaged will depend, in part, on the intensity (or strength) of those preparatory processes (Braver, 2012; Shenhav et al., 2017; Unsworth & Robison, 2020; Unsworth & Miller, 2021). Within our current framework, intensity refers to how much attention/attentional effort is allocated to a given task (Unsworth & Robison, 2020; Unsworth et al., 2020; Unsworth & Miller, 2021; see also Shenhav et al., 2017). When intensity is high, overall control levels are appropriate. However, when intensity is low, current control levels are inadequate. Thus, the intensity of attention determines, in part, how well control is implemented. Within the antisaccade task, then, it is important to ramp up the intensity of attention during the preparatory interval to ensure that preparatory control processes are fully engaged, and the task goal is maintained in working memory. If the intensity of attention is not adequately ramped up during the preparatory interval, then preparatory control processes will not be fully engaged resulting in a greater likelihood of attentional capture by the cue and a subsequent error in responding. Furthermore, motivation levels will likely influence the intensity of attention and overall performance (Kelly et al., 2017; Unsworth & Miller, 2021). Thus, in our current view, preparatory control consists of goal management processes (i.e., goal selection, goal activation, and goal maintenance; Unsworth & Robison, 2020) and the overall intensity of attention applied to those processes (Unsworth et al., 2020; Unsworth & Miller, 2021). Note, this does not mean that the intensity of attention and goal management processes are identical. It is theoretically possible to have high intensity, but impoverished goal management (and vice versa). Thus, the intensity of attention (within and between individuals) likely influences goal management processes, but they are also distinct. In the current study we primarily focus on possible variation in the intensity of preparatory control. Future work is needed to better disentangle these constructs.

It is likely that individual differences in antisaccade performance are partially due to variation in preparatory control processes. That is, those individuals who are better able to increase the intensity of attention during the preparatory interval will likely be able to maintain the task goal in working memory resulting in better overall performance than individuals who cannot (or do not) increase the intensity of attention for preparatory control. Recent research has begun to examine this possibility by examining how manipulating the preparatory interval influences antisaccade accuracy and individual differences in antisaccade performance. For example, Unsworth et al. (2011) suggested that when there is little time to ramp up preparatory control processes at short preparatory intervals, errors are more likely to occur. But, as the preparatory interval increases, the likelihood of ramping up preparatory control processes should increase, leading to fewer errors. Moffitt (2013) examined WMC differences in antisaccade performance across preparatory delays in three experiments and found that WMC and antisaccade were correlated, but WMC only marginally interacted with delay in one experiment. Moffitt suggested that a key component of the WMC to antisaccade relation was the ability to prepare for the upcoming trial, although it was noted that the results were somewhat inconclusive. Meier et al. (2018) similarly examined WMC differences as a function of preparatory interval and found a significant interaction between WMC and delay, such that WMC differences were larger as the delay interval increased. Consistent with Moffitt (2013), Meier et al. suggested that part of the reason that WMC is related to performance on the antisaccade is because high WMC individuals are better at engaging preparatory control processes than low WMC individuals (see Unsworth et al., 2021b for a recent replication). These results provide some evidence for the notion that preparatory processes are important for individual differences in antisaccade. However, Unsworth et al. (2021b) noted a major limitation of these prior studies was that they did not actually measure preparatory control processes during the preparatory interval, but rather made inferences about preparatory control processes by examining changes in accuracy as a function of preparatory interval. Thus, in order to more fully test the hypothesis that variation in preparatory control processes is important, we need to try and measure these processes as they occur.

One way of examining variation in preparatory control processes is to utilize pupillary responses that occur during the preparatory interval as an index of the intensity of attention (Unsworth et al., 2020; Unsworth & Miller, 2021). A great deal of prior research suggests that the pupil dilates in response to the cognitive demands of a task (see Beatty & Lucero-Wagoner, 2000; Goldinger & Papesh, 2012; Laeng et al., 2012 for reviews). These effects reflect task-evoked pupillary responses where the pupil dilates relative to baseline levels due to increases in the intensity of attention (attentional effort) in a number of tasks (Beatty & Lucero-Wagoner, 2000; Just & Carpenter, 1993; Kahneman, 1973). These pupillary responses are associated with the locus coeruleus norepinephrine system (e.g., Aston-Jones & Cohen, 2005; Gilzenrat et al., 2010; Joshi et al., 2016; Unsworth & Robison, 2017a, 2017b), which is thought to be important for regulating the intensity of attention and mobilizing attentional effort (Sara & Bouret, 2012; Unsworth et al., 2022; Varazzani et al., 2015). Examining individual differences in AC, we recently found that preparatory pupillary responses tended to increase during the delay interval in a sustained attention task, and the magnitude of the pupillary response was related to performance on the task, other measures of AC, measures of WMC, and self-reports of off-task thinking (Unsworth et al., 2020). Specifically, high AC individuals demonstrated a larger ramp up in the pupil during the preparatory interval compared to low AC individuals (who demonstrated a decrease in pupillary responses), suggesting that high AC individuals increased preparatory control, but low AC individuals did not. In another recent study, Hutchison et al. (2020) found that pupillary responses during the preparatory interval were larger for antisaccade than prosaccade trials (see also Wang et al., 2015) and that trial-to-trial variability in the pupillary responses were related to overall accuracy and self-reports of mind-wandering such that individuals who had more variability in pupillary responses tended to demonstrate more errors and report more mind-wandering than individuals with little variability in pupillary responses. Thus, measuring preparatory pupillary responses should provide a means of better examining variation in preparatory control in the antisaccade.

Present Study

The aim of the present study was to better elucidate individual differences in antisaccade performance via an examination of oculometric indicators of preparatory control. Prior research has suggested that the antisaccade provides a measure of inhibitory abilities associated with the need to suppress unwanted saccades when the cue appears (e.g., Everling & Fischer, 1998; Munoz & Everling, 2004; Roberts et al., 1994). Thus, it is possible that preparatory processes do not matter much for variation in performance. If preparatory processes do matter for variation in performance, it is important to examine possible reasons for differences in preparatory control. Specifically, examining pupillary responses during the preparatory delay as a measure of the intensity of attention we will test three possibilities based on Unsworth et al. (2020; see also Moffitt, 2013). First, it is possible that high and low AC individuals both ramp up their intensity of attention during the preparatory interval, but that high AC individuals ramp up their intensity of attention to a greater extent than low AC individuals resulting in strengthened preparatory processes and better overall performance (*Ramp up* hypothesis; see also Meier et al., 2018; Moffitt, 2013; Unsworth et al., 2020; Unsworth et al., 2021b). Evidence for this possibility comes from prior research demonstrating that pupillary responses increase during the preparatory interval for antisaccade trials (Wang et al., 2015). Additionally, prior research with the psychomotor vigilance task demonstrated that high AC individuals tended to increase their pupillary responses during the preparatory interval in that task (Unsworth et al., 2020). Given strong correlations between performance on the antisaccade and psychomotor vigilance task (Unsworth et al., 2021), we might expect similar results in the antisaccade. An additional, more specific prediction of the *Ramp up* hypothesis is that high AC individuals are better at regulating the intensity of attention than low AC individuals, such that they selectively ramp up attention for difficult tasks or when a task becomes more challenging (*Regulation* hypothesis). This possibility is examined in Experiment 2. Second, it is possible that high and low AC individuals may differ in their ability to sustain the intensity of attention during the preparatory interval, such that high AC individuals are better able to maintain the same level of intensity during the preparatory interval, but low AC individuals cannot sustain the same level of intensity resulting in weakened preparatory processes and worse performance (*Sustain* hypothesis; see also Meier et al., 2018; Moffitt, 2013; Unsworth et al., 2020; Unsworth et al., 2021b). Evidence for this possibility comes from prior research demonstrating that pupillary responses sometimes decrease during the preparatory interval for antisaccade trials (Hutchison et al., 2020). Additionally, in our prior research with the psychomotor vigilance task we found that low AC individuals' pupils tended to decrease during the preparatory interval (Unsworth et al., 2020). A final possibility is that high and low AC individuals differ in the consistency of intensity across trials. That is, most of the time high and low AC individuals have similar intensity levels during the preparatory interval, but low AC individuals are unable to consistently maintain intensity levels across trials, resulting in weakened preparatory processes and worse performance (i.e., the *Consistency* hypothesis; see also Unsworth et al., 2020). For example, in their Experiment 1, Hutchison et al. (2020) found strong correlations (r range = −.40, −.47) between standard deviation of preparatory pupillary responses and antisaccade accuracy, suggesting that high AC individuals demonstrated more consistency than low AC individuals. However, in their Experiment 2, the correlations were weaker (r range = −.06, −.21) and only one of four was significant, suggesting mixed evidence for consistency. Additional evidence for the *Consistency* possibility comes from our prior research with the psychomotor vigilance task suggesting that standard deviation of preparatory pupillary responses in that task were correlated with performance (Unsworth et al., 2020). Of course, we note that these different possibilities are not mutually exclusive as our prior research with the psychomotor vigilance task has suggested evidence for all three possibilities.

Another potential means of examining variation in preparatory control in the antisaccade is to measure fixation stability during the preparatory interval. It is thought that during the preparatory interval that the fixation system (frontal eye fields and superior colliculus) is activated in order to suppress automatic saccades toward the flashing cue (Coe & Munoz, 2017; Munoz & Everling, 2004). Prior research suggests that maintaining fixation and preventing unwanted saccades during the preparatory interval is critical for generating correct antisaccades (Barton et al., 2008; Munoz & Everling, 2004; Munoz et al., 2003). For example, Munoz et al. (2003) found a strong correlation between the frequency of unwanted saccades on a prolonged fixation task and antisaccade errors. Thus, the ability to maintain stable fixation during the preparatory interval should provide another indicator of preparatory control that is correlated with antisaccade performance. Fixation stability refers to the ability to maintain fixation on a stimulus for a brief amount of time and various measures of dispersion (Holmqvist et al., 2011), including standard deviation of eye position are examined. Unsworth et al. (2019) found that AC (measured with the antisaccade and psychomotor vigilance tasks) was related to fixation stability in a prolonged fixation task, suggesting that individuals lower in AC demonstrated more fixation instability than high AC individuals. Additionally, Unsworth et al. (2020) found that fixation stability measured during the preparatory interval of the psychomotor vigilance task was related to pupillary responses during the preparatory interval, behavioral indicators of lapses of attention, self-reports of off-task thinking, as well as latent factors for AC and WMC (see also Robison & Brewer, 2020). Thus, fixation stability seems crucial for performance on various AC tasks, and particularly the antisaccade, where fixation must be maintained during the preparatory interval to prevent unwanted saccades in order to rapidly respond to target stimuli. As such, fixation stability might represent the ability to maintain a constrained attentional focus during the preparatory interval and high AC individuals may be better able to maintain a constrained focus than low AC individuals (Heitz & Engle, 2007; Poole & Kane, 2009; Unsworth & Spillers, 2010).

Finally, we measured other factors thought to be related to variation in antisaccade performance including WMC, off-task thinking, motivation, and their potential relations with the eye measures of preparatory control. A secondary goal of the current study was to examine if the relation between WMC and antisaccade, which has been demonstrated many times previously, is partially due to variation in preparatory control processes. As noted previously, several prior studies suggest that a key reason that WMC is related to antisaccade is because of variation in preparatory control processes (e.g., goal management; Kane et al., 2001; Meier et al., 2018; Moffitt, 2013; Unsworth et al., 2004; Unsworth et al., 2012; Unsworth et al., 2021b). Thus, we examined whether the oculometric indicators of preparatory control would fully or partially account for the shared variance between WMC and antisaccade.

Experiment 1

Experiment 1 examined individual differences in preparatory control and antisaccade performance by measuring pupillary responses and fixation stability during the preparatory interval of the antisaccade. Participants also performed multiple measures of WMC, and we assessed self-reports of off-task thinking to examine how these factors were related to indicators of preparatory control and antisaccade performance.

Method

We report how we determined our sample size, all data exclusions, manipulations, and measures.

Participants

A total of 151 participants were recruited from the subject-pool at the University of Oregon, a comprehensive state university. Participants were 58.3% female with an average age of 19.50 (SD = 1.70). We determined that a minimum sample size of 120 participants would be sufficient to find correlations in the range of .25 to .30, with power of .80 and alpha set at .05 (two-tailed), given similar relations between antisaccade and other variables of interest (WMC, off-task thinking) seen in prior research (Unsworth et al., 2021b). Participants received course credit for their participation. Each participant was tested individually in a laboratory session lasting approximately two hours. We tested participants over two full academic quarters, using the end of the second quarter as our stopping rule for data collection. Data for six participants were excluded from the pupillary analyses due to missing data. With these data exclusions, power of .80, and alpha set at .05 (two-tailed) we had sufficient power to find correlations of .23.

Materials and Procedure

After signing informed consent, all participants completed operation span, symmetry span, reading span, antisaccade, Stroop, and delayed free recall tasks. The Stroop and delayed free recall tasks were part of other studies and are not discussed further.

Antisaccade

This task is based on Kane et al. (2001). Prior to each trial, there was a 2-s baseline period with "+++++" in the center of the screen to determine baseline pupil diameter (luminance = 12 lux).

Following this, participants were instructed to stare at a fixation point which was onscreen for a variable amount of time (preparatory delay: 200 ms; 600 ms; 1,000 ms; 1,400 ms; or 1,800 ms). A flashing white "=" was then flashed 12.7 cm either to the left or right of fixation for 100 ms (luminance = 10 lux). This was followed by the target stimulus (*B*, *P*, or *R*) onscreen for 100 ms and then masking stimuli (an *H* for 50 ms followed by an *8*, which remained onscreen until a response was given). The participants' task was to identify the target letter by pressing a key for *B*, *P*, or *R* (the keys *4*, *5*, *6* on the number pad) as quickly and accurately as possible. In the prosaccade condition the flashing cue (=) and the target appeared in the same location. In the antisaccade condition the target appeared in the opposite location as the flashing cue. Participants received, in order, 10 practice trials to learn the response mapping, 10 practice trials of the prosaccade condition, 10 practice trials of the antisaccade, and 50 trials of the antisaccade condition. The dependent variable was proportion correct on the antisaccade trials (see the online supplemental material for analyses examining eye movement errors as the dependent variable). Eleven thought probes were randomly presented after trials.

Thought Probes

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

Please characterize your current conscious experience.

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

During the introduction to the task, participants were given specific instructions regarding the different categories. Response 1 was considered on-task. Response 2 measures task-related interference and was not included in the analyses. Responses 3 through 5 were considered as off-task thinking were combined into a single off-task measure (proportion of off-task thoughts).

Eye Tracking

Participants were tested individually in a dark room (illuminance = 1 lux). The pupil was dark adapted roughly 3 minutes prior to the real trials. Pupil diameter and gaze were continuously recorded binocularly at 120 Hz using a Tobii T120 eye tracker. Participants were seated 60 cm from the monitor with the aid of a chinrest. Stimuli were presented on a 17-in. monitor with a 1024 × 768 screen resolution. Data was collected via the Tobii eye tracker and further analyzed offline. Data from each participant's left eye was used. Missing data points due to blinks, off-screen fixations, and/or eye tracker malfunction were removed. We did not exclude whole trials for missing data.

Pretrial baseline pupil was computed as the average pupil diameter during the baseline screen (2,000 ms). Pupillary responses during the preparatory delay were corrected by subtracting out the pretrial baseline and the first 20 ms of the preparatory interval and then locked to when the fixation point appeared. To examine the time course of pupillary responses during the preparatory delay, the pupil data were averaged into a series of 20-ms time windows. We examined both the mean and standard deviation of pupillary responses for each 20-ms time window.

Consistent with prior research, fixation stability was computed as the standard deviation of the eye position for each sample averaged along both the horizontal and vertical dimensions (Di Russo et al., 2003; Unsworth et al., 2019) during the preparatory delay. Missing data points due to blinks, off-screen fixations, and/or eye tracker malfunction were removed and not included in the fixation stability averages.

Working Memory Capacity (WMC) Tasks

Operation Span. Participants solved a series of math operations while trying to remember a set of unrelated letters (see Unsworth et al., 2005; Redick et al., 2012). Participants were required to solve a math operation, and after solving the operation, they were presented with a letter for 1 s. Immediately after the letter was presented the next operation was presented. At recall participants were asked to recall letters from the current set in the correct order by clicking on the appropriate letters. For all the span measures, items were scored correct if the item was recalled correctly from the current list. Participants were given practice on the operations and letter recall tasks only, as well as two practice lists of the complex, combined task. List length varied randomly from three to seven items, and there were two lists of each list length for a maximum possible score of 50. The score was total number of correctly recalled items.

Symmetry Span. Participants recalled sequences of red squares within a matrix while performing a symmetry-judgment task (see Unsworth et al., 2009; Redick et al., 2012). In the symmetry-judgment task, participants were shown an 8 × 8 matrix with some squares filled in black. Participants decided whether the design was symmetrical about its vertical axis. The pattern was symmetrical half of the time. Immediately after determining whether the pattern was symmetrical, participants were presented with a 4 × 4 matrix with one of the cells filled in red for 650 ms. At recall, participants recalled the sequence of red-square locations by clicking on the cells of an empty matrix. Participants were given practice on the symmetry-judgment and square recall task as well as two practice lists of the combined task. List length varied randomly from two to five items, and there were two lists of each list length for a maximum possible score of 28. We used the same scoring procedure as we used in the operation span task.

Reading Span. While trying to remember an unrelated set of letters, participants were required to read a sentence and indicated whether or not it made sense (see Unsworth et al., 2009;

Redick et al., 2012). Half of the sentences made sense, while the other half did not. Nonsense sentences were created by changing one word in an otherwise normal sentence. After participants gave their response, they were presented with a letter for 1 s. At recall, participants were asked to recall letters from the current set in the correct order by clicking on the appropriate letters. Participants were given practice on the sentence judgment task and the letter recall task, as well as two practice lists of the combined task. List length varied randomly from three to seven items, and there were two lists of each list length for a maximum possible score of 50. We used the same scoring procedure as we used in the operation span and symmetry span tasks.

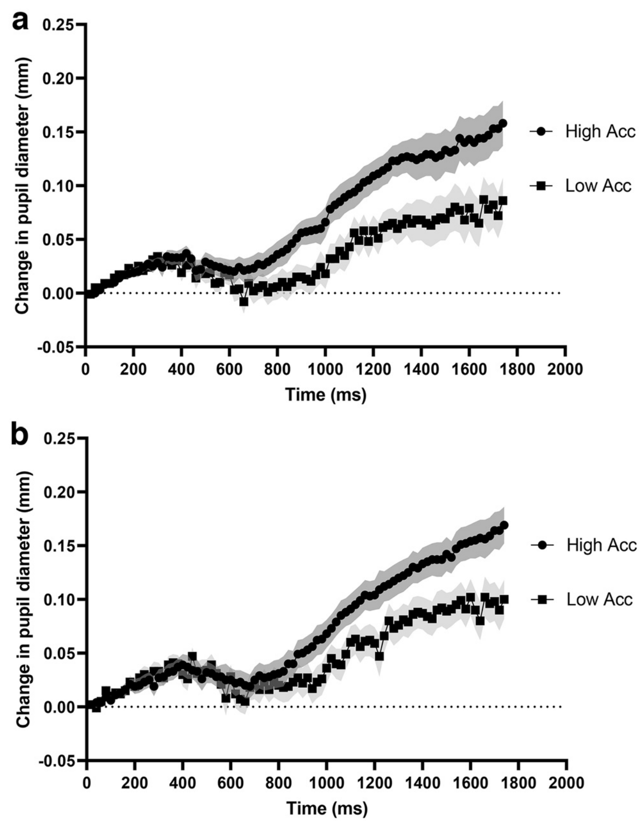
Results

Pupillary Responses During the Preparatory Delay

First, we examined pupillary responses during the preparatory delay. All preparatory delays from 200 ms to 1,800 ms were averaged together into a single pupillary response for each participant. Thus, there were naturally more trials entering into the shortest delays because all delays included at least 200 ms. Examining the pupillary response during the preparatory delay suggested a significant effect of time, $F(86, 12384) = 78.95$, $MSE = .003$, $p < .001$, partial $\eta^2 = .35$, suggesting the pupillary response increased during the delay consistent with prior research (Wang et al., 2015). Next, we tested our main question of interest to examine whether the pupillary response during the preparatory delay differed as a function of individual differences in AC (as indicted by accuracy on the antisaccade). To examine potential individual differences in antisaccade performance, we repeated the above analysis, but now entered in antisaccade accuracy as a covariate. The analysis suggested a main effect antisaccade accuracy, $F(1, 143) = 5.09$, $MSE = .24$, $p = .026$, partial $\eta^2 = .03$, indicating that individuals with high-antisaccade accuracy demonstrated larger preparatory pupil responses than individuals with low-antisaccade accuracy. Critically, there was an interaction between time and antisaccade accuracy, $F(86, 12298) = 4.05$, $MSE = .003$, $p < .001$, partial $\eta^2 = .03$, suggesting that the pupillary response differed as a function of individual differences in AC. The interaction was characterized by an overall linear trend, $F(1, 143) = 8.58$, $MSE = .115$, $p = .004$, partial $\eta^2 = .06$. Neither the quadratic or cubic trends were significant (both ps $> .24$). Similar results were obtained when only examining the 1800 ms condition (see online supplemental materials for examination of the other delay intervals). Specifically, there was an interaction between time and antisaccade accuracy, $F(86, 12212) = 4.62$, $MSE = .003$, $p < .001$, partial $\eta^2 = .03$, as well as a linear trend, $F(1, 142) = 10.99$, $MSE = .115$, $p = .001$, partial $\eta^2 = .07$. Neither the quadratic or cubic trends were significant (both ps $> .14$). In order to illustrate the effects of interest, we present differences in antisaccade accuracy via a quartile split with low-antisaccade accuracy individuals (bottom 25%) and high-antisaccade accuracy individuals (top 25%). Note, however, that all analyses treated antisaccade accuracy as continuous, rather than as arbitrary, discrete groups. As shown in Figure

Figure 1

Change in Baseline Corrected Pupil Diameter as a Function of Time During the Preparatory Delay for High- and Low-Antisaccade (Acc) Accuracy Individuals in Experiment 1



Note. Panel a: full data. Panel b: 1800 ms condition. Shaded areas reflect one standard error of the mean.

1a for the overall analyses, both groups demonstrated increased pupillary responses during the preparatory delay, but high-antisaccade accuracy individuals demonstrated a larger pupillary response than low-antisaccade accuracy individuals. Similar results were demonstrated when examining only the 1,800 ms as seen in Figure 1b.

Correlations Among the Measures

Next, we examined relations between antisaccade accuracy and the other measures.[1] We computed three different eye measures that occurred during the preparatory delay. First, we computed the average change in pupillary response from baseline during the last 80 ms of the 1,800-ms delay interval (i.e., the last four time points shown in Figure 1) to represent differences in the intensity of attention given that it was predicted that the largest differences would occur at the end of the preparatory delay, and this is what

[1] Target detection accuracy in the antisaccade was correlated with antisaccade eye movement errors (Split half reliability = .90) in each experiment and in the combined sample of participants ($N = 299$, $r = -.51$). See the online supplemental material for correlations and regression analyses with eye movement errors.

was demonstrated.[2] This decision was partially post hoc in that we initially planned to only use the last baseline corrected time bin, but because it can be unreliable, we averaged together the last four baseline corrected time bins (similar results are found when only using the last time bin; see also Unsworth et al., 2020). Furthermore, in Experiment 2 we used the same measure in an entirely new sample of participants. Second, we computed the trial-to-trial standard deviation of the baseline corrected pupillary response during the last 80 ms of the preparatory delay to examine possible differences in the consistency of the intensity of attention across trials (e.g., Hutchison et al., 2020; Unsworth et al., 2020). Finally, we computed the within-trial standard deviation of gaze during the preparatory delay to examine fixation instability during the delay (e.g., Unsworth et al., 2020). Shown in Table 1 are the descriptive statistics for all measures. As can be seen, most of the measures had generally acceptable values of reliability and most of the measures were approximately normally distributed with values of skewness and kurtosis under the generally accepted values.

Consistent with prior research we created a WMC composite given that the three working memory span measures were correlated (operation span–symmetry span $r = .33$; operation span–reading span $r = .43$; symmetry span–reading span $r = .19$). The composite WMC score was computed by first z-scoring each WMC measure and then averaging the resulting z scores.

Shown in Table 2 are the correlations between antisaccade and the other measures. Antisaccade accuracy was significantly related to all the measures except for the standard deviation of pupillary responses during the delay. Consistent with prior research, antisaccade was related to WMC and off-task thinking during the task (e.g., Meier et al., 2018; Unsworth et al., 2021b). Antisaccade was positively related to the pupillary response during the preparatory delay and negatively related to variability in gaze during the preparatory delay.[3] These results suggest that preparatory processes (indexed via pupillary responses and fixation instability during the delay) were related to performance on the antisaccade.

To further examine the relations between the measures and antisaccade accuracy, we specified a simultaneous regression in which the different measures were all allowed to predict antisaccade accuracy. Table 3 displays the results; overall, 27% of the variance in antisaccade was accounted for by the various measures. Furthermore, both off-task thinking (7%) and fixation instability (9%) during the preparatory delay accounted for unique variance in antisaccade. Thus, the measures accounted for roughly 16% unique variance and 11% shared variance in antisaccade. Furthermore, WMC no longer accounted for unique variance in antisaccade after accounting for off-task thinking and the measures of preparatory control. Overall, the results suggest that several factors account for variation in antisaccade performance.

Table 1
Descriptive Statistics and Reliability Estimates for All Measures in Experiment 1

Measure	*M*	*SD*	Skew	Kurtosis	Reliability
Antisaccade	.61	.17	−.24	−.98	.85
Ospan	38.95	7.54	−1.16	2.61	.60
Symspan	19.58	5.13	−.59	−.40	.56
Rspan	38.67	7.58	−.50	.14	.64
Off-task	.34	.30	.65	−.75	.68
Delay pupil	.13	.11	.01	.77	.99
Delay PupilSD	.22	.08	.74	.62	.98
Delay GazeSD	.05	.03	1.13	1.12	.83

Note. Ospan = operation span; Symspan = symmetry span; Rspan = reading span; off-task = off-task thoughts; delay pupil = average baseline corrected pupillary response (in mm) during the last 80 ms of the 1,800-ms delay; delay PupilSD = standard deviation of baseline corrected pupillary response (in mm) during the last 80 ms of the 1,800-ms delay; delay GazeSD = standard deviation of gaze during the delay. Reliabilities reflect split-half reliabilities for all measures except the complex span tasks which are alphas computed across all trials.

Table 2
Correlations Among the Measures in Experiment 1

Measure	1	2	3	4	5	6
1. Antisaccade	—					
2. WMC	.23*	—				
3. Off-task	−.36*	−.24*	—			
4. Delay pupil	.23*	.15	−.14	—		
5. Delay PupilSD	−.12	−.10	.07	−.01	—	
6. Delay GazeSD	−.38*	−.10*	.14	−.20*	.06	—

Note. WMC = working memory capacity; Off-task = off-task thoughts; delay pupil = average pupillary response during the last 80 ms of the 1,800-ms delay; delay PupilSD = standard deviation of pupillary response during the last 80 ms of the 1,800-ms delay; delay GazeSD = standard deviation of gaze during the delay.
* $p < .05$.

Discussion

The results from Experiment 1 demonstrated several important findings. Examining preparatory pupillary responses during the delay suggested that high-antisaccade performers demonstrated increased pupillary responses compared to low-antisaccade performers. These results are consistent with the *Ramp up* hypothesis in suggesting that high AC individuals ramp up their intensity of attention during the preparatory delay to a greater extent than low AC individuals. There was little evidence for the *Sustain* hypothesis as there was a general increase in pupillary responses during the preparatory interval (e.g., Wang et al., 2015). Furthermore, there was little evidence for the *Consistency* hypothesis as

[2] Because the pupillary response measure represents a change from baseline pupil diameter, we also examined whether variation in baseline pupil dimeter was related with any of the other measures and could account for the results. In Experiment 1, baseline pupil diameter (split-reliability = .96) was not related to antisaccade accuracy ($r = -.04$) and was only related to the standard deviation of preparatory pupil responses ($r = -.31$; all other rs $< |.05|$). Including baseline pupil diameter into the regression analyses did not change any of the results. Similarly, in Experiment 2 baseline pupil diameter (split-reliability = .95) was not related to antisaccade accuracy ($r = .09$) and was only related to the standard deviation of preparatory pupil responses ($r = -.26$) and to prosaccade accuracy ($r = .17$; all other rs $< |.08|$). Including baseline pupil diameter into the regression analyses did not change any of the results.

[3] We also examined potential differences in overall gaze position during the preparatory delay. The eye tracker uses a normalized gaze coordinate system [0, 1], such that the center of the screen has a value of [0.5, 0.5]. In both experiments average gaze position suggested that participants were looking at the center of the screen (Experiment 1: average gaze position = .47, SD = .05; Experiment 2: average gaze position = .50 SD = .04). Average gaze position during the preparatory delay only correlated with standard deviation of preparatory pupil responses ($r = .18$) in Experiment 2.

Table 3
Simultaneous Regression Predicting Antisaccade in Experiment 1

Variable	β	*t*	sr^2	R^2	*F*
WMC	.11	1.44	.01		
Off-task	−.27	−3.54**	.07		
Delay pupil	.11	1.46	.01		
Delay PupilSD	−.07	−.93	.00		
Delay GazeSD	−.31	−4.05**	.09	.27	10.06**

Note. WMC = working memory capacity; delay pupil = average baseline corrected pupillary response (in mm) during the last 80 ms of the 1,800-ms delay; delay PupilSD = standard deviation of baseline corrected pupillary response (in mm) during the last 80 ms of the 1,800-ms delay; delay GazeSD = standard deviation of gaze during the delay.
** $p < .01$.

trial-to-trial variability of the preparatory pupil responses did not significantly correlate with any of the measures. However, both magnitude of the preparatory pupil response and fixation stability during the delay both correlated with antisaccade accuracy (and with each other) suggesting that preparatory control processes were important for variation in antisaccade performance. Furthermore, both WMC and off-task thinking were correlated with antisaccade performance consistent with prior research (e.g., Meier et al., 2018; Unsworth et al., 2021b). Regression analyses further suggested that off-task thinking and fixation stability accounted for unique variance in antisaccade performance. That is, WMC no longer predicted antisaccade performance once both measures of preparatory control and off-task thinking were accounted for. These results provide evidence for the notion that both preparatory control and off-task thinking (lapses of attention) are important for the relation between WMC and antisaccade (Meier et al., 2018; Unsworth et al., 2021b). Overall, the results suggest several factors are important for variation in antisaccade performance.

Experiment 2

Experiment 2 was conducted to replicate and extend the results from Experiment 1. Specifically, we wanted to ensure the robustness of the results by demonstrating that preparatory pupil responses and fixation stability are important predictors of antisaccade performance. Additionally, we wanted to test a more specific prediction of the *Ramp up* hypothesis based on our intensity of attention framework (Unsworth & Miller, 2021). In this framework, high AC individuals are better at regulating/controlling the intensity of attention than low AC individuals. That is, high AC individuals are better at ramping up the intensity of attention when needed for more difficult tasks or when a task becomes more difficult than low AC individuals. This account predicts that high AC individuals should ramp up their intensity of attention more so on antisaccade trials than on prosaccade trials, whereas low AC individuals will either not ramp up attention enough on antisaccade trials or demonstrate similar ramp ups on both prosaccade and antisaccade trials. Thus, to test the *Regulation* hypothesis, we had participants perform blocks of both prosaccade and antisaccade trials. An additional goal of Experiment 2 was to examine the potential influence of motivation factors on antisaccade performance and preparatory control. Prior research suggests that measures of task-specific motivation are correlated with antisaccade performance (Kelly et al., 2017; Robison & Unsworth, 2018; Unsworth et al., 2021a). Furthermore, prior research suggests the importance of motivation factors for preparatory control processes (Botvinick & Braver, 2015; Braver, 2012). Thus, we included measures of task-specific motivation to examine how motivation was related to overall antisaccade performance and preparatory control. Finally, in Experiment 1 we averaged across all delay intervals to ensure there were enough trials for analysis. However, this could have distorted the results by making them appear more stable than they were (although note we found the same results when only examining the 1,800-ms delay condition). Therefore, in Experiment 2 we included only the 200-ms; 1,000-ms; and 1,800-ms delay conditions to ensure that there were enough trials at the longest delay. To examine these issues, a new sample of participants performed blocks of prosaccade and antisaccade trials while pupillary responses and gaze were recorded. Participants were presented with thought-probes during the task to assess off-task thinking. Prior to and following the task, participants also indicated their motivation to perform well on the task. Participants also performed WMC tasks similar to those of Experiment 1.

Method

We report how we determined our sample size, all data exclusions, all manipulations, and all measures.

Participants

A total of 169 participants were recruited from the subject-pool at the University of Oregon, a comprehensive state university. Participants were 66.9% female with an average age of 19.40 (SD = 1.83). We determined that a minimum sample size of 120 participants would be sufficient to find correlations in the range of .25 to .30, with power of .80 and alpha set at .05 (two-tailed), given similar relations between antisaccade and other variables of interest (WMC, off-task thinking, motivation) seen in prior research (Unsworth et al., 2021; Unsworth et al., 2021b). Each participant was tested individually in a laboratory session lasting approximately two hours. We tested participants over two full academic quarters, using the end of the second quarter as our stopping rule for data collection. Data for 32 participants were excluded from the pupillary analyses due to missing data (20 participants had completely missing data due to an eye tracker malfunction and 12 participants had partial missing data). With these data exclusions, power of .80, and alpha set at .05 (two-tailed) we had sufficient power to find correlations of .24. Participants received course credit for their participation.

Materials and Procedure

After signing informed consent, all participants completed operation span, symmetry span, reading span, antisaccade, Stroop, delayed free recall, picture source recognition, and paired associates recall tasks. The Stroop and long-term memory tasks were part of other studies and are not discussed further.

Antisaccade. This was the same as Experiment 1, except we used only the 200-ms; 1,000-ms; and 1,800-ms delay intervals and we included a block of prosaccade trials as well. Participants received, in order, 10 practice trials to learn the response mapping, 10 practice trials of the prosaccade condition, 42 trials of the prosaccade condition, 10 practice trials of the antisaccade, and 42 trials of the antisaccade condition. The dependent variable was proportion correct on the antisaccade trials. Twelve thought probes were randomly presented after trials in each condition.

Thought Probes. These were the same as in Experiment 1.

Motivation Question. Prior to and after the prosaccade and antisaccade conditions, participants were asked how motivated they felt to perform well on the task (Robison & Unsworth, 2018). Specifically, participants were asked, "How motivated are/were you to perform well on the task?" Participants responded on a 1 to 6 scale. Pre and post motivation in the antisaccade condition were correlated ($r = .87$, $p < .01$), so these responses were averaged together and taken as our primary measure of motivation.

Eye Tracking and WMC Tasks. These were the same as in Experiment 1.

Results

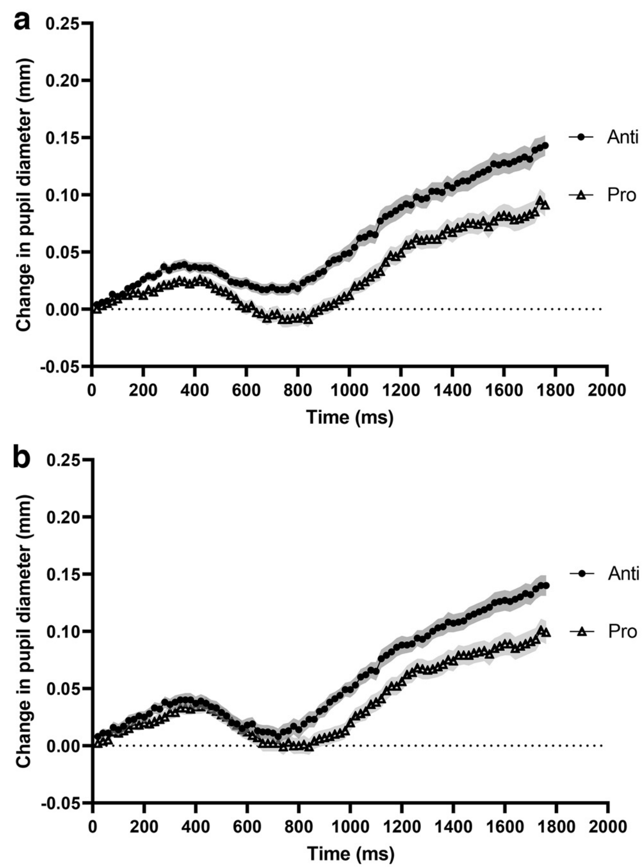
Pupillary Responses During the Preparatory Delay

First, we examined pupillary responses during the preparatory delay for both saccade conditions. Similar to Experiment 1 we averaged across all delay intervals. Examining the pupillary response during the preparatory delay suggested a significant main effect of time, $F(87, 10962) = 109.02$, $MSE = .003$, $p < .001$, partial $\eta^2 = .46$, indicating the pupillary response increased during the delay consistent with Experiment 1. There was also a main effect of saccade type, $F(1, 126) = 23.40$, $MSE = .20$, $p < .001$, partial $\eta^2 = .16$, in which antisaccades demonstrated larger preparatory pupillary responses than prosaccades. Finally, there was a significant interaction between saccade type and time, $F(87, 10962) = 5.92$, $MSE = .002$, $p < .001$, partial $\eta^2 = .05$. Similar results were seen when examining the 1,800-ms condition, in that there was a significant main effect of saccade type, $F(1, 126) = 8.68$, $MSE = .28$, $p = .004$, partial $\eta^2 = .06$, and a significant interaction between saccade type and time, $F(87, 10962) = 5.16$, $MSE = .002$, $p < .001$, partial $\eta^2 = .04$. As is shown in Figure 2a, for the overall analyses, antisaccades demonstrated a larger increase in preparatory pupil responses than prosaccades consistent with prior research (Hutchison et al., 2020; Wang et al., 2015). Similar results were demonstrated when examining only the 1,800 ms (see Figure 2b).

To examine potential individual differences in antisaccade performance, we repeated the aforementioned analysis, but now entered in antisaccade accuracy as a covariate. The analysis suggested no main effect of antisaccade accuracy, $F(1, 125) = .15$, $MSE = .41$, $p = .70$, partial $\eta^2 = .001$. There was an interaction between saccade type and antisaccade accuracy, $F(1, 125) = 5.67$, $MSE = .19$, $p = .019$, partial $\eta^2 = .04$. There was an interaction between time and antisaccade accuracy, $F(87, 10875) = 1.80$, $MSE = .003$, $p < .001$, partial $\eta^2 = .01$. Critically, there was an interaction of saccade type, time, and antisaccade accuracy, $F(87, 10875) = 4.56$, $MSE = .002$, $p < .001$, partial $\eta^2 = .04$, indicating that the pupillary response differed as a function saccade type and individual differences in antisaccade accuracy. Similar to Experiment 1, there was an overall linear trend for the interaction, $F(1, 125) = 8.53$, $MSE = .09$, $p = .004$, $\eta_p^2 = .06$. Neither the quadratic nor the cubic trends were significant (both $ps > .15$). Similar results were obtained when only examining the 1,800-ms condition (see the online supplemental material for examination of the other delay intervals). Specifically, there was an interaction between saccade type, time, and antisaccade accuracy, $F(87, 10875) = 4.12$, $MSE = .002$, $p < .001$, $\eta_p^2 = .03$, as well as a linear trend, $F(1, 125) = 7.38$, $MSE = .09$, $p = .008$, $\eta_p^2 = .06$. Neither the quadratic nor the cubic trends were significant (both $ps > .06$). As shown in Figure 3a, both groups demonstrated increased pupillary responses during the preparatory delay for both prosaccades and antisaccades. However, high-antisaccade accuracy individuals demonstrated an increased pupillary response for antisaccades compared to prosaccades, whereas low-antisaccade accuracy individuals demonstrated similar pupillary responses for both saccade types.

Figure 2

Change in Baseline Corrected Pupil Diameter as a Function of Saccade Condition and Time During the Preparatory Delay in Experiment 2

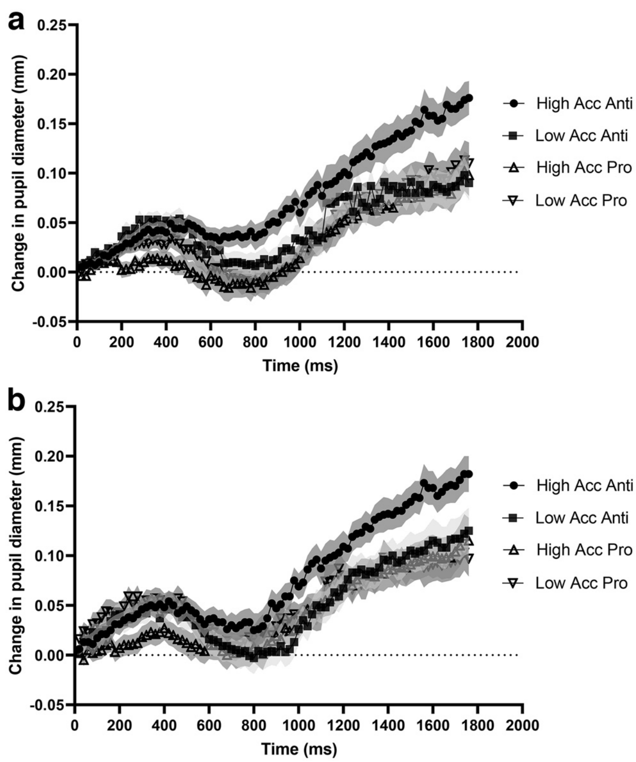


Note. Panel a: full data. Panel b: 1800 ms condition. Shaded areas reflect one standard error of the mean.

Next, we did exploratory analyses examining whether WMC and motivation would interact with saccade type and time, indicating differences in the ability to regulate the intensity of attention during the preparatory interval. Examining WMC suggested an interaction of saccade type, time, and WMC, $F(87, 10875) = 1.48$, $MSE = .002$, $p < .001$, partial $\eta^2 = .01$, indicating that high WMC individuals (similar to high-antisaccade accuracy individuals) demonstrated a larger pupillary response for antisaccades

Figure 3

Change in Baseline Corrected Pupil Diameter as a Function of Saccade Type and Time During the Preparatory Delay for High- and Low-Antisaccade (Acc) Accuracy Individuals in Experiment 2



Note. Panel a: full data. Panel b: 1800 ms condition. Shaded areas reflect one standard error of the mean.

compared to prosaccades, whereas low WMC individuals demonstrated similar pupillary responses for both saccade types. Although we note that this effect was quite small. Examining motivation suggested no interaction of saccade type, time, and motivation, $F(87, 10875) = .63$, $MSE = .002$, $p = .997$, partial $\eta^2 = .005$. There was, however, an interaction of time and motivation, $F(87, 10875) = 1.48$, $MSE = .003$, $p < .001$, partial $\eta^2 = .05$. Thus, high motivation individuals demonstrated larger preparatory pupillary responses than low motivation individuals regardless of saccade type.

Correlations Among the Measures

Similar to Experiment 1, we examined relations between antisaccade accuracy and the other measures and we focused on the eye measures from the antisaccade condition. The same eye measures as Experiment 1 were used. Shown in Table 4 are the descriptive statistics for all measures. As can be seen, most of the measures had generally acceptable values of reliability and most of the measures were approximately normally distributed with values of skewness and kurtosis under the generally accepted values.

Consistent with Experiment 1, the three working memory span measures were correlated (operation span–symmetry span $r = .29$; operation span–reading span $r = .61$; symmetry span–reading span $r = .26$) and we formed a z-score WMC composite. Shown in Table 5 are the correlations between antisaccade and the other measures. Consistent with Experiment 1, antisaccade accuracy was significantly related to all the measures except for the standard deviation of pupillary responses during the delay.

Similar to Experiment 1, we specified a simultaneous regression in which the different measures were all allowed to predict antisaccade accuracy. As seen in Table 6, 23% of the variance in antisaccade was accounted for by the various measures, with only fixation stability (5%) accounting for unique variance in antisaccade. Thus, the measures accounted for roughly 18% shared variance in antisaccade. Like Experiment 1, the results suggest that several factors account for variation in antisaccade performance.

As seen in Table 5, accuracy on prosaccade trials also tended to correlate with the other measures even though performance was very high on these trials. Next, we examined whether antisaccade accuracy would correlate with the other measures after taking prosaccade accuracy into account. Thus, we computed partial correlations between antisaccade accuracy and the other measures, controlling for prosaccade accuracy. These results suggested largely similar correlations as seen in Table 5. Specifically, controlling for prosaccade accuracy the correlations were WMC ($r = .22$), off-task ($r = -.22$), motivation ($r = .23$), delay pupil ($r = .21$), delay PupilSD ($r = .15$), and delay GazeSD ($r = -.31$). Similarly, running the same regression as before, but also including prosaccade accuracy suggested largely similar results as shown in Table 6. Thus, overall the relations between antisaccade and the other measures held after controlling for prosaccade accuracy. However, the converse was generally not the case as prosaccade accuracy no longer correlated with the measures after controlling for antisaccade accuracy. Specifically, controlling for antisaccade accuracy the correlations with prosaccade accuracy were WMC ($r = .09$), off-task ($r = -.10$), motivation ($r = .11$), delay pupil ($r = .09$), delay PupilSD ($r = .02$), and delay GazeSD ($r = -.12$; all $ps > .15$). Furthermore, running a simultaneous regression predicting prosaccade accuracy suggested that 10% of the variance was

Table 4

Descriptive Statistics and Reliability Estimates for All Measures in Experiment 2

Measure	*M*	*SD*	Skew	Kurtosis	Reliability
Antisccade	.61	.17	−.20	−.79	.82
Ospan	37.14	8.44	−.94	1.09	.68
Symspan	18.50	5.31	−.58	−.36	.63
Rspan	37.36	8.39	−.83	.37	.73
Off-task	.41	.35	.48	−1.16	.78
Motivation	3.86	1.37	−.26	−.66	.93
Delay pupil	.14	.11	.16	.76	.99
Delay upilSD	.26	.12	.77	.01	.98
Delay GazeSD	.02	.01	1.00	1.09	.75
Prosaccade	.91	.12	−3.32	14.06	.90
Prosaccade RT	1,527.03	717.10	1.40	3.68	.88

Note. Ospan = operation span; Rspan = reading span; Symspan = symmetry span; Off-task = off-task thoughts; delay pupil = average baseline corrected pupillary response (in mm) during the last 80 ms of the 1,800-ms delay; delay PupilSD = standard deviation of baseline corrected pupillary response (in mm) during the last 80 ms of the 1,800-ms delay; delay GazeSD = standard deviation of gaze during the delay; prosaccade = accuracy on prosaccade trials; prosaccade RT = correct reaction time on prosaccade trials. Reliabilities reflect split-half reliabilities for all measures except the complex span tasks which are alphas computed across all trials.

Table 5
Correlations Among the Measures in Experiment 2

Measure	1	2	3	4	5	6	7	8	9
1. Antisaccade	—								
2. WMC	.23*	—							
3. Off-task	−.27*	−.13	—						
4. Motivation	.28*	.05	−.57*	—					
5. Delay pupil	.27*	.22*	−.13	.20*	—				
6. Delay PupilSD	−.15	−.01	.20*	−.12	−.14*	—			
7. Delay GazeSD	−.35*	−.17*	.15*	−.22*	−.28*	.03	—		
8. Prosaccade	.37*	.17*	−.19*	.18*	.18*	−.04	−.24*	—	
9. Prosaccade RT	−.32*	−.16*	.10	−.17*	−.12	−.002	.21*	−.33*	—

Note. WMC = working memory capacity; Off-task = off-task thoughts; Delay pupil = average pupillary response during the last 80 ms of the 1,800-ms delay; Delay PupilSD = standard deviation of pupillary response during the last 80 ms of the 1,800-ms delay; Delay GazeSD = standard deviation of gaze during the delay; Prosaccade = accuracy on prosaccade trials; Prosaccade RT = correct reaction time on prosaccade trials.
* $p < .05$.

accounted for, but none of the measures accounted for unique variance in prosaccade accuracy.

Because prior research has suggested that general speed factors might also be important for antisaccade performance (e.g., Crawford et al., 2013; Rey-Mermet et al., 2019; Unsworth et al., 2004; Unsworth et al., 2021b), we did an exploratory analyses examining correct reaction times (RTs) in the prosaccade condition to see if the ability to respond rapidly in the task (baseline RT) would predict antisaccade performance. Thus, we computed the average correct RT in the prosaccade condition and examined the relations with the other measures. As seen in Table 5, Prosaccade RTs were significantly correlated with antisaccade accuracy ($r = -.32$), WMC ($r = -.16$), motivation ($r = -.17$), and fixation stability ($r = .21$). Including prosaccade RTs in the simultaneous regression predicting antisaccade accuracy (see Table 6) suggested that 27% of the variance in antisaccade was accounted for, and both prosaccade RTs and fixation stability predicted unique variance. Thus, basic speed factors also accounted for some of the variation in antisaccade performance.

Table 6
Simultaneous Regressions Predicting Antisaccade in Experiment 2

Variable	β	*t*	sr^2	R^2	*F*
WMC	.14	1.77	.02		
Off-task	−.11	−1.16	.01		
Motivation	.12	1.23	.01		
Delay pupil	.12	1.41	.01		
Delay PupilSD	−.09	−1.15	.01		
Delay GazeSD	−.25	2.98**	.05	.23	6.30**
WMC	.12	1.49	.01		
Off-task	−.09	−.93	.01		
Motivation	.11	1.11	.01		
Prosaccade	.25	3.08**	.05		
Delay pupil	.10	1.21	.01		
Delay PupilSD	−.09	−1.19	.01		
Delay GazeSD	−.21	−2.50**	.04	.29	7.12**
WMC	.12	1.47	.01		
Off-task	−.12	−1.24	.01		
Motivation	.09	.95	.01		
Prosaccade RT	−.22	−2.71**	.04		
Delay pupil	.11	1.37	.01		
Delay PupilSD	−.10	−1.24	.01		
Delay GazeSD	−.21	−2.60**	.04	.27	6.72**

Note. WMC = working memory capacity; Off-task = off-task thoughts; Delay pupil = average pupillary response during the last 80 ms of the 1,800-ms delay; Delay PupilSD = standard deviation of pupillary response during the last 80 ms of the 1,800-ms delay; Delay GazeSD = standard deviation of gaze during the delay; Prosaccade = accuracy on prosaccade trials; Prosaccade RT = correct reaction time on prosaccade trials.
** $p < .01$.

Discussion

Consistent with Experiment 1, high-antisaccade accuracy individuals demonstrated larger preparatory pupil responses than low-antisaccade accuracy individuals on antisaccade trials consistent with the *Ramp up* hypothesis. Experiment 2 further demonstrated that high-antisaccade accuracy individuals had larger preparatory pupil responses on antisaccade trials compared to prosaccade trials, while low-antisaccade accuracy individuals demonstrated similar preparatory pupillary responses on both prosaccade and antisaccade trials. These results are consistent with the *Regulation* hypothesis, suggesting that high AC individuals are better able to regulate the intensity of attention than low AC individuals. Similar (albeit weaker) results were also demonstrated for WMC. Interestingly, task-specific motivation did not interact with a saccade type, suggesting that high motivation individuals ramped up their intensity of attention more than low motivation individuals regardless of the type of task, suggesting that motivation and ability factors differentially influence the intensity of attention to preparatory control processes.

Correlation and regression analyses suggested that the magnitude of the preparatory pupil response (but not variability in preparatory pupil), fixation stability, WMC, off-task thinking, and task-specific motivation all correlated with antisaccade performance, but only fixation stability accounted for unique variance. Thus, there was a great deal of shared variance among the measures. These relations tended to hold even after controlling for prosaccade accuracy. Finally, prosaccade RTs also accounted for unique variance in antisaccade, suggesting that baseline RT/speed factors also contribute to individual differences in antisaccade. Although it should be noted that these RTs reflect fairly general speed factors, and it is not clear what aspects of speed are related to antisaccade performance and the other measures.

Combined Analysis

Given the similar results in the two experiments, we further examined the data via a combined cross-experimental analysis. This was done in order to better examine potentially small relations among the measures with a larger combined sample with more power. Specifically, in the combined sample (N = 320) we had sufficient power to detect correlations .16 or larger. Measures were standardized within each sample to account for differences between the experiments. As seen in Table 7, all the measures were correlated with each other except for variability in preparatory pupillary responses. Entering all the measures into a simultaneous regression predicting antisaccade (see Table 8) suggested that all of the measures (except for variability in pupillary responses) accounted for unique variance in antisaccade. Off-task thinking and fixation stability accounted for quite a bit of unique variance, while WMC and preparatory pupillary responses accounted for a small amount of unique variance. Overall, 24% of the variance was accounted for, with 15% of the variance being unique and 9% of the variance shared by the different measures. These results suggest that individual differences in preparatory control are important for variation in antisaccade.

For our final analysis with the combined data, we specifically examined whether the measures of preparatory control and off-task thinking would mediate the relation between WMC and antisaccade. The regression analyses suggest that the preparatory control and off-task thinking measures largely account for the relation between WMC and antisaccade. However, these analyses do not give a full sense of how these measures account for the relation between WMC and antisaccade. That is, is the mediation largely due to off-task thinking, preparatory pupil responses, fixation stability, or some combination? In order to address this question, we specified a structural equation model in which a latent WMC factor (based on the three WMC task) predicted manifest variables for off-task thinking, preparatory pupil responses, fixation stability, and antisaccade. Off-task thinking, preparatory pupil responses, and fixation stability also had direct paths to antisaccade performance. Finally, we post hoc allowed the error variances for preparatory pupil responses and fixation stability to correlate because they were correlated, and modification indices suggested that the model fit could be improved by freeing this path. The overall fit of the model was acceptable, $\chi^2(10) = 17.52$, $p = .064$, RMSEA = .05, NNFI = .95, CFI = .98, SRMR = .04. Shown in Figure 4 is the resulting model. As can be seen, WMC had direct relations to off-task thinking, preparatory pupil responses, and fixation stability, but the direct effect from WMC to antisaccade was not significant (t = 1.77). These results suggest that the relation between WMC and antisaccade was mediated by the other three variables. Indeed, the indirect effect from WMC to antisaccade was significant (indirect = .13, t = 3.84). Note, that these results are slightly different from the regression analyses with the combined data suggesting that WMC had a small unique contribution to antisaccade. The discrepancy is likely due to how WMC is treated in the two analyses. In the regression analyses we used the prior z-score composite which assumes equal weighting of the three WMC tasks. However, in the structural equation model, WMC is a latent factor whereby the different WMC tasks have different weights (factor loadings) based on the correlations among the WMC tasks (i.e., Operation span factor loading = .79; Symmetry span = .40; Reading span = .68). This slight change resulted in the direct effect no longer reaching conventional levels of significance. Furthermore, had we used a factor composite in the regression analyses we would have gotten similar results such that WMC no longer had a unique contribution to antisaccade (β = .10,

Table 7
Correlations Among the Measures in the Combined Data

Measure	1	2	3	4	5	6
1. Antisaccade	—					
2. WMC	.23*	—				
3. Off-task	−.31*	−.18*	—			
4. Delay pupil	.25*	.18*	−.13*	—		
5. Delay PupilSD	−.02	−.04	.01	.03	—	
6. Delay GazeSD	−.37*	−.14*	.15*	−.24*	−.03	—

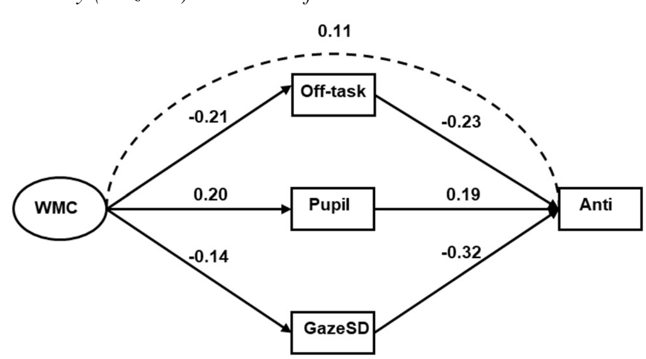
Note. WMC = working memory capacity; Off-task = off-task thoughts antisaccade; Delay pupil = average pupillary response during the last 80 ms of the 1,800-ms delay; Delay PupilSD = standard deviation of pupillary response during the last 80 ms of the 1,800-ms delay; Delay GazeSD = standard deviation of gaze during the delay.
* $p < .05$.

Table 8
Simultaneous Regression Predicting Antisaccade in the Combined Data

Variable	β	t	sr^2	R^2	F
WMC	.13	2.25*	.01		
Off-task	−.23	−4.12**	.05		
Delay pupil	.13	2.21*	.01		
Delay PupilSD	−.02	−.40	.00		
Delay GazeSD	−.29	−5.05**	.08	.24	15.95**

Note. WMC = working memory capacity; Off-task = off-task thoughts; Delay pupil = average pupillary response during the last 80 ms of the 1,800-ms delay; Delay PupilSD = standard deviation of pupillary response during the last 80 ms of the 1,800-ms delay; Delay GazeSD = standard deviation of gaze during the delay.
* $p < .05$. ** $p < .01$.

Figure 4
Structural Equation Model in Which Working Memory Capacity (WMC) Predicts Off-Task Thinking (Off-Task), Preparatory Pupillary Responses During the Delay (Pupil), and Fixation Stability (GazeSD) and Each of These Predict Antisaccade



Note. Single-headed arrows connecting variables to each other represent standardized path coefficients, indicating the unique contribution of the variable. Solid lines are significant at the $p < .05$ level.

$p = .10$). Thus, across both analyses, variation in preparatory control (preparatory pupil and fixation stability) and off-task thinking (lapses of attention) accounted for a large portion of the shared variance between WMC and antisaccade. Off-task thinking, preparatory pupil responses, and fixation stability all had significant direct effects on antisaccade consistent with the above analyses. Collectively, several factors are important for variation in antisaccade performance.

General Discussion

In two experiments we examined individual differences in preparatory control in the antisaccade task. In both experiments participants performed the antisaccade while their eyes were continuously tracked. We found that high-antisaccade accuracy individuals demonstrated larger pupillary responses than low-antisaccade accuracy individuals. Experiment 2 further demonstrated that high-antisaccade accuracy individuals demonstrated a larger preparatory pupil response for antisaccade trials compared to prosaccade trials, whereas low-antisaccade accuracy individuals demonstrated similar preparatory pupil responses on prosaccade and antisaccade trials. Correlation analyses demonstrated that preparatory pupil responses (but not variability in preparatory pupil responses), fixation stability, WMC, and off-task thinking were related to antisaccade performance in both experiments. Furthermore, in Experiment 2 both task-specific motivation and baseline RTs in prosaccade trials correlated with antisaccade performance, suggesting additional factors were important for variation in antisaccade. In the combined sample, with more power, preparatory pupil responses (but not variability in preparatory pupil responses), fixation stability, WMC, and off-task thinking all accounted for unique variance in antisaccade performance. Additionally, most of the variance between WMC and antisaccade was mediated by off-task thinking, preparatory pupil responses, and fixation stability. These results suggest that a combination of factors account for variation in antisaccade performance.

Preparatory Control and Antisaccade Performance

Previously we suggested that variation in preparatory control was likely a partial reason for individual differences in antisaccade performance. That is, variation in antisaccade is partially due to individual differences in the ability to voluntarily control the intensity of attention during the preparatory interval. When the intensity of attention is high, preparatory control is fully implemented resulting in an accurate response. However, when the intensity of attention is low, preparatory control is not fully employed, resulting in a greater likelihood of an error. Furthermore, we suggested that there are several potential ways that individual differences in preparatory control can manifest in terms of the intensity of attention during the preparatory interval. Specifically, we suggested possible differences in the ability to ramp up the intensity of attention (*Ramp up* hypothesis), sustain the intensity of attention (*Sustain* hypothesis), and/or consistently maintain the intensity of attention across trials (*Consistency* hypothesis). Examining preparatory pupil responses as an index of the intensity of attention primarily demonstrated evidence for the *Ramp up* hypothesis consistent with prior theorizing (Meier et al., 2018; Moffitt, 2013; Unsworth et al., 2021b). As noted above, in both experiments, high and low AC individuals demonstrated increased pupil responses during the preparatory interval, but high AC individuals demonstrated larger preparatory pupil responses than low AC individuals. Thus, high AC individuals increased their intensity of attention to a greater extent during the preparatory interval than low AC individuals.

Furthermore, Experiment 2 demonstrated evidence for the *Regulation* hypothesis, which suggests that high AC individuals are better at regulating their intensity of attention and ramping up intensity when needed (and possibly decreasing intensity when needed) than low AC individuals. Specifically, high AC individuals ramped up their intensity more for antisaccades than prosaccades, whereas low AC individuals ramped up similarly for prosaccade and antisaccade trials. Interestingly, high motivation individuals demonstrated larger ramp ups than low motivation individuals on both saccade types suggesting possible differences between the ability to regulate intensity and preparatory control and overall motivation levels. Collectively, both experiments suggested AC abilities are important in order to ramp up and regulate the intensity of preparatory control processes in the antisaccade task.

These conclusions are consistent with a recent study by Hood et al. (2022) that came out while the current study was under review. Specifically, Hood et al. examined preparatory pupillary responses in a fixed delay (5 s) intermixed prosaccade and antisaccade task in which participants were cued as to whether the upcoming trial would require a prosaccade or antisaccade. Hood et al. found that high-antisaccade performers demonstrated increased pupillary responses toward the end of the delay interval selectively for antisaccades, whereas low-antisaccade performers demonstrated increased pupillary responses at the beginning of the delay interval and demonstrated similar increases for prosaccades and antisaccades. Similar results were seen when examining individual differences in WMC. Correlational results suggested that WMC, preparatory pupillary responses, standard deviation of preparatory pupillary responses, and self-reported off-task thinking all correlated with antisaccade accuracy, and these measures (except for off-task thinking) accounted for unique variance in antisaccade accuracy. Hood et al. concluded that under temporal certainty, higher antisaccade performers and higher WMC individuals were more efficient at engaging attention control for demanding tasks. The current results are very consistent with the results from Hood et al. in suggesting that variation in preparatory control processes, indexed via pupillary responses, are important for variation in antisaccade. Furthermore, Hood et al.'s results suggest that high AC individuals are better at regulating the intensity of attention than low AC individuals. Despite these similarities, there are some key differences between the studies. Specifically, Hood et al. examined preparatory control processes under conditions of temporal certainty (fixed delay interval) whereas the current study examined preparatory control under temporally uncertain conditions (varied delay intervals). Additionally, Hood et al. examined preparatory processes over relatively long delay intervals (5 s), whereas the current study examined much shorter delay intervals (200 ms to 1,800 ms). Hood et al. also utilized a cued intermixed antisaccade task, whereas in the current study prosaccade and antisaccades were blocked. Finally, the current study also examined motivation and fixation stability as additional sources of variance in antisaccade performance. As such, the two studies provide complementary results and generally consistent conclusions on the nature of individual differences in preparatory control processes in the antisaccade.

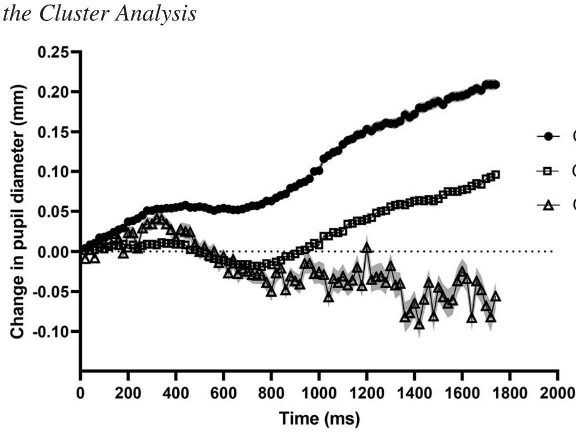
Whereas both current experiments demonstrated evidence for the *Ramp up* hypothesis, there was little evidence for either the

Sustain or *Consistency* hypotheses. That is, according to the *Sustain* hypothesis, low AC individuals cannot sustain the intensity of attention during the preparatory interval as well as high AC individuals, resulting in a decreased pupillary response for low AC individuals. There was little evidence for this hypothesis as both high and low-antisaccade performers demonstrated increased pupillary responses during the preparatory interval. In order to explore whether some individuals demonstrated a decreased pupillary response, we submitted the preparatory pupillary responses for antisaccade trials for both experiments to a two-step cluster analysis. Cluster analysis is a tool used to determine group membership by minimizing within group differences and maximizing between-groups differences (Everitt et al., 2001; Kaufman & Rousseeuw, 2005). The cluster analysis suggested the presence of three groups consisting of 131, 125, and 21 participants each. Shown in Figure 5 are the results. As is shown, Group 1 demonstrated large preparatory pupillary responses while Group 2 demonstrated more moderate preparatory pupillary responses. Importantly, Group 3 demonstrated a decreased preparatory pupil response. This group consisted of only 21 participants, suggesting some limited support for the *Sustain* hypothesis.

Overall, these results are slightly different from some prior research. In particular, Hutchison et al. (2020) demonstrated a general decrease in preparatory pupil responses on the antisaccade especially for their long (8 s) delay condition. Additionally, examining the psychomotor vigilance task, Unsworth et al. (2020) found evidence for the *Sustain* hypothesis in that low AC individuals demonstrated decreased preparatory pupil responses, whereas high AC individuals demonstrated increased preparatory pupil responses. A key difference between the current study and prior research is that in the current study our preparatory intervals were relatively short (200 ms to 1,800 ms), whereas in Hutchison et al. (2020) the preparatory interval was much longer (4 s to 8 s). Likewise, in Unsworth et al. (2020) the preparatory interval ranged from 2 s to 10 s. Thus, it is possible that more evidence for the *Sustain* hypothesis could arise with much longer preparatory intervals. Future research is needed to test this notion.

Figure 5

Change in Baseline Corrected Pupil Diameter as a Function of Time During the Preparatory Delay for the Three Groups From the Cluster Analysis



Note. Shaded areas reflect one standard error of the mean.

There was also little evidence for the *Consistency* hypothesis which suggests that low AC individuals have difficulties maintaining the intensity of attention across trials, resulting in weakened preparatory control and worse performance on a subset of trials. This would result in low AC individuals having a larger trial-to-trial standard deviation of preparatory pupil responses than high AC individuals. However, in neither experiment (nor in the combined dataset) did standard deviation of preparatory pupil responses correlate with antisaccade performance. In both experiments, the correlations were weak and in the predicted direction, but were not significant. Thus, in the current study there was little evidence for the *Consistency* hypothesis in terms of variability in intensity across trials. These results are also somewhat different from prior research in that in their Experiment 1, Hutchison et al. (2020) found strong correlations between standard deviation of the preparatory pupil response and antisaccade performance. However, these relations did not generally replicate in their second experiment where the correlations were much weaker and only one was significant. However, significant relations were seen in Hood et al. (2022). Additionally, examining the psychomotor vigilance task, Unsworth et al. (2020) found that standard deviation of the preparatory pupil response was consistently related to performance. Thus, some prior research has found evidence for the *Consistency* hypothesis. A key difference is that prior research that has found significant correlations between performance and variability in preparatory pupillary responses has typically utilized much longer delay intervals (4 s to 10 s; Hood et al., 2022; Hutchison et al., 2020; Unsworth et al., 2020) than the current study. Thus, similar to the *Sustain* hypothesis, more evidence for the *Consistency* hypothesis could be found with much longer preparatory intervals. Future research is needed to explicitly test this hypothesis.

We should also note that the current *Consistency* hypothesis is a bit different from how we have measured *Consistency* in a prior investigation of individual differences in antisaccade. Specifically, in Unsworth et al. (2021b) we tested a version of the *Consistency* hypothesis by examining self-reported off-task thinking and lapses of attention rather than examining pupillary responses and found that off-task thinking was consistently related to antisaccade performance. Similar results were found in the current study where off-task thinking demonstrated consistent relations with antisaccade. Thus, when consistency is measured with self-reports of off-task thinking there seems to be a stable relation with antisaccade. However, when consistency is measured via trial-to-trial variability in preparatory pupil responses, the relation is not very robust. This suggests that self-reports of off-task thinking and variability in preparatory pupil responses are likely measuring different (but sometimes related) processes. For example, Hutchison et al. (2020) found that off-task thinking and variability in preparatory pupil responses tend to be positively related (six of the seven possible correlations were significant) in the antisaccade and in Experiment 2 of the current study they were positively correlated. Hood et al. (2022) also found a positive correlation between off-task thinking and variability in pupillary responses. Similarly, Unsworth et al. (2020) found consistent positive correlations in the psychomotor vigilance task. One difference between the current study and prior research is that the prior studies (Hutchison et al., 2020; Unsworth et al., 2020) examined the standard deviation of the overall mean preparatory pupil response, whereas in the current study we examined the standard deviation of the peak preparatory pupil response (i.e., the last 80 ms of the preparatory interval). Therefore, we reanalyzed the data examining the standard deviation of the overall mean preparatory pupil response and found very similar results to what we reported. Thus, future research is needed to better examine whether variability in preparatory pupil responses and off-task thinking are related, and both partially index consistency of attention.[4] It should also be noted that a possible limitation of the current study is how off-task thinking was measured. Specifically, like much prior research, thought probes were presented randomly after some trials. This could lead to reactivity effects where current trial performance could influence thought-probe responses (i.e., reporting more mind-wandering following an error). Hutchison et al. (2020) provided evidence consistent with this notion and found reduced correlations when the thought probes were presented in lieu of a target response. However, Hood et al. (2022) found that reactivity effects seemed to influence off-tasking thinking reports on prosaccades rather than antisaccades.[5] Nonetheless, it is possible that reactivity effects are influencing off-task thinking reports and correlations with the other measures.

In addition to examining preparatory control via pupil responses, we also examined individual differences in preparatory control via fixation stability during the preparatory interval. As noted previously, maintaining fixation and preventing unwanted saccades during the preparatory interval is critical for executing correct antisaccades (Barton et al., 2008; Munoz & Everling, 2004; Munoz et al., 2003) and likely represents the ability to maintain a constrained attentional focus during the preparatory interval. In line with this notion, we found consistent correlations between fixation stability (or instability) and antisaccade performance in each experiment and the combined dataset. Furthermore, fixation stability accounted for unique variance in antisaccade performance in all analyses. These results provide evidence suggesting that preparatory control processes are important for maintaining fixation and a constrained focus of attention during the preparatory interval. The results also demonstrated that the preparatory pupil response and fixation stability were correlated, suggesting that these different indices of preparatory control were related. This suggests that high AC individuals ramp up their intensity of attention during the preparatory interval more than low AC individuals, which likely aids in the ability to maintain fixation and a constrained focus of attention and avoid attentional capture from the cue. At the same time, the regression analyses demonstrated that the preparatory pupil response and fixation stability accounted for unique variance in antisaccade, suggesting that although related, these two also likely measured slightly different aspects of preparatory control. Future research is needed to better examine similarities and differences between preparatory pupil responses and fixation stability.

Working Memory and Antisaccade

As noted previously, a secondary goal of the current study was to examine whether preparatory control processes partially account for the relation between WMC and antisaccade as prior research has suggested (e.g., Hood et al., 2022; Kane et al., 2001; Meier et al., 2018; Unsworth et al., 2004; Unsworth et al., 2021b). In Experiment 1, WMC demonstrated weak and nonsignificant correlations with preparatory pupil responses and fixation stability. However, in Experiment 2 and the combined dataset, WMC was related to both preparatory pupil responses and fixation stability. That is, high WMC individuals ramped up their intensity of attention more during the preparatory interval than low WMC individuals. High WMC individuals were also better able to regulate their intensity of attention and ramp up more for antisaccade trials than prosaccade trials compared to low WMC individuals (consistent with Hood et al., 2022). Thus, part of the reason WMC is related to antisaccade seems to be due to variation in preparatory control (Meier et al., 2018; Unsworth et al., 2021b). Consistent with prior research, WMC was also was related to off-task thinking during the antisaccade (e.g., Meier et al., 2018; Unsworth et al., 2021b). Further examining these relations with structural equation modeling in the combined dataset suggested that the relation between WMC and antisaccade was largely due to variation in preparatory control (preparatory pupil responses and fixation stability) and off-task thinking (lapses of attention).[6] These results provide important information that variation in preparatory control processes are critical for the relation between WMC and antisaccade. They further demonstrate that individual differences in lapses of attention are critical for the WMC to antisaccade relation. As such, these results are consistent with prior research suggesting that multiple factors are responsible for the consistent correlation between WMC and antisaccade (Meier et al., 2018; Unsworth et al., 2021b).

Conclusions

The current results suggest that variation in preparatory control are important for understanding individual differences in AC and their influence on performance on the antisaccade task. High

[4] We have also examined variability in pre-trial pupil diameter as a measure of fluctuations/consistency in arousal and attentional state (Robison & Brewer, 2020; Unsworth & Robison, 2017a). Therefore, we examined relations between trial-to-trial standard deviation of pre-trial baseline pupil diameter and the other measures. In Experiment 1, standard deviation of pre-trial baseline correlated with the other pupil variability measures (rs = .39, .47) and with fixation stability (r = .17). No other correlations reached conventional levels of significance. In Experiment 2, standard deviation of pre-trial baseline correlated with the other pupil variability measures (rs = .49, .59) and with antisaccade accuracy (r = −.22), off-task thinking (r = .23), and motivation (r = −.18). No other correlations reached conventional levels of significance.

[5] There was more off-task thinking reported on antisaccade trials (M = .42, SD = .35) than prosaccade trials (M = .30, SD = .33), $t(168) = 5.77$, $p < .001$. Off-task thinking in antisaccade and prosaccade trials were correlated (r = .71), and both were correlated with antisaccade performance (antisaccade off-task $r = -.27$; prosaccade off-task $r = -.19$) and prosaccade performance (antisaccade off-task $r = -.19$; prosaccade off-task $r = -.22$).

[6] We also examined whether the ability to set-up and maintain temporary stimulus-response bindings accounts for the WMC to antisaccade relation (Oberauer et al., 2007; Wilhelm & Oberauer, 2006; Wilhelm et al., 2013). This account suggests that low WMC individuals have poorer performance on the antisaccade task because they are less able to setup and maintain the arbitrary stimulus-response bindings than high WMC individuals. This predicts that the relation between WMC and antisaccade should be accounted for by shared variance with the prosaccade task which has the same arbitrary stimulus-response bindings as antisaccade. Prosaccade accuracy was correlated with both antisaccade accuracy (r = .37) and WMC (r = .17). However, WMC was still related to antisaccade (r = .19) even after controlling for shared variance with prosaccade. Thus, the relation between WMC and antisaccade did not seem to be due the ability to set-up and maintain temporary and arbitrary stimulus-response bindings.

AC individuals are better able to ramp up the intensity of attention and maintain fixation during the preparatory interval than low AC individuals. Additional factors such as WMC, off-task thinking, task-specific motivation, and baseline RT are also important for variation in antisaccade performance. Furthermore, preparatory control processes and off-task thinking were shown to account for most of the shared relation between WMC and antisaccade. Collectively, the current results suggest that individual differences in preparatory control are critically important for variation in antisaccade performance.

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