

Individual Differences in the Dynamics of Attention Control

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Individual differences in the dynamics of attention control were examined in two studies. Participants performed mouse tracker versions of Stroop (Studies 1 and 2) and flankers (Study 2), along with additional measures of attention control and working memory to better examine individual differences in how conflict resolution processes unfold over time. Attention control abilities were related to the amount of attraction to the incorrect response and the time to move toward the correct response on incongruent trials in the Stroop task. In the flanker task, attention control abilities were not related to the amount of attraction to the incorrect response but were related to the time to move toward the correct response on incongruent trials. Mouse tracker measures in both Stroop and flankers demonstrated acceptable psychometric properties and tended to load moderately on an attention control factor along with other attention control tasks. These results are consistent with the notion that conflict resolution processes in Stroop and flankers likely reflect both overlapping and distinct (i.e., restraining and constraining attention) processes that are related to broader attention control abilities.

Public Significance Statement

Our ability to control attention and prevent distraction is important for a number of everyday tasks. In the present study, we demonstrate that individual differences in attention control are related to conflict resolution processes in Stroop and flanker tasks. High-attention control individuals are better able to prevent capture from the incorrect response and quickly move toward the correct response than low-attention control individuals. These results further our understanding of how variation in attention control is critical for successful conflict resolution.

Keywords: attention control, conflict resolution, mouse tracking, individual differences, working memory

Attention control abilities are needed in a number of daily situations where we need to focus our attention and block out distractors. Attention control (AC) refers to the set of processes that allow us to focus attention, to sustain and regulate the intensity of attention, and to resist attentional capture from internal and external distraction. Individuals seem to vary considerably in their AC abilities, such that high-AC individuals are better at actively maintaining task goals and preventing distraction than low-AC individuals. Given the importance of AC to a number of domains, AC abilities are thought to be a fundamental cognitive construct that is critical for individual differences in broad abilities (e.g., Engle, 2002; Engle & Kane, 2004; Kane & Engle, 2002; Unsworth, Miller, & Robison, 2021; Unsworth & Spillers, 2010). In the present work, we examined individual differences in the dynamics of AC during conflict tasks by utilizing mouse tracking techniques to better understand how conflict is resolved in a more continuous manner.

Individual Differences in Attention Control

Previous factor analytic studies have demonstrated that AC tasks like Stroop, flankers, antisaccade, go/no-go, cued search, Simon, psychomotor vigilance, and others are weakly to moderately correlated with one another and tend to load on the same factor in confirmatory factor analyses (e.g., Friedman et al., 2008; Friedman & Miyake, 2004; Kane et al., 2016; Miyake et al., 2000; Redick et al., 2016; Unsworth, Miller, & Robison, 2021; Unsworth & Spillers, 2010).¹ This AC factor tends to correlate strongly with other cognitive abilities such as working memory, long-term memory, and fluid intelligence (e.g., Friedman et al., 2008; Kane et al., 2016; Miyake et al., 2000; Redick et al., 2016; Unsworth, Miller, & Robison, 2021;

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Unsworth & Spillers, 2010). A recent meta-analysis of 90 latent variable studies suggested that most (84%) studies find evidence for a coherent AC factor, and this factor is related to other cognitive ability factors (Unsworth et al., 2024). Furthermore, individual differences in AC abilities assessed in the laboratory tend to predict real-world attention failures (Kane et al., 2017; Unsworth et al., 2012; Unsworth & McMillan, 2017). Thus, there seems to be extensive evidence suggesting that there are coherent individual differences in AC abilities, and these AC abilities are related to other cognitive abilities.

Recent work suggests that a broad AC factor is likely composed of different subcomponent AC factors. For example, Friedman and Miyake (2004) found that prepotent response inhibition (e.g., Stroop and antisaccade) and resistance to distractor interference (e.g., flankers) were related (.67) but distinct factors. Kane et al. (2016) additionally suggested that AC abilities likely represent two distinct but related subfactors. These include the ability to *restrain* attention and prevent prepotent responses from guiding behavior (similar to prepotent response inhibition) and the ability to *constrain* attention to target items among distractors (similar to resistance to distractor interference). Kane et al. found that restraint and constraint could be modeled as two separate factors that were strongly correlated (.60), and both were related to working memory and task-unrelated thoughts. Additional research suggests that the ability to *sustain* attention across both short and long intervals and prevent lapses of attention is also important (Kane et al., 2016; Unsworth, 2015; Unsworth et al., 2010; Unsworth, Miller, & Robison, 2021; Unsworth & Robison, 2020; Unsworth, Robison, & Miller, 2021; Unsworth & Spillers, 2010; Welhaf & Kane, 2024). Measures of restraining, constraining, and sustaining attention load onto the same AC factor, and this factor is related to other cognitive abilities (Ellis et al., 2021; Redick et al., 2016; Unsworth & McMillan, 2014; Unsworth, Miller, & Robison, 2021; Unsworth et al., 2009; Unsworth & Spillers, 2010). Furthermore, in our recent meta-analysis and reanalysis of prior latent variable studies, we found evidence suggesting that there were distinct factors for restraining, constraining, and sustaining attention, and these lower order factors were accounted for by higher order AC factor (Unsworth et al., 2024). Thus, recent research suggests that AC abilities can be fractionated into distinct, yet correlated abilities that are related to other important cognitive abilities.

While a number of studies have found evidence for individual differences in AC, some recent studies have found little evidence for variation in AC. Specifically, a few studies have suggested that many AC tasks demonstrate weak and near zero correlations at the task level, resulting in an inability to find a coherent latent AC factor (e.g., De Simoni & von Bastian, 2018; Gärtner & Strobel, 2021; Krumm et al., 2009; Rey-Mermet et al., 2018, 2019; see also Karr et al., 2018). Thus, some recent research casts doubt on the notion that there are individual differences in AC.

In many studies of AC, researchers have relied on conflict tasks, whereby controlled and automatic processes are typically in opposition to assess AC. This is accomplished in tasks where the task goal is incompatible with more automatic tendencies. For example, in the Stroop task (Stroop, 1935), participants are required to name the color in which color names are printed. When the color and the word match ("RED" presented in red ink; congruent trials), the task is quite easy. When the color and the word conflict ("RED" presented in blue ink;

incongruent trials), however, both reaction time and error rates increase. Theoretically, this is because the prepotent response conflicts with the task goal ("Say the color not the word"), and AC processes are needed to maintain the task goal and resolve the conflict (e.g., Cohen et al., 1990; Kane & Engle, 2003). The size of the congruency effect (i.e., the reaction time difference between incongruent and congruent trials) is thought to typically reflect the strength of the conflict and the amount of AC allocated to deal with the conflict (e.g., Braem et al., 2019). Thus, individuals with larger congruency effects are thought to experience more interference and have weaker/slower AC than individuals with smaller congruency effects.

While conflict measures provide important indicators of conflict and control, there are also some issues associated with them. In particular, such measures can be unreliable and tend to be multidimensional with several processes contributing to performance. For example, recent work has demonstrated that AC tasks that rely on reaction time (RT) difference scores (such as Stroop and flankers) tend to have poor reliability estimates (e.g., Draheim et al., 2021; Friedman & Miyake, 2004; Hedge et al., 2018; Kane et al., 2016; Paap & Sawi, 2016; Redick et al., 2016; Rey-Mermet et al., 2018; Unsworth, Miller, & Robison, 2021). Thus, one reason that some AC tasks demonstrate weak correlations with each other is because some of the measures are simply not very reliable. Although we note that just because some studies have demonstrated poor reliability estimates for some conflict tasks, it is premature to suggest that these tasks are necessarily unreliable. Indeed, several studies have also demonstrated more acceptable reliability estimates for some congruency effects in conflict tasks (e.g., Draheim et al., 2021; Friedman & Miyake, 2004; Hedge et al., 2018; MacLeod et al., 2010; Redick et al., 2016; Rey-Mermet et al., 2019; von Bastian et al., 2020; Unsworth, Miller, & Robison, 2021; Whitehead et al., 2020). As such, it is important to keep in mind that reliability estimates are highly contextualized, reflecting the current task and sample. As such, changes in task parameters (e.g., number of trials, proportion congruency, etc.) and changes in samples can influence between-subject variability and corresponding reliability estimates.

Another potential issue with RT measures of congruency effects is that they reflect an end product of the various cognitive processes that occur between stimulus onset and the response and thus do not provide critical information on how cognitive processes unfold over time (e.g., Bundt et al., 2018; Freeman & Ambady, 2010; Kinder et al., 2022; Smith et al., 2022; Song & Nakayama, 2009). Computational models such as the diffusion model for conflict tasks (Ulrich et al., 2015) can aid in understanding summary measures such as RT and accuracy, but more direct evidence of how conflict is resolved over time, and a better understanding of individual differences in AC in conflict tasks is needed.

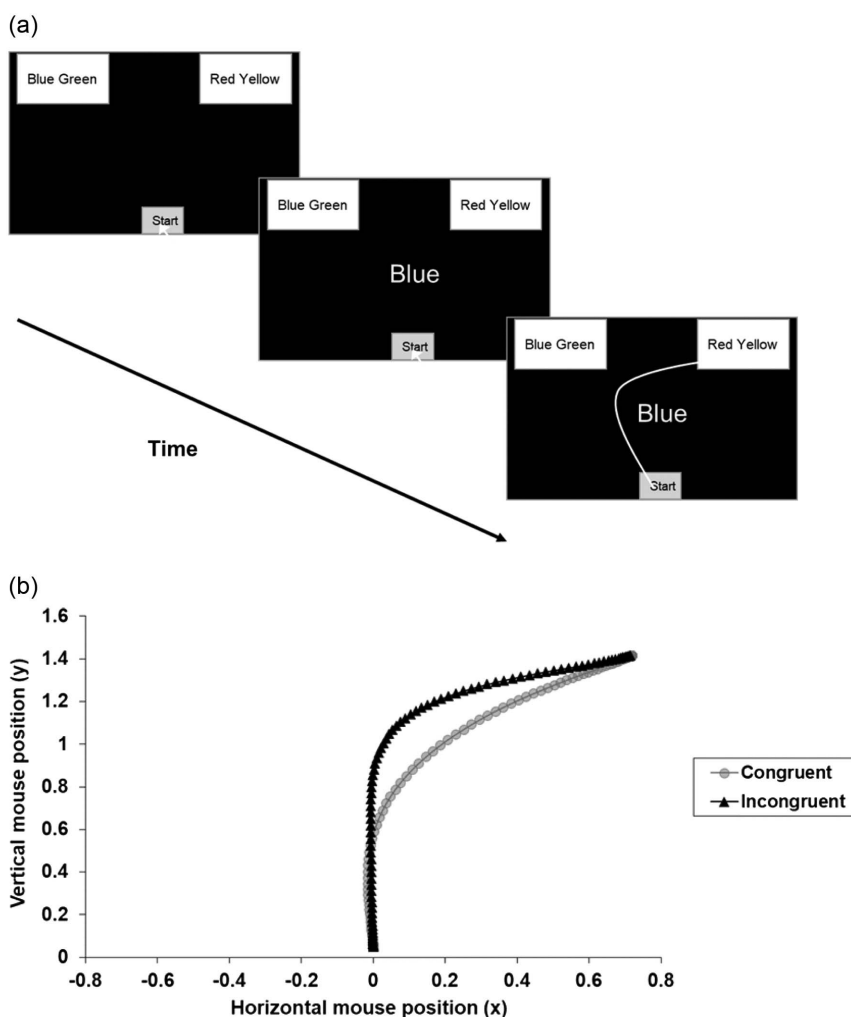
Assessing the Dynamics of Attention Control With Tracking Tasks

A promising means of examining how conflict resolution processes dynamically unfold over time is the use of tracking tasks (e.g., Freeman, 2018; Freeman et al., 2011; Song & Nakayama, 2009; Spivey & Dale, 2006; Stillman et al., 2018). In these tasks, participants are typically instructed to click a button on the bottom of the computer screen. A stimulus is then presented, and participants

have to make a decision about the stimulus by moving the cursor to the correct response in one of the top corners of the screen. Because the cursor position is sampled roughly 60–75 times per second, it is possible to precisely track the mouse trajectories during the course of a trial. These mouse trajectories can then be examined to better understand how decision processes unfold in real time. That is, did the cursor move quickly and directly to the correct response, or did the cursor initially move toward the incorrect response, suggesting an attraction to the incorrect response, before moving to the correct response? Thus, tracking provides an important means of elucidating how decisions evolve and the strength that response alternatives have on the underlying decision (e.g., [Freeman, 2018](#); [Stillman et al., 2018](#)). The overall idea is that the motor movements are continuously updated, and thus, mouse (and reach) movements can be used to study decision processes in real time, rather than merely as the end product such as RT and accuracy.

Recently, a number of studies have used tracking tasks to better examine conflict resolution processes in AC tasks. For example, shown in [Figure 1a](#) is a mouse tracking version of the Stroop task ([Bundt et al., 2018](#); [Incera & McLennan, 2016](#); [Ruitenberg et al., 2019](#)). In this task, participants first click on the Start button to initiate the trial. A colored word is then presented in the center of the screen. Consistent with the standard Stroop task, on some trials, the color and word are congruent; and on other trials, they are incongruent. The participant's job is to click on the box with the correct color (and not word). In the example, participants should click on the Red Yellow box, because the color is yellow and should not click on the Blue Green box, which would be the incorrect response. As noted previously, the utility of the mouse tracking task is that it allows for a dynamic real-time assessment of conflict, whereas standard RT and accuracy measures only provide an end point of AC processes. For example, as shown in [Figure 1a](#) on this

Figure 1
Mouse Tracker Stroop



Note. (a) Example trial for mouse tracker version of Stroop. (b) Mouse trajectories for correct congruent and incongruent trials.

trial, the participant started to move the mouse toward Blue indicating a strong attraction to the incorrect response. However, the participant corrected their movement and eventually clicked on the correct response. Thus, a long reaction time in this task is driven by the fact that early on there is a strong attraction to the incorrect response that needs to be overridden in order to make the correct response. Shown in Figure 1b are typical results for congruent and incongruent trials averaged over trials. As can be seen, incongruent trials are associated with a stronger attraction to the incorrect response compared to congruent trials resulting in a Stroop effect in the mouse trajectories (e.g., Bundt et al., 2018; Incera & McLennan, 2016; Ruitenberg et al., 2019).

Several dependent measures can be extracted to examine conflict resolution processes such as initiation time, movement time, and area under the curve (AUC). Initiation time refers to the time from stimulus onset until movement onset. Movement time refers to the time from mouse movement onset to the click on the response box. Overall RT is thus broken down into initiation time and movement time. AUC refers to the geometric area between the participant's empirical response trajectory and the ideal trajectory (i.e., a straight line from the start box to the correct response box). As seen in Figure 1b, incongruent trials were associated with longer movement times and greater AUC than congruent trials, suggesting that there was a greater attraction to the incorrect response in incongruent trials than congruent trials, partially resulting in longer movement times for incongruent trials. Furthermore, the time course of conflict resolution can be examined by examining the horizontal mouse position over time during the course of a trial. Thus, tracking tasks provide a rich temporal profile of conflict resolution processes.

Utilizing these techniques, recent research has examined conflict resolution processes in a number of AC tasks such as Stroop, flankers, and Simon. For example, Incera and McLennan (2016) found a congruency effect on overall RTs (but no difference in initiation times) in a mouse tracking version of Stroop. Incera and McLennan (2018) replicated these results in both Stroop and an arrow version of flankers. In reach tracking tasks, Erb et al. (2016) found congruency effects on initiation time, movement time, and maximum deviation for both Stroop and letter flanker tasks and found that these were moderated by prior trial congruency. Erb et al. (2016) suggested that initiation times might reflect a threshold adjustment process that puts a temporary break on subsequent responding, and reach curvature reflects a controlled selection process in which top-down processes are needed to resolve the conflict. Erb et al. further suggested that both are needed in Stroop and flanker tasks, suggesting similarities between the tasks but differences as well. Bundt et al. (2018; see also Ruitenberg et al., 2019) did not find a significant congruency effect in initiation times in Stroop but did find congruency effects in movement times and AUC. Additional studies have demonstrated congruency effects in movement times (or overall RT) and measures of curvature (AUC or maximum deviation) but not initiation times in color Stroop, spatial Stroop, Simon, and flanker tasks (e.g., Kinder et al., 2022; Menciloglu et al., 2021; Quétard et al., 2023; Scherbaum et al., 2010; Tafuro et al., 2020; Tseng & Damian, 2023; Yamamoto et al., 2016; Ye & Damian, 2023). Collectively, prior research suggests that tracking tasks demonstrate congruency effects similar to button-press and vocal response paradigms in a number of AC tasks and further suggest that these tasks can provide important information on how conflict resolution processes unfold over time.

Recent research has also begun to utilize tracking tasks to better understand variation in AC. For example, Incera and McLennan (2016; see also Incera and McLennan, 2018) found that bilinguals had slower initiation times than monolinguals on the Stroop task. Importantly, bilinguals had faster movement times than monolinguals especially on incongruent trials, suggesting that bilinguals were faster at conflict resolution than monolinguals. Erb et al. (2020) examined age differences in AC in a reach tracking version of the flanker task and found that older adults demonstrated a larger congruency effect in overall RTs compared to younger adults. Interestingly, this effect was localized to differences in initiation times whereby older adults were slower to begin reaching especially on incongruent trials compared to younger adults. No age differences in congruency effects were found for movement times or maximum deviation, suggesting that older and younger adults were similarly attracted to the incorrect response. Erb et al. suggested that older adults likely had a higher threshold (and hence longer initiation times) than younger adults, possibly due to differences in speed-accuracy trade-offs where older adults strategically slowed down in order to achieve high accuracy rates. In another study, Erb, Welhaf, et al. (2021) examined individual differences in working memory in a reach tracking version of flankers. As noted previously, several studies have demonstrated that individual differences in working memory are related to AC and to congruency effects in the flanker task (e.g., Heitz & Engle, 2007; Kane et al., 2016; Redick & Engle, 2006; Unsworth & Spillers, 2010). Consistent with prior research, Erb, Welhaf, et al. (2021) found that working memory was negatively correlated with congruency effects in overall RT. This effect was not localized to either initiation times or movement times. Furthermore, examining curvature suggested that low-working-memory individuals demonstrated greater attraction to the incorrect response on incongruent trials than high-working-memory individuals. Erb et al. suggested that high-working-memory individuals were better at conflict resolution than low-working-memory individuals. Collectively, several recent studies have demonstrated that tracking tasks can provide important information on the nature of individual differences in AC.

The Present Study

Prior research suggests that there are individual differences in AC abilities measured with various conflict tasks. However, as noted above, RT differences in these tasks reflect the end product of various processes and do not provide enough information on how AC processes dynamically unfold over time. Furthermore, these measures might be susceptible to individual differences in processing speed and speed-accuracy trade-offs, making it difficult to disentangle the many possible different sources of variance (e.g., Draheim et al., 2019; Rey-Mermet et al., 2019). In the present study, our main goal was to examine individual differences in the dynamics of AC via tracking versions of Stroop and flankers in order to better elucidate variation in AC. For example, individual differences in congruency effects in the Stroop are thought to reflect the strength of the conflict between the prepotent response (say the word) and the correct response (say the color) and the amount of AC allocated to deal with the conflict. However, some researchers have suggested that congruency effects in RT could reflect differences in speed of processing or differences in speed-accuracy trade-offs (e.g., Draheim et al., 2019;

Rey-Mermet et al., 2019). Thus, it is not clear that differences in RT in this task actually reflect differences in AC and conflict resolution. Tracking versions of Stroop can therefore provide important information of potential differences in conflict.

If individual differences in congruency effects are partially a result of differences in the ability to restrain attention and prevent habit from guiding behavior (e.g., Kane & Engle, 2003; Kane et al., 2016), then low-AC individuals should have more attraction/capture to the incorrect response than high-AC individuals, even though both ultimately click on the correct response. If, however, individual differences in AC reflect differences in the time to resolve the conflict between responses (e.g., Kane & Engle, 2003), then individual differences would not be reflected in differences in AUC but rather differences in movement time only. That is, high- and low-AC individuals would demonstrate similar attraction to the incorrect response, but high-AC individuals would be faster at resolving the conflict than low-AC individuals.

If individual differences in task performance are due to the differences in processing speed, we might expect differences in both initiation time and movement time with no differences in AUC, as both high- and low-AC individuals demonstrate similar capture by the conflict, but high-AC individuals are simply faster overall. Such an account might also predict that speed of processing should influence congruent and incongruent trials equally, leading to no differences in congruency effects. Finally, if differences are due to differences in speed-accuracy trade-offs, then we might expect differences to primarily arise in initiation times as some individuals might wait until the conflict has largely been resolved before initiating the movement of the mouse (e.g., Erb et al., 2020; Incera & McLennan, 2016). By measuring different aspects of mouse movements that occur during a trial, mouse tracking provides a powerful opportunity to better examine reasons for individual differences in conflict tasks.

The second goal of the present study was to examine similarities and differences between the Stroop and flanker tasks as markers of conflict, as both tasks are thought to be measures of general AC abilities but might measure different aspects of AC. Several studies have found that congruency effects in these tasks are weakly to moderately related and, in some studies, these two tasks load on the same overall factor (e.g., Draheim et al., 2021; Unsworth, Miller, & Robison, 2021; Unsworth & Spillers, 2010). However, other studies suggest that these two tasks demonstrate near zero correlations and do not necessarily load together on a factor (e.g., Rey-Mermet et al., 2018, 2019). Yet, weak correlations between these tasks might be expected if they are measuring distinct but related aspects of AC. Prior work (Friedman & Miyake, 2004; Kane et al., 2016; Poole & Kane, 2009; Unsworth & Spillers, 2010) suggests that the Stroop task measures the ability to restrain attention and prevent the prepotent response from guiding behavior, whereas the flanker task measures the ability to constrain attention to target stimuli in the presence of distractors. For example, Heitz and Engle (2007) did a time course analysis examining conditional accuracy functions for high- and low-working-memory individuals as they performed a version of the flanker task and suggested that participants constrained their spotlight of attention to get the correct response (Gratton et al., 1988; White et al., 2011). Importantly, Heitz and Engle suggested that high-working-memory (and presumably high-AC) individuals were faster at constraining their spotlight of attention than low-working-memory (and presumably low-AC) individuals, but both groups were similarly

captured by the distractor stimuli. Unlike the Stroop task, these results and interpretation suggest that in the flanker task high- and low-AC individuals might demonstrate similar attraction to the incorrect response, but that high-AC individuals are faster at resolving the conflict (constraining their spotlight) than low-AC individuals. In terms of mouse tracking measures, high- and low-AC individuals should demonstrate similar areas under the curve, but AC-related differences should arise in movement time reflecting differences in the rate of constraint. Thus, if restraining and constraining attention reflect distinct, yet correlated facets of AC, we should find different patterns of relations with the mouse measures, and the Stroop and flanker measures should be weakly to moderately correlated. It is also possible that both tasks measure a more general AC/conflict resolution ability, and AC should correlate with AUC and movement time in both tasks, and cross-task measures should strongly correlate. By examining different mouse tracking measures, we should be able to better understand similarities and differences in variation in AC in Stroop and flanker tasks.

The third goal of the present study was to examine whether the mouse tracking versions of the AC tasks would demonstrate increased reliability and validity over the button-press versions. As noted previously, RT differences of congruency effects can sometimes demonstrate poor reliability estimates and weak correlations with other AC measures, possibly due to low between-subject variance in some cases. Recent research has examined whether new and different measures of AC can provide a better assessment of AC (e.g., Draheim et al., 2021; Rey-Mermet et al., 2019; Unsworth, Miller, & Robison, 2021). Furthermore, recent research suggests that mouse tracking conflict tasks might provide a more sensitive index of conflict than button-press tasks (e.g., Leontyev et al., 2018; Yamauchi et al., 2019). As such, the third goal of the present study was to examine the measurement properties of the mouse tracking tasks in comparison to button-press versions to see if the mouse tracking tasks would provide more reliable and valid measures.

To examine these issues, we conducted two individual differences studies in which participants performed both traditional button-press and mouse tracking versions of conflict tasks (Stroop in Studies 1 and 2 and flanker in Study 2) along with additional measures for AC and several working memory measures to examine how individual differences in these constructs were related to performance on the mouse tracking tasks.

Transparency and Openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in our study. Note because we use many of the same tasks across studies, the methods and descriptions for those tasks will be the same as prior published articles for consistency. Data and code are available on the Open Science Framework (<https://osf.io/4v5za/>). This study was not preregistered.

Study 1

In Study 1, participants performed both a mouse tracking version of the Stroop task and a button-press version of Stroop along with additional measures of AC and working memory. We examined whether congruency effects in the mouse movement measures (initiation time, movement time, and AUC) would be related to AC and working memory. We further examined whether the mouse

movement measures would demonstrate better reliability and validity than RT effects in the button Stroop.

Method

Participants

Participants were recruited from the subject-pool at the University of Oregon. The current data are subset of data from [Unsworth and Miller \(2024\)](#) in which 213 (out of 320) participants completed the mouse tracker version of Stroop. Note we added in the mouse tracker version of Stroop approximately 2 months after data collection on the larger study had already begun. We tested participants over one and a half academic quarters, using the end of the second quarter as our stopping rule for data collection with the aim of getting a minimum of 200 participants. Of the participants, 150 reported their gender as female, and 62 reported their gender as male with an average age of 19.46 ($SD = 1.91$). One participant had very low accuracy on congruent and neutral flanker trials, and their flanker performance data were excluded. Two participants had movement times on the mouse tracker Stroop more than four standard deviations from the mean and their movement time data were excluded.

Materials and Procedure

After signing informed consent, all participants completed operation span, symmetry span, reading span, long-term memory measures not relevant to the present study, antisaccade, arrow flankers, Stroop, letter comparison, number comparison, and the mouse tracker version of Stroop. All tasks were administered in the order listed above. All tasks were programmed in E-Prime 2.0 (E-prime 2.0 software, Psychology Software Tools, Inc., Sharpsburg, Pennsylvania) except the mouse tracker version of Stroop which was programmed in Mouse Tracker ([Freeman & Ambady, 2010](#)). The entire experimental session took approximately 2 hr to complete.

Attention Control Tasks

Antisaccade. In this task ([Kane et al., 2001](#)), participants were instructed to stare at a fixation point which was onscreen for a variable amount of time (200–2,200 ms). A flashing white “=” was then flashed 12.7 cm either to the left or right of fixation for 100 ms. The target stimulus (a B, P, or R) then appeared onscreen for 100 ms, followed by masking stimuli (an H for 50 ms followed by an 8, which remained onscreen until a response was given). The participants’ task was to identify the target letter by pressing a key for B, P, or R (the Keys 4, 5, and 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 prosaccade trials, 10 practice antisaccade trials, and 60 real antisaccade trials. The dependent variable was proportion correct on the antisaccade trials.

Arrow Flankers. This is a variant of the executive control measure in the Attention Network Test ([Fan et al., 2002](#)) used by [Redick and Engle \(2006\)](#). Participants were presented with a fixation point for 400 ms. This was followed by an arrow directly above the fixation point for 1,700 ms. The participants’ task was to indicate the direction the arrow was pointing (pressing the F for left pointing

arrows and pressing J for right pointing arrows) as quickly and accurately as possible. On neutral trials, the arrow was flanked by two horizontal lines on each side. On congruent trials, the arrow was flanked by two arrows pointing in the same direction as the target arrow on each side. Finally, on incongruent trials, the target arrow was flanked by two arrows pointing in the opposite direction as the target arrow on each side. There were 30 trials per condition (90 total real trials), and all trial types were randomly intermixed. Participants first performed 15 practice trials and then the real trials. The dependent variable was the congruency effect in RTs (incongruent – neutral) for correct trials.

Stroop. Participants were presented with a color word (red, green, or blue) presented in one of three different font colors (red, green, or blue; [Stroop, 1935](#)). The participants’ task was to indicate the font color via key press (red = 1, green = 2, blue = 3). Participants were told to press the corresponding key as quickly and accurately as possible. Participants received 15 trials of response mapping practice and six trials of practice with the real task. Participants then received 133 experimental trials. Of these trials, 67% were congruent such that the word and the font color matched (i.e., red printed in red), and the other 33% were incongruent (i.e., red printed in green). Similar to the flanker task, the dependent variable was the congruency effect in RTs (incongruent – congruent) for correct trials.

Mouse Tracker Stroop. This task was adapted from [Incera and McLennan \(2016\)](#) and [Bundt et al. \(2018\)](#) utilizing the Mouse Tracker software ([Freeman & Ambady, 2010](#)).² Participants were first presented with a start button centered at the bottom of the screen and boxes at the top left and top right of the screen. As shown in [Figure 1a](#), one box includes two color words (Blue Green), and the other box includes two other color words (Red Yellow). After clicking the start button, a color word (blue, green, red, or yellow) printed in one of four font colors was presented. The task was to indicate the font color by clicking on the appropriate box as quickly as possible. Participants were instructed to moving the mouse immediately after clicking Start. Prior to the real trials, participants completed 16 baseline trials where the word HERE was presented in one of the boxes (50% of the time on the right and 50% of the time on the left), and participants simply had to click on the correct box as quickly as possible. Participants then completed 15 trials in which a blue, green, red, or yellow dot appeared in the middle of the screen, and participants had to click on the correct box as quickly as possible indicating the color of the dot. Participants then completed 15 trials of the Stroop task where a color word printed in different colors was presented in the middle of the screen, and participants had to click on the box with the correct font color as quickly as possible. Finally, participants completed 120 real trials where 67% were congruent, and the other 33% were incongruent.

The Mouse Tracker software recorded the *x*- and *y*-coordinates of the mouse cursor every 13–16 ms during each trial. In addition, it recorded performance time during each trial by logging how many milliseconds elapsed since stimulus presentation. The raw trajectory data were rescaled to standardized coordinate space (*x*-axis range = –1 to 1; *y*-axis range = 0–1.5) and remapped toward the right. Trajectories were time normalized by the software to 101 time steps. The dependent variables were the difference between incongruent

² We thank Sara Incera and Marit Ruitenberg for sharing their tasks and materials with us.

and congruent trials on initiation time, movement time, and AUC. Initiation time refers to the time from stimulus onset until movement onset. Movement time refers to the time from mouse movement onset to the click on the response box. AUC refers to the geometric area between the participant's empirical response trajectory and the ideal trajectory (i.e., a straight line from the start box to the correct response box). We also examined changes in the mouse movements in the x -coordinates over time by examining raw time in time bins of 190 ms.

Working Memory Tasks

Operation Span. Participants solved a series of math operations while trying to remember a set of unrelated letters (see Unsworth et al., 2005). 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 of 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 Redick et al., 2012; Unsworth et al., 2009). 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.

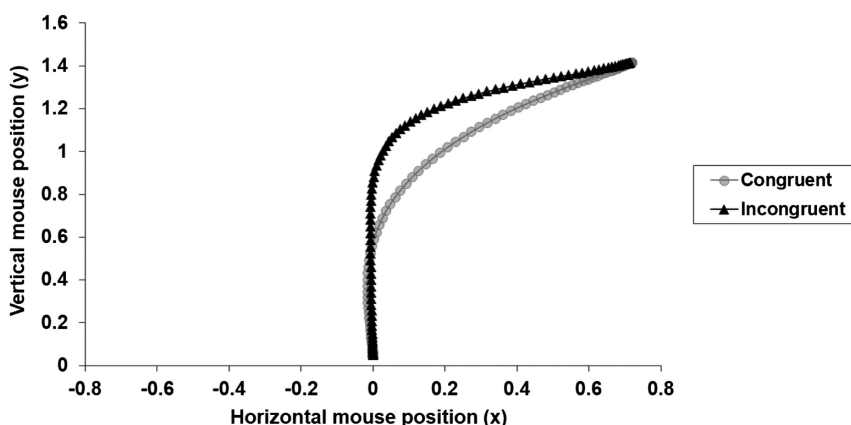
Reading Span. While trying to remember an unrelated set of letters, participants were required to read a sentence and indicated whether or not it made sense (see Redick et al., 2012; Unsworth et al., 2009). Half of the sentences made sense, while the other half did not. Nonsense sentences were created 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

Experimental Effects

Shown in Figure 2 are the mouse movement trajectories for congruent and incongruent trials. As can be seen, congruent trials demonstrated a more direct path to the correct response than incongruent trials, which seemed to demonstrate an initial attraction to the incorrect response and then more movement toward the correct response. To examine these impressions, we examined congruency effects in initiation time (IT), movement time (MT), and AUC. Incongruent trials tended to have longer ITs than congruent trials (173 vs. 170 ms), but this effect did not reach conventional levels of significance, $t(212) = 1.70$, $p = .09$, $d = .12$. Examining MT suggested a congruency effect, whereby incongruent trials were associated with slower mouse movements than congruent trials (1,130 vs. 941 ms), $t(210) = 21.37$, $p < .001$, $d = 1.47$. Similarly, incongruent trials demonstrated larger AUC values than congruent trials (1.31 vs. .69), $t(212) = 19.46$, $p < .001$, $d = 1.33$, suggesting

Figure 2
Time Normalized Mean Trajectories for Congruent and Incongruent Stroop Trials in Study 1



that congruent trials demonstrated a more direct path to the correct response than incongruent trials. Collectively, these results replicate prior research with the Stroop task (e.g., Bundt et al., 2018; Ruitenberg et al., 2019) suggesting congruency effects in which mouse movements are more attracted to the incorrect response on incongruent trials than congruent trials resulting in slower movements toward the correct response.

Individual Differences in Experimental Effects

Next, we examined individual differences in the mouse movement measures. To do so, we created factor composites for AC and working memory (WM). The AC composite score was computed for each participant using principal axis factoring and allowing antisaccade, the button-press Stroop, and flankers to load onto a single factor. The resulting factor loadings were .67, -.15, and -.26, respectively.³ Likewise, we computed a WM factor composite based on Ospan, Symspan, and Rspan (factor loadings = .69, .55, .89). To examine how individual differences in AC and WM were related to the mouse movement measures, we computed correlations between the composites with overall mean (combined across congruent and incongruent trials) and congruency effects (incongruent minus congruent) in the mouse tracking measures.⁴ As seen in Table 1, examining IT suggested no relations with either AC or WM. Examining MT, suggested that AC was correlated with the overall speed of MT as well as congruency effects in MT. The correlation between WM and overall speed of MT was not quite significant ($p = .07$), but the correlation with the congruency effect in MT was significant. Finally, for AUC, both AC and WM correlated negatively with mean AUC but only AC correlated with congruency effects in AUC. Collectively, these results suggest that congruency effects in MT and AUC were related to individual differences in AC, but congruency effects in IT were not. WM demonstrated a weak relation with congruency effects in MT but not with IT or AUC.

Time Course of Mouse Movements

Next, we examined the time course of mouse movements by examining changes in the x -coordinates over time. These analyses provide additional information on how mouse movements change over time as a function of trial type and individual differences. For these analyses, we examined the first 1,350 ms of the response,

given that, by this time, most participants had successfully clicked on the correct response for congruent trials. This allowed us to maximize the number of participants available for analysis. Shown in Figure 3a are the x -coordinates over time for congruent and incongruent trials. As can be seen, participants were initially on the Start button (0.0), but around 450 ms, the mouse began to move for congruent trials resulting in faster movement times for congruent compared to incongruent trials. These impressions were confirmed by a 2 (trial type) \times 15 (time bin) analysis of variance which suggested a main effect of trial type, $F(1, 204) = 559.47$, mean squared error (MSE) = .04, $p < .001$, partial $\eta^2 = .73$, and a main effect of time bin, $F(14, 2,856) = 2372.34$, $MSE = .01$, $p < .001$, partial $\eta^2 = .92$. Critically, there was an interaction between trial type and time bin, $F(14, 2,856) = 139.58$, $MSE = .006$, $p < .001$, partial $\eta^2 = .41$.

We next examined individual differences in AC and WM by entering in each as a covariate in an analysis of covariance.⁵ For AC, there was a main effect of AC, $F(1, 199) = 40.53$, $MSE = .10$, $p < .001$, partial $\eta^2 = .17$, suggesting high-AC individuals had faster mouse movements overall than low-AC individuals. The interaction between AC and trial type did not reach conventional levels of significance, $F(1, 199) = 3.16$, $MSE = .04$, $p = .08$, partial $\eta^2 = .02$. There was an interaction between AC and time bin, $F(14, 2,786) = 15.09$, $MSE = .01$, $p < .001$, partial $\eta^2 = .07$. Critically, there was an AC by trial type by time bin interaction, $F(14, 2,786) = 4.23$, $MSE = .006$, $p < .001$, partial $\eta^2 = .02$. In order to illustrate the effects of interest, we present differences in AC via a quartile split with low-AC individuals (bottom 25%) and high-AC individuals (top 25%). Note, however, that all analyses treated AC as continuous, rather than as arbitrary, discrete groups. As seen in Figure 3b, high-AC individuals had faster movements toward the correct response on congruent trials than low-AC individuals. This difference was increased on incongruent trials (Figure 3c), suggesting that low-AC individuals had greater difficulty resolving the interference on incongruent trials, resulting in a greater pull toward the incorrect response, and delayed movements toward the correct response compared to high-AC individuals.

For WM, there was a main effect, $F(1, 202) = 21.74$, $MSE = .11$, $p < .001$, partial $\eta^2 = .10$. The interaction between WM and trial type was not significant, $F(1, 202) = .03$, $MSE = .04$, $p = .86$, partial $\eta^2 = .00$. There was an interaction between WM and time bin,

³ To ensure that the results were not due to the inclusion of the button-press Stroop in the composite, we recomputed the AC composite with only antisaccade and flankers and reanalyzed the data. The resulting correlations were very similar to the correlations with Stroop included, suggesting that the correlations are not necessarily due to including Stroop in the AC composite.

⁴ The overall mean mouse tracker measures demonstrated good reliability for each task in each study. In Study 1, Stroop mean IT = .98, Stroop mean MT = .94, and Stroop mean AUC = .82. In Study 2, Stroop mean IT = .98, Stroop mean MT = .97, and Stroop mean AUC = .77. In Study 2, flankers mean IT = .97, Stroop mean MT = .95, and Stroop mean AUC = .80.

⁵ We also redid the analyses of covariance with AC and WM entered simultaneously in each study to examine if each accounted for unique variance. In Study 1, the AC \times Trial Type \times Bin interaction remained ($p < .001$) even when both AC and WM entered as covariates. The WM \times Trial Type \times Bin interaction was not significant ($p = .62$). In Study 2, examining Stroop suggested that the AC \times Trial Type \times Bin interaction remained ($p = .04$). The WM \times Trial Type \times Bin interaction was not significant ($p = .98$). In Study 2, examining flankers suggested that the AC \times Trial Type \times Bin interaction remained ($p < .001$) as did the WM \times Trial Type \times Bin interaction ($p = .01$). Thus, AC tended to demonstrate unique effects, but WM was only uniquely related to mouse movements in flankers.

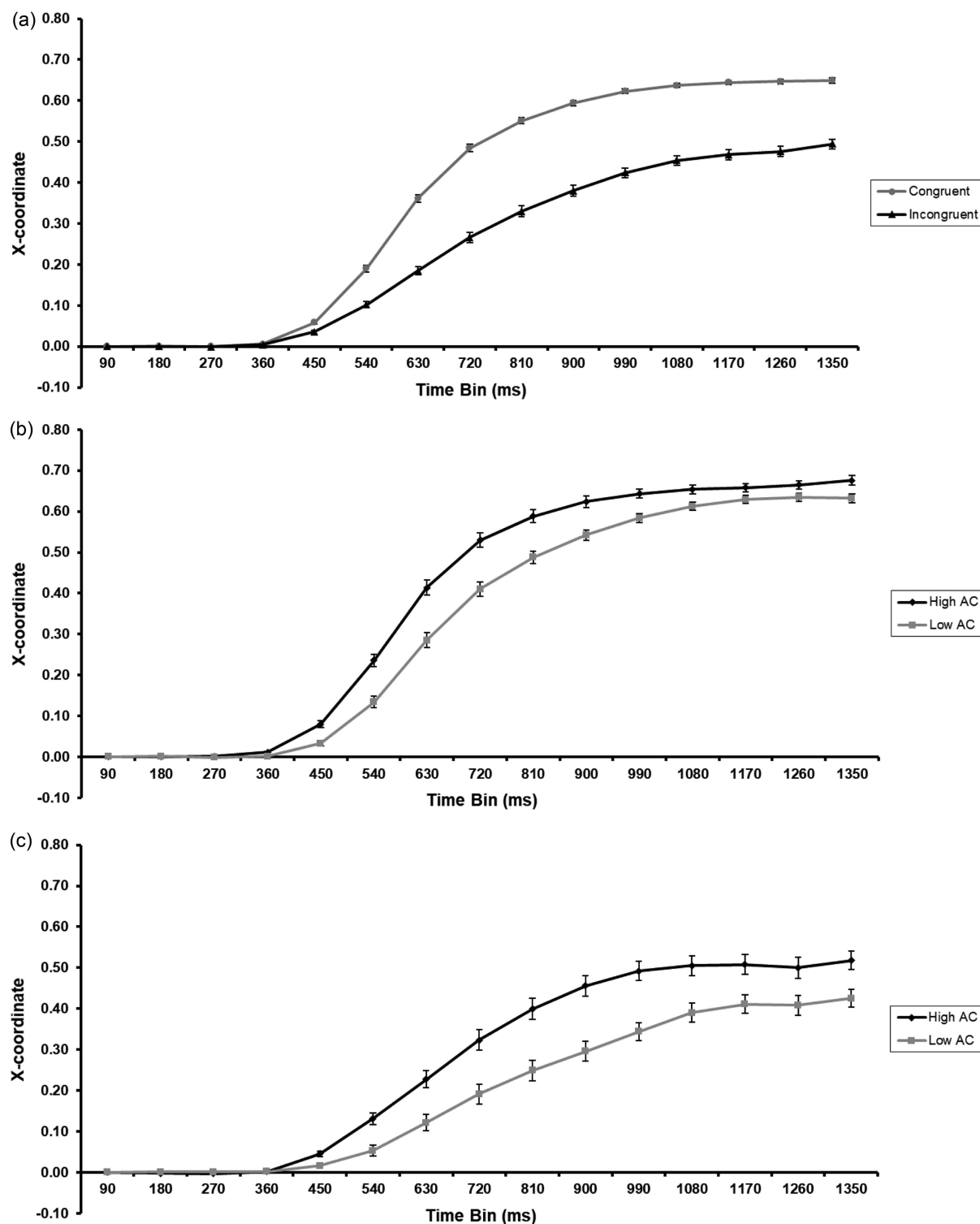
Table 1

Correlations Between AC and WM Composites With Overall Mean and Congruency Effects in the Stroop Mouse Tracking Measures for Study 1

Measure	AC	WM
Mean IT	.05	.08
Congruency IT	.04	.10
Mean MT	-.31*	-.13
Congruency MT	-.28*	-.14*
Mean AUC	-.22*	-.23*
Congruency AUC	-.20*	-.09

Note. AC = attention control; WM = working memory; IT = initiation time; MT = movement time; AUC = area under the curve.

* $p < .05$.

Figure 3*Time Course of Mouse Movements for Stroop in Study 1*

Note. (a) X-coordinate values across time bin for congruent and incongruent trials on the Stroop in Study 1. (b) X-coordinate values across time bin for high- and low-AC individuals on congruent Stroop trials in Study 1. (c) X-coordinate values across time bin for high- and low-AC individuals on incongruent Stroop trials in Study 1. Error bars reflect 1 standard error of the mean. AC = attention control.

$F(14, 2,828) = 8.19$, $MSE = .01$, $p < .001$, partial $\eta^2 = .04$. Unlike AC, the WM by trial type by time bin interaction did not reach conventional levels of significance, $F(14, 2,828) = 1.56$, $MSE = .006$, $p = .08$, partial $\eta^2 = .01$. Thus, high-WM individuals tended to have faster mouse movements overall than low-WM individuals, but this did not necessarily differ as a function of trial type.

Descriptive Statistics, Correlations Among the Measures, and Confirmatory Factor Analysis

Next, we examined psychometric properties for the measures and correlations among the all the measures. Descriptive statistics for all of the measures are shown in Table 2. As can be seen, the measures had generally acceptable values of reliability, and most of the measures were approximately normally distributed.⁶ Importantly, although the Stroop button-press version tended to demonstrate poor reliability (.52), the mouse movement measures demonstrated much better and more acceptable estimates of reliability (MT = .70; AUC = .72). Note, because the congruency effect in IT was not significant and did not correlate with the AC or WM composites, it was not included in these analyses.

Correlations among the measures are shown in Table 3. As can be seen, congruency effects in MT and AUC were strongly correlated suggesting that participants who were more attracted to the incorrect response tended to have slower mouse movements than participants who had more direct paths toward the correct response. Both mouse movement measures were correlated with congruency effects in the button-press version of the Stroop suggesting that the different versions measured partially overlapping variance. Additionally, the mouse movement measures tended to correlate with the other AC tasks, whereas the button-press version of Stroop demonstrated weaker correlations. In fact, the average correlation between the mouse movement congruency effects and the other AC measures was .17, whereas the average correlation between the button-press congruency effect, and the other AC measures was .06. Thus, the mouse movement congruency effects tended to demonstrate better psychometric properties and stronger relations with other AC measures than the button-press version of Stroop.

Next, we used confirmatory factor analysis to examine if the congruency effects in the mouse movements would load onto an overall AC factor with the other AC measures and whether this

Table 2
Descriptive Statistics for Measures in Study 1

Measure	<i>M</i>	<i>SD</i>	Skew	Kurtosis	Reliability	<i>N</i>
StroopMT	188.85	128.37	0.84	1.83	.70	211
StroopAUC	0.62	0.46	0.79	0.88	.72	213
StroopB	147.49	84.82	0.58	0.37	.52	213
Anti	0.57	0.16	−0.04	−0.91	.83	213
Flanker	106.72	69.15	1.09	3.38	.61	210
Ospan	37.84	9.24	−1.22	1.38	.73	212
Symspan	18.83	5.20	−0.57	0.03	.60	213
Rspan	37.32	10.23	−1.25	1.28	.80	213

Note. Reliabilities represent split-half reliabilities. StroopMT = Stroop congruency effect in movement times; StroopAUC = Stroop congruency effect in area under the curve; StroopB = Stroop congruency effect in reaction times for the button-press version; Anti = antisaccade; Flanker = flanker congruency effect; Ospan = operation span; Symspan = symmetry span; Rspan = reading span.

Table 3
Correlations Among the Measures in Study 1

Measure	1	2	3	4	5	6	7	8
1. StroopMT	—							
2. StroopAUC	.75	—						
3. StroopB	.17	.18	—					
4. Anti	−.23	−.18	−.12	—				
5. Flanker	.19	.09	.01	−.18	—			
6. Ospan	−.12	−.12	−.14	.18	−.14	—		
7. Symspan	−.14	−.12	−.08	.14	−.11	.38	—	
8. Rspan	−.12	−.04	−.07	.21	−.10	.61	.49	—

Note. StroopMT = Stroop congruency effect in movement times; StroopAUC = Stroop congruency effect in area under the curve; StroopB = Stroop congruency effect in reaction times for the button-press version; Anti = antisaccade; Flanker = flanker congruency effect; Ospan = operation span; Symspan = symmetry span; Rspan = reading span. Correlations $> .13$ are significant at the $p < .05$ level.

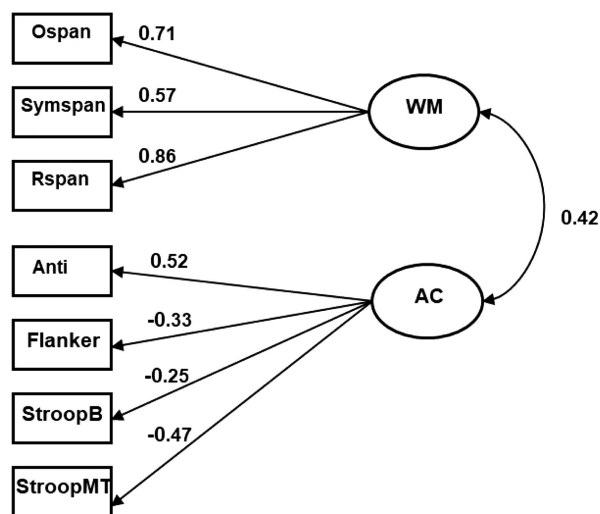
factor would be correlated to a WM factor in order to further examine the validity of the mouse movement measures. To fit the models, we used full information maximum likelihood. For all model testing (using Lisrel; similar results were found when using R), we report several fit statistics (e.g., Bentler, 1990; Browne & Cudeck, 1992; Schermelleh-Engel, Moosbrugger, & Müller, 2003). Nonsignificant chi-square tests indicate adequate model fit; with large samples like ours, however, they are nearly always significant. Comparative fit indices (CFI) and nonnormed fit index (NNFI) of $\geq .90$ indicate adequate fit, whereas the root-mean-square error of approximation (RMSEA) and standardized root-mean-square residual (SRMR) values of $\leq .08$ indicate adequate fit.

We specified a model in which congruency effects in MT in the Stroop, congruency effects in reaction time in the button-press version of Stroop, antisaccade, and congruency effects in the flanker loaded onto an AC factor and Ospan, Symspan, and Rspan loaded onto a WM factor. The two factors were allowed to correlate. Note, we used congruency effects in MT given that this measure demonstrated slightly stronger correlations with the other AC measures than AUC and had a similar reliability estimate as AUC. Similar results were obtained when using congruency effects in AUC. The overall fit of the model was good, $\chi^2(13) = 8.77$, $p = .79$, RMSEA = .00, NNFI = 1.00, CFI = 1.00, SRMR = .03. Shown in Figure 4 is the model. As can be seen, all of the measures loaded onto their respective constructs with the loadings typically being moderate to strong. The button-press version of the Stroop demonstrated a weaker factor loading (−.25) than the Stroop effect in MT (−.47), which was similar in magnitude to the antisaccade loading. The AC and WM factors were correlated, replicating prior research. These results suggest that congruency effects in movement times on the mouse tracker version of Stroop correlated moderately with the other AC measures and loaded onto a broad AC factor, which was correlated with WM.

Discussion

Replicating prior research (e.g., Bundt et al., 2018; Ruitenberg et al., 2019), we found congruency effects in MT and AUC but not in

⁶ Note, because some of the measures were skewed, we also examined the correlations with Spearman's correlation and found nearly identical results in both studies.

Figure 4*Confirmatory Factor Analysis Model for WM and AC for Study 1*

Note. Paths connecting latent variables (circles) to each other represent the correlations between the constructs and the numbers from the latent variables to the manifest variables (squares) represent the loadings of each task onto the latent variable. Solid paths are significant at the $p < .05$ level. WM = working memory; AC = attention control; Ospan = operation span; Symspan = symmetry span; Rspan = reading span; Anti = antisaccade; Flanker = flanker congruency effect in reaction times for the button-press version; StroopB = Stroop congruency effect in reaction times for button-press version; StroopMT = Stroop congruency effect in movement times.

IT in a mouse tracker version of Stroop. Importantly, individual differences in AC were related to congruency effects in both MT and AUC (working memory only demonstrated a weak relation in MT). These results suggest that low-AC individuals were more attracted to the incorrect response and had overall slower movements toward the correct response than high-AC individuals. Congruency effects in MT and AUC were strongly correlated, suggesting part of the reason for longer MT was because of a greater attraction to the incorrect response. Time course analyses further suggested a greater pull toward the incorrect response for low-AC individuals compared to high-AC individuals, and suggested differences in conflict resolution processes. These results provide evidence suggesting that individual differences in broad AC abilities are related to the ability to restrain attention and prevent (or lessen) the influence of the prepotent response from capturing attention. The current results were less consistent with the notion that individual differences were due to other factors such as processing speed or speed–accuracy trade-offs. As noted previously, a processing speed account would suggest differences in both IT and MT, with no differences in AUC. Furthermore, processing speed differences would likely manifest on both congruent and incongruent trials, and thus not necessarily in congruency effects. Given that AC was related to congruency effects in both MT and AUC, but not IT, the current results suggest that the current relations were not likely due simply to differences in processing speed. Likewise, given no differences in IT, the current results also do not suggest differences in speed–accuracy trade-offs as the key source to relations between AC and congruency effects. Thus, the current results are more consistent with the notion that relations between AC and congruency effects in the

mouse tracker Stroop were partially due to the differences in the ability to restrain attention.

Results from Study 1 also demonstrated that the mouse tracker version of Stroop tended to have better psychometric properties (e.g., better reliability) and stronger correlations with the other AC tasks than the button-press version of Stroop. The two versions were correlated with one another, but the button-press version tended to correlate more weakly with all of the other measures than the mouse tracker version. Indeed, the mouse tracker version of Stroop loaded moderately on the AC factor, whereas the button-press version loaded more weakly. Collectively, these results suggest that the mouse tracker version of Stroop provided important information on the nature of individual differences in AC and demonstrated better reliability and validity than the button-press version.

Study 2

In Study 2, we wanted to replicate the Stroop results from Study 1 and examine possible similarities and differences between Stroop and flankers. As noted previously, one possibility is that both tasks are simply measuring overall conflict resolution abilities in which case individual differences in both MT and AUC should be correlated with AC and should correlate across the two tasks. Another possibility is that the two tasks are measuring distinct but related aspects of a broader AC construct (i.e., restraining and constraining attention). If this is the case, then we should see that individual differences in AC are correlated with both AUC and MT in Stroop consistent with Study 1. However, in the flanker task, we should see that individual differences in AC are correlated with MT but not necessarily with AUC. This would suggest that high-AC individuals are faster at resolving the conflict (via a faster rate of constraining their spotlight of attention) than low-AC individuals, even though both demonstrate a similar attraction to the incorrect response. Consistent with Heitz and Engle (2007), a time-course analysis of mouse movements should demonstrate that early in incongruent trials on flankers, mouse movements should pull toward the incorrect response as there is more information consistent with the incorrect response. Following this initial pull toward the incorrect response, mouse movements should then be directed toward the correct response as the spotlight constrains to the target stimulus (see also Erb, Smith, et al., 2021; Kinder et al., 2022). Critically, both high- and low-AC individuals should demonstrate similar initial attraction to the incorrect response, but high-AC individuals should have faster movements toward the correct response than low-AC individuals. Consistent with some prior research, congruency effects in Stroop and flankers might then demonstrate a weak positive correlation, suggesting some similarities and differences in conflict resolution across the tasks.

To examine these issues, we had a large sample of participants perform both mouse tracker and button-press versions of Stroop and flankers along with additional measures of AC (antisaccade and psychomotor vigilance) and measures of working memory (operation span, symmetry span, colored squares change detection, and letter change detection). We added in the psychomotor vigilance task to ensure we had an overall broader AC factor that included putative measures of restraining, constraining, and sustaining attention. Additionally, we added in the two change detection measures of working memory (and dropped reading span) in order to measure a broader working memory factor that was not just composed of complex span tasks.

Method

Participants

A total of 319 participants were recruited from the subject-pool at the University of Oregon. Of the participants, 223 reported their gender as female, 94 reported their gender as male, and one did not report their gender, with an average age of 19.22 ($SD = 1.90$). Each participant was tested individually in a laboratory session lasting approximately 2 hr. We tested participants over two full academic quarters, using the end of the second quarter as our stopping rule for data collection with the aim of getting a minimum of 300 participants. However, data collection was stopped approximately a week and a half early due to the laboratory being shut down due to the onset of the COVID-19 pandemic in March of 2020. Note, data were missing for 38 participants on the mouse tracker tasks because one of our research assistants mistakenly did not run any of their participants on the mouse tracker tasks. Once we figured out what was happening we corrected the mistake and planned to run additional participants to make up for the lost data, but the lab was shut down due to COVID-19. An additional 30 participants had missing data for the flanker mouse tracker task, because it was run at the end of the session and some participants did not stay to finish all of the tasks. Twelve participants had their button-press flanker data excluded because they had accuracy of less than 10% on incongruent trials. Two participants had their psychomotor vigilance data excluded, because their slowest 20% of reaction times were more than four standard deviations from the mean. One participant had their color change detection data excluded for having overall low accuracy and potentially mis-mapping the keys. Three participants had their flanker AUC data excluded, four participants had their flanker MT data excluded, and three participants had their Stroop MT data excluded for being four standard deviations away from the mean.

Materials and Procedure

After signing informed consent, all participants completed operation span, symmetry span, color change detection, letter change detection, four long-term memory tasks, antisaccade, arrow flankers, Stroop, psychomotor vigilance task, mouse tracker Stroop, and mouse tracker flankers. All tasks were administered in the order listed above.

Attention Control Tasks

Antisaccade. Same as Study 1.

Arrow Flankers. Same as Study 1.

Stroop. Same as Study 1.

Psychomotor Vigilance Task. In this task, participants were presented with a row of zeros on screen. After a variable amount of time the zeros began to count up in 17-ms intervals from 0 ms (as determined by the 60-Hz monitor refresh rate). The participants' task was to press the spacebar as quickly as possible once the numbers started counting up. After pressing the space bar, the response time was left on screen for 1 s to provide feedback to the participants. Interstimulus intervals were randomly distributed and ranged from 1 s to 10 s. The entire task lasted for 10 min for each individual (roughly 75 total trials). The dependent variable was the average RT for the slowest 20% of trials (Dinges & Powell, 1985; Unsworth et al., 2010).

Mouse Tracker Stroop. Same as Study 1.

Mouse Tracker Flankers. This task was adapted from Incera and McLennan (2018) utilizing the Mouse Tracker software (Freeman & Ambady, 2010). Participants were first presented with a start button centered at the bottom of the screen and boxes at the top left and top right of the screen. After clicking the start button, participants had task to indicate the direction the center arrow was pointing. On neutral trials the arrow was flanked by two horizontal lines on each side. On congruent trials the arrow was flanked by two arrows pointing in the same direction as the target arrow on each side. Finally, on incongruent trials the target arrow was flanked by two arrows pointing in the opposite direction as the target arrow on each side. The task was to indicate the direction of the center arrow by clicking on the appropriate box as quickly as possible. Participants were instructed to moving the mouse immediately after clicking Start. Prior to the real trials, participants completed 16 baseline trials where the word HERE was presented in one of the boxes (50% of the time on the right and 50% of the time on the left), and participants simply had to click on the correct box as quickly as possible. Participants then completed six practice trials of the flanker task. Finally, participants completed 90 real trials (30 neutral, 30 congruent, and 30 incongruent).

Working Memory Tasks

Operation Span. Same as Study 1.

Symmetry Span. Same as Study 1.

Color Change-Detection. This task was adapted from Robison et al. (2023) and we use their methods. Each trial started with a black fixation cross against a gray background for 1,000 ms. The fixation screen was followed by a 750-ms blank screen. The target items appeared for 250 ms. Three target items always appeared on the left and right hemifield of the screen. The target items were colored squares each subtending 3° of visual angle. The colors were sampled randomly without replacement from seven preselected colors. Target items were followed by a 900-ms blank delay screen. At the end of the delay screen, the items reappeared with one square circled by a black ring. The participants' task was to decide whether this square was the same color or a different color than its initial presentation. Participants made their responses by pressing two keys marked "S" for "same" and "D" for "different" (the "F" and "J" keys on the keyboard). After a 1,000-ms blank delay screen, the next trial began. There were 40 real trials in the task, and the dependent variable from the task was the proportion correct.

Letter Change-Detection. This task was adapted from Robison et al. (2023) and we use their methods. Each trial started with a fixation cross in black text against a gray background for 1,000 ms. The fixation screen was followed by a 750-ms blank screen. The target items appeared for 250 ms. Six target letters, sampled without replacement from all consonants, appeared at six preset locations, spaced equally around an invisible circle. Target items were followed by a 900-ms blank delay screen. At the end of the delay screen, the letters reappeared with one letter outlined by a black box. The participants' task was to decide whether this letter was the same letter or a different letter than its initial presentation. Participants made their responses by pressing two keys marked "S" for "same" and "D" for "different" (the "F" and "J" keys on the keyboard). After a 1,000-ms blank delay screen, the next trial began. There were 40 real trials in the task, and the dependent variable from the task was the proportion correct.

Results

Experimental Effects

Similar to Study 1, we first examined congruency effects in the Stroop and flankers. Shown in Figure 5a are the mouse movement trajectories for congruent and incongruent trials in Stroop. Consistent with Study 1, congruent trials demonstrated a more direct path to the correct response than incongruent trials, which seemed to demonstrate an initial attraction to the incorrect response and then more movement toward the correct response. Examining IT suggested no congruency effect with incongruent and congruent trials having similar ITs (159 vs. 160 ms), $t(280) = .45, p = .33, d = .03$. Examining MT suggested a congruency effect, whereby incongruent trials were associated with slower mouse movements than congruent trials (1,113 vs. 920 ms), $t(277) = 25.08, p < .001, d = 1.50$. Similarly, incongruent trials demonstrated larger AUC values than congruent trials (1.37 vs. .70), $t(280) = 24.03, p < .001, d = 1.43$, suggesting that congruent trials demonstrated a more direct path to the correct response than incongruent trials. These results broadly replicate Study 1.

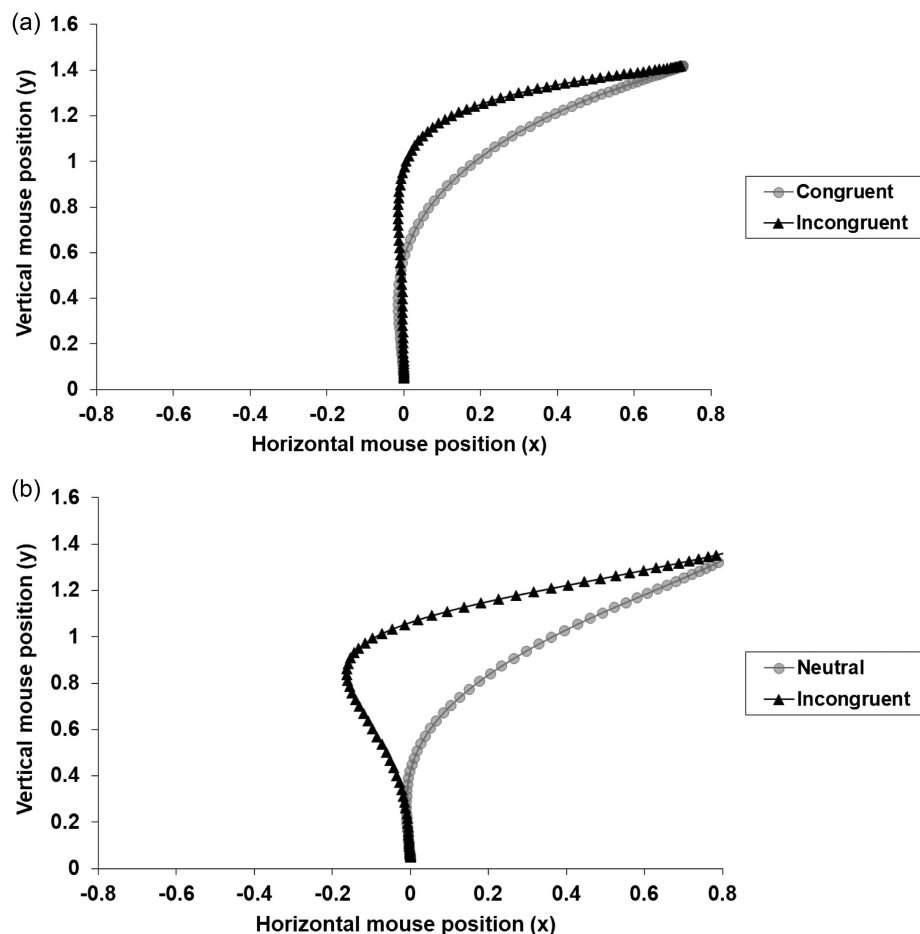
Shown in Figure 5b are the mouse movement trajectories for neutral and incongruent trials in flankers. Overall similar results were

obtained when examining congruent trials. Similar to Stroop, neutral trials demonstrated a more direct path to the correct response than incongruent trials, which demonstrated a large initial attraction to the incorrect response and then more direct movements toward the correct response. Examining IT suggested no congruency effect with incongruent and neutral trials having similar ITs (165 vs. 163 ms), $t(250) = .96, p = .17, d = .06$. Examining MT suggested a congruency effect, whereby incongruent trials were associated with slower mouse movements than neutral trials (1,027 vs. 851 ms), $t(246) = 29.43, p < .001, d = 1.87$. Incongruent trials likewise demonstrated larger AUC values than neutral trials (1.52 vs. .57), $t(247) = 32.61, p < .001, d = 2.07$, suggesting that neutral trials demonstrated a more direct path to the correct response than incongruent trials. Thus, congruency effects were found in both Stroop and flankers.

Individual Differences in Experimental Effects

Next, we created factor composites for AC and WM to examine individual differences in the mouse movements in Stroop and flankers. The AC composite score was computed for each participant using principal axis factoring and allowing antisaccade, the button-press

Figure 5
Time Normalized Mean Trajectories



Note. (a) Time normalized mean trajectories for congruent and incongruent Stroop trials in Study 2. (b) Time normalized mean trajectories for neutral and incongruent flanker trials in Study 2.

Stroop, the button-press flankers, and the psychomotor vigilance task to load onto a single factor. The resulting factor loadings were .66, -.08, -.29, and -.52, respectively. Note the button-press Stroop did not load significantly on the factor, but we included it in the factor composite for completeness. Likewise, we computed a WM factor composite based on Ospan, Symspan, color change detection, and letter change detection (factor loadings = .52, .52, .37, and .44). To examine how individual differences in AC and WM were related to the mouse movement measures, we computed correlations between the composites with overall mean and congruency effects in the mouse tracking measures for both Stroop and flankers. The results are shown in Table 4. Examining Stroop, revealed that IT was generally not related to either AC or WM. Overall speed in MT was correlated with both AC and WM, but congruency effects in MT were only related to AC. Overall AUC and congruency effects in AUC were related to AC but not related to WM. These results broadly replicate Study 1 suggesting that congruency effects in MT and AUC were related to AC, but congruency effects in IT were not. Furthermore, WM demonstrated a weak (not quite significant) effect with MT and no effect on IT or AUC.

Next, we examined mouse movements in flankers to see if similar results would be found. For IT, the only significant correlation was a positive correlation between overall IT and AC. Overall speed in MT and congruency effects in MT were related to both AC and WM. For AUC, the only significant correlation was between overall AUC and AC. Overall, examining mouse movements in flankers demonstrated that individual differences in AC and WM were related with congruency effects in MT but not to congruency effects in AUC or IT. The correlations between AC and WM with congruency effects in MT were significantly stronger than the correlations with congruency effects in AUC (both $t_s > 3.1$). These results are slightly different from the Stroop results which demonstrated relations between AC and congruency effects in both MT and AUC, suggesting similarities and differences between Stroop and flankers and their overall relations with individual differences in AC.

Table 4

Correlations Between AC and WM Composites With Overall Mean and Congruency Effects in the Stroop and Flankers Mouse Tracking Measures for Study 2

Measure	AC	WM
Stroop		
Mean IT	.10	-.12
Congruency IT	.09	.03
Mean MT	-.36*	-.20*
Congruency MT	-.24*	-.11
Mean AUC	-.31*	-.08
Congruency AUC	-.19*	-.05
Flankers		
Mean IT	.17*	-.11
Congruency IT	.03	.03
Mean MT	-.43*	-.19*
Congruency MT	-.29*	-.20*
Mean AUC	-.22*	.02
Congruency AUC	-.02	.02

Note. AC = attention control; WM = working memory; IT = initiation time; MT = movement time; AUC = area under the curve.

* $p < .05$.

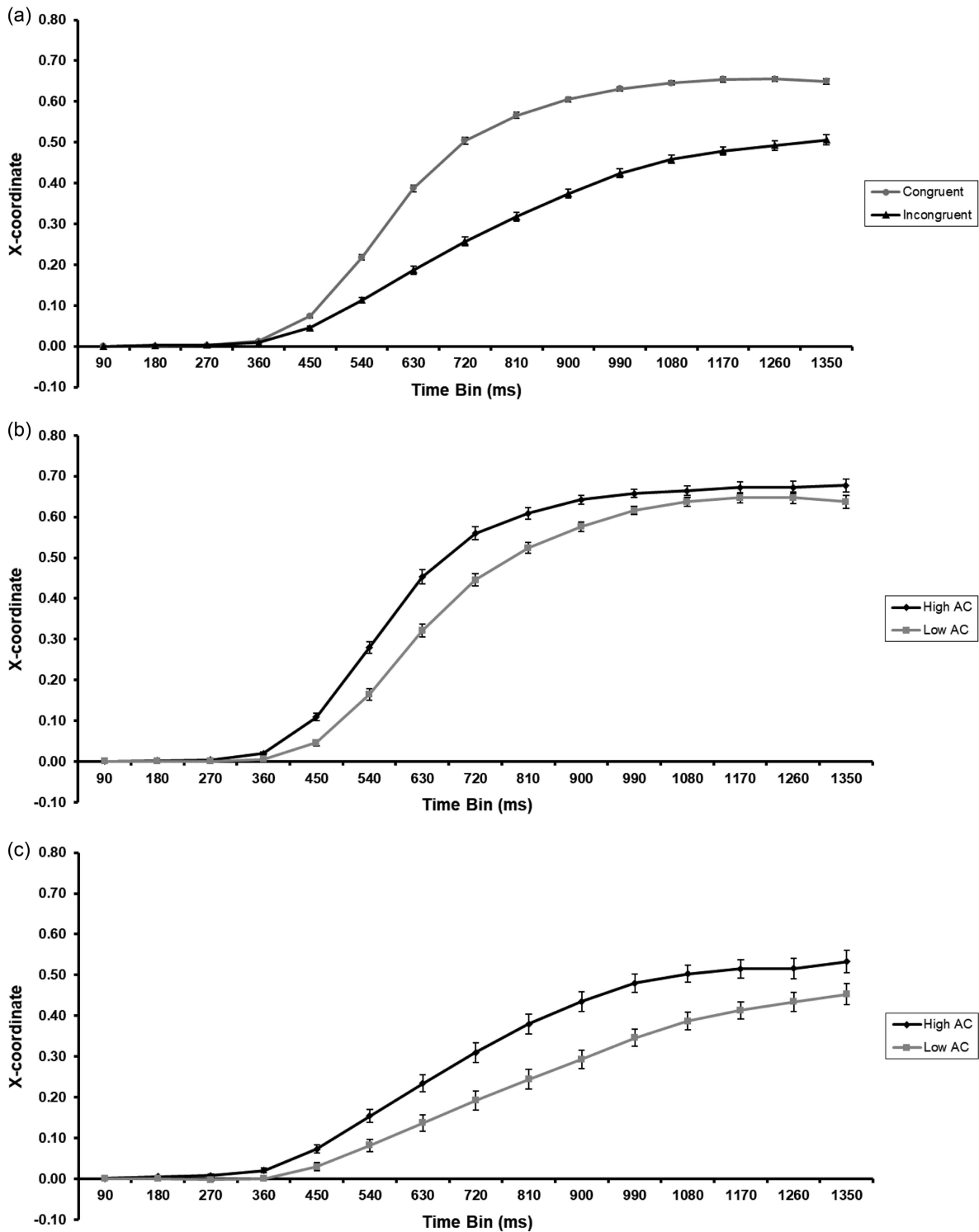
Time Course of Mouse Movements

Consistent with Study 1, we next examined the time course of mouse movements by examining changes in the x -coordinates over time in both Stroop and flankers. First, we examined mouse movements in the Stroop. Shown in Figure 6a are the x -coordinates over time for congruent and incongruent trials. Similar to Study 1, participants were initially on the Start button, but around 450 ms, the mouse began to move more rapidly and more directly to the correct response for congruent trials resulting in faster movement times for congruent compared to incongruent trials. These impressions were confirmed by a 2 (trial type) \times 15 (time bin) analysis of variance which suggested a main effect of trial type, $F(1, 259) = 707.70$, $MSE = .05$, $p < .001$, partial $\eta^2 = .73$, and a main effect of time bin, $F(14, 3,626) = 2752.94$, $MSE = .011$, $p < .001$, partial $\eta^2 = .91$. Critically, there was an interaction between trial type and time bin, $F(14, 3,626) = 195.37$, $MSE = .006$, $p < .001$, partial $\eta^2 = .43$.

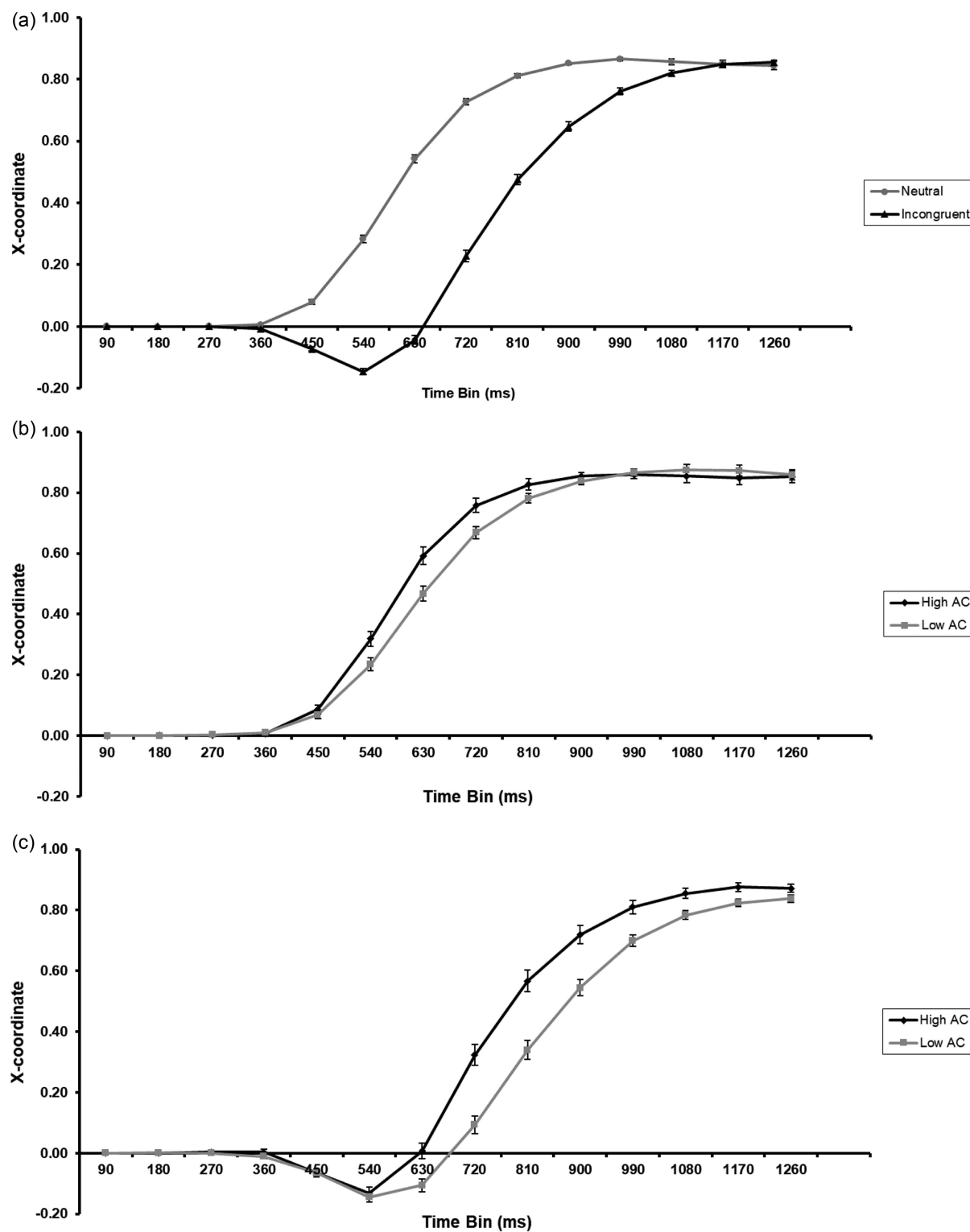
We next examined individual differences in AC and WM by entering in each as a covariate in analysis of covariance. For AC, there was a main effect of AC, $F(1, 243) = 31.60$, $MSE = .11$, $p < .001$, partial $\eta^2 = .12$, suggesting high-AC individuals had faster mouse movements overall than low-AC individuals. The interaction between AC and trial type was not significant, $F(1, 243) = 1.18$, $MSE = .05$, $p = .28$, partial $\eta^2 = .01$. There was an interaction between AC and time bin, $F(14, 3,402) = 9.19$, $MSE = .01$, $p < .001$, partial $\eta^2 = .04$. Critically, there was an AC \times Trial Type \times Time Bin interaction, $F(14, 3,402) = 3.95$, $MSE = .006$, $p < .001$, partial $\eta^2 = .02$. As seen in Figure 6b, high-AC individuals had faster movements toward the correct response on congruent trials than low-AC individuals. Importantly, as seen in Figure 6c, this difference was increased on incongruent trials consistent with Study 1.

For WM, there was a main effect, $F(1, 246) = 11.10$, $MSE = .12$, $p < .001$, partial $\eta^2 = .04$, suggesting high-WM individuals had faster mouse movements overall than low-WM individuals. The interaction between WM and trial type was not significant, $F(1, 246) = .10$, $MSE = .05$, $p = .75$, partial $\eta^2 = .00$. There was an interaction between WM and time bin, $F(14, 3,444) = 5.07$, $MSE = .01$, $p < .001$, partial $\eta^2 = .02$. Unlike AC, the WM \times Trial Type \times Time Bin interaction was not significant, $F(14, 3,444) = 1.43$, $MSE = .006$, $p = .14$, partial $\eta^2 = .01$. Similar to Study 1, high-WM individuals tended to have faster mouse movements overall, but this did not interact with trial type.

Next, we examined mouse movements in flankers. Shown in Figure 7a are the x -coordinates over time for neutral and incongruent trials. For these analyses, we examined the first 1,260 ms of the response, given that by this time, most participants had successfully clicked on the correct response for neutral trials. Similar to Stroop, participants were initially on the Start button, but around 450 ms, the mouse began to move more rapidly and more directly to the correct response for neutral trials resulting in faster movement times for neutral compared to incongruent trials. In fact, consistent with prior research (e.g., Kinder et al., 2022; Ye & Damian, 2023), mouse movements suggested a strong attraction to the incorrect response early on in incongruent trials, and then around 650 ms, the mouse began to move toward the correct response. These impressions were confirmed by a 2 (trial type) \times 14 (time bin) analysis of variance which suggested a main effect of trial type, $F(1, 206) = 752.38$, $MSE = .06$, $p < .001$, partial $\eta^2 = .79$, and a main effect of time bin, $F(13, 2,678) = 4773.78$, $MSE = .013$, $p < .001$, partial $\eta^2 = .96$.

Figure 6*Time Course of Mouse Movements for Stroop in Study 2*

Note. (a) X-coordinate values across time bin for congruent and incongruent trials on the Stroop in Study 2. (b) X-coordinate values across time bin for high- and low- AC individuals on congruent Stroop trials in Study 2. (c) X-coordinate values across time bin for high- and low-AC individuals on incongruent Stroop trials in Study 2. Error bars reflect one standard error of the mean. AC = attention control.

Figure 7*Time Course of Mouse Movements for Flankers in Study 2*

Note. (a) X-coordinate values across time bin for congruent and incongruent trials on the flankers in Study 2. (b) X-coordinate values across time bin for high- and low-AC individuals on neutral flanker trials in Study 2. (c) X-coordinate values across time bin for high- and low-AC individuals on incongruent flanker trials in Study 2. Error bars reflect one standard error of the mean. AC = attention control.

Critically, there was an interaction between trial type and time bin, $F(13, 2,678) = 475.81$, $MSE = .01$, $p < .001$, partial $\eta^2 = .70$. These results are broadly consistent with prior time-course analyses by Gratton et al. (1988) and Heitz and Engle (2007), suggesting that early in incongruent trials, there is a stronger pull toward the incorrect response, but as more evidence is accumulated the attraction to the correct response increases.

We next examined individual differences in AC and WM. For AC, there was a main effect of AC, $F(1, 195) = 30.10$, $MSE = .08$, $p < .001$, partial $\eta^2 = .13$. The interaction between AC and trial type was significant, $F(1, 195) = 11.40$, $MSE = .05$, $p < .001$, partial $\eta^2 = .06$. There was an interaction between AC and time bin, $F(13, 2,535) = 19.44$, $MSE = .01$, $p < .001$, partial $\eta^2 = .09$. Critically, there was an AC \times Trial Type \times Time Bin interaction, $F(13, 2,535) = 11.86$, $MSE = .008$, $p < .001$, partial $\eta^2 = .06$. As seen in Figure 7b, high-AC individuals had slightly faster movements toward the correct response on neutral trials than low-AC individuals. Importantly, as seen in Figure 7c, this difference was increased on incongruent trials. High- and low-AC individuals demonstrated a similar strong attraction to the incorrect response early in the trial, but then high-AC individuals' mouse movements moved more rapidly toward the correct response than low-AC individuals.

For WM, there was a main effect, $F(1, 199) = 20.58$, $MSE = .08$, $p < .001$, partial $\eta^2 = .09$. The interaction between WM and trial type did not reach conventional levels of significance, $F(1, 199) = 2.93$, $MSE = .06$, $p = .09$, partial $\eta^2 = .02$. There was an interaction between WM and time bin, $F(13, 2,587) = 6.79$, $MSE = .01$, $p < .001$, partial $\eta^2 = .03$. The WM \times Trial Type \times Time Bin interaction was significant, $F(13, 2,587) = 6.01$, $MSE = .009$, $p < .001$, partial $\eta^2 = .03$. Similar to the AC results, high- and low-WM individuals demonstrated similar mouse trajectories on neutral trials, but on incongruent trials high-WM individuals had faster mouse movements to the correct response (after initial movements to the incorrect response) than low-WM individuals. These results are consistent with Heitz and Engle (2007) suggesting that high- and low-WM individuals differ in the speed of resolving interference in flankers.

Descriptive Statistics, Correlations Among the Measures, and Confirmatory Factor Analysis

Similar to Study 1, we next examined psychometric properties for the measures and correlations among all the measures. Descriptive statistics for all of the measures are shown in Table 5. As can be seen, the measures had generally acceptable values of reliability and most of the measures were approximately normally distributed. The one exception was the letter change detection task which demonstrated poor reliability. Congruency effects in both the mouse movement measures and reaction times from the button-press tasks demonstrated acceptable levels of reliability.

Correlations among the measures are shown in Table 6. As can be seen, congruency effects in MT and AUC were strongly correlated in the Stroop suggesting that participants who were more attracted to the incorrect response tended to have slower mouse movements than participants who had more direct paths toward the correct response. Additionally, mouse movement measures in Stroop were correlated with congruency effects in the button-press Stroop consistent with Study 1. For flankers, MT and AUC were correlated, but not nearly as strongly as the same relations in Stroop, suggesting that MT and

Table 5

Descriptive Statistics for Measures in Study 2

Measure	<i>M</i>	<i>SD</i>	Skew	Kurtosis	Reliability	<i>N</i>
StroopMT	193.20	128.43	0.83	0.44	.69	278
StroopAUC	0.67	0.47	0.54	−0.28	.67	281
StroopB	147.97	81.64	0.48	0.40	.60	309
FlankerMT	175.90	93.94	0.49	0.41	.67	247
FlankerAUC	0.95	0.46	0.51	−0.19	.66	248
FlankerB	106.69	68.61	1.47	3.31	.69	302
Anti	0.57	0.16	0.15	−0.63	.74	312
PVT	474.70	105.60	1.40	2.69	.91	300
Ospan	37.97	8.89	−1.25	1.88	.73	311
Symspan	18.86	5.29	−0.67	0.21	.69	318
CDC	0.81	0.10	−0.61	0.72	.61	315
CDL	0.70	0.09	−0.20	−0.24	.42	318

Note. Reliabilities represent split-half reliabilities. StroopMT = Stroop congruency effect in movement times; StroopAUC = Stroop congruency effect in area under the curve; StroopB = Stroop congruency effect in reaction times for the button-press version; Flanker MT = flanker congruency effect in movement times; Flanker AUC = flanker congruency effect in area under the curve; FlankerB = flanker congruency effect in reaction times for the button-press version; Anti = antisaccade; PVT = psychomotor vigilance task; Ospan = operation span; Symspan = symmetry span; CDC = color change detection; CDL = letter change detection.

AUC in flankers share less common variance. Congruency effects in the button-press flankers was correlated with congruency effects in both MT and AUC (although more strongly in MT). Similar to Study 1, the Stroop mouse movement measures tended to correlate with the other AC tasks (avg. $r = .17$), whereas the button-press version of Stroop demonstrated weaker and near zero correlations (avg. $r = .05$). Congruency effects in both MT (avg. $r = .19$) and RT in the button-press (avg. $r = .21$) in flankers demonstrated similar relations with the other AC measures.

Consistent with Study 1, we used confirmatory factor analysis to examine if the congruency effects in the mouse movements would load onto an overall AC factor with the other AC measures and whether this factor would be correlated to a WM factor. We specified a model in which congruency effects in MT in the Stroop and flanker mouse tasks, congruency effects in reaction time in the button-press version of Stroop flankers, antisaccade, and the psychomotor vigilance task loaded onto an AC factor and Ospan, Symspan, color change detection, and letter change detection loaded onto a WM factor. The two factors were allowed to correlate. To fit the models, we used full information maximum likelihood. The overall fit of the model was not acceptable, $\chi^2(34) = 81.3$, $p < .001$, RMSEA = .07, NNFI = .74, CFI = .81, SRMR = .06. In this model, the button-press Stroop did not load significantly on the AC factor and modification indices suggested that freeing the relation between the residual variances for flanker MT and flanker button-press tasks could improve model fit. Given the Stroop button-press task did not load significantly and the fact that two flanker tasks were moderately correlated ($r = .44$), we dropped the Stroop button-press task and allowed the residuals for the two flanker tasks to correlate. The overall fit of the model was good, $\chi^2(25) = 37.4$, $p = .053$, RMSEA = .04, NNFI = .95, CFI = .92, SRMR = .04. Shown in Figure 8 is the model. As can be seen, all of the measures loaded onto their respective constructs with the loadings typically being moderate to strong. In fact, the average factor loading onto the AC factor (.43) was similar to the average factor loading onto the WM factor (.46). This is likely due

Table 6
Correlations Among the Measures in Study 2

Measure	1	2	3	4	5	6	7	8	9	10	11	12
1. StroopMT	—											
2. StroopAUC	.78	—										
3. StroopB	.20	.27	—									
4. FlankerMT	.11	.13	.01	—								
5. FlankerAUC	-.03	.10	.00	.36	—							
6. FlankerB	.21	.20	.11	.44	.19	—						
7. Anti	-.19	-.17	-.02	-.20	.07	-.18	—					
8. PVT	.19	.05	-.01	.10	.02	.14	-.36	—				
9. Ospan	-.05	.00	.02	-.06	-.01	-.11	.19	-.07	—			
10. Symspan	-.06	-.09	-.06	-.23	-.04	-.22	.20	-.15	.34	—		
11. CDC	-.04	.02	-.03	-.07	.04	-.07	.17	-.10	.12	.16	—	
12. CDL	-.11	-.02	.00	-.10	.07	-.12	.21	-.18	.20	.16	.29	—

Note. StroopMT = Stroop congruency effect in movement times; StroopAUC = Stroop congruency effect in area under the curve; StroopB = Stroop congruency effect in reaction times for the button-press version; Flanker MT = flanker congruency effect in movement times; Flanker AUC = flanker congruency effect in area under the curve; FlankerB = flanker congruency effect in reaction times for the button-press version; Anti = antisaccade; PVT = psychomotor vigilance task; Ospan = operation span; Symspan = symmetry span; CDC = color change detection; CDL = letter change detection. Correlations $>.12$ are significant at the $p < .05$ level.

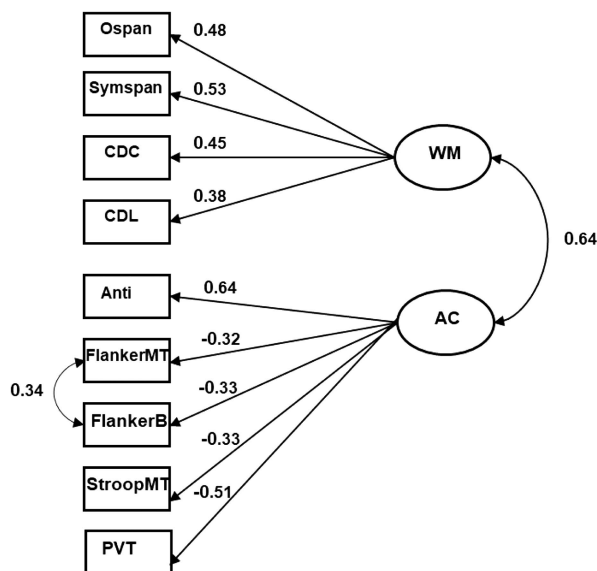
to the fact that the average correlation across the AC tasks (.21) in the factor analysis was similar to the average correlation across WM tasks (.21) in the factor analysis. The AC and WM factors were correlated, replicating prior research and Study 1. Overall, like Study 1, these results suggest that congruency effects from the mouse tracker tasks

were related to the other AC measures and loaded moderately onto an AC factor which was correlated with WM.

Discussion

The results from Study 2 broadly replicated and extended the results from Study 1. We found congruency effects in the Stroop task for both MT and AUC and these congruency effects correlated with individual differences in AC (interactions with WM were not significant). Time course analyses further suggested that low-AC individuals had a stronger attraction to the incorrect response and were slower to move to the correct response on incongruent trials than high-AC individuals. Examining flankers similarly suggested congruency effects in MT and AUC. However, examining individual differences in AC (and WM) suggested that relations only arose for MT and not for AUC (or IT). Examining the time course of responses suggested that early on in incongruent trials, there was a strong attraction to the incorrect response, followed by a reversal and more direct movements toward the correct response. Critically, both high- and low-AC individuals demonstrated a similar attraction to the incorrect response, but high-AC individuals were faster to move to the correct response than low-AC individuals. These results are consistent with the notion that individual differences in AC were related to differences in the ability to restrain attention and prevent the prepotent response from guiding behavior in the Stroop task, such that low-AC individuals were more captured by the incorrect response and slower to resolve conflict than high-AC individuals. For the flanker task, the results were consistent with the notion that high- and low-AC individuals demonstrated similar capture to the incorrect response, but high-AC individuals were faster at resolving the conflict via a faster rate of constraining their spotlight of attention than low-AC individuals (i.e., Heitz & Engle, 2007). Thus, there were different patterns of mouse trajectory relations with AC for Stroop and flankers. Furthermore, MT in the both the Stroop and flanker tasks were correlated with the other AC tasks but were weakly correlated with each other (.11), and both loaded onto an overall AC factor that was correlated with WM. These results suggest similarities and differences in the relations between Stroop and flankers.

Figure 8
Confirmatory Factor Analysis Model for WM and AC for Study 2



Note. Paths connecting latent variables (circles) to each other represent the correlations between the constructs and the numbers from the latent variables to the manifest variables (squares) represent the loadings of each task onto the latent variable. Solid paths are significant at the $p < .05$ level. WM = working memory; AC = attention control; Ospan = operation span; Symspan = symmetry span; CDC = color change detection; CDL = letter change detection; Anti = antisaccade; Flanker MT = flanker congruency effect in movement times; FlankerB = flanker congruency effect in reaction times for the button-press version; StroopMT = Stroop congruency effect in movement times; PVT = psychomotor vigilance task.

General Discussion

In two studies, we examined individual differences in the dynamics of AC. In each study, participants performed mouse tracker versions of Stroop (Studies 1 and 2) and flankers (Study 2) to better examine conflict resolution processes and how they unfold over time. Consistent with some prior research we found congruency effects in both MT and AUC (but not IT) in Stroop (e.g., Bundt et al., 2018; Ruitenberg et al., 2019), and similar results were found in flankers. Examining relations between AC and WM with congruency effect effects in each mouse tracker measure suggested a number of interesting findings. Specifically, AC correlated with congruency effects in both MT and AUC (but not IT) in the Stroop task in each study. WM correlated with congruency effects in MT in Study 1 (and not quite significantly in Study 2) in Stroop, but correlations with AUC and IT were not significant. Furthermore, congruency effects in MT and AUC in Stroop were strongly correlated in both studies (Study 1: $r = .75$ and Study 2: $r = .78$). These results suggest that individual differences in AC were related to conflict resolution processes in the Stroop in both studies. In particular, low-AC individuals demonstrated a greater attraction to the incorrect response and slower movements toward the correct response than high-AC individuals. These results are consistent with the notion that in the Stroop task, low-AC individuals were more captured by the incorrect response and slower to resolve the conflict than high-AC individuals. Individual differences in WM demonstrated weaker and less consistent correlations. Time course analyses further reinforced these notions by demonstrating that low-AC individuals had a greater pull toward the incorrect response early in incongruent trials, resulting in delayed movements toward the correct response compared to high-AC individuals.

Examining individual differences in congruency effects in flankers in Study 2 suggested a slightly different pattern of results. AC correlated with congruency effects in MT, but correlations with AUC and IT were not significant. Similarly, WM correlated with congruency effects in MT but not in AUC and or IT. Furthermore, congruency effects in MT and AUC in flankers were moderately correlated ($r = .36$). These results suggest that individual differences in AC (and WM) were related with conflict resolution abilities in flankers. Specifically, high- and low-AC (and high and low WM) demonstrated similar attraction to the incorrect response on incongruent trials, but low-AC individuals were slower to move toward the correct response than high-AC individuals. These results are consistent with the notion that low-AC individuals were slower to resolve the conflict than high-AC individuals on incongruent trials. Similar to Stroop, time-course analyses reinforced these notions by demonstrating that high- and low-AC individuals demonstrated similar capture by the incorrect response on incongruent trials around 540 ms into the trial, but then high-AC individuals demonstrated faster movements toward the correct response than low-AC individuals. Thus, both AC and WM were related to individual differences in the time to resolve conflict in flankers but were not related to variation in the degree of capture by the incorrect response. Note, this is not to say that there were not individual differences in capture in flankers. As seen in Table 6, there were reliable individual differences in congruency effects in AUC in flankers, and these were related to congruency effects in the button-press version of flankers, suggesting that some of the variance in the standard congruency effect is likely due to variation in the amount of capture by the incorrect response.

This variation, however, was not related to broad AC abilities or WM in the present study.

Collectively, the current results are broadly consistent with the notion that individual differences in conflict resolution processes in Stroop and flankers are related to AC abilities. At the same time, the current results suggest that there are similarities and differences across tasks. As noted above, in the Stroop task, AC was related to both MT and AUC (and these were strongly correlated), whereas in flankers, AC was only related to MT (and MT and AUC demonstrated a weaker correlation). These results are consistent with the notion that these tasks are likely both measuring broad AC/conflict resolution abilities but measure different aspects of AC. As noted previously, some prior work (Friedman & Miyake, 2004; Kane et al., 2016; Poole & Kane, 2009; Unsworth & Spillers, 2010) suggests that the Stroop task measures the ability to restrain attention and prevent the prepotent response from guiding behavior, whereas the flanker task more so measures the ability to constrain attention to target stimuli in the presence of distractors. Furthermore, Heitz and Engle (2007) suggested that high- and low-WM (and likely high- and low-AC) individuals were similarly captured by the distractors, but that high-WM (and presumably high-AC) individuals were faster at constraining their spotlight of attention to target stimuli compared to low-WM (and low-AC) individuals. The current results are very much in line with these predictions in demonstrating that AC was unrelated to AUC in flankers (but was related to AUC in Stroop) but was related to MT in flankers. Furthermore, the time-course analyses suggested that high- and low-AC individuals demonstrated a similar attraction to the incorrect response at the same time during the trial, but high-AC individuals then demonstrated faster and more direct movements toward the correct response than low-AC individuals. These results are strikingly similar to the time-course analyses presented by Heitz and Engle (2007) demonstrating differences between high- and low-WM individuals in terms of conditional accuracy functions. As such, the current results suggest that high- and low-AC individuals (and high- and low-WM individuals) differ in their rate of attentional constraint. The results further suggest that high- and low-AC individuals differ in their ability to restrain attention and prevent (or lessen) the amount of attentional capture from the irrelevant stimulus in the Stroop task. Additionally, the extent to which flankers and Stroop are partially indexing different facets of AC would suggest that congruency effects in each should demonstrate weak to moderate relations at the task level which is typically seen. Thus, the current results suggest that there are similarities and differences in conflict resolution abilities in Stroop and flankers in which high-AC individuals are better at both restraining their attention in Stroop and constraining their attention in flankers compared to low-AC individuals.

As noted previously, other potential explanations for why AC might be related to performance in Stroop and flankers include variation in processing speed and variation in speed-accuracy trade-offs (e.g., Draheim et al., 2021; Rey-Mermet et al., 2019; Unsworth, Miller, & Robison, 2021). A processing speed account suggests that high-AC individuals are simply faster at processing information than low-AC individuals and thus should have faster overall responses compared to low-AC individuals. There was some evidence for this account in terms of relations between MT and AC in each study. Specifically, average MT in the Stroop was correlated with AC in both Study 1 ($r = -.31, p < .001$) and Study 2 ($r = -.36, p < .001$). However,

IT was not correlated with AC in either Study 1 ($r = .05, p = .50$) or Study 2 ($r = .10, p = .10$). For flankers, AC was correlated with both average MT ($r = -.43, p < .001$) and IT ($r = .17, p = .008$), but the correlation with IT was positive suggesting that high-AC individuals were slightly slower to initiate a response than low-AC individuals on all trials. Thus, in each study and each task, high-AC individuals demonstrated faster MT across all trials than low-AC individuals suggesting the possibility that they differ in basic processing speed. However, AC was not related to IT in the Stroop in either Study and was positively related to IT in flankers, suggesting that any possible speed differences were localized to movement times and did not necessarily reflect differences in how fast mouse movements were initiated. Furthermore, for all MT measures, there was an interaction with trial type suggesting that AC was related to MT more on incongruent trials than congruent/neutral trials. Thus, although some of the performance differences might be attributable to differences in processing speed, there was considerable evidence that these differences were localized to mouse movement times (and not just overall performance) with larger effects occurring on incongruent than congruent/neutral trials, consistent with differences in conflict resolution abilities.

In terms of differences in speed–accuracy trade-offs, there was not much evidence for this possibility in the data. As previously mentioned, a speed–accuracy trade-off account would suggest that differences should primarily arise in IT as some individuals might wait to resolve the interference before beginning their movements toward the correct response as seen with bilingual individuals (Incera & McLennan, 2016) and older adults (Erb et al., 2020). However, in the current data, congruency effects in IT were not related to AC in any task. As noted above, there was a positive correlation between AC and overall average IT in flankers, suggesting that high-AC individuals were slower to initiate movements than low-AC individuals across trials. Combined with a negative correlation for MT, this suggests possible differences in speed–accuracy trade-offs. Importantly, this was not localized to incongruent trials, suggesting that differences in congruency effects were not necessarily due to differences in speed–accuracy trade-offs. These results again suggest that individual differences in congruency effects in the present study were partially indexing variation in conflict resolution abilities and were not necessarily due to individual differences in processing speed or speed–accuracy trade-offs.

The current results provide important evidence that individual differences in task performance on conflict tasks likely represents variation in conflict resolution abilities. Prior work has suggested issues with standard RT differences of congruency effects, which sometimes demonstrate poor reliability estimates and weak correlations with other AC measures. Indeed, in the present study, congruency effects in the button-press version of the Stroop task demonstrated poor reliability in Study 1 (.52) and a bit better reliability in Study 2 (.60). Furthermore, congruency effects in the button-press version of Stroop demonstrated weak correlations with the other AC measures in both studies (Study 1: avg. absolute correlation = .06; Study 2: avg. absolute correlation = .05). In contrast, the mouse movement measures tended to demonstrate better reliability estimates in each study (.67–.72) and demonstrated stronger correlations with the other AC measures (Study 1: avg. absolute correlation = .17; Study 2: avg. absolute correlation = .17). The mouse tracker version of Stroop also tended to load more strongly on the AC factor than the button-press version of Stroop. Thus, there was evidence that the mouse tracker version of Stroop was

more reliable and valid than the corresponding button-press version of Stroop. For flankers, both versions demonstrated similar reliability estimates, similar overall correlations with the other AC tasks, and loaded at a similar level on the AC factor. This suggests that the two versions demonstrated similar reliability and validity. Collectively, the current results suggest that mouse tracking measures demonstrate acceptable psychometric properties and can be beneficial for assess variation in AC.

Limitations, Constraints on Generality, and Future Directions

The current results provide important information on the dynamic nature of individual differences in AC assessed with conflict tasks. At the same time, there are some limitations which need to be addressed. First, reliability estimates for the mouse movement measures tended to be better (at least for Stroop) than reliability for button-press measures. Although these reliability estimates were in a more acceptable range, they were still not great. There is considerable debate on what constitutes an acceptable or excellent reliability estimate, but in general, higher estimates are better. Thus, a limitation of the current studies is that our reliability estimates could have been better. For each task, we administered roughly 90–133 trials. Future research could increase the number of trials per task to potentially increase the overall reliability estimates for the congruency effects.

A second limitation of the present study was that the *Ns* for the mouse tracker tasks in Study 2 were lower than the other measures due to missing data which was due to three factors. First, there was some confusion as to whether these tasks were supposed to be run given that they were programmed in Mouse Tracker, whereas the other tasks were programmed in E-prime, and thus some participants did not have data for the mouse tracker tasks. Second, the lab was shut down early due to the onset of COVID-19 which reduced our ability to finish the study and add additional participants. Third, because the mouse tracker tasks were at the end of the session, there was missing data for participants who choose not to complete the whole session of testing. Future research should aim for larger sample sizes with more complete data to replicate and extend the current results.

A third limitation is that we only examined differences between Stroop and flankers, and it would have been beneficial to have additional constraint and restraint AC tasks to have better coverage of these two components of AC (e.g., Friedman & Miyake, 2004; Kane et al., 2016). Thus, future research is needed to better examine similarities and differences between attentional constraint and restraint at a broader latent factor level.

A final limitation of the present study is that nearly all of the participants were college students from a comprehensive state university. Thus, the current samples are likely composed of more high-ability participants than is ideal. Partial range restriction of the ability distributions can result in weaker correlations than would be seen with a broader ability range. Furthermore, the samples were less diverse than the general population. Future research should include a broader range of abilities and a more diverse sample to ensure the results generalize to the broader population.

Conclusions

The current results suggest that individual differences in AC (and to some extent WM) were related to individual differences in

conflict resolution processes that dynamically unfold over the course of a trial. In the Stroop task, AC was related to the amount of attraction of the incorrect response and the time to move toward a correct response on incongruent trials, suggesting individual differences in the ability to restrain attention. In the flanker task, AC was not related to the amount of attraction to the incorrect response, but was related to the time to move toward the correct response on incongruent trials, suggesting variation in the ability to constrain attention. These results are consistent with the notion that conflict resolution processes in Stroop and flankers likely reflect both overlapping and distinct processes that are related to broader AC abilities. Utilizing tracking tasks provides a promising means of better examining individual differences in the dynamics of AC.

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