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Faster, Smarter, and More Attentive: The Control of Attention Is About More Than Just Conflict Resolution

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Mental speed theories of intelligence suggest that people are smarter because they are faster. We argue that attention control plays an important and fundamental role in mediating the relationship between basic sensory processes and more complex cognitive processes such as fluid intelligence. One of the most successful paradigms for establishing a mental speed theory of intelligence is the inspection time task. In this article, we examine the mental speed and the attention control perspectives on the inspection time task and its relationship with fluid intelligence. Integrating experimental and correlational approaches, we find that attention control statistically explains the inspection time task's correlation with fluid intelligence and working memory capacity. Attention control and inspection time are correlated beyond their relationship with other measures of processing speed. Further, while we find no evidence that selective attention specifically is related to inspection time performance, both attention control and inspection time predicted declines in accuracy as participants sustained their attention over time; other measures of processing speed did not predict sustained attention performance. Collectively, these results indicate that inspection time is related to the ability to control attention, especially the ability to sustain attention over time.

Public Significance Statement
This research challenges the idea that the speed of information processing is directly related to intelligence. Instead, it highlights the importance of the ability to control and sustain attention to process information quickly and to successfully perform more complex cognitive tasks that involve reasoning, problem-solving, and working memory.

Keywords: processing speed, executive functioning, cognitive control, fluid intelligence, working memory capacity

The speed with which a person can process information is often associated with differences in intelligence by scientists and laypeople alike. Children who rapidly understand new concepts or skills are often deemed to be intelligent. In contrast, children who require more time to do so might be viewed less favorably. The link between speed and intelligence had been noted since the early days of psychology as a scientific discipline (Galton, 1883; Gilbert, 1895), but it did not become a mainstay of intelligence research until the 1950s and 1960s with the onset of the information processing paradigm (Eysenck, 1967; Roth, 1964). For a detailed historical overview, see Mashburn et al. (2024). The consensus of this work is that those who can process information more quickly also tend to score higher on measures of intelligence (Sheppard & Vernon, 2008; Vernon, 1987). A strong, reductionist

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interpretation of this work would contend that individuals are more intelligent *because* they are faster (Eysenck, 1967; Jensen, 1998; Salthouse, 1996), what we refer to as the "processing speed" or "mental speed" theory of intelligence.

In contrast to mental speed theories of intelligence, top-down mechanisms of attention control (Burgoyne & Engle, 2020; Engle, 2018; Rueda, 2018), inhibition and resolving conflict (Friedman & Miyake, 2004; Miyake & Friedman, 2012; Oberauer, 2005), updating and binding items in working memory (Oberauer, 2005; Oberauer et al., 2007) have all been suggested as significant contributors to differences in intelligence. For instance, we and others have argued that the control of attention is a fundamental ability that drives performance differences across a large variety of tasks and domains (Burgoyne & Engle, 2020; Engle, 2018; Kovacs & Conway, 2016; Rueda, 2018; Rueda et al., 2023).

Traditionally, the control of attention has been studied in situations requiring the resolution of stimulus and response conflict—such as in tasks like the Stroop and flanker. However, we view the control of attention more broadly.[1] It encompasses the ability to intensely focus and sustain attention in order to guide perception, thoughts, and behavior in a goal-directed manner. While the presence of conflict in a task can act as an exogenous signal to engage the control of attention, one can also endogenously decide to intensely focus and sustain their attention in the absence of any explicit conflict (Tsukahara et al., 2020). Further, sustaining one's attention, whether in the presence of external conflict or not, will be challenged by the conflict from internal distractions (off-task thoughts) and competing goals. As such, the control of attention has been linked to attentional lapses, mind wandering, and general goal maintenance ability (Kane & McVay, 2012; McVay & Kane, 2012; McVay et al., 2009; Robison et al., 2020; Unsworth & McMillan, 2014).

More specifically, we contend that individuals differ in how intensely they can focus their attention—resulting in a greater perceptual acuity—and how long they can sustain that focus of attention—resulting in more lapses of attention and consequently a worse perceptual acuity (for a similar conceptualization, see Unsworth & Miller, 2021). In support of this, we have previously shown that the ability to control attention is highly predictive of one's ability to make fine sensory discriminations (Tsukahara et al., 2020). For instance, in a pitch discrimination task, those higher on attention control were able to notice a smaller difference in pitch between two tones. Further, although sensory discrimination ability strongly correlated with fluid intelligence, attention control was able to fully mediate that relationship. That is, attention control was a common determinant of people's ability to make sensory discriminations and their fluid intelligence.

These findings and our perspective on attention control provide an entirely different interpretation of the speed–intelligence relationship than what mental speed theories have advocated. From our perspective, the speed by which one can process information will be determined by a top-down process of how intensely one can focus and sustain their attention (Heitz & Engle, 2007). If this is true, similar to our findings with sensory discrimination (Tsukahara et al., 2020), we should see that attention control is a common determinant of people's speed of information uptake and their fluid intelligence. This would suggest that people are not *smarter* because they are *faster*, but that they are *smarter and faster* because they have a greater control of their attention.

One of the most successful paradigms for establishing a mental speed theory of intelligence is the inspection time task (Deary & Stough, 1996). The inspection time task tests how *quickly* a person can make a simple sensory discrimination. Typically, the task requires discriminating which of the two vertical lines are longer. The discrimination itself is easy but the *duration* for which the lines are displayed varies. The shortest duration at which an individual can accurately respond (e.g., 85% accuracy) is determined either through an adaptive task procedure or by fitting a psychometric function to their performance data. This duration, or their inspection time, is thought to reflect the individual's speed of processing basic sensory information (White, 1993).

The inspection time task is considered as one of the most robust single-task predictors of intelligence, meta-analytic $r = -.3$ (corrected $r = -.5$; Grudnik & Kranzler, 2001; Kranzler & Jensen, 1989; Nettelbeck, 1987), and is among the most convincing evidence for a mental speed theory of intelligence (Deary & Stough, 1996). However, we should be cautious of the mental speed interpretation. Faster inspection times may not be a direct cause of intelligence differences, since faster inspection times could result from other traits or cognitive processes (Mashburn et al., 2024). In this article, we examine the mental speed and the attention control perspectives on the inspection time task and its relationship with fluid intelligence.

Inspection Time as Mental Speed

The mental speed theory of intelligence attempts a mechanistic understanding of why different mental tests positively correlate with one another, suggesting that the rate with which individuals can execute simple cognitive operations determines their intelligence (Kail & Salthouse, 1994; Salthouse, 1996).[2] This is analogous to the processing power of a computer, which is partially determined by the number of operations that the central processing unit(s) can perform per second, that is, the clock speed. The mental speed theory of intelligence is supported by research which indicates that people of different intelligence levels also differ in the rates with which they can perform putatively simple cognitive tasks (for reviews, see Mashburn et al., 2024; Sheppard & Vernon, 2008). Choice reaction time tasks, in which participants are instructed to press one button when a certain stimulus appears (e.g., a red square) and another button for a different stimulus (e.g., a blue square), feature prominently in this literature. Some choice reaction time studies operationalize processing speed as the mean reaction time on correct trials, but others attempt to isolate the time it takes to reach a decision (i.e., decision time) from the time it takes to execute a motor

[1] Our broader view is also consistent with other conceptualizations of attention/cognitive control. For instance, Fan (2014) proposed that cognitive control and its underlying brain networks play a pivotal role in dealing with conditions under uncertainty. Weigard et al. (2021) also suggested that attention control may operate in nonconflict conditions.

[2] Here, we would like to distinguish a strong rendering of mental speed theory as the basis of cognitive ability differences from multivariate work attempting to place speed abilities into a broader psychometric context. For example, several studies have attempted to enumerate and classify one or more "speed" abilities within larger psychometric taxonomies of cognitive abilities, but they do not necessarily propose that mental speed leads to cognitive ability differences in any direct way (e.g., Ackerman et al., 2002; Roberts & Stankov, 1999). Indeed, these researchers have been critical of the strong mental speed view (e.g., Stankov & Roberts, 1997).

response (i.e., movement time; Jensen & Munro, 1979; Roberts & Stankov, 1999; Sheppard & Vernon, 2008).

Many early studies showed consistent but modest correlations between choice reaction time task performance and intelligence, especially for decision time estimates. These usually occurred in the range of $r = -.30$ to $-.40$ (see Brand, 1981; Deary & Stough, 1996; Mackintosh, 1986; Roberts & Stankov, 1999). These highly replicable findings suggested a genuine link between choice reaction time and intelligence. However, the consistently modest relationship has generated concern about the viability of mental speed as a core explanation of intelligence, since choice reaction time measures only ever explained a minor portion of variance (less than 20%) in intelligence test performance (Brand & Deary, 1982; Deary & Stough, 1996).

Early studies of the inspection time task seemed to allay this concern. For example, Nettelbeck and Lally (1976) observed correlations of $r \approx -.90$ with performance IQ as measured by Wechsler's Adult Intelligence Scale across two administrations of the inspection time task. Meanwhile, no correlations between reaction time and IQ were observed. Brand (1981) reviewed several similar studies, all showing a strong correspondence between intelligence estimates and inspection time performance, rs $> .70$, especially among people with very low intelligence test scores. Subsequent meta-analyses indicated that the true correlation is likely much lower, roughly $r = -.50$ (Grudnik & Kranzler, 2001). Earlier estimates of the correlation were probably inflated by the small, artificially broad samples employed by researchers (Grudnik & Kranzler, 2001; Kranzler & Jensen, 1989; Mackintosh, 1986; Nettelbeck, 1987). However, even this more modest estimate situates inspection time as one of the strongest chronometric predictors of mental ability, making it worthy of special focus (Deary & Stough, 1996).

The inspection time task is argued to be relatively process pure compared to many other speed tasks, which might explain its especially close relationship with general intelligence. There are minimal psychomotor demands which might pollute the speed–intelligence relationship (Jensen, 1998; Jensen & Reed, 1990). Inspection time measures the time to decide about a stimulus separately from the time it takes to carry out the response. Further, the inspection time task has no strong memory component. This apparent simplicity coupled with its close relationship with intelligence makes the inspection time task a strong grounding for the mental speed theory, in part, because there appears to be little room for other explanatory mechanisms beyond individual differences in basic stimulus evaluation processes.

However, one enduring alternative to mental speed supposes that inspection time may reflect individual differences in the ability to control attention. Although the role of attention in inspection time tasks has been studied by some researchers (Bors, 1999; Fox et al., 2009; Nettelbeck, 2001), it has been a blind spot in understanding the cognitive basis of inspection time and processing speed more broadly.

Inspection Time as Attention Control

The role of attention in basic perception is well known. For instance, most neural models of perception are based on the principles of biased competition by top-down influences, such as attention (Desimone & Duncan, 1995; Usher & Niebur, 1996). The focus of attention enhances the activation of populations of neurons that encode stimulus features and attenuates activity in nearby, nonrelevant populations. This increases the signal-to-noise ratio of the neural signal, enhancing the representation of the stimulus for later processing stages (Kok, 1997; O'Craven et al., 1997; Treue & Martinez-Trujillo, 2006). Additionally, the perceptual decoupling model of mind wandering suggests that the occurrence of mind wandering reflects a shift of attention away from the environment and thus results in a decoupling from perception (Schooler et al., 2011). Therefore, fluctuations of attention in the form of attentional lapses, mind wandering, or goal maintenance failures may impact the fidelity of perceptual processing.

Indeed, in his review, Nettelbeck (2001) suggested that inspection time performance is "possibly mediated by attentional capacities that prime and maintain alertness (vigilance), that focus selective attention, and control rapid scanning" (p. 460; see also Mackintosh, 1986). Several studies have found that lapses of attention and measures of sustained attention correlate with inspection time (Bors, 1999; Hutton et al., 1997; Nettelbeck & Young, 1989). However, these studies are severely limited by the sample size, population of interest (e.g., some only sample young children), and the validity of their sustained attention measures. For instance, Bors et al. (1999) considered error rates on the longest inspection time trials as indicators of lapsing attention. They assumed that participants ($N = 31$) should only make errors on the slowest inspection time trials if they were not focused on the task. Controlling for accuracy rates on the slowest inspection time trials (140 ms) reduced the correlation between inspection time and IQ from $-.39$ to $-.17$ for one inspection time task and from $-.36$ to $-.21$ for another. Neither partial correlation was statistically significant. This suggests that the ability to sustain attention may determine inspection time performance, but a more convincing measurement of sustained attention with a larger sample is desirable.

Beyond sustaining attention, selectively focusing attention may be important for performing an inspection time task well. Event-related potential studies have found that higher intelligence is correlated with a larger visual N1 component in the inspection time task (Hill et al., 2011). The visual N1 is a negative event-related potential component that peaks around 150–200 ms after the onset of a stimulus and is thought to reflect the focusing of attention to target stimuli at particular spatial locations (Coull, 1998; Hill et al., 2011; Vogel & Luck, 2000). More intelligent individuals having larger N1 amplitudes may suggest that they are superior at focusing attention on the critical spatial location where the inspection time stimuli will appear (Bors et al., 1993; Hill et al., 2011; Vogel & Luck, 2000).

Adding further support to the notion that inspection time may demand attentional resources, Fox et al. (2009) reversed the correlation between inspection time and intelligence by manipulating the availability of attentional resources. Their small number of participants ($N = 25$) performed a visual inspection time task and a concurrent auditory shadowing task to manipulate attentional load. Importantly, the shadowing task and inspection time task shared virtually none of the same processing demands. Despite this, when instructed to focus primarily on the shadowing task, participants with higher intelligence showed decreased performance on the inspection time task, indicated by longer inspection times. This suggests that how focused one is on performing the task plays an important role in explaining the inspection time–intelligence relationship, since diverting attention from the inspection time task lengthened discrimination thresholds. It also suggests that those better at selectively focusing attention are both more intelligent and better at performing the inspection time task (Fox et al., 2009).

Collectively, these studies suggest a potential role for attention control in the inspection time–intelligence relationship but are hampered by small samples ($N \leq 40$) and other methodological limitations. We hoped to provide a stronger test of the hypothesis that attention control may help to explain inspection time and its relationship with intelligence.

The Present Study

The primary aims of the present study were to (a) test whether attention control is related to inspection time and can explain its relationship with intelligence and (b) to better understand *how* attention control mechanisms relate to inspection time. To address the first aim, we took an individual differences approach assessing performance differences across a large set of attention, processing speed, and intelligence tests. For the second aim, we took a combined differential–experimental approach to better understand the underlying attentional mechanisms at work in the inspection time task.

One challenge for individual differences research lies in isolating variance related to the specific cognitive processes of interest. That isolation is required to make valid, specific claims about the relationships between constructs. We attempted to accomplish this in three ways. First, we included both visual (Draheim et al., 2021, 2023) and auditory (Burgoyne et al., 2024) tasks to measure attention control, ensuring a broad, modality-general factor (Engle, 2018). Second, we measured and statistically controlled for other constructs that might account for some of the variation in attention control and inspection time, specifically noninspection time measures of processing speed. As discussed previously, the inspection time literature has been concerned with the nature of the relationship between processing speed and intelligence. By including other "processing speed" measures, we provide a more stringent test of the relationships among inspection time, intelligence, and attention control. Additionally, our attention control measures themselves may capture some variation in processing speed ability (Frischkorn et al., 2019). By measuring processing speed more directly with noninspection time tasks, we can statistically control for processing speed and test whether attention control has incremental validity in explaining the inspection time–intelligence relationship. Our third strategy for maximizing validity involved experimentally manipulating tasks to modify their attention demands. This allowed us to isolate attentional mechanisms that may play a role in inspection time performance, specifically selective attention and sustained attention.

To investigate the relationship between selective attention and inspection time, we manipulated the number of stimuli and distractors in the inspection time task itself. We developed three versions of the inspection time task: (a) a standard inspection time task with some modifications discussed below, (b) a selective inspection time task which cued participants to respond to a subset of lines (i.e., either the two red or two blue lines) and to ignore the other subset, and (c) an inspection time task in which participants judged which of four lines was the longest rather than the standard two lines. The latter two novel inspection time tasks each presented four lines during the critical inspection time trial, but differed in whether there was a selective attention component. Those individuals lower on attention control should show more of a decrement in performance from the standard to selective inspection time task, because they should have a harder time ignoring the irrelevant lines compared to those higher on attention control.

To investigate the relationship between sustained attention and inspection time, we used a novel attention control measure that manipulates how long attention must be sustained, the sustained attention-to-cue task (SACT; Draheim et al., 2023; Tsukahara & Engle, 2023). This sustained attention task also requires the quick identification of a briefly presented target stimulus. Therefore, this task likely also captures some differences related to inspection time or to processing speed more generally. However, our critical test was whether participants with different levels of inspection time performance also differed in how their target identification accuracy declines as they sustain their attention for increasingly longer durations. If inspection time tasks reflect some aspect of ability to sustain attention, those with faster inspection times should also show smaller performance decrements the longer attention must be sustained. This finding would be challenging to explain from a strong mental speed interpretation of the inspection time task, and would be more consistent with theories of attention control and its relation to attentional lapses, mind wandering, and goal maintenance (Kane & McVay, 2012; McVay & Kane, 2012; McVay et al., 2009; Robison et al., 2020; Unsworth & McMillan, 2014).

Finally, we included working memory capacity as an additional criterion construct. While much of the inspection time literature has focused on intelligence, working memory capacity is strongly related to fluid intelligence and is a key facet of cognitive functioning (Cowan et al., 2024; Kane et al., 2005; Kovacs & Conway, 2016, 2019; Kyllonen & Christal, 1990; Oberauer, 2005). Although working memory capacity has received less attention in the inspection time literature, it is central to broader research on processing speed. For instance, the time-based resource sharing model suggests that processing speed influences working memory capacity by reducing memory decay (Barrouillet & Camos, 2021). Additionally, many of the same tensions between processing speed and attention control as predictors of intelligence apply to working memory capacity (Frischkorn et al., 2019; Mashburn et al., 2024; Schmitz & Wilhelm, 2016). To address this gap, we include measures of working memory capacity to assess the generality of our findings and enhance comparability with research on noninspection time speed tasks, where working memory is often examined alongside or instead of intelligence.

Method

Participants

We recruited participants from the Georgia Institute of Technology, surrounding Atlanta colleges, and the broader Atlanta community. All participants were required to be native English speakers and 18–35 years of age. Participants scheduled each study session according to their own availability, but they were not allowed to complete more than one session per day. We compensated participants up to $200 for completing five 2.5-hr in-laboratory sessions ($30 for Session 1, $35 for session 2, $40 for Session 3, $45 for Session 4, and $50 for

Session 5). Georgia Tech students enrolled in an undergraduate psychology course were given the option to receive 2.5 hr of course credit or monetary compensation for each session. Participants who frequently rescheduled, missed appointments, or regularly failed to follow directions were not invited back for subsequent sessions. This study was approved by the Georgia Institute of Technology's Institutional Review Board under Protocol H20165.

A total of 327 participants completed at least four sessions. We included participants who only completed the first four sessions of the study, because the fifth session consisted of tasks not relevant to the present work. After data cleaning procedures, described below, statistical analyses were conducted on a total of 293 participants, therefore, our sample should be large enough for stable estimates of correlations (Schönbrodt & Perugini, 2013).

Tasks and Procedures

Data were collected as part of a larger data collection effort, which consisted of administering over 40 cognitive tasks. We report on a subset of the data, focusing specifically on the set of tasks used to answer research questions particular to the present study. Further information regarding the scope of the data collection effort and other research products based on it can be found at the following link: https://osf.io/qbwem/.

During data collection, participants were seated in individual testing rooms with a research assistant assigned to proctor each session. The research assistant's job was to run each cognitive test, ensure the participant understood the instructions, and make sure participants were following the rules of the lab, such as not using their phones during the study. The research assistant took extensive notes on participant conduct, which was used to make decision about data exclusions (e.g., participant was consistently on their phone, falling asleep, or not falling instructions across tasks and sessions). Up to seven participants could be tested in each session, although typically two to four participants were scheduled for each timeslot. There were three timeslots per day, Monday through Friday, starting at 9 a.m., 12 p.m., and 3 p.m. Demographic information was collected and is presented in Table 1.

The cognitive tasks were administered on either a Windows 10 or Windows 7 computer with an LED-backlit LCD 24″ Dell P2422H monitor. The tasks were programmed in E-Prime 3.0 and E-Prime 2.0 software. Of the tasks relevant to the present study, we report data on measures of *inspection time*, *attention control*, *processing speed*, *fluid intelligence*, and *working memory capacity*.

Inspection Time

Three versions of the inspection time task were developed to assess individual differences in inspection time at the latent construct level and to assess the role that selective attention may play in inspection time. The inspection time tasks were administered on different sessions but in the same order for every participant; standard inspection time was on Session 1, selective inspection times was on Session 2, and the four-line inspection time task was on Session 3.

The *standard inspection time* task used the standard procedure of discriminating the length of two vertical lines. However, the stimuli were modified to address an issue that has plagued the classic "Pi" version of the task (Evans & Nettelbeck, 1993; Stough et al., 2001).

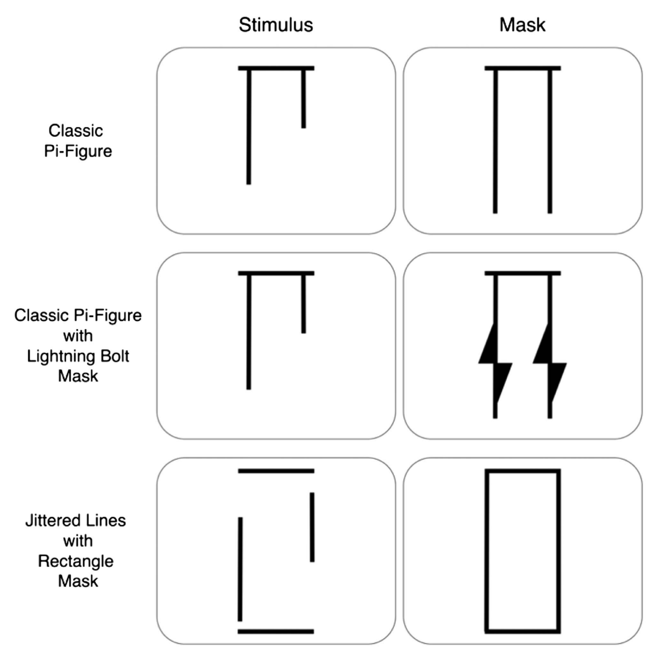
Table 1
Demographic Information

Demographic	Statistic
Age (years)	*M* = 22.0
	SD = 4.1
	Range = 18–35
Gender	Male = 40.1%
	Female = 58.2%
	Self-Identify/Other = 1.4%
	Transgender Male = 0.3%
At least some college?	Yes: 87.1%
	No: 12.9%
Ethnicity	White: 30.3%
	Black or African American: 11.8%
	Asian or Pacific Islander: 41.5%
	Other[a]: 16.4%

[a] Other includes Hispanic or Latino, Native American, "other," and mixed. Due to experimenter error, a small number of participants did not complete the demographic questionnaire.

Figure 1 illustrates how the standard inspection time task was modified compared to classic versions of the task. The classic Pi version of the inspection time task uses a stimulus made up of two parallel vertical lines differing in length and joined at the tops by a horizontal cross bar, referred to as the pi-figure because of its

Figure 1
Modifications Made to the Inspection Time Stimuli



Note. Different types of the stimulus and mask used in the inspection time task. The top and middle rows represent classic versions of the inspection time task that uses the pi-figure. The middle row represents a common modification of the original mask that uses a lightning bolt design to reduce, but not eliminate, the apparent perception of motion, flickering, or brightness that occurs on the side of the shorter line. The bottom row represents the stimulus and mask used in the present study. These modifications were made to eliminate the apparent perception.

resemblance to the Greek letter π. The pi-figure is then quickly masked with a figure in which the two vertical lines are extended downward to be of the same length. This setup leads some participants to perceive motion, flickering, or brightness when the stimulus is masked, especially for the shorter line (Evans & Nettelbeck, 1993).[3]

There is evidence that using the apparent perception as a strategy in the task results in faster inspection times (Chaiken & Young, 1993; Eisma & de Winter, 2020; Stough et al., 2001) and there are mixed findings as to whether or not using the strategy impacts the correlation of inspection time with intelligence (Grudnik & Kranzler, 2001; although see Stough et al., 2001). Nevertheless, eliminating the apparent perception of motion in the inspection time task would maximize internal validity by ensuring that all participants are performing the same task.

Attempts have been made to eliminate the apparent motion effect, but they have mostly focused on changing the nature of the mask stimulus. The most popular variation is the "lightning bolt" mask and, while this does appear to reduce the effect, it does not eliminate it entirely (Stough et al., 2001). To eliminate this apparent perception, we modified the pi-figure itself rather than the mask (Figure 1). We randomly jittered the position of the two vertical lines such that the tops or bottoms do not start at the same place. Further, there was both a top and bottom horizontal bar in which the two vertical lines were positioned in between. The mask consisted of the two vertical lines being extended to the top and bottom bars, resulting in a rectangle outline. This combination of jittering the lines and extending them both upward and downward on the mask eliminates any bias of perceptual effects occurring on either the shorter or longer line.

Adaptive Procedure. To determine a participant's inspection time, an adaptive procedure was used for the three inspection time tasks. Participants completed six nonadaptive practice trials followed by 64 trials that followed a weighted up-down staircase procedure with a 3:1 up-down ratio to converge at an inspection time (stimulus duration) in which the participant can perform at about 75% accuracy (Kaernbach, 1991). The starting stimulus duration was 750 ms. For the first 15 trials, when a participant made an incorrect response the stimulus duration for the next trial was increased by 201 ms and decreased by 67 ms following a correct response (3:1 up-down ratio). The step size of the staircase became smaller throughout the task while preserving the 3:1 up-down ratio. From trial 16–31, the step size changed to 150 ms following an incorrect response and 50 ms following a correct response. From trial 32–48, the step size changed to 99 ms following an incorrect response and 33 ms following a correct response. From trial 48–67, the step size changed to 51 ms following an incorrect response and 17 ms following a correct response. The change in step sizes was intended to get a more fine-grained adjustment in stimulus duration as participants moved through the task. To estimate an inspection time score, we employed a method of calculating the median stimulus duration for the last four reversals (Hairston & Maldjian, 2009; although they used the average of the last five reversals). A reversal is when the accuracy on the current trial is different from the accuracy on the previous trial. Conceptually, reversals represent boundaries of the task becoming easier (a correct trial following a series of incorrect trials) and harder (an incorrect trial following a series of correct trials) for the participant. Figure 2 shows data from two real participants on the standard inspection time task and depicts their performance through the adaptive procedure and how their inspection time score was calculated. The critical dependent measure on the three inspection time tasks was the median stimulus duration of the last four reversals.

Standard Inspection Time. Participants completed an inspection time task in which they had to discriminate between two lines of differing lengths. Each trial began with a ready signal (i.e., "Get ready") which remained until participants pressed a button to advance. Afterward, they saw a fixation cross for 1,000 ms, followed by the appearance of two vertical lines which were jittered so as not to appear on the same vertical plane. These served as the target stimuli. There were also two horizontal lines appearing above and below the vertical lines. The inspection time stimuli were presented for an adaptive amount of time based on their previous trial performance, as described in the adaptive procedure above. The vertical lines were then masked by thicker (.44°) lines which extended to the top and bottom horizontal lines. Using a mouse, participants then clicked the location of the longer line (which occurred in each location 50% of the time). Participants then received feedback on their response for 750 ms.

From a 675-mm viewing distance, the longer line subtended a 7.31° visual angle, whereas the shorter one only subtended a 5.53° visual angle. The length of the horizontal line was 5.99° visual angle. Both the vertical stimuli and the horizontal lines were .44° visual angle thick.

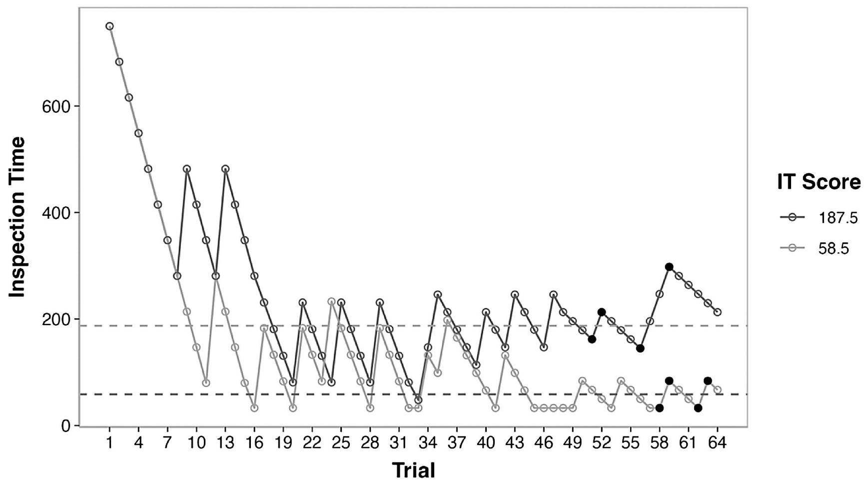
Selective Inspection Time. Participants also completed a selective inspection time task in which they needed to selectively attend to and discriminate two of four colored lines of differing lengths. Each trial began with a ready signal (i.e., "Get ready") which remained until participants pressed a button to advance. They then saw a fixation cross for 1,000 ms followed by the word "Blue" or "Red" presented for 750 ms in black font at the center of the display indicating whether to attend to and discriminate between either the blue or red lines, respectively. A total of four vertical lines were displayed, two red and two blue lines (see Figure 3). The inspection time stimuli were presented for an adaptive amount of time based on their previous trial performance, as described in the adaptive procedure above. The vertical lines were then masked by thicker vertical lines that extended to the top and bottom horizontal lines. Using a mouse, participants then clicked the location of the longer line. Participants then received feedback on their response for 750 ms.

On any given trial, the line colors for the inspection time stimuli were alternating, from left-to-right, as either Blue-Red-Blue-Red or Red-Blue-Red-Blue. For each color, there was a longer line and a shorter line, with the longer line in one color (e.g., Blue) being longer than the shorter line in the other color (e.g., Red). That is, there were two longer lines (7.31° and 9.09° vertical visual angle), one in each color, and two shorter lines (5.53° and 3.75° vertical visual angle), one in each color. The order of the line lengths was alternating, from left-to-right, as either Short-Long-Short-Long or Long-Short-Long-Short. The combination of color and line lengths resulted in 16 total combinations of trials that were randomly administered within blocks of 16 trials. The dimensions of the horizontal lines and the mask stimuli were identical as in the standard inspection time task.

[3] This happens because the mask requires that the shorter line is extended downwards more than the longer line, so it appears to be moving faster.

Figure 2

Example of the Inspection Time Adaptive Procedure



Note. The data are from two actual participants in the standard inspection time task. Each point represents the stimulus duration (*y*-axis) on a given trial (*x*-axis). The stimulus duration gets longer (steps up) after an incorrect response and gets shorter (steps down) after an incorrect response at a 3:1 up-down ratio. Reversals are the peaks (a switch from incorrect to correct responses reflecting the stimulus duration is too long for the participant) and valleys (a switch from correct to incorrect responses reflecting the stimulus duration is too quick for the participant). The flour black filled-in points near the end of each participant's performance are their last four reversals. The inspection time (IT) score was calculated as the median of the last four reversals and are displayed as horizontal dashed lines.

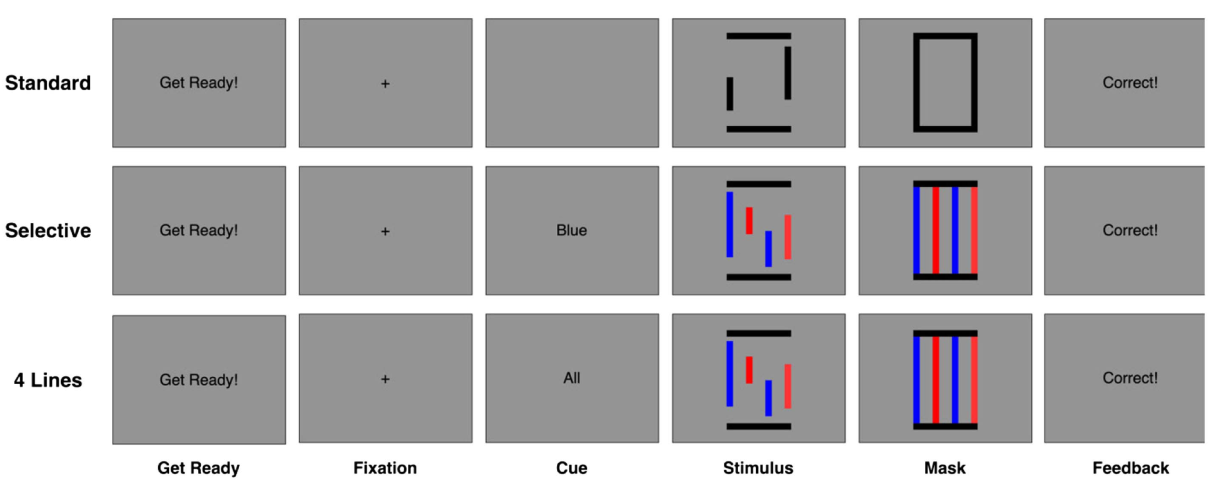
Four-Line Inspection Time. Participants also completed a four-line inspection time task in which they needed to discriminate between four vertical lines of differing length. The procedure was nearly identical to the selective inspection time task. However, instead of seeing the cued words "Blue" or "Red" the word "All" was displayed in black font in the center of the display on every trial (see Figure 3). Instead of comparing only two lines the instruction was to compare all four lines and indicate which line was the longest by using the mouse.

Sustained Attention

To assess whether sustained attention ability was related to inspection time performance, we assessed the decline of the focus of

Figure 3

Trial Sequence for the Three Inspection Time Tasks



Note. Stimuli are not to scale and are only representative of the actual stimuli used in the task. See the online article for the color version of this figure.

attention over a relatively short period of time (seconds) using the SACT.

Sustained Attention-to-Cue Task (Tsukahara & Engle, 2023). In this task, participants needed to sustain their attention at a location that was briefly visually cued as illustrated in Figure 4. Once the cue disappeared, participants attempted to attend to the now-uncued location on the blank screen for a variable duration before identifying a briefly presented target letter at the center of the previously cued location. These visual stimuli were presented against a gray background.

Each trial began with a 1-s period of fixation on a central black point. Following the fixation, a 750-ms interval displayed the words "Get Ready!" at the previously cued location, accompanied by an auditory beep. This interval was designed to prepare and engage the participant for the upcoming trial. Subsequently, a circular cue was presented. To guide the participant's attention, the large circle immediately started to shrink in size until it reached a fixed size. The entire duration of the circle cue on the display was approximately 500 ms. Once the cue reached the fixed size, it was removed from the display. The display then remained blank over the entire sustained attention interval. The interval varied between 0 and 2–12 s, in 500-ms steps (e.g., 2, 2.5, 3, 3.5 … s).

The location of this area was determined semirandomly to ensure an equal distribution in the top-left, top-right, bottom-left, and bottom-right quadrants of the screen. After the variable sustained attention interval, an array of letters appeared at the previously cued location. The target letter was displayed in a dark gray font at the center of this array. The nontarget letters were presented in a silver font and were randomly arranged around the target letter within a 96 × 96-pixel square, with a minimum separation of 24 pixels to prevent overlap. The array of letters was visible for 250 ms, after which the target letter was briefly masked with a "#" symbol for 300 ms. After the mask, a response screen with B, P, and R response options was displayed, and a mouse was used to select which had been the dark-gray target letter. After a response, there was a blank buffer display presented for 500 ms.

The task consisted of six practice trials in which feedback was provided and a criterion of getting three out of the six practice trials correct before moving on to the real trials. The task had three blocks of 22 trials for 66 trials without feedback. Each sustained attention duration occurred once per block. There was a self-timed break given after the first and second block of trials.

Attention Control

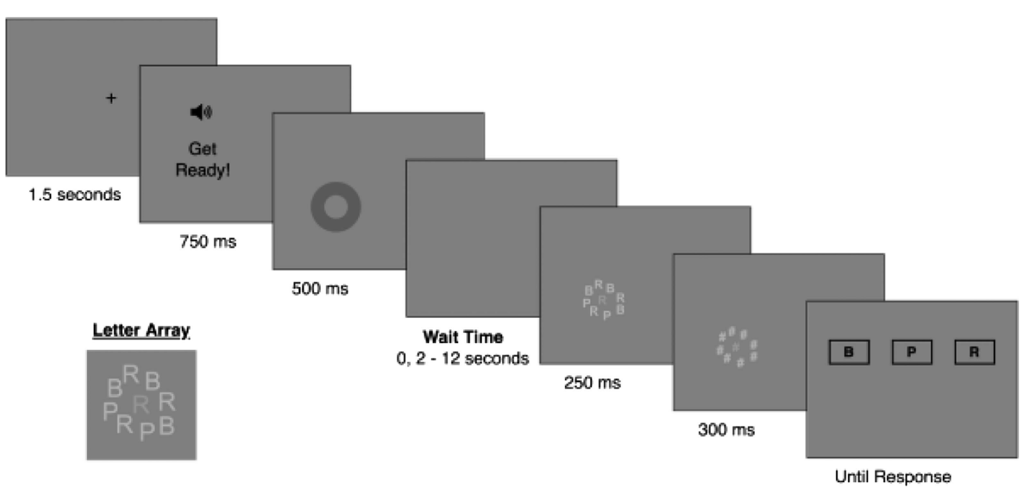
We measured attention control with the antisaccade, selective visual arrays, a Stroop task with an adaptive response deadline, and auditory versions of the flanker, Simon, and Stroop tasks with an adaptive response deadline. See Draheim et al. (2021, 2023), Martin et al. (2021), Tsukahara and Engle (2023), and Burgoyne et al. (2024) for the reliability and validity of the attention control measures.

Antisaccade (Hallett, 1978; Hutchison, 2007). Participants were tasked with identifying either a "Q" or an "O" that appeared briefly on the opposite side of the screen as a distractor stimulus. After a central fixation cross appeared for 1,000 or 2,000 ms, an asterisk (*) flashed at 12.3° visual angle to the left or right of the central fixation for 100 ms. Afterward, the letter "Q" or "O" was presented on the opposite side at 12.3° visual angle of the central fixation for 100 ms, immediately followed by a visual mask (##). Participants had to indicate if they observed the letter as a "Q" or an "O." Participants completed 16 slow practice trials, with letter duration set to 750 ms, followed by 72 test trials. The task was scored based on accuracy as the proportion of correct responses.

Selective Visual Arrays With Orientation Judgment—VAorient-S (Draheim et al., 2023; Shipstead et al., 2014; Vogel et al., 2005). Following a 1,000-ms period of central fixation, a cue word ("RED" or "BLUE") appeared, instructing the participant to focus their attention on either red or blue rectangles. Next, a target array of rectangles, encompassing different orientations (horizontal, left diagonal, right diagonal, and vertical) in both red and blue, was presented for 250 ms. This was followed by a

Figure 4

Trial Sequence for the Sustained Attention to Cue Task



Note. The critical element of the task is the variable wait time. The duration of the wait time varied from none (0 s), short (2–5 s), medium (5.5–8.5 s), and long (9–12 s).

blank screen lasting 900 ms. Next, a probe array with only the cued-color rectangles was presented, with one rectangle highlighted by a white dot. The orientation of the highlighted rectangle was either the same as it was in the target array, or different, with equal likelihood. Participants used the keyboard to indicate whether the orientation of the highlighted rectangle had changed or remained the same. The target array consisted of either three or five rectangles per color (10 and 14 total). Each array set size had 48 trials. Capacity scores (k) for each array size were computed using the single-probe correction method (Cowan et al., 2005; Shipstead et al., 2014): set size × (hit rate + correction rejection rate − 1). The task performance was scored as the mean k estimate across the two set sizes.

Stroop Task With an Adaptive Response Deadline—Version 2 (StroopDL; Draheim et al., 2023). This task was a modified version of the StroopDL task utilized in Draheim et al. (Draheim et al., 2021). Similar to the initial iteration, this version was shown to be a reliable and valid indicator of attention control (Draheim et al., 2023). The task involved a color Stroop paradigm, where the words "RED," "GREEN," and "BLUE" were sequentially presented in red, green, or blue font colors. The words were either congruent with the color (e.g., the word "RED" in red font color) or incongruent with the color (e.g., the word "RED" in blue font color). Participants were instructed to identify the font color by pressing 1, 2, or 3 on the number pad, corresponding to green, blue, and red, respectively. To facilitate response mapping, the keys had colored paper with matching colors taped onto them. There was a 2:1 ratio of congruent to incongruent trials with 96 and 288 trials overall. The task was administered over four blocks of 72 trials each with an optional rest break between blocks. Practice trials were administered in different blocks, with 24 response mapping practice trials, 18 standard Stroop trials without response deadlines, and 18 nonadaptive response deadline practice trials.

An adaptive procedure was employed to determine the participant's response deadline threshold, aiming for approximately 75% accuracy. This adaptive process solely considered incongruent trials. On each incongruent trial, if an incorrect response was given or the reaction time exceeded the response deadline, the response deadline was extended (allowing more time to respond) for the subsequent trial. Conversely, if a correct response was made and the reaction time fell below the response deadline, the deadline was reduced (allowing less time to respond) for the next trial. The response deadline commenced at a relatively manageable level of 1.5 s. A 3:1 up-to-down ratio was used for the step sizes such that the step size (change in response deadline) for incorrect/too slow of trials was three times larger than the step size for correct/deadline met trials. The step size started at 240:80 ms, decreased to 120:40 ms after 17 incongruent trials, decreased to 60:20 ms after 33 incongruent trials, decreased to 30:10 ms after 49 incongruent trials, decreased to 15:5 ms after 65 incongruent trials, and finally settled at 9:3 ms after 81 incongruent trials. Feedback was given in the form of an audio tone and the words "TOO SLOW! GO FASTER!" presented in red font when the response deadline was not met.

Auditory Simon With Adaptive Response Deadline (Auditory SimonDL; Burgoyne et al., 2024). In the Auditory SimonDL task, participants indicated which ear received an auditory stimulus while ignoring the semantic content of the stimulus. To facilitate this, participants wore headphones throughout the test. They were instructed to press the "P" key to indicate that the auditory stimulus was presented to the right ear and the "Q" key to indicate that it was presented to the left ear. These instructions remained visible on the computer screen throughout the task. The auditory stimulus consisted of the spoken words "Left" or "Right" produced by a computer-generated voice. Trials could either be congruent (e.g., the word "LEFT" presented to the left ear) or incongruent (e.g., the word "LEFT" presented to the right ear). The trial order was determined using a random seed to keep the order consistent across participants. Trials were selected randomly if congruent trials occurred twice as often as incongruent trials by the task's completion. Participants completed three blocks of 96 trials, with a self-paced break between each block, for a total of 288 trials (192 of the trials were congruent and 96 were incongruent).

Participants needed to accurately respond to the stimulus before a response deadline for the trial to be scored as correct. The response deadline was adaptive and varied according to a staircase procedure that used a 3:1 up-to-down step–size ratio based on performance on incongruent trials. Specifically, the response deadline started at 1,230 ms and adapted based on whether the participant responded correctly before the response deadline: If so, the response deadline was reduced by a factor of 1× to make the task more difficult; if not, the participant was given the feedback "Too Slow" and the response deadline was increased by a factor of 3× to make the task easier. The value of "x" started at 80 ms at the task's onset and progressively reduced to 40, 20, 10, 5, and 3 as participants completed each sixth of the task, meaning that the step size decreased as the task progressed. This 3:1 adaptive procedure, with two response options, was designed to converge on an accuracy rate of 75% on incongruent trials, following the principles outlined by Kaernbach (1991). The primary outcome measure was the average response deadline (in ms) over the last four reversals of the staircase function. These reversals corresponded to trials where the deadline either increased after having been reduced or decreased after having been increased. Thus, the outcome measure reflects the speed and accuracy of the participants over the task.

Auditory Stroop With Adaptive Response Deadline (Auditory StroopDL; Burgoyne et al., 2024). In Auditory StroopDL, participants indicated whether words presented auditorily to both ears referred to males or females while ignoring the tone of the voice used as the auditory stimulus. Participants wore headphones for the test. They were shown a list of words and told which words referred to males (i.e., "brother," "dad," "father," and "boy") and which words referred to females (i.e., "sister," "mom," "mother," "girl"). They were directed to press the "P" key if the auditory stimulus referred to a male and the "Q" key if it referred to a female. These instructions remained displayed on the screen throughout the task. The auditory stimuli consisted of the preceding word list, spoken by either a male or female computer-generated voice. Trials could be congruent (e.g., the word "brother" presented using the male voice) or incongruent (e.g., the word "brother" presented using the female voice).

The trial order was established using a random seed to maintain consistency across all participants. Trials were randomly selected if congruent trials occurred twice as often as incongruent trials by the task's completion. Participants completed three blocks, each comprising 96 trials, and were allowed self-paced breaks between blocks, for a total of 288 trials (192 trials being congruent and 96 being incongruent). Participants needed to accurately respond to the stimulus before a response deadline for the trial to be scored as correct. The adaptive response deadline was programmed using the exact same parameters as those for the Auditory Simon DL task described above. The outcome measure was the average response deadline (in ms) over the final four reversals of the staircase function. Thus, the outcome measure reflects the speed and accuracy of the participants over the task.

Auditory Flanker With Adaptive Response Deadline (Auditory FlankerDL; Burgoyne et al., 2024). In Auditory FlankerDL, participants indicated whether a voice presented auditorily to the center of the headphones (i.e., presented to both ears) uttered the word "bat" or "bed" while ignoring words that were presented to just the left headphone or just the right headphone (see Chan et al., 2005 for a similar approach). Participants were instructed to press the "P" key to indicate that the centrally presented auditory stimulus referred to a "bat" and the "Q" key to indicate that the centrally presented auditory stimulus referred to a "bed." These instructions were displayed on the screen for the duration of the task.

The auditory stimuli used in the task were created using two male computer-generated voices and two female computer-generated voices uttering the words "bat" or "bed"; each voice constituted a different version of the stimulus. On each trial, the participant was presented with one voice uttering a word to both headphones, a second voice uttering a word to the left headphone, and a third voice uttering a word to the right headphone. Voice stimuli were selected randomly, so on a given trial any three of the four voices could be presented to either or both headphones. Trials could be congruent (e.g., the word "bat" presented centrally as well as to the left ear and the right ear) or incongruent (e.g., the word "bat" presented centrally while the word "bed" was presented to the left ear and the right ear). The trial order was determined using a random seed to keep the order consistent across participants. Trials were selected randomly on the condition that congruent trials occurred twice as often as incongruent trials by the completion of the task. Participants completed three blocks of 96 trials, with a self-paced break between each block, for a total of 288 trials (192 of the trials were congruent and 96 were incongruent). Participants needed to accurately respond to the stimulus before a response deadline for the trial to be scored as correct. The adaptive response deadline was programmed using the exact same parameters as those for the Auditory SimonDL task described above. The outcome measure was the average response deadline (in ms) over the final four reversals of the staircase function. Thus, the outcome measure reflects both the speed and accuracy of the participants on incongruent trials over the course of the task.

Processing Speed

We also administered several noninspection time measures of processing speed. We opted to make our processing speed task battery fairly diverse, owing to some ambiguity about what exactly is reflected by hallmark speed measures and whether they measure a common underlying construct (Mashburn et al., 2024; Schmitz & Wilhelm, 2019). We elected to include some reaction time tasks and some accuracy-based, clerical speed tests.

Digit Comparison (Redick et al., 2012). Participants were shown 3, 6, or 9 numbers that appeared on the left and right side of a horizontal line drawn between them. The participant's task was to determine whether the strings of digits were identical or different. They responded using the mouse. Participants were given two blocks of 30 s of trials and attempted to answer as many items correctly as possible. Participants earned one point for each correct response and lost one point for each incorrect response; the measure of performance was the number of points earned at the conclusion of the task.

Letter Comparison (Redick et al., 2012; Salthouse & Babcock, 1991). This task was almost identical to the digit string comparison task; however, instead of digits, the participant made comparisons about strings of three, six, or nine letters.

Pattern Comparison (Redick et al., 2012). The participant was shown two symbols that appeared on either side of a horizontal line and indicated whether they were the same or different. Participants were given two blocks of 30s of trials and attempted to answer as many items correctly as possible. Participants earned one point for each correct response and lost one point for each incorrect response; the measure of performance was the number of points earned at the conclusion of the task.

Simple RT (Bors et al., 1993). On each trial of the simple reaction time task, participants were asked to press a button, either red or blue, when an empty square turned either red or blue. Participants always knew in advance what the upcoming response would be and were simply supposed to press the button when the stimulus color appeared. Each trial began with a reminder about what the upcoming response would be. With a keypress, participants advanced to a central fixation cross which, after 500 ms, was then replaced by an unfilled square with a white border subtending a $1.58° \times 1.58°$ visual angle. After 1,000 ms, an alert tone signaled that participants would soon need to make a response. When the empty square turned either red or blue, participants pressed the appropriate key. Participants completed two runs of 12 trials, 12 where the response was red, and 12 where the response was blue. Whether participants began with red or blue was randomly determined by the program. Each run of 12 real trials was also preceded by four practice trials of the appropriate color.

Choice RT (Bors et al., 1993). The choice reaction time task was very similar to the simple reaction time task, with the following exceptions. Participants completed a single run of 24 trials in which they decided whether a filled square was red or blue, but they did not know in advance which would occur. After the central fixation, two unfilled squares appeared on the left and right sides of the screen separated by a roughly 9.46° gap. One square would always be filled with red, while the other would always be filled with blue. Participants responded by pressing either the red or blue key once the appropriate square was filled by that color. Before completing the 24 real trials, participants completed four practice trials.

Prosaccade (Hallett, 1978; Hutchison, 2007). Participants saw a central fixation cross for either 2,000 or 3,000 ms followed by an alerting tone for 300 ms. After the alerting tone, an asterisk appeared for 250 ms at 12.3° visual angle to the left or the right of the central fixation, followed immediately by a target "Q" or an "O" for 150 ms in the same location. Subsequently, the target letter and the corresponding point on the opposite side of the screen were masked by "##." Participants had up to 5,000 ms to respond and did so by pressing the associated key on the keyboard. After responding, accuracy feedback was displayed for 500 ms, followed by a blank intertrial interval of 1,000 ms. Participants completed 72 trials. The main dependent variable of interest is the mean reaction time (RT) on correct trials.

Fluid Intelligence

Raven's Advanced Progressive Matrices (Raven et al., 1998). In this task, participants were presented with a matrix of figures that follow a logical pattern across rows and columns. For each problem in this task, a 3 × 3 matrix of eight abstract figures was presented with the bottom-right element missing. Participants had to identify the logical pattern and select one of eight answer choices that fit the logical pattern of the matrix. Participants were given 10 min to solve 18 of the odd numbered problems from the full test. Scores on this task were calculated as the total number of problems solved correctly.

Letter Sets (Ekstrom et al., 1976). Participants were shown five groups of four-letter sequences (e.g., NOPQ DEFL ABCD HIJK UVWX). Their goal was to discern a shared pattern within four of these groups and pinpoint the group of letters that deviated from this pattern (for instance, all letter sets followed consecutive alphabetical order except for DEFL). Participants were given 10 min to solve 30 problems. Scores on this task were calculated as the total number of problems solved correctly.

Number Series (Thurstone, 1938). For each problem in this task, a series of numbers were presented that progressed in a particular logical fashion. Participants had to identify the rule and select the next number, out of five answer choices, that should occur next in the series of numbers to be consistent with the logical rule. Participants were given 5 min to complete 15 problems. Scores on this task were calculated as the total number of problems solved correctly.

Working Memory Capacity

Advanced Symmetry Span (Draheim et al., 2018). Participants attempted to remember a series of spatial locations in a 4 × 4 matrix. Each spatial memorandum was interleaved with a processing task in which participants judged whether a 16 × 16 configuration of black and white squares was symmetrical about the vertical midline. On each trial, participants are presented with a symmetry judgment, followed by a 4 × 4 grid with one square highlighted in red. The location of the red square was the to-be-remembered spatial location. Participants completed a variable number of alternations (—two to seven) until a recall screen appeared. Participants then attempted to recall the locations of the red square in their correct serial order. There was a total of 12 trials (two blocks of six trials), set sizes ranged from —two to seven, and each set size occurred twice (once in each block). The dependent variable is the edit distance score (Gonthier, 2022).

Advanced Rotation Span (Draheim et al., 2018). Participants tried to remember a series of directional arrows of varying sizes. These were interleaved with a mental rotation task in which participants mentally rotated a letter and decided whether it is mirror reversed. On each trial, participants first solved a mental rotation problem followed by the presentation of a single arrow with a specific direction (eight possible directions; the four cardinal and four ordinal directions) and specific size (small or large). Both the direction and size of the arrow were the to-be-remembered features. This alternation continued until a variable set size of arrows was presented, when participants tried to recall the set in their correct serial position. There are 12 trials (two blocks of six trials), set sizes ranged from —two to seven, and each set size occurs twice (once in each block). Once again, the dependent variable is the edit distance score (Gonthier, 2022).

Data Processing

On any given task, missing data were present due to data cleaning and other factors such as a participant not having enough time to complete a task on a given session, and the task program crashing during administration. Data cleaning consisted of (a) removing problematic participants and (b) removing outliers. For the attention control, complex span, inspection time, and processing speed tasks, problematic participants were detected as having an overall accuracy equal to or less than chance performance and their scores for that task were set to missing. For the complex span tasks, overall accuracy was assessed based on the processing task (e.g., symmetry judgments for the symmetry span task). Based on this criterion, one participant was identified as problematic on the SACT, 11 on antisaccade, one on selective visual arrays, three on auditory flankerDL, three on auditory simonDL, eight on prosaccade, one on symmetry span, and three on rotation span.

For all cognitive tasks, a multipass outlier method was used on the task scores. On each pass, z scores were computed, then univariate outliers were identified as having scores ±3.5 standard deviations or greater from the mean score on that pass, and outlier scores were replaced with missing data. This process for each task was repeated until no further outliers were detected. Based on this procedure, seven outliers were identified on the SACT with two outlier passes, six on StroopDL with two outlier passes, 12 on auditory flankerDL with four outlier passes, 21 on auditory simonDL with six outlier passes, seven on auditory StroopDL with two outlier passes, two on standard inspection time with one outlier pass, four on selective inspection time with two outlier passes, four on four-line inspection time with two outlier passes, six on Simple RT task with two passes, eight on Choice RT task with two passes, and 16 on prosaccade with three passes.

Modeling Approach and Fit Statistics

For all confirmatory factor analyses and structural equation models, we used maximum likelihood estimation with robust standard errors and full information maximum likelihood estimation for missing data. Variables were standardized prior to estimation.[4] To maximize interpretability, we scored all tasks such that they should correlate positively with one another, that is, higher scores indicate better performance. This was done to simplify the interpretation of speed correlations, where higher values normally indicate slower processing and worse performance. To that end, we converted all such variables to z scores, multiplied the transformed scores by -1, and back-converted them to their nonstandardized scale. This was done to preserve the magnitude of the transformed correlations.

We report multiple fit statistics: The χ^2 is an absolute fit index comparing the fit of the specified model to that of the observed covariance matrix. A significant χ^2 can indicate lack of fit but is heavily influenced by sample size. In large samples, such as the one used in the present studies, even a slight deviation between the data

[4] The statistical significance and interpretation of path values in all models do not change when unstandardized variables are used.

and the model can lead to a significant χ^2 statistic. Therefore, we also report the comparative fit index (CFI), which compare the fit of the model to a null model in which the covariation between measures is set to zero, while adding penalties for additional parameters. For CFI, large values indicate better fit (i.e., >.90 or ideally, >.95). For the root-mean-square error of approximation (RMSEA) fit statistic, values less than .05 are considered great, while values less than .10 are considered only adequate. For the standardized root-mean-square residual (SRMR), which computes the standardized difference between the observed and predicted correlations, a value of less than .08 indicates good fit (Hu & Bentler, 1999).

To avoid any confusion regarding our use of language in describing and interpreting the results, we do not make any claims that there is evidence of causal relationships given that we are analyzing correlational cross-sectional data. When we use terms such as "explains … a correlation/association" or "accounts for the relationship," we use these in a purely statistical sense and not implying evidence of a causal explanation. Furthermore, our structural equation models were not designed to test a specific causal model and directional arrows should not be interpreted in causal terms. We chose and interpret our mediation models not in reference to a causal hypothesis but to provide useful statistical information (point estimates of indirect effects) to test the unique relationships that attention control and the processing speed factors have with inspection time, fluid intelligence, and working memory capacity. Therefore, when we use terms such as mediation, direct effect, or indirect effect, we use these simply to identify statistical terms in the model, consistent with standard mediation notation—and not to imply causal effects.

Selective and Sustained Attention Models

To investigate the role of selective attention in the inspection time, we conducted analysis of covariances to test the interaction between task condition (standard, selective, and four lines) and attention control on inspection time threshold scores. The attention control factor in the model was estimated by performing a confirmatory factor analysis and using the Bartlett approach (Grice, 2001) to estimate factor scores. We used the Bartlett method because these factor scores tend to underestimate the latent factor correlations, thus producing somewhat more orthogonal factors; whereas the regression method to estimate factor scores tends to overestimate factor correlations, thus producing somewhat more redundant factors.

To investigate the relationship between sustained attention and inspection time, we conducted mixed effect models with a random intercept term to test the interaction between the sustained attention interval (as a continuous variable) and cognitive ability on performance in the SACT. Cognitive ability factors in the model were estimated using the same method we used in the analysis of covariances.

Transparency and Openness

The study's design and its analyses were not preregistered. The data analyzed in this study were part of a larger data collection effort. A summary of the larger data collection procedure and a reference list of all publications to come out of this sample can be found at https://osf.io/qbwem. All materials, data, and analysis scripts for the present study are publicly available at https://osf.io/uxywg/.

All data processing, cleaning, scoring, and analyses were conducted in R statistical software (R Core Team, 2020). The visual arrays, complex span, and all adaptive task scores were calculated using the *englelab* (Tsukahara, 2021) R package. For data analysis, the *psych* (Revelle, 2022) package was used to calculate Cronbach's alpha, the *lavaan* (Rosseel, 2012) package was used for confirmatory factor analysis and structural equation models, the semTools (Jorgensen et al., 2022) package was used to calculate Monte Carlo 95% confidence intervals for indirect effects, the *afex* (Singmann et al., 2022) package was used to conduct analysis of covariances, the *lme4* (Bates et al., 2015) package what used to conduct multilevel models, the *emmeans* (Lenth, 2021) package was used to conduct main effect and interaction contrasts, and the *ggeffects* (Lüdecke, 2018) and *ggplot2* (Wickham, 2016) packages were used to plot model results.

Results

Descriptive Statistics

Demographic information is summarized in Table 1. The participant's average age was 22 ($SD = 4$) years old, and a majority were female (58.2%). The majority of participants (87%) had attended at least some college.

Inspection time was measured using an adaptive procedure that aims to converge at 75% accuracy. To test whether the adaptive procedure is indeed converging at this level of accuracy, we conducted polynomial mixed effect models predicting accuracy as a function of trial. We compared Bayesian information criteria (BIC) values for models that progressively added the next polynomial term until the minimum BIC value was reached—this approach balanced fit to the data and model simplicity. Figure 5 shows the preferred polynomial model for each inspection time task. In all cases, the adaptive procedure did converge near 75% accuracy. A quartic polynomial model was preferred for the standard ($BIC_{cubic} = 16{,}819.35 > BIC_{quartic} = 16{,}817.53 < BIC_{quintic} = 16{,}822.15$) and selective ($BIC_{cubic} = 18{,}129.12 > BIC_{quartic} = 18{,}122.16 < BIC_{quintic} = 18{,}124.74$) inspection time tasks, and a quintic polynomial model was preferred for the four-line inspection time task ($BIC_{quartic} = 18{,}578.21 > BIC_{quintic} = 18{,}575.64 < BIC_{sextic} = 18{,}578.46$).

The threshold score for each inspection time task was calculated as the median inspection time of the last four reversals (see Figure 2 for an illustration). The mean inspection time across participants was 116.53 ms ($SD = 47.85$) for the standard version, 173.88 ms ($SD = 58.51$) for the selective version, and 179.95 ms ($SD = 62.58$) for the four-line version. The three inspection time tasks had good internal consistency estimates of reliability (ranging from .73 to .84). Descriptive statistics for every task are presented in Table 2.

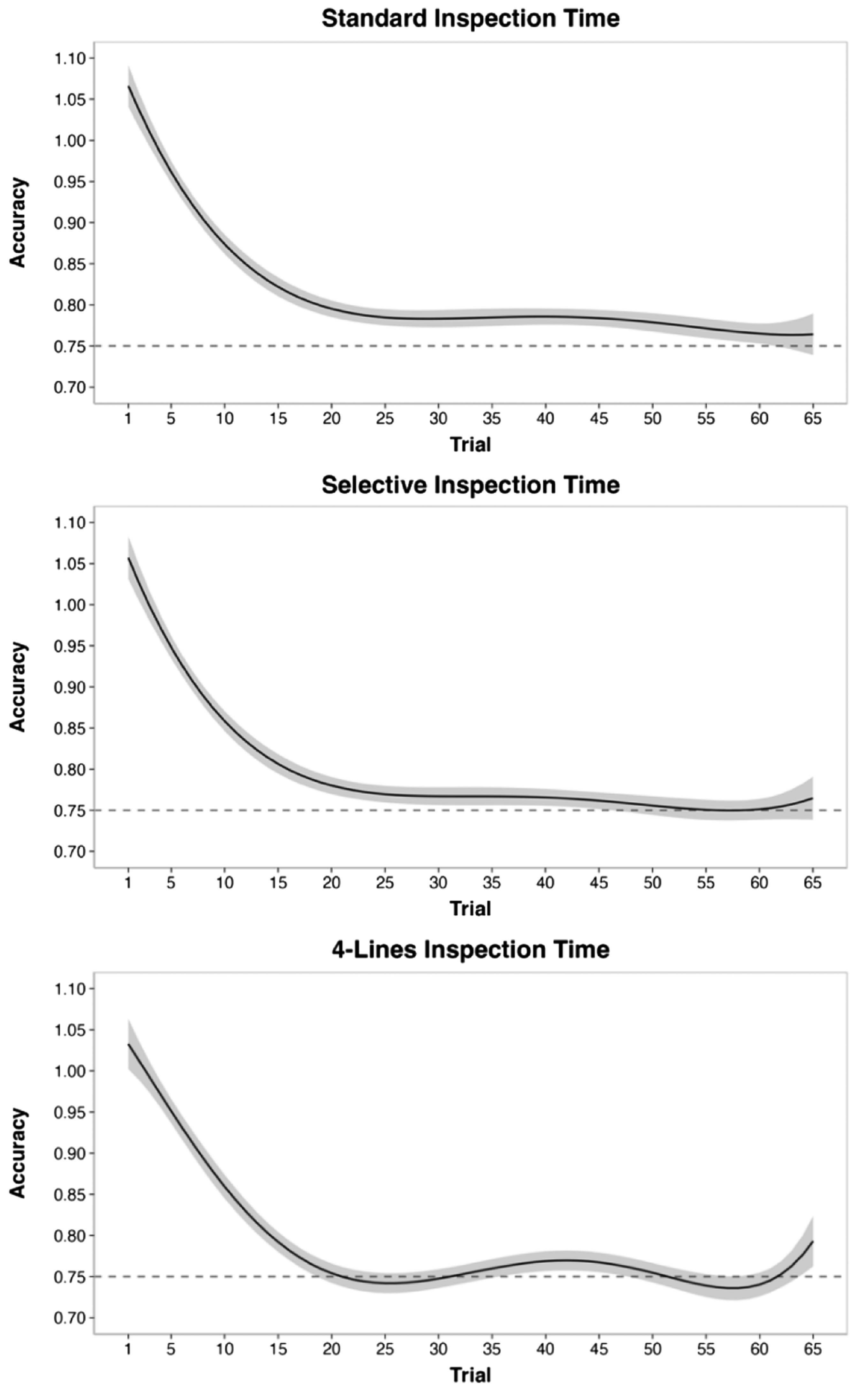
Confirmatory Factor Analysis

A confirmatory factor analysis was conducted with each task loaded onto their respective latent factor,[5] see Appendix for full correlation matrix. Though we attempted to load all noninspection time processing speed measures onto a single latent variable, model fit was significantly better when we allowed reaction time and

[5] For the three inspection time tasks, we set the loading values to be equal to reduce any bias in the latent factor toward one or two of the tasks.

Figure 5

Converged on Accuracy in the Standard, Selective, and Four-Line Inspection Time Tasks



Note. The inspection time tasks used an adaptive procedure with a 3:1 up-down ratio to converge on an inspection time (stimulus duration) threshold at about 75% accuracy. Accuracy started out quite high for all tasks, because the stimulus duration was quite long, 750 ms. Performance converged at around 75% accuracy by the end of the adaptive procedure. A model with up to quartic polynomial terms was preferred for the standard and selective inspection time tasks. A model with up to quintic polynomial terms was preferred for the four-line inspection time task. Predicted model values with 95% confidence intervals are plotted.

Table 2
Descriptive Statistics (N = 293)

Measure	*M*	*SD*	Skew	Kurtosis	Reliability	% Missing
Inspection time (ms)						
IT standard	116.53	47.85	1.06	0.97	[a]	2.73
IT selective	173.88	58.51	0.47	−0.15	[a]	2.39
IT four lines	179.52	62.58	1.30	2.49	[a]	3.41
Attention control						
Antisaccade (ACC)	0.81	0.12	−0.64	−0.58	.87[b]	5.12
VAorient-S (*k*)	2.49	0.68	−0.44	−0.08	.81[c]	1.37
Visual StroopDL (ms)	1,004.57	475.87	1.74	3.02	[a]	4.44
SACT (ACC)	0.89	0.10	−1.16	0.93	.87[b]	4.10
Auditory FlankerDL (ms)	1,272.34	585.46	1.30	0.99	[a]	6.49
Auditory SimonDL (ms)	942.64	417.28	1.48	1.63	[a]	9.22
Auditory StroopDL (ms)	1108.56	298.49	1.27	1.28	[a]	1.71
Processing speed comparison (pts)						
Digit comparison	30.06	5.53	−0.51	0.10	.88[c]	0.00
Letter comparison	20.68	4.04	0.17	0.41	.82[c]	0.00
Pattern comparison	39.23	5.84	0.01	−0.35	.94[c]	0.68
Processing speed RT (RT)						
Prosaccade	425.67	79.32	0.76	0.37	.94[b]	6.83
Simple RT	347.01	87.35	0.94	0.40	.79[b]	5.80
Choice RT	334.10	52.84	0.84	0.58	.87[b]	2.39
Fluid intelligence (correct)						
Raven's matrices	11.51	2.73	−0.39	−0.16	.77[b]	1.71
Letter sets	16.58	4.37	−0.16	−0.62	.85[b]	3.07
Number series	10.07	3.01	−0.28	−0.68	.73[b]	0.68
Working memory (edit dist.)						
Symmetry span	35.25	8.81	−0.50	−0.03	.80[b]	3.41
Rotation span	29.38	8.49	−0.39	0.05	.79[b]	1.71

Note. ms = milliseconds; IT = inspection time; ACC = accuracy as proportion of correct responses; *k* = capacity score; pts = points with +1 for correct and −1 for incorrect; RT = reaction time; correct = total number of correct answers; edit dist. = edit distance scores; DL = deadline; SACT = sustained attention-to-cue task.
[a] Because of the adaptive staircase procedure the last four reversals are not independent observations and therefore Cronbach's alpha or split-half reliability are not valid reliability estimates. [b] Cronbach's alpha calculated across all aggregated items. [c] Split-half reliability with Spearman–Brown correction.

accuracy measures to load separately, $\Delta\chi^2(5) = 45.36$, $p < .001$, $BF_{10} = 4{,}807.88$. Because we expected to use it in a different, subsequent analysis, we did not include the SACT in any of our confirmatory factor analysis or structural equation models. Our final measurement model fit the data well, $\chi^2(157) = 258.41$, $p < .001$, CFI = .92, RMSEA = .05 [.04, .06], SRMR = .06.

Inspecting the model in Figure 6 reveals several important findings. First, inspection time correlated highly with attention control ($r = .76$) and moderately to highly with the other latent factors (ranging from $r = .38$–.56). There was a moderate correlation of inspection time with fluid intelligence ($r = .38$), slightly lower than what has been reported in previous meta-analyses (Grudnik & Kranzler, 2001; Kranzler & Jensen, 1989; Nettelbeck, 1987), and a similarly sized correlation was observed with working memory capacity ($r = .38$). However, the strongest correlations with fluid intelligence, $r = .67$, and working memory capacity, $r = .59$, were attention control. In fact, attention control was strongly related to all other constructs, ranging from $r = .59$–.76.

Overall, this initial model provides evidence that attention control and inspection time tasks are strongly related, and that attention control is strongly related to other aspects of speeded performance. Critically for our research questions, inspection time performance was related to both fluid intelligence and working memory capacity, allowing us to explore this relationship further with structural equation modeling.

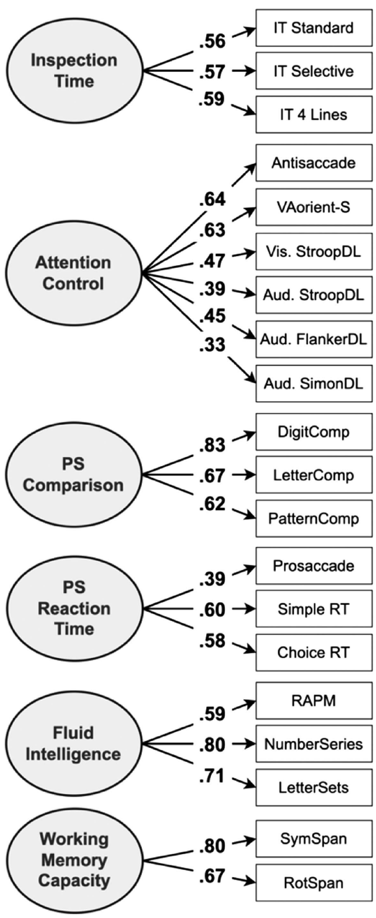
Mediation Models

Next, a structural equation model was conducted to test whether attention control or either of the processing speed factors statistically mediated the relationship from inspection time to fluid intelligence and working memory capacity (Figures 7 and 8).[6] Attention control, processing speed comparison, and processing speed reaction time were specified as *correlated* mediators. This model allowed us to examine the *unique* contributions of attention control and processing speed for statistically mediating the inspection time–fluid intelligence and inspection time–working memory capacity relationships.

For fluid intelligence, there was a full mediation such that there was no longer a significant relationship between inspection time and fluid intelligence after accounting for the attention control and processing speed factors ($\beta = -.25$, 95% CI [−.63, .13], $p = .193$). There were significant unique indirect effects through attention control ($\beta = .56$, 95% CI [.14, 1.04]), and processing speed comparison ($\beta = .13$, 95% CI [.04, .25]), but not through processing speed reaction time ($\beta = -.05$, 95% CI [−.24, .14]). Therefore, both attention control and processing speed comparison mediated the

[6] Note that the indirect effects through attention control and the processing speed factors were tested using 95% confidence intervals obtained through the Monte Carlo method as described in Preacher and Selig's.

Figure 6
Confirmatory Factor Analysis



		1.	2.	3.	4.	5.	6.
1.	**Inspection Time**	-					
2.	**Attention Control**	.762	-				
3.	**Processing Speed Comparison**	.392	.614	-			
4.	**Processing Speed Reaction Time**	.560	.721	.519	-		
5.	**Fluid Intelligence**	.379	.669	.626	.458	-	
6.	**Working Memory Capacity**	.377	.587	.411	.419	.521	-

$\chi^2(157) = 258.41$, $p < .001$, CFI = .92, RMSEA = .05 [.04, .06], SRMR = .06

Note. IT = inspection time; Vis. = Visual; DL = deadline; Aud. = Auditory; PS = processing speed; Comp = comparison; RT = reaction time; RAPM = Raven's Advanced Progressive Matrices; Sym = Symmetry; Rot = Rotation; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; SRMR = standardized root-mean-square residual.

relationship between inspection time and fluid intelligence. Note that the unique indirect effect through attention control is considerably larger than through processing speed comparison, but they did not significantly differ (see overlapping 95% CIs).

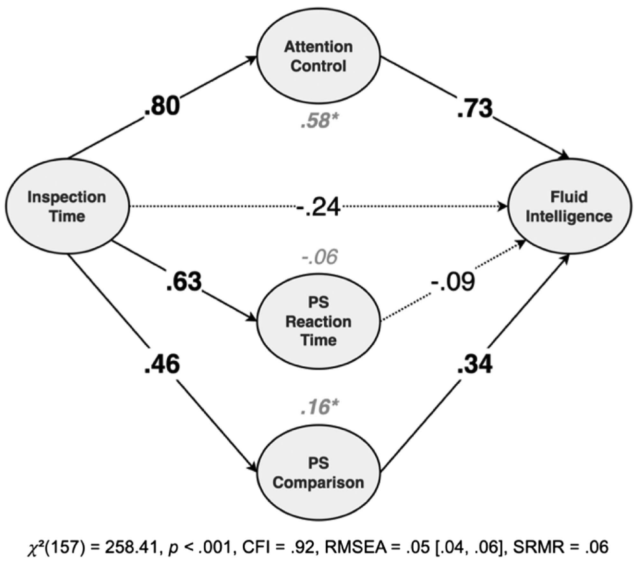
For working memory capacity, the results were similar but even more in favor of attention control as the primary mediator. There was a full mediation such that there was no longer a significant relationship between inspection time and working memory capacity ($\beta = -.16$, 95% CI [−.56, .24], $p = .442$). In this case, there was only a significant unique indirect effect through attention control ($\beta = .52$, 95% CI [.08, 1.35]). The indirect effects through processing speed comparison ($\beta = .03$, 95% CI [−.07, .13]) and reaction time ($\beta = -.01$, 95% CI [−.20, .20]) were small and nonsignificant.

Inspection Time and Attention Control: Is It All Just Processing Speed?

Both of the above mediation models converge on the interpretation that measures of attention control can help statistically explain the relationship between measures of inspection time and complex cognition *over and above other measures of processing speed*. This is consistent with the notion that inspection time reflects, among other things, individual differences in the ability to focus attention. However, these models should not be overinterpreted.

As seen in Figure 6, inspection time, attention control, and the processing speed factors are strongly correlated with one another. It is possible that attention control and inspection time tasks are, to some degree, all measuring aspects of processing speed ability. For example, recall the strong correlation between attention control and processing speed reaction time factors in our confirmatory factor analysis ($r = .72$). This prompts the question, is anything unique to inspection time and attention control after accounting for individual differences in processing speed and other cognitive abilities? To test this, we conducted a model in which the processing speed factors, fluid intelligence, and working memory capacity predicted inspection time and attention control (Figure 9). The critical test here is whether the residual variances in inspection time and attention control (after accounting for processing speed, fluid

Figure 7
Attention Control and Processing Speed Comparison Mediated the Inspection Time–Fluid Intelligence Relationship



Note. Correlations between the mediators were large and significant (rs = .39–.55), but are omitted from the figure for visual clarity. Coefficients for indirect effects are given in gray. All bold values and solid paths were significant at the $p < .05$ level. This figure and Figure 8 are from the same model but presented separately for visual clarity. In the model, the residual correlation between fluid intelligence and working memory capacity was, $r = .18$, $p = .173$. PS = processing speed; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; SRMR = standardized root-mean-square residual.
$^{*}p < .05$.

intelligence, and working memory capacity) are correlated. If they are, this suggests that there is something common to inspection time and attention control over and above differences in processing speed and the other cognitive ability factors. Indeed, we found there was a strong residual correlation between inspection time and attention control ($r = .64$, $p < .001$).

These models provide evidence that differences in inspection time reflect more than just differences in processing speed, at least as measured by the comparison and reaction time tasks. To provide a stronger test that inspection time differences are due to mechanisms of attention control, we also investigated specifically whether selective attention and/or sustained attention play a role in determining inspection time by testing alternative models.

Inspection Time and Selective Attention

We compared performance across the three inspection time tasks to test whether selective attention can explain why attention control is highly correlated with inspection time. If selective attention does play a role in the relationship between inspection time and attention control, then we would expect a particular interaction between changes in performance across the inspection time tasks and attention control ability. That is, high attention control individuals should more effectively be able to filter out the nonrelevant lines and only selectively attend to and compare the relevant lines; therefore, high attention control individuals should have a similar inspection time for the standard (two lines only) version and the selective (two lines, two distractors) version of the inspection time task. If low attention control individuals are not able to effectively filter out the nonrelevant lines in the selective version, then low attention control individuals should have a similar inspection time for the selective (two lines, two distractors) version and the four lines version of the inspection time task.

First, there was a main effect of task on inspection times, $F(1.99, 532.49) = 148.12$, $p < .001$, $\omega_p^2 = 0.20$. Compared to the standard version of the task, inspection times were longer for the selective version, $t(267) = 14.26$, $p < .001$, Cohen's $d = 0.92$, and four lines version, $t(267) = 15.84$, $p < .001$, Cohen's $d = 0.99$. There was no significant difference in inspection times for the selective version compared to the four lines version of the task, $t(267) = 1.16$, $p = .481$, Cohen's $d = .08$. There was a significant interaction between task and attention control ability, $F(1.99, 529.39) = 4.34$, $p = .014$, $\omega_p^2 = 0.01$. However, the interaction was not in the expected direction if selective attention is a mechanism for determining inspection time as there should have been an interaction with attention control from the standard to selective inspection time task. Figure 10 shows that high and low attention control individuals showed the same decrement in performance from the standard to selective inspection time task, $F(1, 266) = 3.49$, $p = .063$, $\omega_p^2 < 0.01$. The interaction occurred between the standard and four-lines inspection time tasks, lower attention control individuals showed a greater decrement in performance from the standard to four-line inspection time task, $F(1, 266) = 9.30$, $p = .003$, $\omega_p^2 = 0.01$. This pattern of results can also be observed by looking at the correlations of each inspection time task with the attention control latent factor. Numerically, the correlation with attention control increases from the standard inspection time task ($r = .297$, 95% CI [−.399, −.187]) to the selective inspection time task ($r = .348$, 95% CI [−446, −241]) and most strongly with the four-line inspection time task ($r = −.422$, 95% CI [−.513, −.321]).

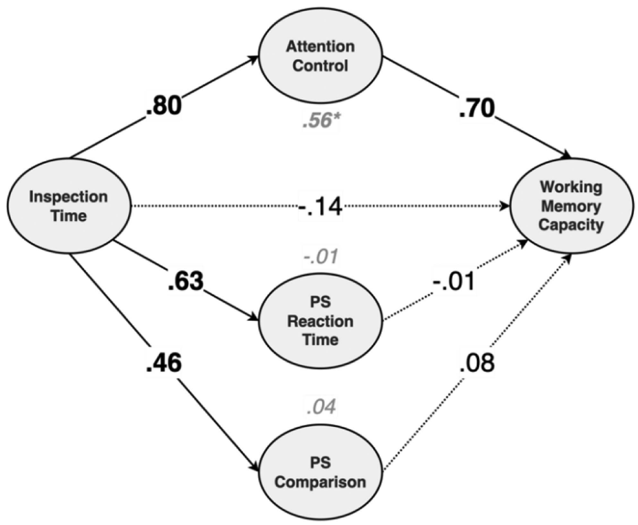
There was also no significant interaction between task (selective and four lines) and the standard inspection time, $F(1, 266) = 1.71$, $p = .192$, $\omega_p^2 < 0.01$, see Figure 11. These results do not support the hypothesis that selective attention can explain why attention control is correlated with inspection time.

We also tested models specifying an interaction between the processing speed factors and fluid intelligence with inspection time tasks. There was no interaction between task and processing speed comparison, $F(1.99, 530.05) = 1.98$, $p = .139$, $\omega_p^2 < 0.01$. There was no interaction between task and processing speed reaction time, $F(1.99, 530.35) = 0.89$, $p = .412$, $\omega_p^2 < 0.01$. Finally, there was no interaction between task and fluid intelligence, $F(1.99, 530.28) = 1.41$, $p = .244$, $\omega_p^2 < 0.01$. In short, the present results provide no compelling evidence for a role for selective attention in performing the inspection time task, nor that the effect of task was moderated by any of our ability covariates.

Inspection Time and Sustained Attention

We used the SACT to test whether inspection time is related to the sustaining of attention over time. The SACT involves orienting the focus of attention to a cued location and sustaining it there for a variable amount of time to identify a target letter

Figure 8
Attention Control Mediated the Inspection Time–Working Memory Capacity Relationship



Note. Correlations between the mediators were large and significant (*r*s = .39–.55) but are omitted from the figure for visual clarity. Coefficients for indirect effects are given in gray. All bold values and solid paths were significant at the $p < .05$ level. Figure 7 and this figure are from the same model but presented separately for visual clarity. In the model, the residual correlation between fluid intelligence and working memory capacity was, $r = .18$, $p = .173$. PS = processing speed; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; SRMR = standardized root-mean-square residual.
* $p < .05$.

surrounded by nontarget letters at the cued location. The cue is removed during the sustained attention interval, and, therefore, one must endogenously sustain the focus of attention at the target location across the interval. We have shown that accuracy on this task declines the longer attention has to be sustained (Tsukahara & Engle, 2023). Critically, we have also shown that those higher on attention control ability, but not working memory capacity or fluid intelligence, show less of a decline in accuracy as the sustained attention interval increases. This task, therefore, has discriminate validity for capturing differences in the ability to sustain attention over time as reflected by individual differences in attention control ability and not cognitive ability more generally (Tsukahara & Engle, 2023).

If sustained attention can explain why inspection time is highly correlated with attention control ability, then we expect that those with a faster inspection time, compared to those with a slower inspection time, to show less of a decline in performance as the sustained attention interval increases on the SACT. Furthermore, if inspection time is capturing more individual variability on attention control than speed of processing, then we would not expect processing speed to be related to the decline in accuracy as the sustained attention interval increases.

The sustained attention intervals included 0 and 2–12 s in 500-ms intervals. In a mixed effect model, we found that there was an inspection Time × Interval interaction; $b = -.004$, 95% CI [−0.005, −0.002], $\beta = -.037$, 95% CI [−0.051, −0.024], $t(18{,}539) = -5.37$, $p < .001$, Δ Marginal $R^2 = .002$,[7] such that those with a faster inspection time showed less of a decline in proportion correct as the sustained attention interval got longer (Figure 12). Note that the inspection Time × Interval interaction was still significant even when the 0-s interval was removed from analysis, $b = -.004$, 95% CI [−0.005, −0.002], $\beta = -.034$, 95% CI [−0.048, −0.020], $t(17{,}696) = -4.76$, $p < .001$. We also observed an attention Control × Interval interaction, $b = .002$, 95% CI [0.001, 0.004], $\beta = .024$, 95% CI [0.010, 0.037], $t(18{,}539) = 3.45$, $p < .001$. Those higher on attention control ability showed less of a decline in proportion correct as the sustained attention interval got longer (Figure 13). Crucially, we found that there was no processing speed Comparison × Interval interaction, $b = .001$, 95% CI [0.000, 0.002], $\beta = .012$, 95% CI [−0.002, 0.025], $t(18{,}539) = 1.68$, $p = .094$, nor a processing speed reaction Time × Interval interaction, $b = -.001$, 95% CI [−0.002, 0.000], $\beta = -.012$, 95% CI [−0.025, 0.002], $t(18{,}539) = -1.72$, $p = .086$, see Figures 14 and 15.

In summary, individuals with faster inspection times and with higher attention control were better at sustaining attention over time, as evidenced by a shallower decline in proportion correct as the sustained attention interval increased. In contrast, those with faster processing speed, on noninspection time speed measures, showed no difference in proportion correct over the sustained attention interval.

It should be noted that these models assume a linear scale on sustained attention performance. That is, the difference in accuracy at one point on the scale (e.g., .95 to .90 proportion correct) is equivalent to a difference in accuracy at other points on the scale (e.g., .85 to .80 proportion correct). Additionally, when the model was run as a logistic binomial model the inspection Time × Interval interaction was no longer significant, $\beta = -.011$, $z = -.461$, $p = .644$, nor was the attention Control × Interval interaction, $\beta = -.043$, $z = -1.72$, $p = .086$. This reflects that the interaction is removable (Loftus, 1978), that is, it depends on the scaling of the dependent variable. Therefore, we are limited to interpreting the interaction as a decline in proportion correct (linear scale) rather than the probability of a correct response (logistic scale). There was no significant interaction of wait time and the processing speed factors regardless of which scaling was used.

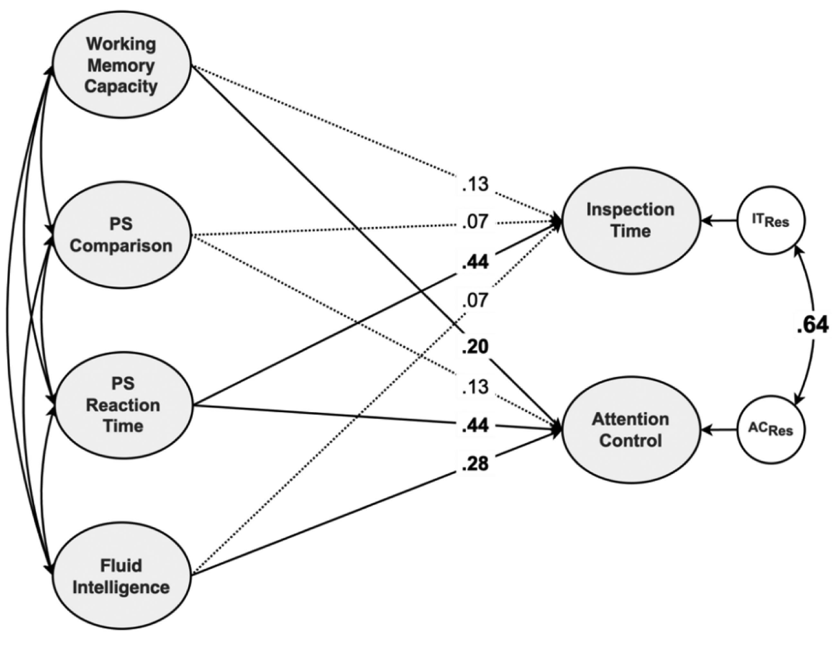
Exploratory Analyses

An additional way of assessing sustained attention in the inspection time tasks is to look at the standard deviation of performance throughout the adaptive staircase procedure. Standard deviation of performance is a commonly used metric of attentional consistency or fluctuations in attention (McVay & Kane, 2009). If attentional consistency is a factor driving performance differences in the inspection time task, then we should see that those with a smaller standard deviation (more attentional consistency) will also have a faster inspection time. For each inspection time task, we calculated the standard deviation of the stimulus duration values (*y*-axis in Figure 2), as these reflect changes in performance across the adaptive staircase. We only used the trials after the first change in

[7] Δ Marginal R^2 was calculated as the difference in Marginal R^2 with and without the term in the model.

Figure 9

Processing Speed Cannot Account for the Relationship Between Inspection Time and Attention Control



Note. All bold values and solid paths were significant at the $p < .05$ level. Correlations between predictors are depicted in the model, the values are as follows. Working memory capacity–PS comparison: $r = .41$. Working memory capacity–PS reaction time: $r = .42$. Working memory capacity–fluid intelligence: $r = .52$. PS comparison–PS reaction time: $r = .52$. PS comparison–fluid intelligence: $r = .63$. PS reaction time–fluid intelligence: $r = .46$. PS = processing speed; IT = inspection time; AC = attention control; Res = residual; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; SRMR = standardized root-mean-square residual.

step size, trials 16–64, to reduce the influence of change in performance at the start of the task.[8] We found that for each inspection time task, the standard deviation of stimulus duration values correlated with the final inspection time threshold values (calculated at the end of the task); inspection time standard: $r = -.45$, $p < 001$; inspection time selective: $r = -.25$, $p < .001$; inspection time four lines: $r = -.40$, $p < .001$. That is, smaller standard deviations were associated with faster inspection times. Additionally, after controlling for each other, inspection time threshold scores and the standard deviation both correlated with attention control for each task, see Table 3.

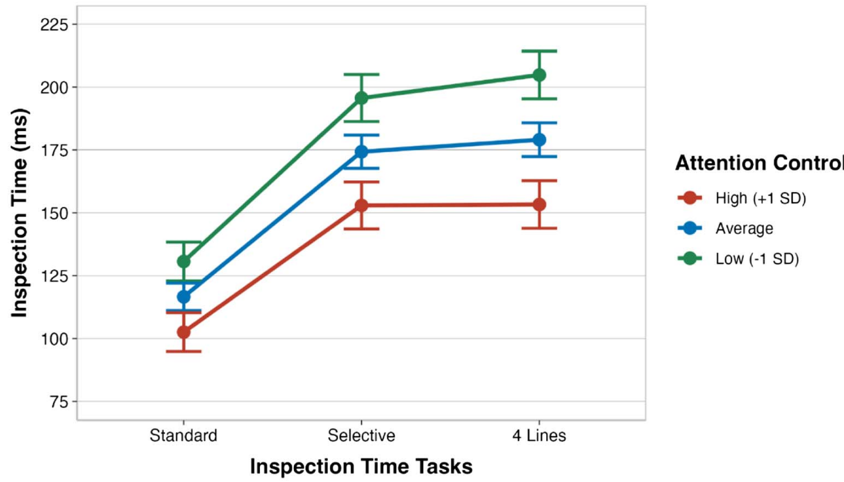
Additionally, we explored how attentional lapses on the inspection time tasks correlated with threshold scores and attention control. We defined attentional lapses as those trials in which there was an error and the stimulus duration (inspection time) for that trial was above their threshold score on the task—these are trials in which the participant should be able to make a correct response given their threshold score, and thus, the error may reflect a momentary lapse of attention. Strangely, more attentional lapses were associated with faster inspection times on each task; inspection time standard: $r = .33$, $p < .001$; inspection time selective: $r = .44$, $p < .001$; inspection time four lines: $r = .34$, $p < .001$. Also, the bivariate correlations between attentional lapses and attention control were near zero and nonsignificant; inspection time standard: $r = -.11$, $p > .05$; inspection time selective: $r = -.07$, $p > .05$; inspection time four lines: $r = -.05$, $p > .05$. Given these patterns of correlations, it is possible that there is a suppressor effect going on between inspection time threshold scores and attentional lapses. Indeed, when partial correlations were analyzed (controlling for threshold scores), fewer attentional lapses were associated with higher attention control as would be expected, see Table 4.

Although these analyses provide additional evidence for the role of sustained attention in inspection time, they are highly exploratory

[8] By including the first so many trials, the standard deviation would actually reflect how fast of stimulus duration the participant was able to converge on at the very start of the task; and therefore, a larger standard deviation would reflect those with a faster inspection time rather than some indication of attentional consistency. In fact, when including all trials in calculating the standard deviation, we did observe that those with faster inspection times also had higher standard deviations, because they showed a larger change in values at the start of the task (from 750 ms) converging on their faster inspection time. This is also related to the fact that the first trial was set at an easy 750 ms, if a lower starting value was used then this would not be as much of a concern.

Figure 10

Interaction Between Attention Control and Inspection Time Tasks



Note. Estimated marginal means based on the model at +1 *SD* above the mean, the mean, and −1 *SD* below the mean on Attention Control (measured by the antisaccade, selective visual arrays, and visual StroopDL, auditory StroopDL, auditory FlankerDL, and auditory SimonDL). Error bars represent 95% confidence intervals. $N = 268$. DL = deadline. See the online article for the color version of this figure.

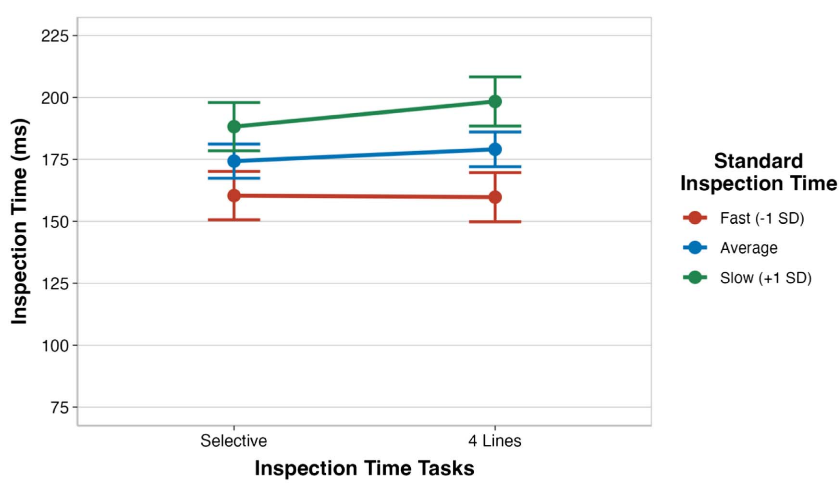
and future work should investigate more closely the relation between attention consistency, attentional lapses, and inspection time.

Discussion

The inspection time task has been a hallmark paradigm for establishing a mental speed theory of intelligence—that the speed in which information can be processed is the causal determinant of differences in intelligence (Brand & Deary, 1982; Deary & Stough, 1996; Eysenck, 1967; Grudnik & Kranzler, 2001; Jensen, 1998; Kranzler & Jensen, 1989; Nettelbeck, 1987; Salthouse, 1996). In this study, we investigated whether attention control can statistically account for the relationship between inspection time and fluid intelligence. To do so, we adopted an individual differences approach, which incorporated a diverse set of attention control measures across both the visual and auditory modalities. We also administered several other measures of processing speed, so that we could consider the

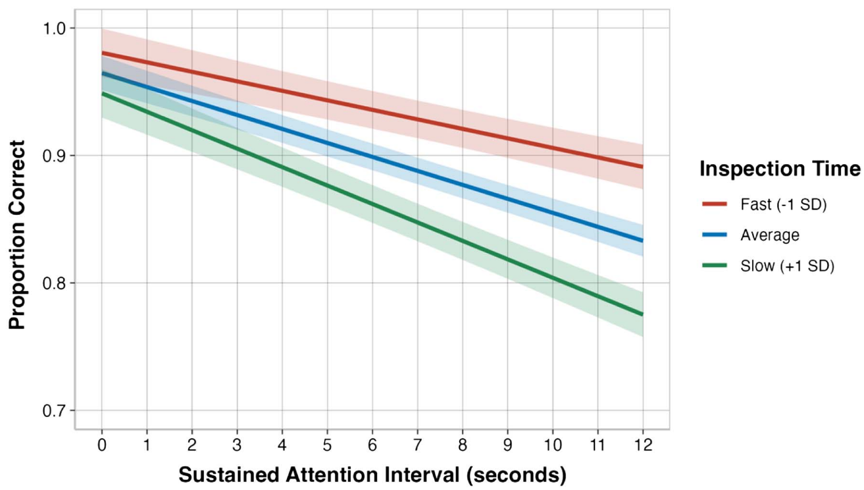
Figure 11

No Interaction Between Inspection Time Standard and Selective Attention on the Inspection Time Task



Note. Estimated marginal means based on the model at −1 *SD* below the mean, the mean, and +1 *SD* above the mean on the standard inspection time task. Error bars represent 95% confidence intervals. $N = 268$. See the online article for the color version of this figure.

Figure 12
Interaction Between Inspection Time and Sustained Attention Interval

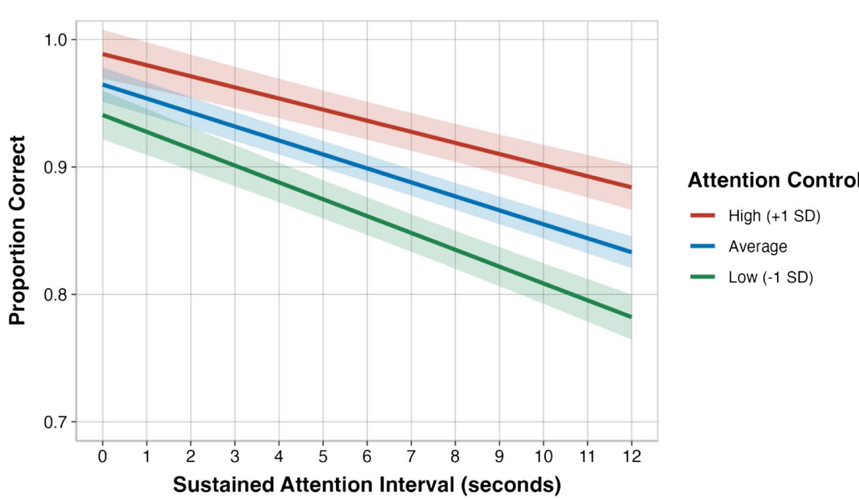


Note. Model estimates of the change in proportion correct as the sustained attention interval (on the sustained attention-to-cue task) increased for fast (−1 standard deviation below the mean), average, and slow (+1 standard deviation above the mean) inspection time individuals. Inspection time was determined using Bartlett estimated latent factors scores from the standard, selective, and four-lines version of the task. Error ribbons represent 95% confidence intervals. $N = 281$. See the online article for the color version of this figure.

relationship between attention control and inspection time with more context. We asked several specific questions.

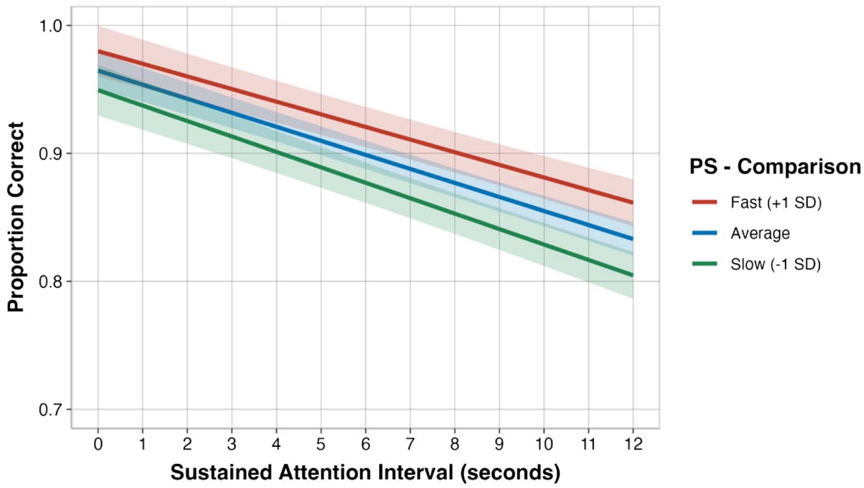
First, we asked whether attention control helps statistically explain the association between inspection time performance and fluid intelligence. If the inspection time task mainly measures the speed of visual information uptake, as the mental speed theory of intelligence would contend, there is little reason to expect a domain-general attention control factor to account for the inspection

Figure 13
Interaction Between Attention Control and Sustained Attention Interval



Note. Model estimates of the change in proportion correct as the sustained attention interval (on the sustained attention-to-cue task) increased for high (+1 standard deviation above the mean), average, and low (−1 standard deviation below the mean) attention control individuals. Attention control was determined using Bartlett estimated latent factors scores from the antisaccade, selective visual arrays, visual StroopDL, auditory StroopDL, auditory FlankerDL, and auditory SimonDL. Error ribbons represent 95% confidence intervals. $N = 281$. DL = deadline. See the online article for the color version of this figure.

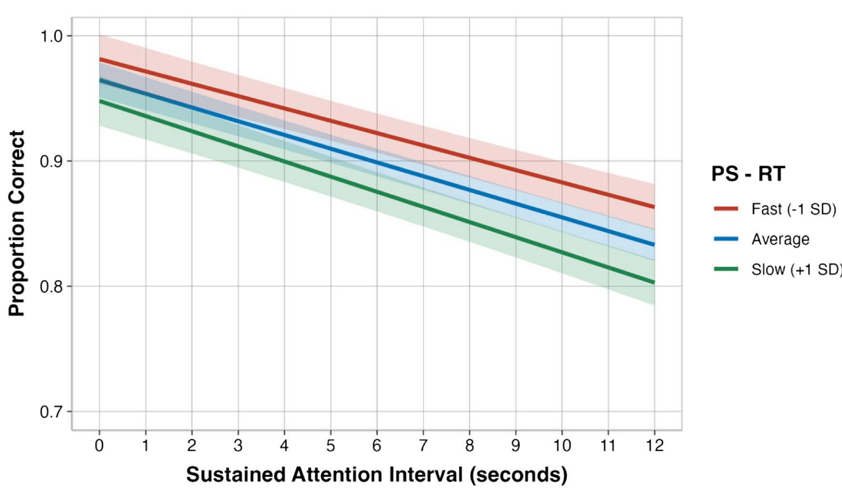
Figure 14
No Interaction Between Processing Speed Comparison and Sustained Attention Interval



Note. Model estimates of the change in proportion correct as the sustained attention interval (on the sustained attention-to-cue task) increased for fast (+1 standard deviation above the mean), average, and slow (−1 standard deviation below the mean) processing speed individuals. Processing speed was determined using Bartlett estimated latent factors scores from the letter, digit, and pattern comparison tasks. Error ribbons represent 95% confidence intervals. $N = 281$. PS = processing speed. See the online article for the color version of this figure.

time–fluid intelligence relationship. To the contrary, in a structural equation model, attention control fully mediated the correlation between inspection time and fluid intelligence—even after controlling for other processing speed factors (Figure 7). In general, this mediation model is consistent with the hypothesis that inspection time tasks are sensitive to individual differences in domain-general attention control. A similar result obtained for the relationship between inspection time and working memory capacity (Figure 8).

Figure 15
No Interaction Between Processing Speed Reaction Time and Sustained Attention Interval



Note. Model estimates of the change in proportion correct as the sustained attention interval (on the sustained attention-to-cue task) increased for fast (−1 standard deviation below the mean), average, and slow (+1 standard deviation above the mean) processing speed individuals. Processing speed was determined using Bartlett estimated latent factors scores from reaction times on the prosaccade, simple RT, and choice RT tasks. Error ribbons represent 95% confidence intervals. $N = 281$. PS = processing speed; RT = reaction time. See the online article for the color version of this figure.

Table 3
Partial Correlations of Inspection Time Standard Deviation With Attention Control

Variable	Partial r	95% CI	Significance
IT standard			
Threshold score	.159	[.044, .271]	$t(283) = 2.18, p = .007$
Standard deviation	−.246	[−.352, −.134]	$t(283) = -4.27, p < .001$
IT selective			
Threshold score	.301	[.192, .403]	$t(284) = 5.33, p < .001$
Standard deviation	−.180	[−.290, −.065]	$t(284) = -3.08, p = .004$
IT four lines			
Threshold score	.349	[.242, .447]	$t(281) = 6.24, p < .001$
Standard deviation	−.161	[−.273, −.046]	$t(281) = -2.74, p = .007$

Note. IT = inspection time; CI = confidence interval.

Taken with the strong correlation between attention control and inspection time factors in our confirmatory factor analysis (Figure 6), these mediation models indicate that inspection time performance and its predictive validity are largely capturing individual difference in attention control.

However, this interpretation hinges upon the validity of the attention control factor. Of particular concern is that perhaps both attention control and inspection time factors are merely instantiations of a more general speed ability (Kail & Salthouse, 1994; Lerche et al., 2020). After all, both of our processing speed factors were moderately to strongly correlated with both attention control and inspection time (see Figure 6). Additionally, it could be that complex tasks which combine several processes will be more predictive of each other—attention control, fluid intelligence, working memory capacity—and that simple tasks will be more related to one another—inspection time and the process speed tasks.

Table 4
Partial Correlations of Inspection Time Attentional Lapses With Attention Control

Variable	Partial r	95% CI	Significance
IT standard			
Threshold score	.347	[.240, .445]	$t(283) = 6.22, p < .001$
Attentional lapses	−.227	[−.334, −.114]	$t(283) = -3.92, p < .001$
IT selective			
Threshold score	.423	[.323, .514]	$t(284) = 7.87, p < .001$
Attentional lapses	−.270	[−.374, −.159]	$t(284) = -472, p < .001$
IT four lines			
Threshold score	.474	[.378, .559]	$t(281) = 9.01, p < .001$
Attentional lapses	−.225	[−.333, −.111]	$t(281) = -3.87, p < .001$

Note. IT = inspection time; CI = confidence interval.

This could explain why attention control mediates the inspection time–cognitive ability relationship.

While this concern is fair, we found that attention control and inspection time remained strongly correlated (residual $r = .64$) even after accounting for the processing speed factors, working memory capacity, and fluid intelligence (Figure 9). This indicates that (a) attention control and inspection time share substantial variance beyond that shared with other measures of processing speed, and (b) it is not as simple as complex tasks are more related to one another and simple tasks are more related to one another.

Collectively, our structural equation models indicate that domain-general attention control is strongly related to inspection time performance. However, on their own, these models are not particularly convincing evidence that inspection time recruits attention control rather than the inverse. While the inclusion of auditory tasks on our attention control factor appears at odds with the interpretation that the visual inspection time is strictly a visual phenomenon, the factor loadings from the auditory tasks on the attention control factor were generally lower than those of the visual tasks. A stronger test was required to satisfactorily conclude that inspection time tasks recruit attention control.

To this end, we tested two experimental manipulations to assess whether inspection time performance relies on selective and sustained attention. Our selective attention manipulation (Figure 3) generated no compelling evidence that the ability to filter distractors was related to inspection time performance. Adding distractors and doubling the size of the stimulus set increased the inspection time estimate, making the task harder. However, the critical interaction with attention control was not significant: High and low attention control individuals showed the same decrement in performance from the standard to selective inspection time task (Figure 10).

While it is possible that other manipulations of selective attention might have generated a different result (e.g., Fox et al., 2009), we found this result surprising given other results in both the attention control and inspection time literatures. For example, Martin et al. (2021) found evidence suggesting that including distractors in visual change detection tasks tends to strengthen their relationship with attention control. We included a similar manipulation in our selective inspection time task and found no evidence of a selective attention advantage. One thing to note is that, given the small stimulus set, participants may not have needed to selectively attend to the cued items to respond accurately. Adding more items to the stimulus and/or distractor sets in our inspection time tasks would be an interesting test of this explanation.

Our analysis of the SACT proved more informative than our selective attention manipulation. We found that participants with faster inspection times showed a smaller decrement in target identification accuracy (proportion correct) as the sustained attention interval increased (Figure 12). A similar interaction was observed for attention control, such that those higher on attention control also showed a smaller decline in accuracy over time (Figure 13). Importantly, neither of the other processing speed factors interacted with sustained attention interval (Figures 14 and 15). We are tempted to interpret this as corroboration of the hypothesis that, in part, the inspection time task indexes the ability to sustain attention at a fixed location in order to identify a briefly presented target. However, there are several alternatives that need to be considered.

One objection to our sustained attention interpretation of the inspection time task is that both the SACT and our inspection time tasks involved making very quick visual discriminations. Thus, it is unsurprising that the two are strongly related. Indeed, if the entire basis of our argument were that the SACT and inspection time tasks were strongly correlated, we would levy the same objection. The crux of our argument, rather, lies with the interaction between inspection time performance and the sustained attention interval. The need for rapid visual discrimination is held constant across all sustained attention intervals of the SACT, so it is unclear why this common demand would lead to the interaction we observed.

To explicate further, assume two participants, one with a fast inspection time and one with a slower inspection time, are both doing a short sustained attention interval trial of the SACT. The target array appears some time later, and both participants, having shifted their gaze slightly, to reorient to the target. All else being equal, the participant with the faster inspection time will be more accurate, since they have processed more of the target letter by the time it is masked. Critically, the exact same situation would be true even of longer intervals. The participant with the faster inspection time, all else being equal, should be more accurate, leading to a main effect of inspection time. However, this does not explain the interaction between inspection time and sustained attention interval in the SACT.

To explain why those with faster inspection times also show less of a performance decrement (proportion correct) across the sustained attention intervals without appealing to sustained attention, one would need to make additional assumptions. For example, perhaps those with faster inspection times are faster at executing corrective saccades to the critical location. While this possibility has not been exhaustively tested, Garaas and Pomplun (2008) reported no consistent correlations between inspection time and oculomotor behaviors, including saccade latencies. As such, there is reason to provisionally discount the hypothesis that those with faster inspection times showed a smaller sustained attention effect, because they are faster at reorienting to the target location.

Instead, we would argue that our findings point to an important role of sustained attention in inspection time and attention control tasks. This could occur in a few different ways. For example, perhaps the gaze position drifts less over the course of a sustained attention interval in those with better attention control than those with lower attention control. Alternatively, those with better attention control could suffer fewer covert lapses of attention, which may or may not precede more overt behaviors, like gaze drift (Carrasco, 2011). Both possibilities could be investigated by combining eye-tracking and pupillometry, while participants performed the inspection time tasks and the SACT, which, unfortunately, the present study did not do. Additionally, sustained attention may play a role in determining inspection time performance. In exploratory analyses, we found that more variability in performance, during the adaptive inspection time tasks, was correlated with a slower inspection time. This may reflect that attentional lapses, mind wandering, or failures of goal maintenance are partly reflected in inspection time threshold scores.

Limitations and Future Directions

Our study had many strengths, including a diverse battery of tasks, a large sample, and a multitude of methods. These generally converged on attention control, especially the ability to sustain attention over time, being important for performing well in an inspection time task and for explaining the inspection time–cognitive ability association. It also suffered from a few limitations. These could include our measurement of noninspection time processing speed. Recently, a predominating method for measuring processing speed in binary choice tasks involves estimating drift parameters in sequential sampling models, like the drift diffusion model (Lerche et al., 2020; Schubert & Frischkorn, 2020). Several features of the present speed tasks make it difficult to fit such models to these data. First, in many cases, there are simply not enough trials to generate stable parameter estimates. For example, in our simple and choice reaction time tasks, there are no more than 24 trials to which to fit the model(s). Even the simplest diffusion models require much more data (Wagenmakers et al., 2007). Furthermore, accuracy rates are too high for some tasks to have accurate parameter estimation (Wagenmakers et al., 2007; but see Voss & Voss, 2007). While the present data do not lend themselves to a diffusion model analysis, it would be interesting to investigate whether the current conclusions based on reaction time and accuracy-based speed tasks would hold for drift rates calculated from other simple binary choice tasks. Another important caveat to the present investigation is the cross-sectional nature of much of the data. Although such correlational results may provide guidance for future investigations, they do not constitute definitive support for any causal hypotheses, and readers should avoid such interpretations of our correlational models.

Given that we found a relation between sustained attention and inspection time, another avenue of research is to investigate the role of sustained attention on simple perceptual and psychophysical paradigms. We had previously shown that attention control also plays a large role in making simple sensory discriminations (Tsukahara et al., 2020). Therefore, these types of tasks may be well-suited to examine the intensity and consistency of attention (Unsworth & Miller, 2021).

On one hand, psychophysical tasks demand a level of intensity of attention as one approaches their threshold (e.g., the fastest one can make an easy discrimination in an inspection time task, or the smallest difference on some dimension between two stimuli one can discern). Although our study was not able to elucidate how the intensity of attention plays a role in these tasks future studies could do so; once you have an individual's threshold value, you can then manipulate the difficulty and thereby the level of intensity of attention required to perform an inspection time or sensory discrimination for that individual.

On the other hand, as our results suggest, the consistency of attention plays a role in determining performance on adaptive psychophysical paradigms. We were able to assess the association of sustained attention with inspection time by using the SACT. In fact, there is a similarity between the inspection time task and the SACT used in this study. Both required an intensity of attention to identify and discern quickly presented stimuli. However, the SACT also manipulated the duration which one must sustained the focus of attention. We found that faster inspection times were associated with less of a decline in the focus of attention as the sustained attention interval increased. Future studies that are designed to specifically examine the intensity and consistency of attention could parametrically manipulate both the intensity of attention required, based on the individual's threshold level, and the duration which the focus of attention must be sustained.

It will also be important to further investigate the relationship between inspection time and sustained attention using tasks other than the SACT. For example, continuous performance tasks are also used to measure the ability to sustain attention, and these tasks are structurally dissimilar to the SACT (Tsukahara & Engle, 2023). Where the SACT requires participants to maintain their attention on a critical spot over the course of a variable, unfilled interval, each trial of a continuous performance task requires participants to decide whether a stimulus warrants a response or not (e.g., press the spacebar for every letter except "X"). Given the different demands on sustained attention in the two tasks, it would be useful to know whether continuous performance test metrics cohere with our conclusions about the SACT.

Conclusion

In previous work, we often defined attention control as the ability to focus attention on task-relevant information in the face of distraction and interference. Part of the reason for the qualifier "in the face of distraction and interference" was because conditions in which there is a conflict between task-relevant and task-irrelevant information are the conditions in which we expected to see the largest individual differences. We now have two major findings that challenge us to revise our perspective in where we expect to see differences related to attention control.

First, we found that performance in simple sensory discrimination tasks correlated strongly with attention control. These tasks presented two stimuli (either simultaneously or sequentially) in which discrimination needed to be made along a certain dimension; for instance, the difference in pitch between two tones or the difference in length between two vertical lines. Critically, these sensory discrimination tasks did not include any conflict, distraction, or interference. Yet, attention control at the latent level was highly predictive of a general sensory discrimination ability (Study 1: $r = .90$; Study 2: $r = .79$; Tsukahara et al., 2020). Second, in the present study showed that attention control plays a large role in performance on the inspection time task. Again, like the sensory discrimination tasks, the inspection time task does not include any conflict, distraction, or interference.

What role does attention control play in these simple perceptual tasks that lack features of conflict between task-relevant and task-irrelevant information? One possibility is that although the tasks themselves do not include these features, we are constantly bombarded with a maelstrom of information coming from our senses and from internally generated thoughts, goals, and desires. That is, conflict is present in other forms than just the features of a particular task. When a task encourages us to perform at our best (e.g., adaptive procedures), this places a demand on us to manage these other nontask sources of distraction and interference and to intensely focus our attention on simple perceptual stimuli. In addition to the demand to intensely focus attention, people will differ on their ability to sustain that intensity of attention (Unsworth & Miller, 2021). In the present study, we found that those whose attention waned more quickly also had worse inspection times. Whether the intensity of attention and sustaining of attention are separable abilities remain to be seen. What the findings presented here, and in Tsukahara et al.'s (2020), suggest is that any context in which there is a high demand to intensely focus and sustain attention should be related to differences in attention control. This moves us beyond thinking about attention control solely as inhibition and resolving stimulus and response conflict.

Constraints on Generality

We do expect that some of our measures, particularly, the fluid intelligence tasks, to have a higher degree of cultural bias or specificity—that is, they are not culture-free. Although the inspection time–intelligence relationship has historically been studied in adult, child, and cognitively impaired populations, this study used reliable cognitive measures that have been well-validated in adult populations but not in child or cognitively impaired populations. Therefore, we do not know the generalizability of the findings from the present study in nonadult, noncognitively healthy populations. We made efforts to recruit from a broad adult population by recruiting noncollege individuals in the Atlanta, GA Metro area; however, the majority of our sample did have college experience. However, we do expect our results to generalize to all cognitively healthy adult populations. We have no reason to believe that the results depend on other characteristics of the participants, materials, or context.

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(*Appendix follows*)

Appendix

Full Correlation Matrix

Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. IT Standard[a]	—																			
2. IT Selective[a]	**.24**	—																		
3. IT Four-lines[a]	**.34**	**.37**	—																	
4. Antisaccade	**.24**	**.30**	**.36**	—																
5. VAorient_S	**.25**	**.23**	**.22**	**.37**	—															
6. StroopDL[a]	.07	**.23**	**.25**	**.31**	**.23**	—														
7. Auditory FlankerDL[a]	**.21**	**.16**	**.28**	**.26**	**.24**	**.18**	—													
8. Auditory StroopDL[a]	**.16**	**.18**	**.26**	**.26**	**.20**	**.30**	**.28**	—												
9. Auditory SimonDL[a]	**.12**	.08	**.18**	**.27**	**.13**	**.16**	**.23**	**.13**	—											
10. Digit comparison	.11	**.21**	**.21**	**.30**	**.32**	**.27**	**.19**	**.20**	.08	—										
11. Letter comparison	.04	**.12**	**.12**	**.21**	**.23**	**.19**	.10	**.13**	.06	**.60**	—									
12. Pattern comparison	**.24**	**.17**	**.23**	**.28**	**.41**	**.14**	**.19**	**.15**	**.17**	**.48**	**.38**	—								
13. Prosaccade[a]	.06	**.19**	**.12**	.10	**.14**	**.19**	.12	**.12**	**.13**	**.28**	**.17**	**.31**	—							
14. SimpleRT[a]	**.23**	**.21**	**.20**	**.27**	**.27**	**.26**	**.27**	.08	**.21**	**.18**	.07	**.29**	**.16**	—						
15. ChoiceRT[a]	**.12**	**.15**	**.19**	**.25**	**.22**	**.18**	**.21**	.08	**.20**	**.22**	**.13**	**.28**	**.26**	**.36**	—					
16. RAPM	**.13**	.08	**.14**	**.28**	**.42**	.09	**.16**	.07	**.16**	**.24**	**.13**	**.36**	.06	**.22**	**.15**	—				
17. Letter sets	.07	**.18**	.12	**.24**	**.29**	**.17**	**.19**	**.14**	**.13**	**.43**	**.41**	**.28**	.09	**.23**	**.15**	**.38**	—			
18. Number series	**.18**	**.23**	**.19**	**.28**	**.44**	**.29**	**.21**	**.16**	**.14**	**.39**	**.28**	**.36**	**.14**	**.26**	**.19**	**.48**	**.59**	—		
19. SymSpan	**.17**	**.20**	.10	**.25**	**.42**	**.19**	**.15**	.08	.07	**.24**	**.19**	**.32**	**.18**	**.19**	**.16**	**.33**	**.30**	**.32**	—	
20. RotSpan	**.12**	**.21**	**.17**	**.25**	**.32**	**.21**	**.13**	**.18**	.08	**.19**	**.15**	**.29**	**.16**	**.12**	**.19**	**.32**	**.18**	**.22**	**.54**	—

Note. Higher scores represent better performance; hence all correlations are positive. Correlations were computed using pairwise deletion. Correlations in bold are statistically significant, $p < .05$. IT = inspection time; DL = deadline; RT = reaction time; RAPM = Raven's Advanced Progressive Matrices.
[a] Variable was reverse scored for ease of interpretation.

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