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Rethinking Attention Control: An Individual Differences Approach

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RETHINKING ATTENTION CONTROL: AN INDIVIDUAL DIFFERENCES APPROACH

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Abstract

While there is extensive literature on visual spatial attention, less is known about auditory spatial attention, especially in terms of attention control. There is also a growing literature highlighting the importance of considering individual differences in attention control ability. Given these points, the purpose of this study was twofold. The first was to understand how auditory attention control is influenced by spatial location as well as vision. The second was to examine whether individual differences in attention control ability can predict task performance in that context. We utilized two tasks for these purposes. Experiment 1a consisted of a cross-modal Stroop task with spatialized spoken color word targets with visual color square distractors. Experiment 1b then measured individual differences in attention control ability using a novel, adaptive version of the classic Stroop task. Task performance on Experiment 1b was compared to Experiment 1a to assess the predictive power of the adaptive Stroop task. The results of Experiment 1a showed that the spatial location of auditory targets did not impact the cross-modal Stroop effect. Experiment 1a addressed the role of auditory spatial location in the cross-modal Stroop task more generally, and also contributed to a novel understanding of the shape of the auditory attention control gradient. The results of Experiment 1b showed that individual differences in attention control ability did not predict performance in Experiment 1a. Experiment 1b addressed levels of attention control as well as the larger question of the importance of individual differences in improving attention control measurement.

Keywords: attention, auditory, individual differences, spatial, Stroop

Chapter 1. Introduction

1.1. Attention Control and the Stroop Task

Attention control has been studied extensively across disciplines in the field of psychology. Also known as cognitive control (Botvinick et al., 2001) and executive control (Baddeley, 1996), attention control is defined as the control of thoughts and behavior in a goal-driven manner (Draheim et al., 2021). Specifically, this construct refers to focusing on one's intentions while ignoring irrelevant distractions. Attention control underpins various cognitive abilities, and it is especially relevant during tasks that require goal maintenance and conflict resolution (Burgoyne & Engle, 2020; Engle, 2002). A modern framework of attention control comprises the maintenance of relevant information and the disengagement of irrelevant information (Shipstead et al., 2016). This framework can explain how attention control underpins two prominent cognitive constructs: fluid intelligence and working memory.

Fluid intelligence is defined as the ability to solve novel problems (Engle et al., 1999) while working memory is defined as the cognitive system responsible for the temporary maintenance of information in a highly accessible state (Baddeley & Hitch, 1974). Strong correlations between these two constructs were initially explained with claims that both constructs were effectively the same, or that working memory acted in a causal manner, as a determinant of fluid intelligence (Carpenter et al., 1990; Kyllonen & Christal, 1990). However, later work built a case for fluid intelligence and working memory being distinct constructs that both require attention control (Engle, 2002; Shipstead et al., 2016). The maintenance and disengagement framework of attention control covers both constructs with increased emphasis on either component of the framework depending on task context. For example, attention control supports performance on fluid intelligence tasks (e.g., generating a non-repeating list of nouns

from a particular category) through the disengagement of no-longer-relevant information. Conversely, attention control supports performance on working memory tasks through the maintenance of goal-relevant information (Burgoyne & Engle, 2020; Shipstead et al., 2016). The fundamental role of attention control in working memory will be revisited shortly.

A traditional task of importance to the current study is the classic Stroop task (Stroop, 1935). During this task, participants are presented with color words that are printed in a font color. Participants are instructed to name the font color while ignoring the color word. Experimental trials are either congruent (i.e., matching colors) or incongruent (i.e., mismatching colors). Incongruent trials require attention control because a participant must focus on naming the goal-relevant font color while ignoring the conflicting color word distractor. Thus, incongruent trials are associated with a delay in response time (RT), relative to congruent trials. This delay is known as the Stroop effect, which is an indicator of attention control because the difference between incongruent and congruent trial RTs indicates conflict resolution.

Since the inception of the classic Stroop task, variations of the paradigm have emerged to suit different types of research questions related to attention control. Broad variations impact multiple fields of psychology, such as the emotional Stroop task influencing clinical psychology (see Chen, 2008 and Williams et al., 1996 for reviews) and forensic psychology (see Price et al., 2012, for a review) and the numerical Stroop task influencing mathematical psychology (Besner & Coltheart, 1979; Henik & Tzelgov, 1982; Hershman et al., 2022) and educational psychology (see Suárez-Pellicioni et al., 2016, for a review). Other variations are suited for more specific topics: the picture-word Stroop task (Glaser & Düngelhoff, 1984; Starreveld & La Heij, 2017) for examining picture-word interference instead of color-word interference, the animacy Stroop task (Bugaiska et al., 2019) for comparing animate versus inanimate entities, the multilingual

Stroop task (Dyer, 1971; Marian et al., 2013) for understanding the effects of language, and the auditory Stroop task (Green & Barber, 1983; Morgan & Brandt, 1989) for addressing a different modality than the typical visual one. One specific variation of importance for the current work is the cross-modal Stroop task (Cowan & Barron, 1987; Elliott et al., 1998).

1.2. The Cross-Modal Stroop Task

The cross-modal Stroop task, rather than using the same modality for targets and distractors, uses one modality for targets and another modality for distractors. This paradigm typically consists of the simultaneous presentation of a color square with a spoken color word. Depending on whether the primary modality of interest is vision or audition, participants are instructed either to name the square color while ignoring the spoken color word or to name the spoken color word while ignoring the square color. Congruent trials consist of matching color pairings in both modalities while incongruent trials consist of mismatching color pairings in both modalities. The cross-modal Stroop effect is the RT delay for incongruent trials, relative to congruent trials, depending on the experimental design of the particular study. The cross-modal Stroop effect is an indicator of attention control across two modalities because the comparison between incongruent and congruent trials taps conflict resolution for auditory targets and visual distractors, or conflict resolution for visual targets and auditory distractors.

There are two interesting patterns of outcomes related to the cross-modal Stroop effect. The first pattern is that the Stroop effect has a clear relationship with working memory while the cross-modal Stroop effect does not (Kane & Engle, 2003; Morey et al., 2012). Morey et al. (2012) used an individual difference factor of working memory capacity (WMC) by administering automated versions of two complex working memory span tasks: the Operation

span task and the Symmetry span task (Unsworth et al., 2005). Their participants completed the classic Stroop task, the cross-modal Stroop task (i.e., target color squares and distractor spoken color words), and the two working memory span tasks. During the Operation span task, participants judged whether an equation was true or not before being given a consonant. After a certain number of trials, participants were prompted to recall the consonants in order. During the Symmetry span task, participants judged whether a block pattern was vertically symmetrical before being given a grid location to remember. After a certain number of trials, participants were prompted to recall grid locations in order. WMC was represented as combined scores on both of these tasks. Results demonstrated a negative correlation between WMC and the size of the classic Stroop effect (i.e., higher WMC was associated with lower interference on the classic Stroop task) and no correlation between WMC and the size of the cross-modal Stroop effect.

Morey et al. (2012) addressed this distinction through “levels of attention control” by stating that working memory tasks measure not only working memory but also attention control (Engle, 2002; Shipstead et al., 2016), and that there are two levels of attention control to consider: fine attention control that is responsible for conflict resolution, and broad attention control that is responsible for goal maintenance. Morey et al. (2012) suggested that the reason for the distinction was observed in differences in the importance of goal maintenance between the working memory tasks, the classic Stroop task, and the cross-modal Stroop task. Specifically, the working memory tasks represented broad attention control as participants needed to engage in goal maintenance to remember targets despite answering goal-irrelevant questions. While Stroop tasks generally measure fine attention control due to conflict resolution, the classic Stroop task primarily represented broad attention control because recovering from a lapse in attention, or goal maintenance, was associated with a consequence. After recovery, a participant perceived the

target font color and distractor color word and were prone to interference when trying to remember which color to name. However, their cross-modal Stroop task (with visual targets and auditory distractors) did not represent broad attention control because there was no consequence for recovering from a lapse in attention. After recovery, participants only saw the target color square, as the distractor spoken color word was not present anymore. This mismatch in levels of attention control between the working memory tasks and their cross-modal Stroop task, particularly in the role of broad attention control in terms of goal maintenance, could explain why WMC was related to the Stroop effect but not the cross-modal Stroop effect (Morey et al., 2012). As a reminder, Stroop tasks generally indicate fine attention control because conflict resolution is inherent to incongruent trials and not congruent trials, and Stroop effects compare the two. However, only some Stroop tasks indicate broad attention control. As detailed above, whether broad attention control is present in a particular cross-modal Stroop task or not depends on the modalities of the target and distractor stimuli.

The second pattern of the cross-modal Stroop effect is that the effect is typically much smaller in size than the classic Stroop effect (Elliott et al., 1998; Elliott et al., 2014). A potential explanation for this difference is spatial integration. The classic Stroop task involves spatial integration of target and distractor: the font color and color word are presented in the same spatial location. Meanwhile, the cross-modal Stroop task involves the spatial separation of target and distractor: the color square is presented on a computer screen while the spoken color word is presented through headphones. Smaller interference in the cross-modal Stroop effect can be attributed to the distractor being spatially separated from the target, which makes the distractor easier to ignore during attention control.

1.3. Spatial Location in the Cross-Modal Stroop Task

Prior cross-modal Stroop work examining spatial integration has found that interference grows considerably whenever the distractor is integrated with the target, such as in classic Stroop. One example (Francis et al., 2017) found that visual distractor interference was greater during spatial integration (i.e., a distractor color word printed in a target font color, presented with a distractor spoken color word) compared to spatial separation (i.e., a distractor color word next to “xxxxx” printed in a target font color, presented with a distractor spoken color word). A second example (Medina et al., 2021) found that incongruent spatial integration (i.e., a distractor color word printed in a mismatching target font color, presented with a distractor spoken color word) led to substantially more interference than congruent spatial integration (i.e., a distractor color word printed in a mismatching a distractor color word printed in a matching target font color, presented with a distractor spoken color word), as well as spatial separation (i.e., any setup where the target was the spoken color word). The importance of the latter study was that it emphasized the role of content congruence in spatial integration.

However, support for the importance of space in the cross-modal Stroop task is mixed. One study conducted a few experiments on visual attention control and spatialized auditory distractors and found that the spatial location of auditory distractors had no effect on the size of the cross-modal Stroop effect (Lutfi-Proctor et al., 2018). The first goal of the current study is to explore the reverse relationship: spatialized auditory attention control and the role of vision.

1.4. Spatial Location of Auditory Targets and Visual Distractors

Multisensory integration (i.e., the interplay between modalities that constitutes perception) is enhanced whenever stimuli from different senses are presented at the same spatial

location. This is known as the “spatial rule” of multisensory integration (Spence, 2013; Stein & Meredith, 1993). This can be a benefit, as prior research using spatial arrays of loudspeakers has demonstrated that auditory task performance improves when gazing at the loudspeaker emitting sound (Best et al., 2020; Pomper & Chait, 2017). However, the spatial rule of multisensory integration can also be a detriment when factoring in content congruence between the target and distractor modalities. As mentioned previously, cross-modal Stroop interference is increased whenever distractors are in the same spatial locations as targets, and interference is greatly increased when those spatially integrated distractors are incongruent with the targets (Francis et al., 2007; Medina et al., 2021).

A contribution of the current study’s goal of exploring spatial auditory attention control and the role of vision is that this goes further than typical research on that topic by examining the role of content congruence, as the Stroop paradigm necessitates comparing incongruent distractors to congruent distractors. Typical studies from the spatial auditory attention literature use neutral visual distractors (Lewald, 1997; Okita & Wei, 1993; Pomper & Chait, 2017) and audiovisual studies that have considered congruence between auditory targets and visual distractors in the cross-modal Stroop task have not used spatialized sounds (Francis et al., 2017; Medina et al., 2021; Roelofs, 2005). Thus, the current study is the first to use the cross-modal Stroop task with spatialized auditory targets.

Mapping out the shape of a spatial auditory attention control gradient will build upon previous work on the spatial auditory gradient, which has not engaged attention control or used distractors (Golob & Mock, 2020; Golob et al., 2021). Prior work on dynamics of the spatial auditory gradient has found that RTs are generally fastest at -90°, 0, and 90° (Golob & Mock, 2020). While understanding this gradient in terms of congruent versus incongruent visual

distractors is important, investigating spatial auditory attention control and the role of vision is just one of two goals of the current study. The second goal is to assess whether individual differences in attention control ability predict task performance in that context.

1.5. Individual Differences in Attention Control

There is a growing literature highlighting the fact that traditional attention control measures (e.g., the classic Stroop task, the Simon task, and the flanker task) exhibit a reliability paradox (Draheim et al., 2021; Hedge et al., 2018). They are sufficient at producing highly reliable experimental effects, hence the popularity of the mentioned tasks. However, they are insufficient at accounting for individual differences in attention control ability, which are powerful predictors of human behavior (Draheim et al, 2021). Two underlying factors explain this drawback.

The first major underlying factor is speed-accuracy interactions. Traditional attention control measures typically report RT rather than accuracy. For example, the Stroop effect difference score is calculated by taking the incongruent RT (i.e., typically the higher, slower RT) and subtracting the congruent RT, rather than by using accuracy. This is because the Stroop task is relatively simple, which leads to high accuracy across trial types. An important point is that humans have natural individual differences in speed-accuracy emphasis not captured by using either RT or accuracy measures (Draheim et al., 2021). The consequence is that participants who are faster but more error-prone in responding are reported, under the Stroop task, to have better attention control ability. While attention control ability may indeed be a contributing factor to faster task performance, differences in speed-accuracy emphasis contribute to task performance as well. In short, previous research has argued that traditional measures of attention control are

not process pure because they rely on RT, which is contaminated by response cautiousness (Draheim et al., 2021; Hedge et al., 2018).

The second underlying factor at play is processing speed. Prior research has identified a confound between processing speed and cognitive ability in tasks where performance is measured by RT and has further questioned the assumption that the use of difference scores fully controls for outside variance such as processing speed (Miller & Ulrich, 2013; Rey-Mermet et al., 2019). Even when RT difference scores reveal large individual differences, it is unclear how much those difference scores reflect differences in ability versus differences in processing speed. To summarize, traditional attention measures are not process pure due to their reliance on RT, which implies that they are contaminated by not only response cautiousness as mentioned above (Draheim et al., 2021; Hedge et al., 2018; Miller & Ulrich, 2013; Rey-Mermet et al., 2017), but also by processing speed.

A solution to the aforementioned challenges in assessing attention control is to modernize the traditional measures. This modernization has recently been done with the classic Stroop task by modifying it into a new task called the adaptive Stroop task (Draheim et al., 2021). The adaptive Stroop task circumvents the RT difference score approach by using a thresholding approach: the task becomes easier or harder (i.e., has longer or shorter presentation times, which are referred to as "response deadlines") based on each participant's performance, and the task is programmed to converge on the same overall accuracy rate for each participant. The measure of performance is the response deadline, instead of RT or accuracy. This adaptive task serves as a novel measurement of attention control that minimizes the influences of speed-accuracy interactions and processing speed. Better performance on the adaptive Stroop task is associated with better performance on the classic Stroop task (Draheim et al., 2021).

1.6. The Current Study

Previous research on the cross-modal Stroop task examining visual attention and the role of spatial audition found that the spatial location of distractor sounds had no effect on the size of the interference on the visual target (Lutfi-Proctor et al., 2018). The first goal of the current study was to explore the reverse relationship: spatial auditory attention and the role of vision. This was addressed in Experiment 1a, which was a methodological replication of Experiment 4 from Lutfi-Proctor et al. (2018). The critical difference was that the spatialized auditory stimuli were the targets while the visual stimuli were the distractors.

The second goal of the current study was to investigate individual differences in attention control ability as they relate to Stroop (see Table 1). This was addressed in Experiment 1b, which assessed the ability for performance on the adaptive Stroop task (which was designed to better account for individual differences) to predict cross-modal Stroop interference from Experiment 1a. The importance of investigating individual differences in attention control ability in the cross-modal Stroop task goes beyond just a lack of prior research on the topic, which consists of just Morey et al. (2012), who posited that their individual difference WMC factor was indirectly an individual difference factor of attention control. By following up Morey et al. (2012), Experiment 1b contributes to the discussion of accounting for the two levels of attention control, fine and broad, in individual difference research in attention control. By following up Draheim et al. (2021), Experiment 1b helps to discover boundary conditions of the novel adaptive Stroop task beyond its ability to correlate with performance on the classic Stroop task.

Table 1. Draheim et al. (2021) and Morey et al. (2012) in terms of relevant findings.

	Results	Summary
Draheim et al. (2021)	Response deadline had a positive correlation with the size of the classic Stroop effect.	Better performance on the adaptive Stroop task was associated with better performance on the classic Stroop task.
Morey et al. (2012)	WMC had a negative correlation with the size of the classic Stroop effect, and no correlation with the cross-modal Stroop effect.	Better performance on WMC tasks was associated with better performance on the classic Stroop task, and unrelated to performance on the cross-modal Stroop task.

Chapter 2. Experiment 1a

As stated previously, recent research on the cross-modal Stroop task has found that the auditory spatial location had no effect on the size of interference for visual attention and auditory distractors (Lutfi-Proctor et al., 2018). The purpose of Experiment 1a was to examine the reverse relationship: if auditory spatial location has an effect on the size of interference for auditory attention and visual distractors. The first hypothesis was that there would be a non-linear auditory gradient. That is, performance would be the worst at 0° (due to spatial overlap with the distractor) and then improve at angles further away (due to increased distance from the distractor). This prediction is supported by prior cross-modal Stroop work on spatial integration demonstrating that interference increases whenever the distractor is spatially overlapped with the target (Francis et al., 2017; Medina et al., 2021). The second hypothesis was a cross-modal Stroop effect. That is, performance on incongruent trials would be worse than congruent trials. The Stroop effect is a reliable finding in the attention control literature that was also observed in the spatial cross-modal Stroop task study by Lutfi-Proctor et al. (2018).

2.1. Method

Participants

We recruited 180 Louisiana State University undergraduate students who participated for course or extra credit. The current study had a final *N* = 120 after excluding 60 participants: 34 for technical issues with the experiment presentation software, 5 for instruction issues (e.g., participants who did not sufficiently raise the volume of their verbal responses to be detected by the microphone), 4 for poor catch trial performance (see the Results section for more details), 4 for missing data, and 13 for ineligibility (see Figure 1). Participants were not eligible to participate if they reported color blindness, abnormal hearing, or a first language other than

English. Further, participants were given perception checks to verify that they could perceive the locations of spatialized sounds before starting the study (Golob & Mock, 2020; Lutfi-Proctor et al., 2018). During the perception check, participants listened to 10 trials consisting of 2 tones each at the 5 spatial locations: -90°, -45°, 0°, R45°, and R90°. The instructions were to mark down an “x” for each perceived sound location on a sheet of paper that had perpendicular lines to indicate the midline and interaural axes. All participants passed the perception checks.

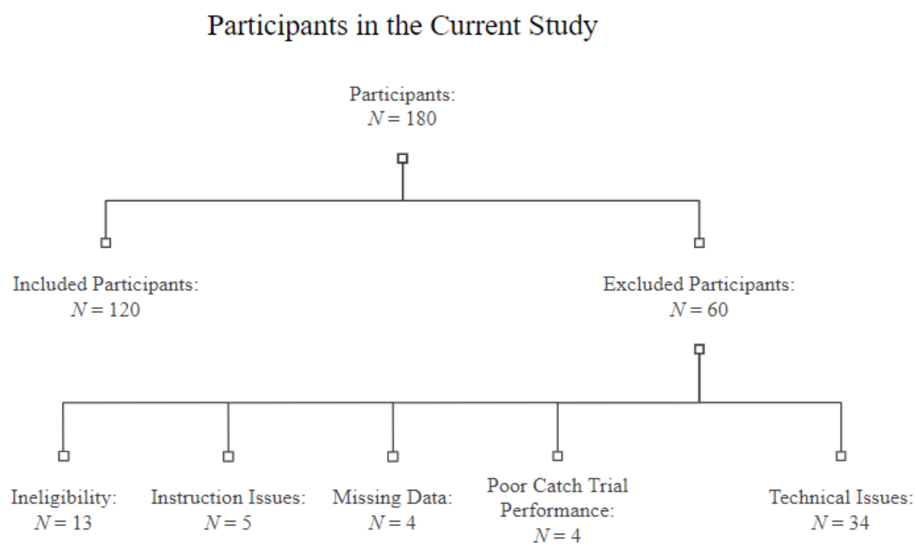

Figure 1. Participants in terms of inclusions, exclusions, and the exclusion criteria.

The current study consisted of examining the predictive relationship between performance on the adaptive Stroop task (Experiment 1b) and performance on a variant of the classic Stroop task (Experiment 1a). We conducted an a priori power analysis using G*Power 3.1 (Faul et al., 2009) for sample size estimation based on Draheim et al. (2021), which compared performance on the classic Stroop task to performance on the adaptive Stroop task and detected a small effect size. We used the F test family of tests and a linear multiple regression test with the “number of predictors” input as 1 and the effect size input as $f^2 = 0.08$ ($\beta = .80$ and $\alpha = .05$).

Based on this power analysis, the minimum sample size needed was $N = 101$. Considering the possibility of a smaller effect size in the current study due to both the large sample size of Draheim et al. (2021) as well as our comparison between the adaptive Stroop task and a variant of the classic Stroop task rather than the classic Stroop task itself, we conducted a second power analysis with a lower effect size input of $f^2 = 0.06$. Based on this power analysis, the minimum sample size needed was $N = 133$. The final sample size of $N = 120$ was sufficient for the current study as it fell within the range of the recommended sample sizes ($N = 101$; $N = 133$).

Materials and Design

During this experiment, auditory targets were presented in a male voice and spatialized so that they appeared from a 90° or 45° angle to the left (-90° and -45°), a 90° or 45° angle to the right, or directly in front of the participant (0°). Spatialized sounds were created by applying interaural time and level differences as well as head-related transfer functions that correspond to the five locations (Tucker Davis, Gainesville, FL). Humans perceive spatialized sound using auditory cues contained in head-related transfer functions, which are acoustic filtering effects that describe soundwave interactions with relevant anatomical structures such as the human head and pinnae, or outer ears (Mokhtari et al., 2019; Zhong et al., 2013). Previous work shows that perception of spatialized binaural stimuli is comparable to the perception of sound sources in free field (Wightman & Kistler, 1989). Sounds were presented to the participant through over-the-ear headphones, which was the only other difference from Experiment 4 of Lutfi-Proctor et al. (2018) that used Etymotic ER-3C insert earphones. This decision was made because Lutfi-Proctor et al. (2018) described an unpublished replication of Experiment 4 where the only difference was Etymotic ER-3C earphones versus over-the-ear headphones, and the results were identical. The use of specific, expensive, high-fidelity earphones in the current study were also

avoided to ease replicability. The five sound locations were in blocks (e.g., participants experienced auditory targets only presented at one of the 90° angles, then only presented at 0°, etc.). The order of the blocks was randomized to control for order effects, and participants were informed at the start of each block whether the sounds would be presented from the left side, right side, or in front of them. Before each block, participants were notified about where auditory stimuli would appear from and were given an identical instruction screen to the instruction screen at the very beginning of the experiment: that they were to repeat, as quickly and accurately as possible, spoken color words while looking at the center of the screen and ignoring visual stimuli except for black circles (to which they should respond with "circle").

Task Methodology

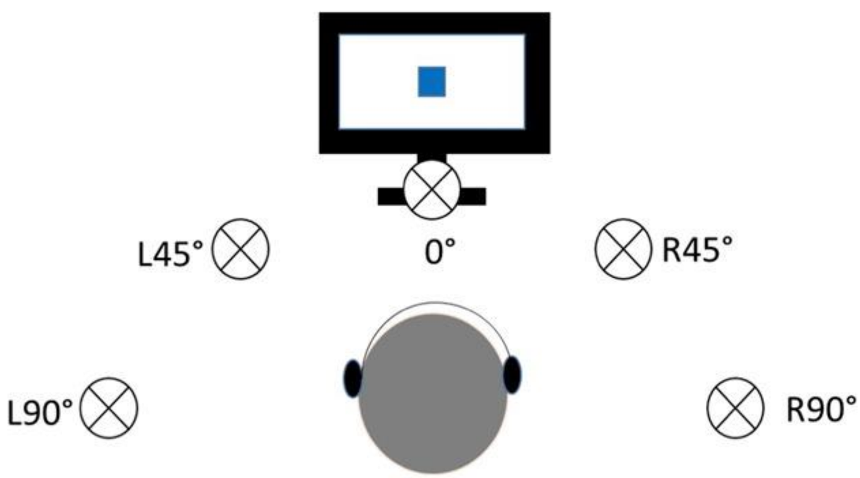

Figure 2. Visual depiction of the present experiment (Lutfi-Proctor et al., 2018). The current methodology differs from Lutfi-Proctor et al. (2018) in that the targets are the spatialized auditory stimuli, and the distractors are the visual stimuli, rather than vice-versa.

The auditory targets were color words, and visual distractors were color squares, blank screens, or black circles. There were three main colors in the experiment: red, blue, and green.

This led to 6 possible incongruent color combinations (red-green, red-blue, blue-red, blue-green, green-red, and green-blue) and 3 possible congruent combinations (red-red, blue-blue, and green-green). Other than the incongruent and congruent trials (i.e., mismatching or matching color squares), there were also control trials (i.e., blank screens) and catch trials (i.e., black circles) (Medina et al., 2021). The purpose of catch trials was to ensure that participants were looking at the screen.

Each trial began with a fixation cross in the center of the screen, which remained for 500 ms, followed by a simultaneous onset of auditory target (i.e., a color word) and visual distractor (i.e., a color square, a blank screen, or a black circle). Participants were instructed to look at the center of the screen and respond as quickly and accurately as possible by repeating the spoken color word except when they saw a black circle. When they saw a black circle, their task was to say “circle” instead of the spoken color word. This catch trial condition prevented participants from looking away or closing their eyes to prevent interference on the auditory task (Medina et al., 2021; Roelofs, 2005). A microphone was connected to Chronos (Psychology Software Tools, Pittsburgh, PA), a response box that logged vocalization onsets and recorded RTs. After each trial, the experimenter answered three questions: the response given by the participant, whether a false start had taken place (i.e., the microphone was triggered before the participant gave their response), and whether they had made an error in answering the first two questions.

This experiment was a 5 (spatial location: -90°, -45°, 0°, R45°, R90°) × 3 (distraction type: congruent, incongruent, control) within-subjects design. The proportion of congruent to incongruent to control trials was equal: each of these visual distraction conditions were presented 120 times over the course of the experiment, along with 5 catch trials. Each spatial location had 73 trials. These 73 trials consisted of the congruent, incongruent, and control trials 24 times each,

along with 1 catch trial. Overall, there was a total of 365 experimental trials as well as 50 practice trials, which consisted of 10 practice trials before each spatial location block. The experiment was administered using the E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA) and took approximately 30 minutes to complete.

2.2. Results

Overall error rates during Experiment 1a were low (*M* = 0.01, *SD* = 0.01). Inaccurate trials and catch trials were excluded from the RT analyses. Regarding the catch trials, which were used to "catch" participants gazing away from the visual distractors, participants had at least an 80% accuracy rate except for 4 participants (*N* = 3: 0% accuracy; *N* = 1; 50%). These 4 participants were excluded from the analyses. For all analyses, $\alpha = 0.05$, and the Greenhouse-Geisser correction was used in cases where sphericity was violated.

A 5 (spatial location) x 3 (distraction type) repeated-measures ANOVA was used to analyze the means of medians of RTs. There was a main effect of distraction type, F (2, 238) = 39.20, $p < 0.01$, $\eta_p^2 = 0.25$. Post hoc comparisons using the Bonferroni correction indicated that congruent RT (*M* = 697; *SD* = 104) was significantly lower than incongruent RT (*M* = 706, *SD* = 105) and control RT (*M* = 712, *SD* = 105), while incongruent RT and control RT did not significantly differ from each other. There was no significant main effect of location (F (4, 431) = 1.08, $p = 0.36$, $\eta_p^2 = 0.01$) or significant interaction (F (7, 848) = 0.41, $p = 0.90$, $\eta_p^2 = 0.00$).

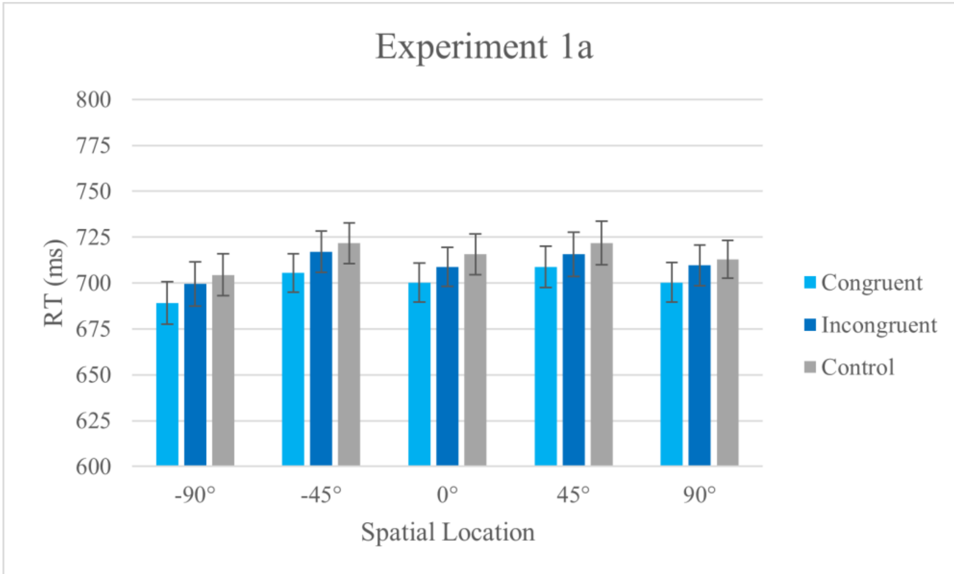

Figure 3. RTs with standard error bars for Experiment 1a.

2.3. Discussion

Experiment 1a examined if auditory spatial location has an effect on the size of interference for auditory attention and visual distractors. To recap the predictions, if performance is worst at 0° (due to spatial overlap with the distractor) and improves at angles further away (due to increased distance from the distractor), this would support prior research stating that multisensory integration is enhanced whenever stimuli from different senses are presented at the same spatial location (Spence, 2013; Stein & Meredith 1993) as well as prior research demonstrating a detriment in the cross-modal Stroop task (with non-spatialized auditory stimuli) when considering content congruence, as incongruent distractors in the same space as the target become harder to ignore (Medina et al., 2021). Improved performance at -90°, 0°, and 90° specifically would support prior work on the spatial auditory gradient (Golob & Mock, 2020). If performance is linear, or is the same across spatial locations, this would support an argument for auditory spatial location generally not mattering in the cross-modal Stroop task with spatialized

auditory stimuli (Lutfi-Proctor et al., 2018). Experiment 1a also examined the Stroop effect under a spatial cross-modal paradigm with visual distractors and spatialized auditory targets.

The results from the repeated-measures ANOVA demonstrated a cross-modal Stroop effect, which was consistent with one of our hypotheses as well as Lutfi-Proctor et al. (2018) and the Stroop task literature at large. However, spatial location for auditory targets did not appear to influence cross-modal Stroop interference, which was at odds with our prediction that performance should be the worst at 0° and then improve at angles further away. Also, performance seemed to trend towards RTs being fastest at -90°, 0°, and 90° (see Figure 3), which aligned with prior work on the spatial auditory gradient without distractors (Golob & Mock, 2020). The trend of RTs being fastest at -90° has not been observed in similar paradigms previously and the closest example of spatial auditory asymmetry, which is a "right ear advantage" during dichotic listening tasks (Hugdahl et al., 2008; Yurgil & Golob, 2010), refers to 90° instead."

The present results, taken with the finding that spatial location for auditory distractors did not influence cross-modal Stroop interference either (Lutfi-Proctor et al., 2018), built a case for spatial location in the auditory modality not exerting influence regardless of goal maintenance (i.e., whether the auditory stimuli are targets or distractors). This differs from the finding that spatial location has an impact on the size of the Stroop effect (Flowers & Stoup, 1997; Kahneman & Chajczyk, 1983; Risko et al., 2005), which suggests that there may be different underlying mechanisms of the cross-modal Stroop effect and the Stroop effect. Further research in the cross-modal Stroop task is needed to clarify the impact of spatial location for auditory stimuli, which thus far has been demonstrated to not have an influence on the cross-modal Stroop task in both a visual target and auditory distractor variant (Lutfi-Proctor et al., 2018) and an

auditory target and visual distractor variant (the current Experiment 1a). Finally, it is worth noting that even though there was no influence of auditory spatial location on the size of the interference effect in both studies, RTs in Experiment 1a were generally slower than RTs in Experiment 4 of Lutfi-Proctor et al. (2018). This RT slowing is in line with prior cross-modal Stroop work demonstrating slower RTs for auditory targets compared to visual targets (Medina et al., 2021), and overall supports the fundamental role of target modality in the cross-modal Stroop paradigm.

Chapter 3. Experiment 1b

Previous research has highlighted that traditional attention control measures are insufficient at detecting individual differences in attention control ability, which is generally a powerful predictor of human behavior (Draheim et al., 2021). Two underlying factors rooted in reliance on RT are speed-accuracy interactions and processing speed (Draheim et al., 2021; Hedge et al., 2018; Miller & Ulrich, 2013; Rey-Mermet et al., 2017). The adaptive Stroop task (Draheim et al., 2021) was recently designed to better detect individual differences in attention control by minimizing these factors through the use of a response deadline measure, as opposed to RT-accuracy measures.

Apart from investigating spatial auditory attention in Experiment 1a, a second goal of the current study was to assess the predictive power of individual differences in attention control ability by using the adaptive Stroop task. Prior research has shown that better performance on the adaptive Stroop task is associated with better performance on the classic Stroop task (Draheim et al., 2021). Comparing the results of Experiment 1b to Experiment 1a can reveal the impact of individual differences in attention control ability on a non-adaptive, non-classic Stroop task. Our hypothesis was a lack of a significant relationship between response deadline in Experiment 1b and the size of the cross-modal Stroop effect in Experiment 1a. We predicted this due to both variations to the classic Stroop task in Experiment 1a (i.e., the cross-modal Stroop task with spatialized auditory stimuli), as opposed to using the classic Stroop task such as in Draheim et al. (2021), as well as the growing literature highlighting insufficiencies in typical, non-adaptive Stroop task designs in measuring the construct of attention control (Draheim et al., 2021; Hedge et al., 2018; Miller & Ulrich, 2013; Rey-Mermet et al., 2017).

3.1. Method

Participants

The same participants from Experiment 1a completed Experiment 1b after a break. As mentioned above, these were Louisiana State University undergraduate students who participated for course or extra credit and were not eligible to participate if they reported color blindness, abnormal hearing, or a first language other than English. Further, they were screened using perception checks to confirm hearing ability for the five spatial locations.

Materials and Design

During this experiment, the adaptive Stroop task was administered to participants. This contained the classic Stroop task: participants were shown the color words “red”, “blue”, or “green” in red, blue, or green font. Participants were instructed to indicate the font color as quickly and accurately as possible by pressing the 1, 2, or 3 key on a number pad. Each key had a color-coded sticky note taped over it. Because participants indicated colors with keyboard presses instead of vocalized responses, Chronos (Psychology Software Tools, Pittsburgh, PA) was not used in Experiment 1b.

The methodological development from the classic Stroop task was that the difficulty of this task was determined by an adaptive response deadline (Draheim et al., 2021). Each trial had a response deadline that limited how much time the participant had to respond before they heard a loud beep and forfeited the opportunity to respond on that trial. Eighteen blocks of 18 trials each (total 324 trials) were administered. The response deadline decreased (i.e., less time to respond) when the participant was accurate on at least 15 trials within each block, and increased (i.e., more time to respond) when the participant was accurate on 14 or less trials within each block. The first block had a response deadline of 1,230 ms. For the first six blocks, the response

deadline either decreased by 90 ms or increased by 270 ms for the next block, again depending on whether the participant was accurate on at least 15 of the 18 trials. For subsequent blocks, the response deadline either decreased by 30 ms or increased by 90 ms. The stimuli remained on the screen until the response deadline. Each block had 12 congruent and 6 incongruent trials in random order with a randomized 400 ms to 700 ms interstimulus interval. To summarize, response deadlines increased or decreased to converge upon an 83.33% accuracy threshold (accuracy on 15 of 18 trials per block) for each participant.

The response deadline was the same for incongruent and congruent trials. Congruent and incongruent trials were treated equally in determining whether the deadline increased or decreased for the next block (i.e., participants need to be correct and respond before the deadline on at least 15 of 18 total trials for the response deadline to decrease, independent of whether these trials were incongruent or congruent). The dependent variable was the response deadline after the final block. This experiment was administered using the E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA) and took approximately 20 minutes to complete.

3.2. Results

Response deadlines in the current study (M = 996.34, SD = 314.20) were comparable to response deadlines from the initial adaptive Stroop task study (M = 1013.01, SD = 345.33) (Draheim et al., 2021). Accuracy on the adaptive Stroop task in the current study (M = 87.68%, SD = 3.5%) was also consistent with the adaptive Stroop task's design of converging participants on an 83.33% accuracy rate. An analysis for response deadlines ±3.5 SD away from the mean (Draheim et al., 2021) identified one outlier, which was included because the outcomes were the same with or without it.

A linear regression was conducted using response deadline in Experiment 1b as the independent variable and the cross-modal Stroop effect (i.e., the difference score calculated by incongruent trial RT minus congruent trial RT in Experiment 1a) as the dependent variable. Response deadlines did not explain a significant amount of variance in the cross-modal Stroop effect, F (1, 118) = 0.06, p = 0.80, $R^2_{adjusted}$ = -0.01 (see Figure 4). A correlation matrix was also used for analyzing relationships between response deadlines and means of medians of congruent, incongruent, and control RTs in the cross-modal Stroop task. There were no significant Pearson's r values associated with response deadlines, which demonstrated that response deadline was not significantly correlated with congruent RT, incongruent RT, or control RT (see Table 2).

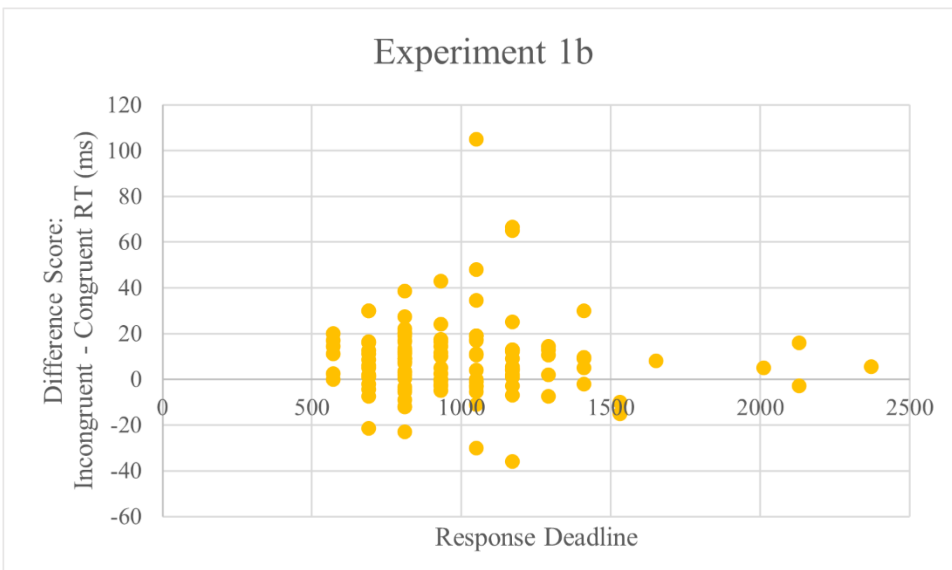

Figure 4. Response deadline in Experiment 1b as a predictor of the cross-modal Stroop effect (i.e., difference scores calculated as incongruent trial RT minus congruent trial RT) in Experiment 1a. Positive difference scores indicate higher RT, or more delay, on incongruent trials. Negative difference scores indicate higher RT, or more delay, on congruent trials.

Table 2. Response deadline and means of medians of congruent, incongruent, and control RTs. Note: * = $p < 0.01$.

	Response Deadline	Congruent RT	Incongruent RT	Control RT
Response Deadline	—			
Congruent RT	-0.02	—		
Incongruent RT	-0.03	0.99*	—	
Control RT	-0.03	0.98*	0.98*	—

3.3. Discussion

Experiment 1b assessed whether individual attention control ability, as represented by deadline scores on the novel adaptive Stroop task (Draheim et al., 2021), could predict cross-modal Stroop interference in Experiment 1a. To recap the predictions, if the findings indicated significant predictive power, this outcome would support the use of the adaptive Stroop task in its base form as a flexible attention control measure that can predict performance in another Stroop task that has additional elements at play (i.e., the auditory modality and multiple spatial locations). This would also suggest that, despite a surge of recent literature suggesting that the typical Stroop task does not properly measure control (Draheim et al., 2021; Hedge et al., 2018; Miller & Ulrich, 2013; Rey-Mermet et al., 2017), the typical Stroop taps into the construct enough that the adaptive Stroop task can still predict performance on it. Conversely, if there is not significant predictive power, this outcome would suggest that the use of the adaptive Stroop task to predict performance in distinct tasks might require changes to its base form to suit various research purposes. No significant predictive power would also suggest that the adaptive Stroop task is measuring something fundamentally different than the typical Stroop task, which would be in line with recent attention control research.

Before discussing the results from Experiment 1b compared to Experiment 1a, it is

important to review Experiment 1b alone in terms of the response deadlines. Response deadlines in the current study were comparable to the response deadlines from Draheim et al. (2021). This finding lends support to the reliability of the adaptive Stroop task considering two noteworthy differences in sample size and diversity. Firstly, the current study's sample size (N = 120) was a fraction of the sample size from Draheim et al. (2021; N = 403). Secondly, the current study exclusively sampled from the university participant pool at Louisiana State University, while Draheim et al. (2021) sampled from both the university participant pool at the Georgia Institute of Technology (Georgia Tech) as well as the local community. This difference in sampling may be relevant because, by recruiting a much larger sample that did not exclusively consist of undergraduate students, Draheim et al. (2021) likely had a more representative sample with greater variability in age, ethnicity, income level, education level, and more, yet we were able to reliably replicate their response deadlines. Also, accuracy on the adaptive Stroop task in the current study was consistent with the adaptive Stroop task's design of converging participants on an 83.33% accuracy rate. Draheim et al. (2021) did not report accuracy data on the adaptive Stroop task for comparison. Future research using the adaptive Stroop task should report accuracy data to confirm the effectiveness of the task's adaptation to participants, which is especially important given the novelty of the task.

The results from the linear regression comparing Experiment 1b to Experiment 1a demonstrated that the response deadline had no significant predictive power on the size of the cross-modal Stroop effect from Experiment 1a, which aligned with our hypothesis. We used Pearson's correlation to be consistent with prior work in this area, such as Morey et al. (2012) who used Pearson's correlations to examine relationships between the size of the Stroop effects across tasks and WMC. However, it is worth noting that future research conducting correlations

with response deadlines might consider different types of correlations other than Pearson's, such as Spearman's and Kendall's, given that response deadlines appeared to not be fully continuous and that Pearson's correlations carry certain assumptions (e.g., normality, linearity, and homoscedasticity) that seemed questionable in the present experiment (see Figure 4) but could have been less so given an increased sample size similar to Draheim et al. (2021).

We also conducted a secondary correlation analysis that compared response deadline with congruent RT, incongruent RT, and control RT. This approach was similar to Medina et al. (submitted) who examined neuroticism and conscientiousness in the cross-modal Stroop task by comparing scores on each individual difference factor with congruent RT, incongruent RT, and control RT. The Experiment 1b correlation analysis demonstrated that there was no significant relationship between response deadline and congruent RT, incongruent RT, and control RT. Overall, the present results differed from the finding that the response deadline has a significant, but weak, positive correlation with the classic Stroop effect (Draheim et al., 2021). This pattern of results suggests that the positive correlation detected in Draheim et al. (2021) was likely due to the task similarity in attention control measures given that the adaptive Stroop task is essentially an adaptive version of the classic Stroop task. Once task similarity was removed from the equation by adding auditory and spatial components to the Stroop task in the current study, the relationship between the two disappeared. There are three ways to interpret this.

The first interpretation of this difference is that non-adaptive Stroop tasks generally measure some useful mechanism of attention control that adaptive Stroop tasks do not capture, as there needs to be task similarity for there to be a relationship between an adaptive and non-adaptive Stroop task (Draheim et al., 2021). In other words, there is the possibility that there would have been a significant relationship if Experiment 1b used an adaptive version of the

spatial, cross-modal Stroop task and was then compared to the non-adaptive version of the same task in Experiment 1a. Once task differences are accounted for, if non-adaptive Stroop tasks are measuring attention control due to significant relationships to adaptive Stroop tasks that were designed to account for measurement issues in attention control, then non-adaptive Stroop tasks versus adaptive Stroop tasks need to be examined more closely in terms of what aspects of attention control each version is capturing. This interpretation supports moving forward with both non-adaptive and adaptive Stroop tasks since they are both tapping attention control well enough to be related to each other's performance but must be measuring different mechanisms due to their fundamental design differences, which are important to explore. The second interpretation of the difference, which is similar, is that typical Stroop tasks overall do not tap into attentional processes sufficiently. This interpretation instead predicts that if Experiment 1b used an adaptive version of the spatial, cross-modal Stroop task and was then compared to the non-adaptive version of the same task in Experiment 1a, there would have been a significant relationship but only because the adaptive version is measuring the same construct of attention control but in an improved way (Draheim et al., 2021; Hedge et al., 2018; Miller & Ulrich, 2013; Rey-Mermet et al., 2017). Unlike the first interpretation, this second interpretation supports the use of adaptive Stroop tasks as replacements for non-adaptive Stroop tasks moving forward.

The third interpretation of the difference is that it is due to a mismatch in levels of attention control when comparing the adaptive Stroop task to the cross-modal Stroop task. Morey et al. (2012) originally proposed that the reason they detected a significant negative correlation between WMC and the Stroop effect (i.e., higher WMC was associated with lower interference on the classic Stroop task), but no significant correlation between WMC and the cross-modal Stroop effect, was due to a difference in levels of attention control measured by the working

memory tasks, the classic Stroop task, and the cross-modal Stroop task. Working memory tasks tapped broad attention control, or goal maintenance, due to the need to memorize goal-relevant targets while responding to goal-irrelevant questions. The classic Stroop task also tapped broad attention control because participants recovering from a lapse in attention, or goal maintenance, would be met with the visual target and distractor and were prone to interference when trying to remember which color to name. The cross-modal Stroop task with visual targets and auditory distractors, on the other hand, did not tap goal maintenance because recovering from a lapse in attention was not associated with any consequence: after recovery, participants only saw the target color square, as the distractor spoken color word was no longer present.

This third interpretation applies to the current study when considering the levels of attention control measured by the Experiment 1a and Experiment 1b tasks. Experiment 1a used the cross-modal Stroop task with auditory targets and visual distractors, which was the opposite of the stimuli from the cross-modal Stroop task used in Morey et al. (2012). This difference is critical because the cross-modal Stroop task in Experiment 1a did measure broad attention control: participants recovering from a lapse in attention only saw the visual distractor, as the target spoken color word was no longer present. Meanwhile, Experiment 1b used the adaptive Stroop task (Draheim et al., 2021), which was an adaptive version of the classic Stroop task. This difference is also critical because the adaptive Stroop task did not measure broad attention control due to its adaptive nature: each trial limited how much time the participant had to respond before they heard a loud beep and forfeited the opportunity to respond on that trial. Because the task promoted changes in performance based on lapses in attention, the final response deadlines did not represent participant goal maintenance. In summary, the measurement mismatch present in the current study was that Experiment 1a measured the broad level of

attention control while Experiment 1b did not. Additionally, variability in the dataset could have contributed to these patterns of results. Morey et al. (2012) reported variability in terms of the size of the cross-modal Stroop effect for visual targets (*M* = 27 ms, *SD* = 43 ms). Their reported *M* was larger than the current effect with auditory targets, and their *SD* suggested that the size of their cross-modal Stroop effect varied both above and below zero, like in our own data (see Figure 4).

Chapter 4. General Discussion

4.1. Summary of Findings

There were two goals of the current study. The first was to examine attention control for spatialized auditory targets in terms of visual distraction. The second was to examine whether individual differences in attention control ability predict performance in that context. Experiments 1a and 1b were conducted to address each goal respectively.

Experiment 1a was a spatial cross-modal Stroop task. Participants needed to name auditory color word targets from five spatial locations while ignoring visual color square distractors in front of them. Results from Experiment 1a did not demonstrate a significant impact of spatial location on the size of the cross-modal Stroop effect (see Figure 3). However, the main effect of distraction type was significant, which replicated the pattern of findings from Lutfi-Proctor et al. (2018). Experiment 1a detecting the same pattern of findings as Lutfi-Proctor et al. (2018) when the modalities were reversed has particular importance regarding distraction type. A main effect of distraction type in the current study built upon the previous finding that spatialized sounds do not play a role on the size of the cross-modal Stroop effect (Lutfi-Proctor et al., 2018) by establishing that this remains true despite the level of goal maintenance required, or how one exerts attention control. That is, the lack of a spatialized sound effect persisted even when the spatialized sounds are the targets instead of the distractors.

The lack of spatial location influence in Experiment 1a overall suggested that there is a linear gradient shape for auditory attention control: auditory attention control for one spatial location does not differ significantly from auditory attention control at another location. This outcome is surprising given that previous work on the shape of the auditory attention gradient has demonstrated faster responses for auditory stimuli at 0°, -90°, and 90° (Golob & Mock,

2020). This difference may be due to methodology in that the cited study did not involve attention control for distractors– the current study is the first to establish the shape of a spatial auditory attention control gradient in terms of targets and distractors, while also accounting for content congruence unlike previous spatial auditory work using neutral visual distractors (Lewald, 1997; Okita & Wei, 1993; Pomper & Chait, 2017) or no distractors (Golob & Mock, 2020; Golob et al., 2021). This builds upon previous work emphasizing the role of content congruence in spatial integration (Medina et al., 2021) by examining the same paradigm, the cross-modal Stroop task, while adding the spatialization of auditory stimuli.

Experiment 1b was an adaptive Stroop task designed to detect individual differences in attention control (Draheim et al., 2021). Participants needed to name the font color targets of color words while ignoring the word distractors. Previous work has shown that response deadline has a significant, but weak, positive correlation with the size of the classic Stroop effect (Draheim et al., 2021). However, results from Experiment 1b demonstrated that the response deadline had no significant predictive impact on the size of the cross-modal Stroop effect.

We offered three interpretations for this finding. The first two interpretations both involve the nature of adaptive Stroop tasks versus non-adaptive Stroop tasks but differ in their views of non-adaptive Stroop tasks. The first interpretation is that non-adaptive Stroop tasks measure some useful mechanism of attention control that adaptive Stroop tasks do not capture. This view is driven by the finding that, given task similarity, the adaptive version of a particular non-adaptive Stroop task correlates with it (Draheim et al., 2021). According to this first interpretation, given task similarity between Experiment 1a and Experiment 1b (i.e., the spatial, cross-modal Stroop task compared to an adaptive version of it), we should have detected a significant relationship just as Draheim et al. (2021) did. This interpretation provides support for

using both non-adaptive and adaptive Stroop tasks to measure different aspects of attention. The second, related interpretation is that the lack of relationship in the current study was due to the lack of ability for non-adaptive Stroop tasks to measure attention control sufficiently and that, given task similarity, there would be a significant relationship, but it is better to use the adaptive version regardless because it is more effective at measuring attention control. This interpretation provides support only for using non-adaptive Stroop tasks.

The third interpretation, which comes from a different perspective than the initial two interpretations, focuses on the levels of attention control required within a given task. Morey et al. (2012) stated that they did not detect a relationship between WMC and the cross-modal Stroop effect due to the working memory tasks accounting for broad attention control (i.e., goal maintenance) and the cross-modal Stroop task with visual targets and auditory targets not accounting for broad attention control due to a lack of consequence for lapses in attention. It is possible that we did not detect a relationship between the adaptive Stroop task and the spatial cross-modal Stroop task with auditory targets and visual distractors due to the adaptive Stroop task not accounting for natural, broad attention control (i.e., it prompted changes in participant behavior with a beep during an attentional lapse) and the cross-modal Stroop task with auditory targets and visual distractors accounting for broad attention control due to the consequence for lapses in attention. In other words, it is possible that we did not detect a relationship due to a level of attention control mismatch between our individual difference factor and an attention control task, which is what Morey et al. (2012) suggested occurred in their own study.

4.2. Applications

Experiment 1a generates future directions for better understanding spatial auditory

attention. One future direction stems from the fact that the spatial location of auditory stimuli does not seem to influence performance on the cross-modal Stroop task in both a visual target and auditory distractor variant (Lutfi-Proctor et al., 2018) and an auditory target and visual distractor variant (Experiment 1a). The next step would be to use an auditory Stroop task (i.e., auditory target and auditory distractor). This would no longer be a "cross-modal" Stroop task, but this would further clarify the impact, if any, of spatialized auditory stimuli in the Stroop paradigm.

This direction also makes sense when considering a follow-up on the "linear" spatial auditory attention gradient by assessing the role of cross-modal context. This can be done by inspecting how the auditory attention gradient shape differs in a unimodal context, which can be done by using an auditory Stroop task. It is important to examine the spatial auditory attention control gradient in this way specifically because this involves distractors while prior work on the spatial auditory gradient has either not engaged attention control due to having no distractors (Golob & Mock, 2020; Golob et al., 2021) or has used neutral visual distractors (Lewald, 1997; Okita & Wei, 1993; Pomper & Chait, 2017) that do not test the role of content congruence.

Experiment 1b generates future directions for rethinking attention control through an individual differences approach in order to refine measurement of the construct. Different future directions stem from our three interpretations of the results from Experiment 1b.

The first interpretation, that non-adaptive Stroop tasks measure some useful mechanism of attention control that adaptive Stroop tasks do not, requires isolated comparisons to the adaptive Stroop task where both the non-adaptive and the adaptive Stroop tasks are suited to the same research questions. An approach to addressing this possibility in future research is to edit stimuli in the adaptive Stroop task to create adaptive Stroop task variants suited towards specific

research questions. This approach would be similar to the classic Stroop task and its development into other variants decades after its inception (Stroop, 1935) that are suited to various purposes except with an adaptive spin. Under this first interpretation, a cross-modal adaptive Stroop task should predict performance on the non-adaptive cross-modal Stroop task, an emotional adaptive Stroop task should predict performance on the non-adaptive emotional Stroop task, and so forth. These findings would be in line with the finding that the adaptive Stroop task is correlated with performance on the classic Stroop task (Draheim et al., 2021). The purpose of this approach is to stimulate discussion that further disentangles adaptive Stroop tasks from non-adaptive Stroop tasks, since they are both tapping attention control well enough to be related to each other's performance but must be tapping into different aspects of attention control due to their foundational differences in design. This approach would also help researchers understand under what conditions (i.e., research questions) the adaptive Stroop task variant does not predict performance on its parallel non-adaptive Stroop task. The applications are endless with this interpretation, as the wide range of existing Stroop task variants (e.g., emotional Stroop, numerical Stroop, multilingual Stroop, etc.) can each be subject to adaptive versions to be used alongside them for measuring different aspects of attention control in the context of their respective research topics. The related second interpretation, that typical Stroop tasks overall do not tap into attentional processes sufficiently, also suggests moving forward with the adaptive Stroop task but for a more process pure measure of attention control that updates non-adaptive Stroop task variants. This operates under the assumption that non-adaptive and adaptive tasks tap into the same construct, but adaptive tasks are more effective in doing so due to capturing important individual differences (Draheim et al., 2021; Hedge et al., 2018; Miller & Ulrich, 2013; Rey-Mermet et al., 2017). Under this second interpretation, adaptive Stroop task variants

can be considered replacements to non-adaptive Stroop task variants rather than versions to be used alongside their parallels.

The third interpretation, that there is a mismatch between levels of attention control represented by the cross-modal Stroop task (with auditory targets and visual distractors) and the adaptive Stroop task, can be addressed in the future by researchers accounting for the two levels of attention control when exploring relationships between an individual difference factor and an attention control task such as in Morey et al. (2012) and in the current study, or just between two tasks more generally. This is important to account for because it removes a confound when investigating research questions unrelated to the discussion of levels of attention control. The levels of attention control are also worth exploring as the focus of future research questions, which can inform the way researchers discuss the mechanisms underlying individual difference factors and attention control measures. In short, related correlational research in the future should verify that their tasks match in terms of levels of attention control before investigating other research questions, or that the tasks mismatch purposefully to support research questions related to levels of attention control.

4.3. Conclusion

To conclude, the current study explored how auditory attention in the cross-modal Stroop task is influenced by vision and spatial location, and how individual differences in attention control ability (as measured by the adaptive Stroop task) could predict task performance in that context. Results showed that auditory spatial location does not play a role in the cross-modal Stroop task with auditory targets and visual distractors. This outcome has implications for understanding auditory spatial location in the cross-modal Stroop task, which seems to exert no

significant influence regardless of goal maintenance, or whether the auditory stimulus is a distractor (Lutfi-Proctor et al., 2018) or a target. Our use of congruent and incongruent distractors also contributes to a novel understanding of spatial auditory attention control more generally, as past research on the auditory attention gradient has either not engaged distractors (Golob & Mock, 2020; Golob et al., 2021) or only used neutral visual distractors (Lewald, 1997; Okita & Wei, 1993; Pomper & Chait, 2017). The results also demonstrated that individual differences in attention control ability did not predict performance on the cross-modal Stroop task. This outcome has implications for accounting for the levels of attention control when comparing individual difference factors and attention control tasks (Morey et al., 2012). More broadly, this investigation contributes to the evolving literature on attention control by supporting recent research that emphasizing an individual differences approach (Burgoyne & Engle, 2020; Draheim et al., 2021; Hedge et al., 2018; Miller & Ulrich, 2013; Rey-Mermet et al., 2017) to refining attention control measurement.

Appendix A. Institutional Review Board Approval

LSU | Office of Research & Economic Development

TO:	Emily Marie Elliott LSUAM | Col of HSS | Psychology | CC00124
FROM:	Alex Cohen Chairman, Institutional Review Board
DATE:	11-Nov-2022
RE:	E2060
TITLE:	An Investigation of Cognitive Performance
New Protocol/Modification/Continuation:	Continuation
Review Date:	11-Nov-2022
Status:	Approved
Approval Date:	11-Nov-2022
Approval Expiration Date:	10-Nov-2023
Re-review Frequency	Three years
LSU Proposal Number:	
By:	Alex Cohen, Chairman

Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.

7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc. Approvals will automatically be closed by the IRB on the expiration date unless the PI requests a continuation.**

** All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/research*

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Appendix B. Informed Consent Form

Consent to Serve as a Subject in Research

I consent to serve as a participant in a research investigation that focuses on the memory abilities and reaction times of both children and adults. The study is entitled "An Investigation of Cognitive Processes" sponsored by Louisiana State University and is to be conducted under the direction of Emily Elliott, Ph.D.

I understand that the study will involve these procedures: In the presence of one of the members of the research team, I will engage in a task with visual stimuli (words, arrows, or numbers). Then I will be asked to indicate my response to the visual stimuli either through verbal repetition or through a nonverbal response such as a computer keypress or mouse-click. I will also be asked to provide information about my grade point average (GPA), which includes self-report, as well as official confirmation of the GPA from LSU by the research director. Task results will be compared to GPA information.

The responses will be coded so that my name will not be linked to my responses in any of the oral or written reports that result from the studies. The scores will be kept strictly confidential and will not enter school records in any way. Only the research director will have access to specific student grades, and will assign a participant number during data collection to anonymize aggregated data. The entire session, which will be conducted in the Psychology Department at Louisiana State University, will take 1 hour or less. I understand that, depending on the study, I may be asked to return for one or more additional sessions, but that my willingness to participate in one session will not obligate me to return.

The study is expected to benefit children and adults by helping to gain an understanding of people's abilities to perform cognitive tasks. Individuals are often faced with situations with multiple sources of input, and it is important for them to be able to focus on one item, while potentially ignoring other items. This research could generate practical suggestions for classroom settings, and may help educators to be more aware of children's abilities to focus their attention in the presence of distracting materials. There are no diagnostic implications of the research for individual participants; it cannot determine if someone has generally good or poor memory in a practical sense.

Refusal to consent to participate will involve no penalty. I understand that I am free to withdraw my consent and discontinue participation at any time without penalty. I will receive the agreed-upon reward for the session even if I withdraw from the study before it is complete. I understand that this study is not expected to involve risks or harm any greater that those ordinarily encountered in daily life. I understand also that it is not possible to identify all potential risks in an experimental procedure, but that all reasonable safeguards will be taken to minimize the known and unknown potential risks.

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to Emily Elliott, (225)578-7460. If I have questions about subjects' rights or other concerns, I can contact Alex Cohen, Chairman of the

LSU Institutional Review Board, irb@lsu.edu. I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.

Signature: ______________________________ Date: ____________

Print name: ___________________________

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Vita

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