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The Role of Visual Stimuli in Cross-Modal Stroop Interference

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Abstract

It has long been known that naming the color of a color word leads to what is known as the Stroop effect (Stroop, 1935). In the traditional Stroop task, when compared to naming the color of a color-neutral stimulus (e.g. an X or color patch), the presence of an incongruent color word decreases performance (Stroop interference), and a congruent color word increases performance (Stroop facilitation). Research has also shown that auditory color words can impact the color naming performance of colored items in a similar way in a variation known as cross-modal Stroop (Cowan & Barron, 1987). However, whether the item that is colored interacts with the auditory distractor to affect cross-modal Stroop interference is unclear. Research with the traditional, visual Stroop task has suggested that the amount of color the visual item displays and the semantic and phonetic components of the colored word can affect the magnitude of the resulting Stroop interference; as such, it is possible the same components could play a role in cross-modal Stroop interference. We conducted two experiments to examine the impact of the composition of the colored visual item on cross-modal Stroop interference. However, across two different experiments, three test versions, and numerous sets of trials, we were only able to find a small effect of the visual stimulus. This finding suggests that while the impact of the auditory stimuli is consistent and robust, the influence of non-word visual stimuli is quite small and unreliable and, while occasionally being statistically significant, it is not practically so.

Keywords

Cross-modal Stroop; auditory distractors; Stroop interference; habituation; dimension strength

Auditory distractors have long been known to impact our performance (Cowan & Barron, 1987; Spence, Ranson, & Driver, 2000; Beaman, 2004; Roelofs, 2005), and one way in which we examine the effect of auditory distractors is the cross-modal Stroop task. The original or traditional Stroop task involves a target and distractor that are in the same

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modality—visual. Participants name the color of the ink of an incongruent or congruent written color word or a nonverbal control stimulus such as a row of x's (Stroop, 1935; Langer & Rosenberg, 1966; Logan & Zbrodoff, 1979; Roelofs, 2005). Cross-modal Stroop varies from the traditional Stroop task in that the target and distractor are in different modalities—the target is visual while the distractor is auditory. During cross-modal Stroop, one names the color of visual items while hearing congruent and incongruent auditory color words or silence. Within incongruent trials, the visual item and auditory color word do not match; for example, a green square may be seen while hearing the word "red." As the task is to name the color of the visual item, the correct answer is "green." For congruent trials, the color of the visual item and the auditory color word are the same; a red square, for example, would be presented with the auditory word "red," with the correct answer being "red." During control or neutral trials, one typically names the color of the visual item in silence.

For traditional Stroop, incongruent trials lead to slower response times (RTs) and lower accuracy levels than control trials—or those experienced in silence. This is called *Stroop interference*. Furthermore, RTs of congruent trials are sometimes faster than those of control trials, and this is known as *Stroop facilitation*. The *Stroop effect* consists of both facilitation and interference. These results have been found consistently and in participants of all ages who can read for traditional Stroop (MacLeod, 1991). With the exception of facilitation, these results have also been reliably found for cross-modal Stroop (Cowan & Barron, 1987; Shimada, 1990; Elliott, Cowan, & Valle-Inclan, 1998; Roelofs, 2005). However, why facilitation in cross-modal Stroop is not as robust as facilitation in traditional Stroop is not clear at this time, and is not the focus of the current study (Elliott et al., 1998; Roelofs, 2005; Morey, Elliott, Wiggers, Eaves, Shelton, & Mall, 2012). The purpose of the current study was to examine the import of the visual stimulus in the cross-modal Stroop task and, thereby, inform the theoretical accounts of the cross-modal Stroop effect.

The Visual Stimuli in the Stroop Task

Over the years, many different cross-modal Stroop experiments have used different items as their visual stimulus. Some have used colored circles (Cowan, 1989; Shimada, 1990), others colored color words (Cowan & Barron, 1987), and still others have used symbols (Elliott, Morey, Morey, Eaves, Shelton, & Lutfi-Proctor, 2013). Whether the impact of the auditory distractor varies depending upon the visual stimulus being attended to is unclear; however, in traditional Stroop, research suggests that there are three factors that may lead to various amounts of interference: the amount of color provided, the semantic properties, and the phonological properties of the visual stimulus.

In traditional Stroop, it has been shown that coloring only one letter of the written distractor word decreases the amount of interference found. For this version of the Stroop task, most of the letters are presented in a neutral color (e.g. black) and one letter is presented in a color congruent or incongruent to the color word (Monahan, 2001; Brown, Joneleit, Robinson, & Brown, 2002; Marmurek, 2003; Besner, Stolz, & Boutilier, 1997). Neutral trials usually consist of non-color words that, again, only contain one colored letter (e.g. Brown et al., 2002). Although, Stroop interference is generally still found, it is considerably smaller than the interference found when the whole word is presented in a color. However, this shrinking in the Stroop effect is not due to the RTs of incongruent trials speeding up. Rather, the neutral trials are slowing down (Monahan, 2001).

Research with the traditional Stroop task has also suggested that the more meaningful the irrelevant word, the more interference there will be. Klein (1964) conducted a Stroop experiment with four different colors (red, green, yellow, and blue). All participants saw a "colors-alone" card, which consisted of colored patches, and then one of six interference cards. On one interference card, the participants received trials in which the four different ink colors were used as the distractor words; however, other interference cards used four completely different color words (tan, purple, grey, black), color related words (fire, grass, lemon, sky), common unassociated words (put, heart, take, friend), rare words (sol, helot, eft, abjure), or unpronounceable nonsense syllables (hjh, evgjc, bhdr, gsxrq) as the distractor words. The time it took to read the entire card was compared to the time it took to name the colors on the colors-alone card (approximately 44s). Klein (1964) found that the color words that were also used as the color inks caused the most interference (37.5s longer than the colors alone card), followed by the other color words (18s), the color related words (15.5s), the common unassociated words (12s), then the rare words (7.5s), and, finally, the unpronounceable nonsense syllables (5s). Despite the fact that some of Klein's word choices were not ideal (grass, for example, shares the same first letter as green), the research area has since expanded.

Additional research suggests that while all words interfere with ink color naming, the more related the word is to the ink color the larger the facilitation and interference caused (Dalrymple-Alford, 1972). Therefore, those color words that are in the response set (these words also have representative ink colors) cause more interference than colors not in the response set. Furthermore, the word "snow" induces as much interference when naming the color white as the word "grass" does for naming green; as such, it appears that the hierarchy of interfering words is not due purely to articulation (Dalrymple-Alford, 1972)

In addition to the importance of the semantics of the distractor words, it has also become apparent that the phonological properties (separate from articulation) of the distractor word are also important. Meyer and Schriefers (1991) looked at picture word Stroop and phonologically related and unrelated words. For disyllabic targets, the phonologically related words had either the first or second syllable of the target (i.e. a target word of hammer with phonologically similar words havik and zomer) while monosyllabic distractor words shared either the onset and nucleus or the nucleus and coda (i.e. a target word of veer with phonologically similar words veen or peer) of the target word. Meyer and Schriefers (1991) found that both the beginning-related and the ending-related words facilitated priming in relation to unrelated words. The timing of the words, though, was very important. Beginning-related words could lead to facilitation if they were presented 150ms before or after the target picture. Ending-related words, however, had to be presented 150ms after the onset of the picture for facilitation to occur.

Although not as extensive as the work conducted with traditional Stroop, Elliott and Cowan (2001) examined the effect of different auditory distractors on cross-modal Stroop interference. They presented three types of auditory stimuli, and examined the amount of

Stroop interference caused when a color word in the response set was heard or when a non-color word was heard; a tone was used as a neutral stimulus. They found that the color words led to larger interference than the non-color words, which were slower than the tone condition.

Altogether, these findings suggest that amount of color presented as well as the semantic and phonological properties of the visual stimuli play an important role, at least in the traditional Stroop task. Furthermore, the properties of the auditory distractor in cross-modal Stroop appear to follow a similar semantic-relatedness pattern as that found in traditional Stroop. The current study questioned if the properties of the visual stimuli in cross-modal Stroop can also have an impact on the effect. To determine whether the cross-modal Stroop task shares this characteristic with the traditional Stroop task, the visual stimuli chosen for color naming were manipulated in the current study. The manipulation of the visual stimulus can also inform the theoretical explanations for the cross-modal Stroop task, and whether the traditional and cross-modal versions of the task share similar underlying mechanisms.

The Current Study

There are two broadly accepted mechanisms involved in the Stroop effect. Firstly, there is an inhibition mechanism: participants have to inhibit the irrelevant dimension (the written or spoken word) in order to respond to the target information (the color of the ink or visual item). Secondly, there appears to be a response competition mechanism; however, exactly what is causing this response competition and where in the process this competition is taking place is unknown, although many would argue that this competition occurs during the response selection phase (Cowan & Barron, 1987; Roelofs, 2005).

One view of the Stroop effect draws upon the idea of the Stroop task involving two dimensions (written/auditory words and color) that vary in strength; essentially, the effect occurs because one dimension (written/auditory words) is stronger than the other (color). Many different mechanisms have been proposed to explain these dimensional strength differences and vary from pathway strength (Botvinic, Carter, Braver, Barch, & Cohen, 2001) to dimensional discriminability (Melara & Algrom, 2003) and depth of processing (Roelofs, 2005). Although the underlying mechanism is under contention, it is generally agreed that the stronger a dimension is, the more accurately and quickly it is named. Support for this view comes from faster word reading times in comparison to color naming in traditional Stroop (Glaser & Glaser, 1982) and for spoken word repeating in contrast to color naming (Roelofs, 2005).

As an alternative to the strength view discussed above, research suggests that the semantic components of the distracting dimension are important for the Stroop effect. In the traditional, written Stroop task, color words cause more interference than non-colors which interfere more than non-verbal stimuli (Dalrymple-Alford, 1972). In cross-modal Stroop, auditory color words lead to more interference than non-color words and non-word sounds (Elliott & Cowan, 2001; Elliott et al., 1998). However, this clear importance of the semantic relatedness of distractors to targets in cross-modal Stroop could be considered surprising when one examines the findings in other auditory distraction paradigms, such as the irrelevant sound effect (ISE). During ISE tasks, participants are asked to focus on and remember visual information, which they recall later in serial order, and to ignore irrelevant auditory information (Colle & Welsh, 1976). Although some ISE studies have suggested that semantically related auditory distractors lead to more errors in recall of the target items (e.g., Bell, Mund, & Buchner, 2011; Neely & LeCompte, 1999), other studies have not replicated these results (e.g., Buchner, Irmen, & Erdfelder, 1996; Oswald, Tremblay, & Jones, 2000).

Why the semantic properties of the auditory distractor would have such a clear impact in cross-modal Stroop and not the ISE is unclear at this time; however, task-specific demands have been proposed as a key component of the ISE (e.g., the interference-by-process view; Marsh, Hughes, & Jones, 2009; Sörqvist, Nöstl, & Halin, 2012). From this viewpoint, the task of color naming is interfered with by conflicting color words, due to the demands of generating a spoken response. Serial recall depends heavily on the processing of cues to order, and the semantic properties of the irrelevant auditory distractors have little to do with the order information of the target items. Nonetheless, we know that the semantic component of the auditory dimension is significant in cross-modal Stroop, but it remains unclear if the semantic components of the visual dimension in cross-modal Stroop are also important. The research with traditional Stroop suggests that this could be the case, but how would this additional visual dimension interact with the auditory dimension? Given the reliance on task specific processes as one explanation for auditory distraction effects, one can predict that the degree to which the additional visual distracting dimension shares overlap with the task demands will determine the degree of disruption that results. Thus, the current study is able to compare the dimensional strength view with the interference-by-process view by manipulating the additional visual distractor dimension.

Beyond the obvious modality differences, the target and distractor represent two different items in cross-modal Stroop as opposed to traditional Stroop where the target and distractor are integrated. Due to the target and distractor not being integrated in cross-modal Stroop, one can easily examine the effect of adding a second distracting dimension to the target by allowing the color-naming item to have a distinct meaning beyond just serving as the color carrier. For example, one could have a row of fours supply the color in cross-modal Stroop. The use of a row of fours adds a third dimension to the cross-modal Stroop task (i.e., color, auditory color word, and numbers). Through this addition of a third dimension, one can examine whether this added distractor dimension interferes with color naming performance beyond the auditory distractor or whether there is no additional effect. Furthermore, one can vary the strength of this visual distractor dimension by having the dimension have a strong semantic component (an @ symbol or a 4) or a weak semantic component (a color patch). This allows for a test of the dimensional strength account of the Stroop effect as one would expect to see greater levels of interference the stronger the third dimension.

Although previous cross-modal Stroop experiments have used an array of visual stimuli, a direct assessment of the degree of interference based on the type of visual stimulus has not been conducted. For example, Elliott et al. (1998) and Hanauer and Brooks (2003) used colored patches while Elliott et al. (2013) experimented with a row of four colored @ symbols. Dots and circles have been used by Cowan (1989) and Shimada (1990) respectively. Roelofs (2005) has used color words that were read (whether they were black or colored is unclear), and strings of x's and colored color words were used in the original cross-modal Stroop experiment (Cowan & Barron, 1987). The following two experiments, therefore, examined and compared the impact different visual stimuli have on the magnitude of Stroop interference in the cross-modal version of the task.

The current experiments compared the impact that an additional, yet integrated, dimension in the visual domain has on cross-modal Stroop interference. According to the dimensional strength view of Stroop effects, those visual stimuli with a third additional strong dimension should display greater levels of interference than those with a weak additional dimensional component. This prediction would lead to a significant interaction of the color carrier and auditory distractor with the highest levels of interference for those trials in which the visual colored item contains a strong third dimension. In contrast, the interference-by-process view predicts that the added visual dimension should have no additional impact on performance, as the content of this dimension is not relevant to the target.

Experiment 1

In Experiment 1, only neutral and incongruent trials were used in order to examine interference alone. Based on previous research with the traditional and cross-modal Stroop task, the visual stimuli were chosen to represent a continuum of how much color the item displays, use in previous literature, and semantic complexity. As such, colored squares, colored symbols (@, *, and ~), colored numbers (4s), and colored letters (X's), as well as black color words were used. Black color words that were read were chosen as opposed to colored color words due to the fact that this condition displays a pattern of interference that is larger than that found with cross-modal Stroop but less than that found in traditional (see Elliott et al., 2013 for more information). Black color words that were read allowed us to examine what occurs when the two "strong" dimensions (written and spoken words) are placed in conflict (Roelofs, 2005).

Method

Participants—A total of 61 Louisiana State University undergraduates participated for course or extra credit. The mean age of the participants was 20.32 years (*SD* = 1.93). Participants were not eligible to participate if they reported abnormal hearing, color vision, mind-altering medications, abnormal uncorrected vision, or a first language other than English. Due to these restrictions, 2 participants were excluded from all data analyses. Of the 59 participants examined, the majority of participants were female (74.6%) with a mean age of 19.56 (*SD* = 2.01).

Materials—This experiment utilized a 2 (test type) × 2 (auditory condition) × 7 (visual condition) mixed-factor design. Incongruent and silent auditory conditions were employed within-subjects as well as the different visual stimuli, while there were two versions of the experiment (test type), which was a between-subjects factor. In one test version, the seven different visual stimuli were intermixed and presented randomly in two sets (the integrated version), while in the second version the different types of visual stimuli were presented in individual blocks (the blocked version). This manipulation was done to determine the effect of having to switch from one visual stimulus to the next from trial to trial, versus having a predictable visual stimulus that was consistent within a block of trials.

In addition, the black words, which were read, should lead to a task switch in the integrated version of the experiment. Participants are switching from the task of naming colors to reading words from trial to trial, although there are a greater number of colors naming trials than word reading trials. This design differs from the blocked version, in which the task goal for each section is clear, and remains constant throughout the block of trials. Participants read words for one block of trials. In the other sections, participants only performed color naming trials. This format is similar to that of Elliott et al. (1998), who found that presenting the different types of trials in blocks (non-color words, incongruent, etc.) led to less interference than presenting the different types of trials randomly integrated.

The visual stimuli and auditory distractors were presented simultaneously for the incongruent (the auditory word was not the same color as the visually presented stimuli) and neutral/silent (the visual stimulus was presented by itself without any auditory stimuli) conditions. Congruent trials were not examined in this design, because, as mentioned above, as facilitation is quite rare in the cross-modal version of the Stroop task and, some have argued, due to different factors than those responsible for interference (MacLeod, 1991). As the main focus of this experiment was the effect of different visual stimuli on Stroop interference, only incongruent and neutral trials were used.

The experiment was presented using E-Prime 2.08 software (Schneider, Eschman, & Zuccolotto, 2002) on a Dell Dimension desktop computer with a 17-inch monitor. A headset microphone connected to a response box logged the vocalization onsets and recorded the participants' response times. The auditory distractors used (the words red, blue, and green) were a recorded female voice and were presented through headphones at a comfortable volume with the volume of the words being subjectively equal. The task was completed in approximately 25 minutes in a room with only the participant and the experimenter.

Procedure—In the integrated version, the participants received instructions, and then saw 21 practice trials at the beginning of the first set (3 trials of each of the 7 visual stimuli), while using the microphone to name the visual stimuli without any auditory distractors. The experimental portion consisted of two sets of 168 randomly ordered trials (for a total of 336 trials) with an optional five-minute break between the two sets. There were an additional 7 practice trials at the beginning of the second set so the microphone could be adjusted if the optional break was used. In the experimental trials, each type of visual stimulus was presented for a total of 48 trials between the two sets with 24 incongruent and 24 neutral/silent trials. There were 6 possible incongruent combinations each presented an equal number of times: *red-blue*, *red-green*, *bluered*, *blue-green*, *green-red*, and *green-blue*.

The blocked version of the experiment was exactly the same as the integrated experiment except that the visual stimuli were presented in blocks as opposed to being randomly intermixed. Three practice trials were presented before each of the seven blocks of different visual stimuli (leading to a total of 21 practice trials), and the blocks were presented in random order.

Each trial began with a fixation cross in the center of the screen for 500ms. The target was presented on the screen with or without an accompanying sound through the headphones. In trials with sounds, the onset of the visual and auditory stimuli was simultaneous. The visual stimuli remained on the screen until the microphone detected a response. The participant named the color of the presented stimulus or read the black word as quickly and accurately as possible. The experimenter then used the keyboard to respond to three questions following each trial: the color word said by the participant, whether a false start had taken place (the participant essentially triggered the microphone with an incomplete response), and whether any errors were made by the experimenter in answering the first two questions.

Results

Mixed-model and repeated-measures ANOVAs were used to analyze response times (RTs), and accuracy levels. Overall, 1.81% of trials contained an inaccurate response, 2.74% involved a false start, and the experimenter made an error responding 0.41% of the time. All trials containing false starts and experimenter errors were removed from the analyses reported below. For all analyses $\alpha = .05$, and the Bonferonni correction was used for all follow-up tests. In all cases where sphericity was violated and the results were significant, the Greenhouse-Geisser correction was used.

Response Times—After removing all inaccurate trials, means of medians were used to examine RTs, and a 2 (test type) × 2 (auditory condition) × 7 (visual condition) mixed-model ANOVA was used to analyze overall RTs across the two versions of the experiment. There was a main effect of auditory condition, $F(1, 57) = 351.26$, $p < .01$, ηp2 = .86, and visual condition, $F(6, 342) = 19.27$, $p < .01$, $\eta_p^2 = .23$. Although the auditory condition by test version interaction was not significant, the visual condition and test version interaction was, $F(6, 342) = 3.61$, $p < .05$, $\eta_p^2 = .06$. However, the auditory by visual condition interaction was not significant, nor was the three-way interaction. Due to the significant two-way interaction, the integrated and blocked versions of the experiment were analyzed and reported separately.

Results from the Blocked Version—Again, the percentage of trials including an inaccurate response was quite low (1.78%) and were removed from all RT analyses. RTs and accuracy levels were analyzed using repeated-measure ANOVAs and are reported separately.

Response Times: Means of medians were used in a 2 (auditory condition) × 7 (visual stimuli) repeated-measure ANOVA. It was found that there was there was a significant main effect of visual condition, $F(4.28, 128.25) = 11.13$, $p < .01$, $\eta_p^2 = .27$ (see Table 1). In addition, there was a significant main effect for auditory condition, $F(1, 30) = 158.39$, $p < .01$, $\eta_p^2 = .84$. The RTs for incongruent trials were significantly slower than the RT for neutral trials, indicating that the blocked version did induce cross-modal Stroop interference (see Figure 1). However, there was no auditory by visual condition interaction, suggesting that the size of the Stroop interference effect did not differ by visual stimulus.

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Inaccuracy: A 2 (auditory condition) × 7 (visual condition) repeated-measures ANOVA was used to determine whether there were any significant differences in errors. There was a significant main effect of visual condition, $F(6, 180) = 2.48$, $p < .05$, $\eta_p^2 = .08$ (words produced significantly less errors), but no main effect for auditory condition, nor was there a significant visual and auditory condition interaction.

Results from the Integrated Version—The percentage of trials including an inaccurate response (1.84%) was quite low, and inaccurate trials were removed from all RT analyses. RTs and errors were analyzed using repeated-measures ANOVAs and are reported separately. As mentioned above, this version of the experiment was divided into two “sets” or groups of trials that were equal in length. We know from previous research that the cross-modal Stroop interference decreases with practice, which is most likely the result of habituation (Elliott et al., 1998; Elliott & Cowan, 2001). As such, it is possible that as the effect of the auditory condition weakens, the effect of the visual stimulus becomes more apparent. Due to the design of the blocked version (the blocks were randomly ordered), we were only able to examine this pattern in the integrated version. Therefore, the following analyses for the integrated version will take the two sets, or groups of trials, into account for a 2 (set) × 2 (auditory condition) × 7 (visual condition) repeated-measures ANOVA.

Response Times: A 2 (set) × 2 (auditory condition) × 7 (visual stimuli) repeated-measures ANOVA was used to analyze the remaining RTs.

It was found that there was no significant main effect of set. However, there was a significant main effect of visual condition, $F(6, 162) = 16.81$, $p < .01$, $\eta_p^2 = .38$, which was qualified by a higher order interaction. In addition, there was a significant main effect for auditory condition, $F(1, 27) = 208.90$, $p < .01$, $\eta_p^2 = .89$. The RTs for incongruent trials were significantly slower than the RTs for neutral trials, indicating cross-modal Stroop interference. Furthermore, there was a significant set and auditory condition interaction, $F(1, 27) = 10.73$, $p < .01$, $\eta_p^2 = .28$, with a larger difference between the incongruent and neutral conditions found in the first set of the experiment than the second (see panel A of Figure 2).

The set and visual condition interaction was not significant, nor was there an auditory and visual condition interaction. However, although sphericity was violated, there was a three-way interaction of auditory condition, visual condition, and set, $F(4.49, 121) = 2.50$, $p < .05$, $\eta_p^2 = .09$. Due to this significant three-way interaction, two separate 2 (auditory condition) × 7 (visual condition) repeated-measures ANOVAs were then run for each set.

For set one, there was again a main effect of visual condition, $F(6, 162) = 6.95$, $p < .01$, $\eta_p^2 = .21$, and a main effect of auditory condition, $F(1, 27) = 155.36$, $p < .01$, $\eta_p^2 = .85$, indicating cross-modal Stroop interference; though once again, the auditory and visual condition interaction was not significant, $F(6, 162) = 1.4$, $p > .05$, $\eta_p^2 = .05$. However, in the second set, there was a main effect of auditory condition, $F(1, 27) = 117.52$, $p < .01$, $\eta_p^2 = .81$, and, although they both violated sphericity, a main effect of visual condition, $F(3.9, 105.26) = 13.83$, $p < .01$, $\eta_p^2 = .34$, and a visual and auditory condition interaction, $F(3.83, 103.5) = 3.22$, $p < .05$, $\eta_p^2 = .11$, were found, indicating that the different visual stimuli led to varying amounts of interference in the second set (see panel B of Figure 2).

Interference scores were then created for set 2 only by taking each participant's mean neutral RT score and subtracting it from their mean incongruent RT score for each individual visual stimulus type. This led to each person having an interference score (or a measure of how much cross-modal Stroop interference they displayed) for all of the visual conditions. A repeated-measures ANOVA was then run on these interference scores. Although sphericity was violated, there was a significant difference in the amount of interference induced by the different visual stimuli, $F(3.83, 103.5) = 3.22$, $p < .05$, $\eta_p^2 = .11$. Although there was a range of interference for the various stimuli, only x's were significantly different in that they produced significantly less interference than all of the other visual conditions.

Inaccuracy: A 2 × 2 × 7 repeated-measures ANOVA was used to determine whether there were any significant differences among the sets, auditory conditions, or visual stimulus types; however, none of the conditions produced any differences in error rates.

Discussion

The different visual stimuli in both versions of the experiment (integrated and blocked) led to significant cross-modal Stroop interference. These findings suggest that participants were unable to ignore the auditory distractors, regardless of the visual stimulus used as the color-naming target. However, despite the fact that there were overall differences in the RTs for the different visual stimuli, there was only one instance of an interaction between the auditory and visual conditions. This interaction occurred during the second set of the integrated version of the experiment. This finding is intriguing, as the overall level of interference actually decreased in the second set compared to the first. It is possible, as predicted, that as the interference from the auditory condition decreased, the interference from the visual condition became more apparent. This may also help to explain why a visual and auditory condition interaction was not found in the blocked version of the experiment: habituation effects may have been washed out due to the random order of the blocks across participants. Within the second set of the integrated version, only a row of colored X's produced a significantly different amount of interference, leading to an average of only 13ms.

Although not significantly different, it is important to note that there was a trend in that both the colored squares and black words induced the largest amounts of interference in the integrated version. This is interesting, as written words are believed to be a strong dimension, but at the same time, color squares were believed to be a visual stimulus with the least strong additional distractor dimension. Furthermore, these two stimuli produced the shortest overall RTs.

We know from previous research that word reading is faster than color naming (Glaser & Glaser, 1982) and that it may take less time to name the color of a fully colored word than a partially colored one (Monahan, 2001). As such, it may also be that color naming for something like a color patch is faster than a row of colored X's or @ symbols. This would mean that baseline overall RTs are faster for these visual stimuli; however, why they would still induce such large amounts of interference is unclear. It may have to do with the contexts of the task. For example, RTs for the written words were only faster in the blocked version of the experiment, not the integrated, which may be explained by the task-switching component in the integrated version.

The fact that reading a color word while ignoring auditory color words led to any detriment in performance is also surprising. While one could argue that the interference found for the words in the integrated version of the experiment could be due to task switching—one had to switch from the task of naming colors to reading a word—the fact that auditory words significantly impacted performance in the blocked version of the experiment suggests this is not the case. Regardless of whether this impact is being caused by the same mechanisms responsible for the Stroop effect, it is still an important finding, as it suggests that a "strong" dimension is capable of being interfered with by another "strong" dimension. The finding of interference within a "strong" dimension is not predicted by many of the Stroop theories (see Roelofs, 2005 for more information).

In Experiment 2, we examined only three different visual stimuli: color squares, a row of four colored X's, and a row of four colored @ symbols, to maximize the differences among the visual stimuli and to try to replicate our results. Given the current and widespread use in emails, @ symbols have a strong semantic component, but display very little of the to-be-named color. Color squares, believed to have a weak semantic component, provide a large amount of color, and X's are intermediate, with a weak semantic component, and a small display of color. In addition, in the integrated version, X's were the only visual stimuli to induce significantly less interference, while squares showed some of the highest levels and @ symbols were intermediate. We also manipulated overall participant strategy in Experiment 2 by including congruent trials, as it has been shown that including congruent trials tends to increase overall interference (Logan and Zbrodoff, 1979; Long & Pratt; 2002; Kane & Engle, 2003).

Experiment 2

As noted above, traditional Stroop research and the dimensional strength view of the Stroop effect suggest that "stronger" dimensions (i.e. those that have a strong semantic component or are more related to the target) should lead to larger amounts of interference than "weak" dimensions due to an increase in response competition. In a second experiment, we attempted to replicate and extend the findings from Experiment 1 and examined three types of visual stimuli only: colored squares, colored @ symbols, and colored X's. The stimuli were chosen based on the results of Experiment 1 (X's were the only stimulus to show significantly different amounts of Stroop interference in comparison to the other visual stimuli) and based upon the strength of the second additional distractor dimension. Squares should have a weak additional distractor dimension, x's should provide an intermediate distractor dimension, and @ symbols the strongest due to its semantic component. Finally, the integrated version from Experiment 1 was chosen for this experiment, as it induced greater levels of interference overall and was the version of the experiment in which we found evidence for the interaction of auditory condition with visual stimulus condition.

Method

Participants—A total of 32 Louisiana State University undergraduates participated for course or extra credit. The mean age of the participants was 21.50 years (*SD* = 5.15). Again, participants were not eligible to participate if they reported abnormal hearing, color vision, mind-altering medications, abnormal uncorrected vision, or a first language other than English. Due to these restrictions, 2 participants was excluded from all data analyses (total N = 30). Of the 30 participants analyzed, 24 were female (80.00%).

Materials and Procedure—This experiment utilized a 2 (set) × 3 (auditory condition) × 3 (visual condition) within-subjects design. The auditory condition consisted of incongruent, congruent, and neutral (silent) trials while the visual stimuli comprised a row of four colored x's, @ symbols, or a single color square. Participants received 27 practice trials followed by two sets of 162 experimental trials for a total of 324 experimental trials. Within each block, each visual and auditory stimulus was presented 54 times. This led to each level of the auditory condition being presented with each level of the visual condition 18 times. All other materials and procedures were identical to the integrated version of Experiment 1.

Results

Repeated-measures ANOVAs were used to analyze RTs and accuracy levels. Overall, 0.74% of trials contained an inaccurate response, 0.60 % involved a false start, and the experimenter made an error responding 0.06% of the time. All trials containing false starts and experimenter errors were removed from the analyses reported below. As in Experiment 1, for all analyses $\alpha = .05$, and the Bonferonni correction was used for all follow-up tests. In all cases where sphericity was violated and the results were significant, the Greenhouse-Geisser correction was used.

Response Times—A 2 (set) × 3 (auditory condition) × 3 (visual condition) repeated-measures ANOVA was used to analyze the response times. There was no significant main effect of set, meaning that participants, overall, did not get better or worse at the task over the experimental session. There was a significant main effect of visual condition, $F(2, 58) = 31.73$, $p < .01$, $\eta_p^2 = .52$, with squares < @ = x (see Panel A of Figure 3). In addition, there was a significant main effect of auditory condition, $F(1.43, 41.55) = 45.15$, $p < .01$, $\eta_p^2 = .61$, with neutral trials < congruent trials < incongruent trials (see Panel B of Figure 3). The set and auditory condition was also significant, $F(2, 58) = 4.43$, $p < .05$, $\eta_p^2 = .13$; however, the set and visual condition, visual and auditory condition, and set, visual, and auditory condition interactions were not significant.

In order to examine the set and auditory condition interaction, we collapsed across visual condition and used a 2 (set) × 3 (auditory condition) repeated-measures ANOVA. Once again, there was a main effect auditory condition, $F(1.43, 32.80) = 45.15$, $p < .01$, $\eta_p^2 = .61$. There was no significant main effect of set, but the auditory condition and set interaction was significant, $F(2, 58) = 4.49$, $p < .01$, $\eta_p^2 = .13$. In the first set, incongruent trials > congruent trials > neutral trials, while in second set, incongruent trials > congruent trials = neutral trials (see Figure 4).

Inaccuracy—Again, a 2 (set) × 3 (auditory condition) × 3 (visual condition) repeated-measures ANOVA was used, this time to analyze errors. Once again there was no significant main effect of set or visual condition; however, there was a main effect of auditory condition, $F(1.71, 49.54) = 4.68$, $p < .05$, $\eta_p^2 = .14$. While none of the follow-up tests for auditory condition were significant, there was a trend with incongruent trials leading to more errors than neutral trials, $p = .07$. There was no significant set and auditory condition interaction, set and visual condition, and visual condition and auditory condition interaction. Nonetheless, the set and visual and auditory condition interaction was significant, $F(4, 116) = 2.59$, $p < .05$, $\eta_p^2 = .08$ (See Table 2). As such, two 3 × 3 repeated-measures ANOVAs were run for each set. For the first set, neither the main effects for visual or auditory condition were significant, nor was the visual and auditory condition interaction. For the second set, there was a main effect of auditory condition, $F(1.56, 45.19) = 5.16$, $p < .05$, $\eta_p^2 = .15$, with incongruent trials producing significantly more errors than congruent trials with neutral trials not being significantly different from either, and there were no main effect of visual condition or a significant visual and auditory condition interaction.

Discussion

As in Experiment 1, we found significant differences among the auditory conditions, which indicated that participants were unable to ignore stimuli in the auditory modality. We did not find any impact of the visual stimulus on the size of the interference effect in Experiment 2. None of the auditory and visual condition interactions were significant in the RT data. Only for errors did we find a significant three-way interaction among auditory condition, visual condition, and set. However, when we examined this interaction further, we found significant differences only in the auditory condition factor across the two different sets. With a similar pattern to the integrated version of Experiment 1, in which the differences took part in set two, there were significant differences in the number of errors produced for incongruent trials in set two, but not set one. This finding will be returned to in the General Discussion section.

In addition, there was no main effect of visual condition for either errors or RTs, and no Stroop facilitation. As mentioned earlier, the lack of facilitation in cross-modal Stroop is quite common. Why our neutral trials were significantly faster than our congruent trials, however, is unclear at this time. However, further analyses implied that the RTs for congruent trials decreased in the second set and were no longer significantly slower than neutrals trials. This suggests, that, at first the auditory distractors produced overall slowing regardless of their relatedness. It was not until the participants became accustomed to the task that a congruent auditory word no longer acted as a distractor. Aside from this, the results for Experiment 2 were remarkably similar to those found for the integrated version of Experiment 1, suggesting that the robust cross-modal Stroop effect is not mediated by the choice of the visual stimulus.

General Discussion

Overall, it appears that the visual stimulus is of less import in cross-modal Stroop than in traditional, visually-based Stroop. Across two experiments, three test versions, and numerous sets of trials, we found a significant visual and auditory condition interaction only once in the second set of the integrated version of Experiment 1. These findings suggest that the dimensional strength of the added distractor dimension did not influence responding in the cross-modal Stroop task. Furthermore, these results support the predictions of the interference by process account and suggest that irrelevant distractors (those not related to the content of the target) generally do not lead to interference.

Interestingly, despite the fact that the visual stimuli did not lead to varying amounts of interference, under some conditions they did produce different RTs overall as well as varying the numbers of errors produced. Overall speed of responding in one dimension has been used as an index of dimensional strength in previous research (Melara & Algom, 2003; Roelofs, 2005). However, the strength of the additional distractor dimension did not seem to have a significant influence on interference, overall RTs, or errors.

Furthermore, the lack of an interaction between the auditory and visual conditions may be due to the fact that the additional distractor dimension of the visual stimuli had absolutely no relationship to color. Whether or not the visual stimulus is an x, @, or ~ provides no helpful information when the task is color naming. The auditory dimension does at least supply information similar to that which one is attempting to focus on. However, in traditional Stroop, even non-verbal stimuli induce a small amount of interference—common non-color words lead to more interference than rare words, which are slower than non-words (Klein, 1964). Why this does not appear to occur for the visual dimension in cross-modal Stroop is unclear. These findings suggest that perhaps there is something different about the cross-modal Stroop task—i.e. the fact that it involves auditory distractors.

When examining the results from the integrated version of Experiment 1 and the results from Experiment 2, one can see that they are remarkably similar, especially in terms of RTs, despite the fact that Experiment 2 contained congruent trials. It is also interesting that across both experiments, the amount of interference decreased in the second set of trials, though not significantly so for Experiment 2. This overall decrease in RTs, however, is not because of task-wide improvement: RTs for incongruent trials decreased, RTs for congruent trials decreased, but RTs for neutral trials remained the same. Participants appear to have improved their ability to ignore the irrelevant auditory distractors and continued to name colors as quickly as they could from the very beginning. This finding is similar to that of Elliott and Cowan (2001) in which they found that participants showed improvement on incongruent cross-modal Stroop trials. Elliott and Cowan (2001) contributed this improvement in performance to habituation. Essentially, over time participants habituated to the distracting auditory words. The fact that we were able to replicate these findings and extend them to potentially include congruent trials is informative and suggests new avenues of research.

As mentioned earlier, the importance of semantics in other auditory distraction paradigms, such as the ISE, does not appear to be as clear as in cross-modal Stroop. While some studies have found that the semantic component of the auditory distractor can have an impact on performance, others have failed to replicate these results. Essentially, if one is asked to recall a list of numbers, whether the auditory distractor consists of numbers, letters, or tones appears to have little impact. The cross-modal Stroop effect, however, does show that the semantic components of the auditory distractor can have an impact on performance. Furthermore, the ISE also does not show clear habitation (again, there is some discrepancy in the literature; Tremblay, & Jones, 1998; Bell, Roer, Bentale, & Buchner, 2012), but evidence for habituation has been shown in the cross-modal Stroop paradigm (Elliott & Cowan, 2001). Together, this suggests that not all auditory distractors are equivalent and, depending on the task demands, an auditory distractor can vary in its potency.

Conclusion

The visual stimulus may have some impact on the amount of interference induced in cross-modal Stroop; however, the effect appears to be quite small and unreliable. This finding suggests that participants can filter out non-word irrelevant visual information in cross-modal Stroop, but they are still unable to ignore irrelevant auditory information. Taken together, the current experiments, along with evidence from the visual version of the traditional Stroop task, imply that the modality of the distractor may influence the effects observed in the Stroop paradigm. In addition, the findings suggest that the concept of dimensional strength is not sufficient in explaining cross-modal Stroop interference. Future research should continue to investigate the underlying processes and mechanisms of distractors from the auditory modality, to what extent participants can reduce distraction effects, and whether the task demands have any influence on the impact of an auditory distractor.

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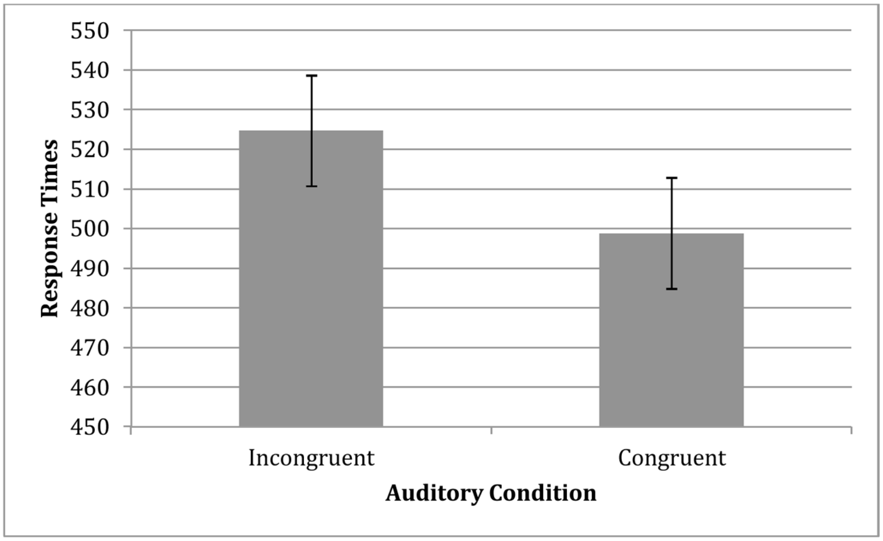
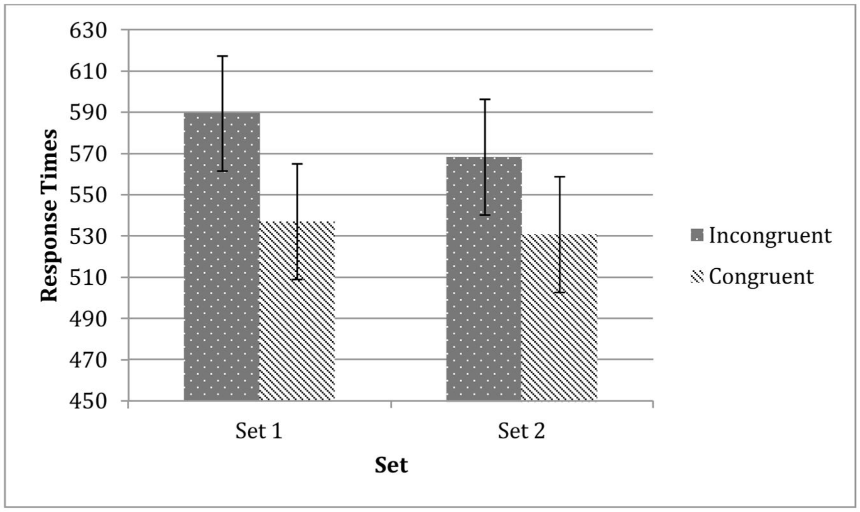
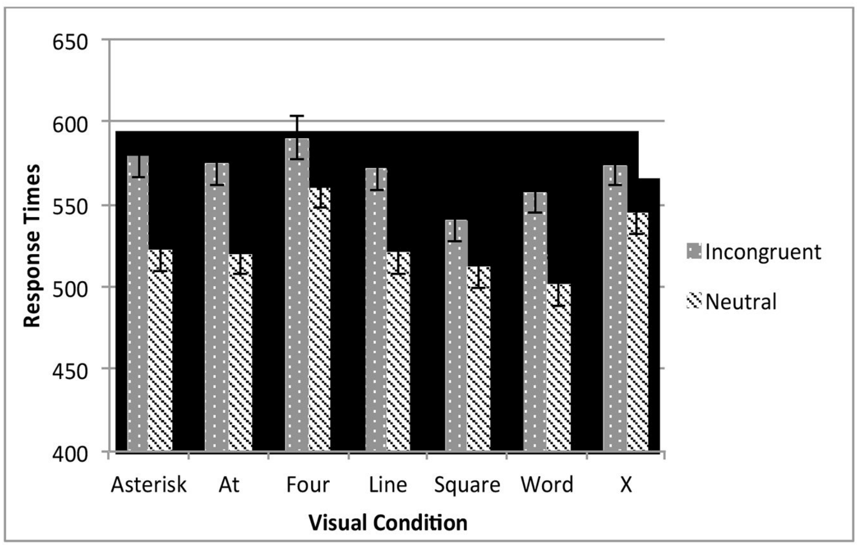


Figure 1.

RTs by auditory condition for the blocked version of Experiment 1. Error bars represent within-subject confidence intervals (Masson & Loftus, 2003).



a.)

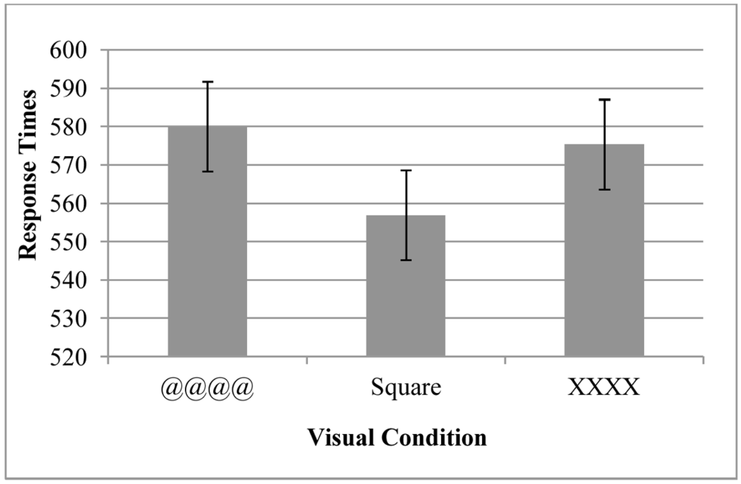


b.)

Figure 2.

RTs for the integrated version of Experiment 1 (error bars represent within-subject confidence intervals; Masson & Loftus, 2003): a.) Auditory condition by set, b.) Auditory by visual condition for Set 2 of the integrated version of Experiment 1.

a.)



b.)

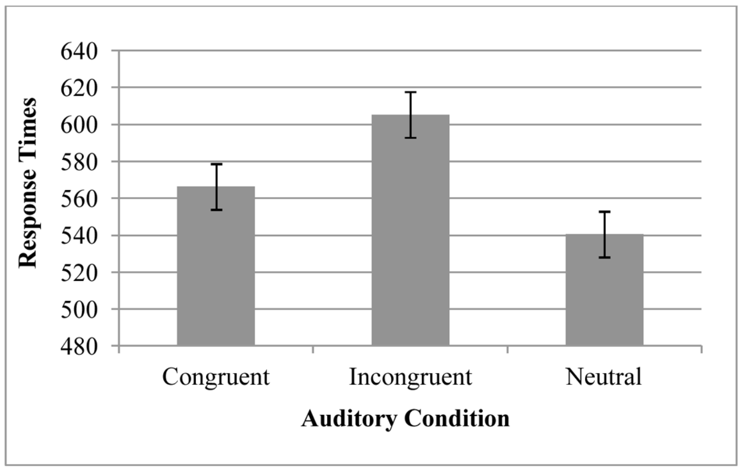


Figure 3.

Experiment 2 RTs by: a.) Visual condition and b.) Auditory condition. Error bars represent within-subjects confidence intervals (Masson & Loftus, 2003).

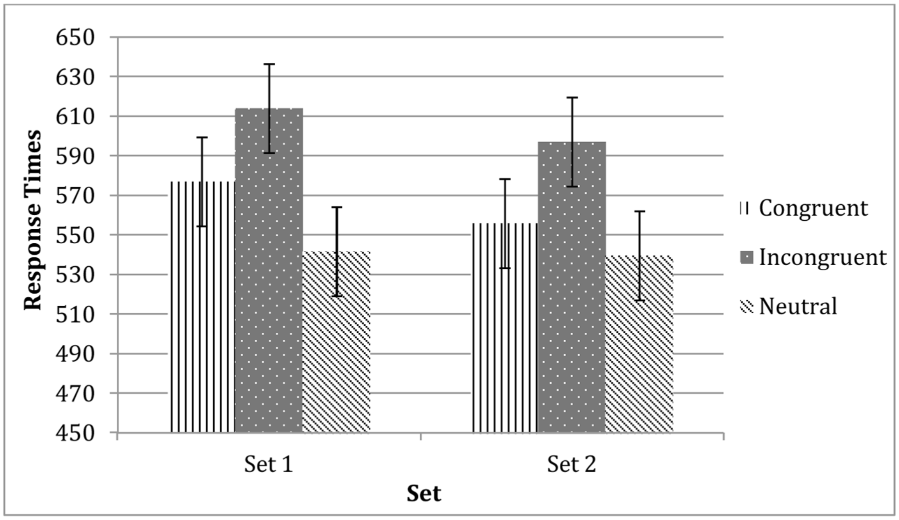


Figure 4.
Experiment 2 set and auditory condition interaction. Error bars represent within-subjects confidence intervals (Masson & Loftus, 2003).

Table 1

Overall mean RTs and standard errors for the visual stimuli in the blocked version of Experiment 1. Standard errors are displayed in the parentheses.

Visual Stimulus	Mean RT
****	516.73 (10.27)
@@@@	520.71 (12.82)
4444	532.88 (13.98)
~~	506.77 (11.30)
Squares	511.81 (11.42)
XXXX	523.22 (19.10)
Words	459.67[+] (12.23)

[+]Words were presented in black to be read, instead of color named. The Word condition responses were significantly faster than all other conditions, $p < .001$ in each case.

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Table 2

Errors for Experiment 2 by set, visual condition, and auditory condition. Standard errors are displayed in the parentheses.

	Set 1			Set 2		
	@@@@	**Square**	**XXXX**	**@@@@**	**Square**	**XXXX**
Congruent	0.75 (0.36)	0.74 (0.35)	0.37 (0.26)	0.75 (0.36)	0.00 (0.00)	0.37 (0.26)
Incongruent	1.53 (0.48)	0.37 (0.26)	0.39 (0.39)	0.95 (0.39)	1.90 (0.63)	1.48 (0.59)
Neutral	0.37 (0.26)	0.93 (0.38)	0.37 (0.26)	0.74 (0.35)	0.57 (0.32)	0.74 (0.35)