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# The Mechanisms of Auditory Distraction: The Roles of Interference-by-Process and Attention Capture

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THE MECHANISMS OF AUDITORY DISTRACTION: THE ROLES OF INTERFERENCE-  
BY-PROCESS AND ATTENTION CAPTURE

A Dissertation

Submitted to the Graduate Faculty of the  
Louisiana State University and  
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by

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## Abstract

It is generally believed that there are two main mechanisms of auditory distraction: attention capture and interference-by-process. Attention capture is said to occur when sounds drag your attention away from what you are attempting to focus on and harm performance as a consequence. Interference-by-process, meanwhile, states that the processing of the sounds can conflict with the processing needed to complete the task of interest. Whether or not the two mechanisms can jointly lead to distraction is unclear at this time. The following dissertation examined the roles of both distraction mechanisms in a cross-modal variant of the Stroop task, in which one names the color of visual items (e.g. color squares) while ignoring auditory color words. I attempted to manipulate the two mechanisms of auditory distraction independently to determine whether 1) both can play a role in distraction simultaneously and 2) whether the mechanisms can be manipulated independently. Experiments 1 and 2 sought to examine the role of attention, while Experiment 3 examined interference-by-process. The results implied that attention, specifically attention capture, appears to have little or no role in the size of the cross-modal effect and that any attention involved is outside the realm of top-down control. Thus, as of this time, there is no clear evidence that both mechanisms of auditory distraction can jointly lead to detriments in performance; however, more work is needed.

## Chapter 1: Introduction

People are constantly bombarded with auditory information. While at times this information can be helpful (e.g. someone honking their car horn may alert you to the fact that a traffic light has turned green, or someone calling your name lets you know that someone is trying to talk to you), in many instances this auditory information is irrelevant and serves as a potential distractor. Essentially, it harms your performance on a focal task—or the task that you are completing whether it be driving, talking, writing an email, or daydreaming.

For many years it was believed by some researchers that irrelevant sounds led to performance detriments because they captured attention (e.g., Cowan, 1995). In other words, the sounds were recruiting attention away from the focal task and performance suffered as a result. This view has been considered the unitary view of auditory distraction by attention capture. However, it soon became apparent that attention capture was not able to explain all of the patterns of results, and thus it was proposed that there may be a second mechanism of auditory distraction, typically referred to as *interference-by-process* (Hughes, Vachon, & Jones, 2005; 2007; Marsh, Hughes, & Jones, 2009). Distraction due to interference-by-process occurs because of the obligatory and unintentional processing of sounds which can, at times, interfere with the intentional processing needed to complete a focal task—assuming the processes share the same characteristics. Together, these two mechanisms of auditory distraction are hypothesized to be responsible for at least most types of auditory distraction. The current dissertation investigated these two mechanisms of auditory distraction and whether attention capture and interference-by-process are capable of being simultaneously responsible for distraction, as well as some of the ways in which one can supposedly distinguish between the two mechanisms.

## 1.1 Interference-by-Process

According to the view of interference-by-process as a mechanism of auditory distraction, there are times when the processing of a distracting sound can interfere with the processing necessary to complete a focal task (e.g., maintaining serial order information; long-term memory retrieval, and/or long-term memory storage). The processes involved may vary depending on the task requirements and stimuli, and may include the processing of order information and the organization of incoming information among other factors. Given the nature of the interference-by-process mechanism, there are probably numerous times it occurs, and in order to determine when it is activated, one first needs to have a thorough understanding of the processes involved. The most well-known and studied example of interference-by-process is the *changing-state hypothesis*, which was applied to explain the serial recall irrelevant sound paradigm and revolves around the changing qualities of the auditory distractor (Hughes et al., 2005; 2007; Marsh et al., 2009; Jones & Macken, 1995).

The irrelevant sound paradigm typically consists of memorizing lists of items (e.g., words, letters, numbers) in silence or with an auditory distractor presented either simultaneously with or immediately after (during a retention period) the list of to-be-remembered items. The list of items is then recalled in serial order. It is generally found that auditory distractors have a negative impact on serial recall performance (e.g., Ellermeier & Zimmer, 1997; Elliott & Cowan, 2005; Hughes, Hurlstone, Marsh, Vachon & Jones, 2013; Salamé & Baddeley, 1982). In order for the effect to occur, the auditory distractor must contain a characteristic referred to as *changing-state*. Essentially, the sound must change acoustically from one segment to the next (e.g. “A, B, A, B, A...”). A *steady-state* item (e.g., “C, C, C, C, C...”) has little to no impact on recall performance. In addition, the content of the sound—speech, white noise, music, etc.—and

the sound's intensity (Colle & Welsh, 1976; Jones & Macken, 1995; Tremblay & Jones, 1999) do not harm recall performance. The irrelevant sound effect (ISE) refers to the difference in serial recall performance when there is sound versus silence. The changing-state effect (CSE) indicates the difference in serial recall performance for a changing-state sound versus a steady-state one (e.g., Elliott et al., 2016).

According to the changing-state hypothesis, auditory information is obligatorily processed (Cherry, 1953; Colle & Welsh, 1976; Cowan & Barron, 1987; Macken, Phelps, & Jones, 2009), though it is possible that not all aspects of auditory stimuli are (i.e., meaning and phonology: Bridges & Jones, 1996; Cherry, 1953; Jones, & Macken, 1995). According to the hypothesis, the changes from one consecutive sound element to the next (A, B, A...) create cues relating to the order of the sounds. These obligatorily processed order cues (for instance, the A came before the B) interfere with the deliberate, goal-driven processing and rehearsing of the order information and order cues for the to-be-remembered items, thus causing the changing-state effect (Hughes et al., 2005; 2007; Marsh et al., 2009). As a steady state sound would not produce these order cues, no processing conflicts would occur.

Some empirical support for the interference-by-process mechanism in the serial recall ISE comes from the finding that while order information is impaired during the presentation of changing auditory distractors, item information remains intact (in other words, participants may be able to correctly recall an item, but not its serial position). For instance, Beaman and Jones (1997) had participants attend to a series of words and recall the items in the order they were presented, or determine which item was missing. When asked to recall the items in order, Beaman and Jones found the typical detriment in performance; however, there was no impact of sounds when participants simply had to state which item was missing. Thus, item memory

appeared to remain intact while the order information was impaired, suggesting it was the conflict of the two similar processes (order information) that was leading to the ISE.

In addition to the serial order ISE, a number of other ISE paradigms have been attributed to interference-by-process mechanisms including a recognition version of the ISE (Stokes and Arnell, 2012), a category-exemplar version (Beaman, 2004; Marsh, Hughes, & Jones, 2008; Marsh et al., 2009; Marsh, Hughes et al., 2015; Marsh, Sörqvist et al., 2015), and a semantic and phonetic fluency version (Jones, Marsh, & Hughes, 2012). Of these three, the category-exemplar ISE version has been examined the most. In this version of the task, participants are given a list of typically 16 words (enough to engage the use of long-term memory). These lists of to-be-remembered words come from various categories (e.g. vehicles, fruits, animals). While participants are remembering these words, they are presented with auditory distractors (they are told to ignore these) which are either from the same semantic category as the to-be-remembered items, from unrelated semantic categories, or silence. Participants freely recall as many items from the list as they can, and it is found that the semantically-related auditory distractors have a negative impact on performance both in terms of the number of items recalled in general and the number of intrusion errors. For example, participants were more likely to include one of the irrelevant items they heard when it was semantically related. Typically there are no differences between the semantically-unrelated distractors and silence in this particular paradigm.

The category-exemplar ISE is typically attributed to interference-by-process, but not the same type of interference-by-process as is used to explain the serial recall version as the focal task is different. It is believed that the semantic encoding of the auditory distractors interferes with the encoding and retrieval processes necessary to complete the primary task (remembering the lists of the to-be-remembered items). Due to the long-list lengths used, participants are most

likely engaging in a semantic-based organization process in an attempt to remember the information efficiently (e.g. grouping all of the animals and fruits together). The processing of the semantic content of the irrelevant sound interferes with this organization, thus leading to a detriment in performance.

In the recognition version of the ISE, participants are shown over 200 words while hearing distracting sounds or silence. At test, participants have to determine whether the shown word was presented during the study period. Stokes and Arnell (2012) found that participants made more errors when the to-be-remembered words were presented with sounds than without. Stokes and Arnell attributed this detriment in performance to a similar interference-by-process mechanism as that of the category-exemplar version: in order to remember the words as they are being presented, the participants try to organize this information in such a way as to make them easier to remember. The processing of the sounds and their organization then interferes when they are presented simultaneously with the to-be-remembered information.

In the semantic and phonetic fluency version, participants are asked to name as many items from a category as possible (e.g. vehicles, four-legged animals, words beginning with r or f). Presenting meaningful words (as compared to non-words and words heard backwards) negatively impacts the number of items participants are able to name. Moreover, meaningful words that are related to the category being named (e.g. one is trying to name vegetables and they hear various different fruits or name words that begin with the letter “f” but hear words beginning with “ph”) harm performance more than words that are not as related (e.g. hearing tools and words beginning with “b” respectively). Jones et al. (2012) attributed this detriment in performance to interference-by-process because in order to name the categorical items, the

participant has to activate that semantic information. The activation of other categories, especially related categories, interferes with this process.

In summary, interference-by-process is due to the processing demands of the focal task sharing/overlapping with the processing of the auditory distractors. This shared processing then leads to a detriment in performance on a focal task. According to this view, by removing the overlapping processing, one is able to eliminate interference-by-process.

## **1.2 Attention Capture**

In contrast to interference-by-process, attention capture is believed to occur when attention is temporarily disengaged from the focal task *regardless of the processes involved* in the focal task and can be either top-down (e.g. the stimulus is relevant to you in some way such as it being your name; Hughes, 2014) or bottom-up in nature (something about the stimulus is driving the attention capture such as salience or a violation from expectation; Hughes 2014).

It was generally agreed that a stimulus captures attention when it violates the expectations set by the upcoming or previous stimuli (Cowan, 1995; Sokolov, 1963). Essentially, a person is exposed to stimuli and begins to create an expectation, or “mental model.” With more exposure, the mental model becomes more and more refined, and, therefore, less and less attention is paid to stimuli which fit with this model (habituation). The degree of mismatch between the incoming stimulus and the mental model determines the likelihood of an “orienting response” or the reorientation of attention towards an ill-fitting stimulus. If a stimulus does not match the mental model, signs of an orienting response should become apparent. If there is a high match between a stimulus and the mental model, there will most likely not be an orienting response. Attention capture is said to occur if the behavioral indices of the orienting response are apparent (e.g. increasing response times and errors), as this would be a sign that

attention has reoriented from the target of interest to a distracting one. However, over time, it became clear that a mental model based solely on a stimulus repeated continuously or a repeated pattern was not enough to explain the patterns of data supposedly attributed to the mechanism of attention capture (e.g. Elliott & Cowan, 2001), and, thus, the algorithmic neural model was proposed. In this updated version of attention capture, the orienting response arises from the violation of a rule or pattern which regulates the organization of the sequential stimuli (Hughes et al., 2007).

There are many examples of attention capture in both the visual and auditory modalities such as the deviant/oddball effect (Parmentier, 2014) and cocktail party effect (Moray, 1959). For the most part, the auditory and cross-modal deviant effect is used in the literature to contrast attention capture involving the auditory modality to interference-by-process (Hughes, 2014; Hughes et al., 2013).

Specifically, the cross-modal and auditory deviant effect involves participants completing a relatively simple focal task, which can be either visual (e.g. categorizing the direction of arrows; Parmentier, Turner, & Perez, 2014) or auditory in nature (e.g. categorizing the movement of sounds; Parmentier & Hebrero, 2013) respectively. While completing the task, the participants are presented with a stream of irrelevant auditory information (e.g. “A, B, C, D, E, F, G...”). Occasionally, a “deviant” stimulus is presented which varies from the predictable, repetitive, or structured sequence generally heard (e.g. “A, B, C, D, **Z**, E, F...”). As such, the deviant does not necessarily capture attention because of the properties of the stimulus (e.g. it being rare or novel), but because the stimulus is violating an expectation that has been established by the repetition of the stimuli (Marsh, R  er, Bell, & Buchner, 2014; Parmentier, Elsley, Andr  s, & Barcel  , 2011).

For example, in the above cross-modal deviant example, the participant would be working on a focal task such as categorizing the direction of visual arrows and would be consistently exposed to auditory letters in alphabetical order. After the participant has built up an “expectancy” for the auditory modality, a “deviant” is presented. The deviant violates the predictable, repetitive, or structured sequence the participant has come to anticipate. In the above example, after enough time, the participant would come to expect that the letters will always be presented in alphabetical order and would built up a mental model (Cowan, 1995; Sokolov, 1963; Hughes et al., 2007); therefore, the presentation of a “Z” after the “D” is not consistent with what the participant has come to anticipate, and his or her attention will be captured by the “Z” as a result. This attention shift leads to a detriment in performance on the focal task, which is reflected by slower reaction times, a decrease in accuracy, and a change in electrophysiological markers (mismatch negativity [MMN], P3a, and reorientation negativity [RON]; for a review of ERPs in the auditory deviant effect see Parmentier, 2014).

In addition to attention capture occurring due to a violation in expectancies (Parmentier et al., 2011), it can also occur because of the semantics of a distractor. For example, in the cocktail party effect (Moray, 1959; Wood & Cowan, 1995) participants complete a dichotic listening task—separate streams of information are presented to each ear and one has to follow one stream and ignore the other. Overall, participants are relatively successful at ignoring the irrelevant stream and are generally only able to report basic properties of the unattended message such as the gender of the speaker and if it was speech or non-speech (Cherry, 1953). However, occasionally participants will hear their name in the unattended channel (approximately one-third of participants; Wood & Cowan, 1995), and attention capture can be inferred as attention was not originally directed towards that channel.

However, attention capture due to the semantics of the distractor is difficult to explain. As mentioned above, research has suggested that the semantic and phonological analysis of sounds is not automatic/obligatory (Bridges & Jones, 1996; Cherry, 1953; Colle & Welsh, 1976; Jones, & Macken, 1995). As such, at least a small amount of attention appears to need to be directed at a sound in order for it to be semantically analyzed. If something must first be attended to before it is semantically analyzed, how then can an item capture attention because of its semantic meaning? One solution is semantic analysis does not always require attention (an answer which has little empirical support, though see Jones et al., 2012). Another option is that cases in which auditory distractors capture attention because of their semantic meaning are not “pure” examples of attention capture. In other words, the auditory information, to at least some degree, is already being attended to (thus allowing semantics to be analyzed) and then due to the semantics of the auditory information, the vast majority of attention is shifted over to the auditory domain. This idea will be examined again in a later section.

### **1.3 Distinguishing Between the Mechanisms of Auditory Distraction**

There are a number of ways in which researchers have differentiated the mechanisms of interference-by-process and attention capture. For example, although performance in attention capture paradigms has been shown to correlate with measures of working memory capacity, most interference-by-process paradigms do not. Working memory capacity refers to the amount of information one is able to store and use (Daneman & Carpenter, 1980), and is generally believed to comprise three facets: being able to efficiently retrieve information from long-term memory, being able to temporarily store information in short-term storage, and being able to control and direct attention (Shipstead, Lindsey, Marshall, & Engle, 2014). As attention capture occurs when one fails to maintain attentional control, it is unsurprising that those with high working

memory capacity (or those who score well on the measures of the construct of working memory and thus have “good” attentional control) are less likely to show attention capture than those with low working memory capacity (Conway, Cowan, & Bunting, 2001; Hutchison, 2011; Hughes et al., 2013; Kane & Engle, 2003; Sörqvist, 2010; Wood & Cowan, 1995). Moreover, as interference-by-process does not necessarily involve attention, and this appears to be the case in the serial recall ISE, one would expect there to be no correlation between this ISE and working memory capacity—a finding consistently upheld (Elliott & Briganti, 2012; Hughes et al., 2013; Sörqvist, 2010; Sörqvist, Marsh, & Nöstle, 2012a) There is, however, a correlation between the category exemplar ISE and working memory capacity in terms of intrusion errors (Beaman, 2004; Marsh et al., 2015).

In addition to differing relationships with working memory capacity, there are differences in the ways the two mechanisms display habituation. Habituation refers to the decrease in responding observed the more times one is exposed to a stimulus (in other words, as an expectation is created and refined, attention capture decreases). Essentially, every time one is exposed to a new stimulus, attention is reoriented to that stimulus. However, this reorientation becomes less and less likely the more times the stimulus is experienced. As habituation involves the reorientation of attention, one would expect to see habituation in attention capture paradigms and not interference-by-process ones—a finding which is relatively consistently upheld (attention capture: Ljungberg et al., 2014; Pan, Takeshita, & Morimoto, 2000; Sörqvist, Marsh, & Nöstle, 2012b; interference-by-process: Ellermeier & Zimmer, 1997; Jones, Macken, & Mosdell, 1997; Tremblay & Jones, 1998).

Lastly, effects of task difficulty and warnings seem to differentiate attention capture and interference-by-process. Research with attention capture has suggested that increasing task

difficulty by either making the task more difficult directly (Hughes et al., 2013; see Parmentier et al., 2008 for the opposite finding) or by increasing the cognitive load—or the amount one has to do overall—(Berti & Schröger, 2003) decreases the likelihood that attention will be captured and thus, performance harmed. In addition, greater concentration also appears to shield against distraction (Sörqvist & Marsh, 2015). Essentially, attention becomes so focused on the focal task that it becomes increasingly difficult for anything irrelevant to capture attention. Moreover, if one is warned that an irrelevant stimulus is about to appear, one is able to prepare for it, and thus, prevent or lessen the impact of the distractor—assuming it is harming performance because of attention capture (Horváth, Sussman, Winkler, & Schröger, 2011; Hughes et al., 2013; Parmentier & Hebrero, 2013; Shelton, Elliott, Eaves, & Exner, 2009; Sörqvist & Marsh, 2015). As the processes interfere in interference-by-process scenarios whether we want them to or not, general warnings that irrelevant information is about to appear have no impact (Hughes et al., 2013); though specific foreknowledge may lessen, though not eliminate, the ISE (i.e. an exact transcript of the sentence about to be heard; a transcript of the exact random words about to be heard does not have the same effect; Röer, Bell, & Buchner, 2015; see Marsh et al., 2015 for the use of warnings in the category-exemplar ISE).

Although broadly speaking, there are several different ways to distinguish between attention capture and interference-by-process (working memory capacity, habituation, task difficulty, and warnings), altogether, the data are not as clear as they may seem at first glance. For example, as working memory capacity may not only be related to attention capture, but also long-term memory (Unsworth & Engle, 2007; Unsworth et al., 2010; Shipstead et al., 2014), this might help to explain the relationship between one of the long-term memory version of the ISE involving intrusion errors (not order effects) and working memory capacity (Beaman, 2004;

Marsh et al., 2015). Moreover, habituation is found within the first few trials of the irrelevant sound effect (less than five; Röer et al., 2014), but the effect does not appear to habituate after this point. Lastly, while certain findings—such as a relationship with working memory or habituation—are able to help one determine whether attention capture is involved, it is the lack of these findings for the most part that allow one to ascertain the role of interference-by-process. At this time, the only way one can determine whether interference-by-processes is playing a role is by understanding exactly what processes are involved and testing whether they and they alone are impacted (Jones et al., 2012; Marsh et al., 2008; Marsh et al., 2009).

Together, these findings suggest one of two possible options: 1) as interference-by-process is such a broad mechanism, it may at times include attention and other processes related to working memory, which is supported by the findings of the other ISE paradigms (e.g., Beaman, 2004; Marsh et al., 2015) or 2) auditory distraction may not always be due to one or the other mechanism exclusively, but instead some combination of the two, which is supported by the findings showing habituation in the ISE (Röer et al., 2014). Both of these options will be examined in the following sections in a paradigm not previously examined under this lens.

#### **1.4 Cross-Modal Stroop Effect: Interference-by-Process and/or Attention Capture?**

One way to examine whether interference-by-process and attention capture can lead to distraction effects simultaneously is to find a scenario in which both mechanisms may be present. For the most part, interference-by-process has been examined with the irrelevant sound paradigm, and attention capture with the auditory and cross-modal deviant scenarios, because the two effects tend to fall nicely under one mechanism or the other. This separation is useful in distinguishing between the two mechanisms in general; however, it limits the ability to see how the two mechanisms interact.

One effect in which both interference-by-process and attention capture may be playing a role is the cross-modal Stroop effect. In the cross-modal Stroop paradigm, participants name the color of visual items (typically color squares though the composition of the visual item has been shown to have little to no effect on the size of the interference observed in the presence of auditory distractors; Lutfi-Proctor, Elliott, & Cowan, 2014), while ignoring congruent and incongruent auditory color words or a control (typically either silence or a tone). Color naming on incongruent trials tends to be the slowest, while there is typically no difference between congruent and control trials (Cowan & Barron, 1987; Elliott, Cowan, & Valle-Inclan, 1998; Lutfi-Proctor, Elliott, & Golob, in preparation).

This cross-modal Stroop effect has been argued to be due to both interference-by-process (Lutfi-Proctor et al., 2014) and attention capture (Parmentier et al., 2014; Lutfi-Proctor & Elliott, in review). Lutfi-Proctor et al. (2014) argued that as the composition of the stimulus which carries the color in cross-modal Stroop has little impact on the effect, cross-modal Stroop is most likely due to interference-by-process. In contrast, Parmentier et al. (2014) have argued that cross-modal Stroop may instead involve attention capture. Research has consistently shown that the semantics of deviant stimuli are analyzed (Parmentier, 2014; Parmentier et al., 2014, Horváth et al., 2011; Parmentier, 2008) and that the semantics of sounds may not be analyzed unless they are attended to some degree (Cherry, 1953). Thus, as the semantics of the auditory distractor appear to be driving the cross-modal Stroop effect, the effect must involve attention of some kind (see also Morey et al., 2012, for a discussion of the role of semantics and response competition).

The mechanism(s) involved in cross-modal Stroop are further complicated by the relationships with working memory capacity, habituation, and the effects of warnings. Although the size of the cross-modal Stroop effect does not appear to have a relationship with working

memory capacity (Elliott, Barrilleaux, & Cowan, 2006; Morey et al., 2012), the effect does habituate (Elliott & Cowan, 2001; Lutfi-Proctor et al., 2014), though not to the degree the deviant effect does. Moreover, knowing one is going to experience an incongruent or congruent trial seems to have no impact (Elliott et al., 1998). Elliott et al. presented the types of trials either within blocks (all incongruent, congruent, or neutral) or randomly intermixed, and found this design manipulation had no impact on the size of the effect, although overall RTs were faster in the blocked trials arrangement.

Overall, the findings from the cross-modal Stroop paradigm match what one would expect from an effect driven by aspects of both interference-by-process and attention capture. The following dissertation examined the relationship of the two mechanisms by directly manipulating the impact of each within the cross-modal Stroop task. If the mechanisms are indeed independent, one should be able to manipulate one mechanism while leaving the other intact.

### **1.5 Divided Versus Selective Attention**

As mentioned above, some researchers have argued that a sound must be attended to before it is semantically analyzed. This creates a conundrum as a result: how can something have captured your attention because of its semantic meaning, if that meaning cannot be inferred without attention having been there in the first place? One possible solution is that the sounds *are* being attended to (Lachter, Forster, & Ruthruff, 2004) and that attention shifts to an even greater degree to the auditory domain as a result of the semantic meaning or, at the very least, attention is playing a strong enough role in an effect that it becomes apparent through measures of habituation, for example. This would mean, however, that one must be attending to the

auditory channel to at least some degree in the first place, and as such, cases in which this occurs would, by necessity, be divided attention rather than selective attention scenarios.

A scenario is said to be one of “selective” attention when one stream of information is attended to and other information is ignored or inhibited. If one were to think of attention as a river which has only so much water, all of that river would be focused on one task and everything else would remain untouched. A divided attention scenario, in contrast, is when one is attending to multiple pieces of information, locations, modalities, etc. In this case, you could have a slightly smaller river than that mentioned above focused on a main task and a little creek alongside the river that is focused on another dimension, such as the auditory information.

For the most part, when we discuss interference-by-process and attention capture, we refer to them in the context of selective attention paradigms. How exactly the two mechanisms work in divided attention scenarios is not clear at this time. It is possible that interference-by-process and attention capture cannot jointly be responsible for auditory distraction in a selective attention paradigm, but can in a divided attention one or vice versa. For example, it is possible in cross-modal Stroop that participants are dividing their attention between the visual and auditory modalities even if the vast majority of attention is focused on the visual targets. This attention to the auditory domain could then lead to the semantic processing of the auditory distractors, which could then capture attention when they are incongruent to the visual target but would not necessarily do so when they are congruent. In contrast, it is possible that both the auditory and visual modality are attended to, leading to the semantics of the auditory modality to be analyzed, and this then leads to interference-by-process with no attention capture involved whatsoever. This would explain how attention appears to be involved in cross-modal Stroop but

does not display all of the results one would expect to see if attention *capture* was playing a role (i.e. the impact of warning cues and the influence of top-down or conscious control).

Why is it, however, that participants would attend to the auditory information in cross-modal Stroop, even though they are told to ignore it, and it frequently harms their performance? Recent research suggested that a deviant stimulus only captures attention and slows response times when it has some informational value about the target (Ljungberg, Parmentier, Leiva, & Vega, 2012; Parmentier, 2014; Parmentier et al., 2010; Wetzel et al. 2013). For example, Parmentier et al. (2014) conducted an experiment in which either standard or deviant sounds were presented before a visual target (this is fairly typical in most cross-modal deviant paradigms). In this experiment, the deviant was either informative (it was always followed by the visual target and could be used to predict its appearance) or uninformative (the visual target was only presented 50% of the time the sounds were heard, and, thus, the distractor did not serve as a warning of the arrival of the target). In addition, the deviant consisted of either white noise or auditory words (“right” and “left”), which were either congruent or incongruent to the visual target (an arrow which participants had to manually report was pointing to either the right or left). Parmentier et al. found that the deviant stimulus only impacted response times when the deviant was informative (i.e. served as a warning of the target), and while there was a semantic effect (the congruency of the auditory word impacted performance) in both the informative and uninformative condition, the size of the semantic effect was greater in the informative condition.

Dalton and Hughes (2014) have suggested these types of results imply that the cross-modal deviant paradigm is not one of selective attention but divided attention instead, as it is unlikely that all stimuli would have to be informative in order to capture attention. Thus, they hypothesize that the importance of the informational value of the deviant means that the

supposedly “task-irrelevant” information is really “task-relevant.” In most deviant scenarios, the deviant is presented before the target and is always coupled with the target (Leiva et al., 2015; Parmentier, 2008; Parmentier et al., 2014; see Parmentier & Hebrero, 2013 for an example in which the target is also the deviant). As such, it is reasonable that the deviant is serving as a warning of the arrival of the target and is therefore relevant for the completion of the task.

Although more recent findings have called the results of the importance of the informational value of a deviant (Ljungberg et al., 2012; Parmentier 2014; Parmentier et al.; 2010; Wetzel et al. 2013) into doubt (Parmentier, 2016), Dalton and Hughes (2014) may still be correct in that some supposedly “selective” attention paradigms are actually “divided” attention ones and that, at least in some scenarios, people do use “irrelevant” information in order to complete a task, even if they are not explicitly aware of doing so. If this were the case, it is still possible that lessening the relevance of distracting information would alter its impact as a distractor.

In the cross-modal Stroop paradigm, the target and distractor are frequently presented at the same time although the stimulus onsets may vary. Nonetheless, the auditory distractor is always accompanied by the target, and, therefore, participants may be using this information to help them complete the task. If one were to break the connection between the visual target and auditory distractor, it is possible that the auditory distractor would not have as detrimental of an impact. If performance is harmed regardless of whether or not the visual and auditory stimuli are always paired, it would imply that the stimulus harms performance because it is truly outside of our ability to control through top-down or conscious influences. If the impact of the auditory stimuli is lessened because it no longer informs of the presence of the target, it would suggest that we monitor the auditory stimuli in an attempt to help complete the task and that the task is

one of divided attention. If this is the case, it raises the question of whether or not attention capture then plays an additional role.

## **1.6 The Current Experiments**

The current dissertation examined whether both interference-by-process and attention capture can lead to distraction simultaneously. One way to accomplish this is to manipulate one mechanism while leaving the other intact. In Experiment 1, I sought to lessen the impact of attention capture by providing predictive or non-predictive warning cues about what type of trial (congruent, incongruent, or control) was about to follow (Horváth et al., 2011; Hughes et al., 2013; Parmentier & Hebrero, 2013; Shelton et al., 2009; Sörqvist & Marsh, 2015). Elliott et al. (1998) manipulated whether trials were presented in blocks or randomly intermixed, but did not explicitly tell participants what to expect. As attention capture has been found to be reduced by warnings in other attention capture paradigms, an impact of predictive and valid warning cues on the size of the cross-modal Stroop effect would suggest that attention capture is playing a role in the disruption caused by irrelevant auditory distractors.

In Experiment 2, I examined whether attending to the auditory information in cross-modal Stroop is further within the realm of top-down control. If this is the case, it would suggest that the task is one of divided attention. If Experiment 1 does not show clear evidence of attention capture, finding that the cross-modal Stroop task is subject to top-down control at a more global level would help to explain why the task shows habituation and how the sounds are semantically analyzed in the first place. Moreover, if performance is altered by changing the informational value of the auditory distractors, it may imply that the size of the cross-modal Stroop effect can be altered through top-down mechanisms, something which has been rarely shown (manipulation of congruency proportions can lessen the size of the effect, but this seems

to be one of the few examples, see Logan & Zbrodoff, 1979). However, it is also possible that the sounds are not being constantly monitored and attended to and, thus, the task is one of selective attention not divided attention, as is frequently assumed in the literature. Nonetheless, this experiment allowed me to examine whether global attentional resources are playing a role in the effect.

Finally, in Experiment 3 I examined the role of interference-by-process. If interference-by-process is occurring, it is hypothetically due to the conflict of processing the meaning of the auditory and visual channels. Thus, if you remove the semantic conflict of one of these channels (e.g. use non-color words as the auditory distractors) the interference from the two processes should disappear. If interference is still found, it would imply either 1) that it is not just the processing of the semantics leading to the effect but the processing of words in general or 2) interference-by-process is not solely causing the effect.

Altogether, the following three experiments allowed me to examine the roles of interference-by-process and attention capture, whether they can be manipulated independently, and what role divided and selective attention plays in the activation of the mechanisms.

## Chapter 2: Experiment 1

As mentioned previously, there are two posited mechanisms of auditory distraction: attention capture and interference-by-process. If the cross-modal Stroop effect is due, at least in part, to attention capture, the effect should be able to be mitigated or eliminated through top-down influences of attention. One of the ways which has been found to allow participants to display this type of control is warning cues at the level of the individual trial. As mentioned above, warning cues can lessen the impact of interference due to attention capture (Horváth et al., 2011; Hughes et al., 2013; Parmentier & Hebrero, 2013; Shelton et al., 2009; Sörqvist & Marsh, 2015).

### 2.1 Method

#### Participants

This experiment tested 72 Louisiana State University undergraduates. Participants were ineligible to participate if they had abnormal hearing, abnormal color vision, and a first language of anything other than English (participants were also asked if they were bilingual). One participant was removed due to problems with the microphone. In addition, eight participants displayed results that were more than three standard deviations away from the mean for either the number of false starts they produced, the number of errors they committed, or in response times. As such, these participants were removed from all of the analyses reported below. Thus, the results reported below are for 63 of the participants (predictive cue,  $N = 34$ ; non-predictive cue,  $N = 29$ ). Participants received either course or extra credit for participating.

**Power analysis.** This experiment consisted of a 3 (auditory distraction) x 2 (cue type) mixed-factor design. Auditory distraction (congruent, incongruent, control) was within-subjects, while cue type (non-predictive or predictive warning cue) was between. Unfortunately, there

were very few studies that could be used to help estimate effect and sample sizes. The best example was Hughes et al. (2013) with serial recall used as the dependent variable. They conducted a 2 (warning or no warning) x 2 (deviant or no deviant) x 2 (task-difficulty) within-subject design. The effect size for the main effect of warning was small and not significant (*Cohen's d* = .30), though Hughes et al. (2013) did find the two significant two-way interactions as well as the significant three-way interaction (they did not report effect sizes for the interactions) after running only running 24 people. In addition, through examining previous cross-modal Stroop studies I was able to calculate an average effect size for the main effect of auditory distraction of  $\eta^2_p = .67$  (Elliott et al., 2014; Lutfi-Proctor et al., 2014).

By using G\*Power 3 (Faul, Erdfelder, Buchner, & Lang, 2009), I estimated that I would need approximately 62 participants total (30-35 in each cue condition). I used the F-test family of tests and the repeated-measures, between factors a priori estimate in particular. The number of groups was input as 2, while the number of repetitions was 3 ( $\beta = .80$  and  $\alpha = .05$ ). Given Hughes et al.'s small sample size and the fact that the interaction would most likely be of a moderate effect size (Hughes et al., 2013), approximately 60-70 participants was deemed to be adequate as there were a large number of trials per participant.

### **Materials and Design**

Participants spoke the color name of visual items while ignoring auditory distractors. The color items consisted of red, blue, and green color squares, while the auditory distractors were the color words *red* (360ms), *blue* (350ms), and *green* (310ms) presented in a female voice, and a tone (the control; 500ms at 300 Hz). All participants experienced 144 congruent experimental trials (each of the three color combinations was experienced 48 times), 144 incongruent experimental trials (each the six color combinations was observed 24 times), and

144 tone experimental trials (with each of the three combinations seen 48 times). Participants were also given visual warning cues which were either predictive or non-predictive. The warning cues consisted of the words “Same”, “Diff” (for different), and “Tone,” presented on the computer screen. In the predictive cue condition the warning cues were always valid; following the word “Same” participants received a trial in which the auditory word and visual color-naming target matched (144 trials). After receiving a “Diff” cue, participants experienced trials in which the auditory word and visual target did not match (144 trials), and on “Tone” trials, participants received a visual target with a tone (144 trials). In the non-predictive condition, the visual warning cues (again the words “Same,” “Diff,” and “Tone”) were not predictive of the type of trial, and were pseudo-randomly assigned so that each warning cue was presented with each auditory condition 48 times. Thus, on one-third of trials, the cue was correct. Table 1 depicts the combinations of warning cues and the subsequent auditory stimulus, demonstrating the matched (1/3) and mis-matched (2/3) combinations.

Table 1: Experiment 1 warning cue and auditory condition combinations for the non-predictive condition

	<u>Auditory Condition</u>		
	Incongruent Trial	Congruent Trial	Tone Trial
Warning Cue	Same	Same	Same
	Diff	Diff	Diff
	Tone	Tone	Tone

The visual items were presented on a 22-inch monitor, while the sounds were heard through headphones at a subjectively comfortable volume. Response times were recorded through a microphone connected to a response box, and the program was run through E-prime (Psychology Software Tools, Pittsburgh, PA). The experiment took approximately 20 minutes to complete, and only one participant and an experimenter were present in the room at a time.

There were 9 practice trials followed by the 432 experimental trials. Trials consisted of congruent (the visual and auditory color match), incongruent (the visual and auditory color do not match), and control (the visual item and a tone), and all trial types were randomly intermixed and presented an equal number of times.

### **Procedure**

All trials began with a fixation cross which remained in the center of the screen for 500ms. Following the fixation cross the warning cue appeared (“Same”, “Diff,” or “Tone”) which also remained for 500ms before the target’s (the visual colored square) and auditory distractor’s onset. The onset of the visual target and auditory distractor was always simultaneous. All participants were told to speak the color of the squares as quickly and accurately as possible and to ignore the sounds.

The microphone was triggered when the participant named the color, after which the program prompted the experimenter with three questions: what color the participant said, whether there was a false start (the microphone was triggered before the participant was able to respond), and whether the experimenter made an error in answering the first two questions (see Appendix A for the exact instructions given to the participants).

After completing the experiment, all participants completed a post-experiment questionnaire asking 1) whether the participants had used the warning cues to complete the experiment and 2) whether they felt the cues had been helpful (see Appendix A for the exact questions used).

### **2.2 Results**

Two 2 (warning cue) x 3 (auditory distraction) mixed-model ANOVAs were used to analyze the means of medians of RTs and the count of inaccurate trials separately. A total of

0.85% of trials were removed due to response errors, 1.78 % because of false starts, and 0.12% for experimenter errors. Across all three experiments reported here, for all analyses  $\alpha = .05$ , and the Bonferroni correction was used for all follow-up tests. In cases where sphericity was violated and the results were significant, the Greenhouse-Geisser correction was used.

In terms of RTs, there was a significant main effect of auditory distraction,  $F(2, 122) = 29.25$ ,  $MSE = 23602.13$ ,  $p < .01$ ,  $\eta^2_p = .32$ , with tone = congruent < incongruent. However, there was no main effect of warning cue,  $F(1, 61) = 0.01$ ,  $MSE = 105.92$ ,  $p = .94$ ,  $\eta^2_p < .01$ , nor a significant interaction,  $F(2, 122) = .13$ ,  $MSE = 107.99$ ,  $p = .88$ ,  $\eta^2_p < .01$  (see Figure 1).

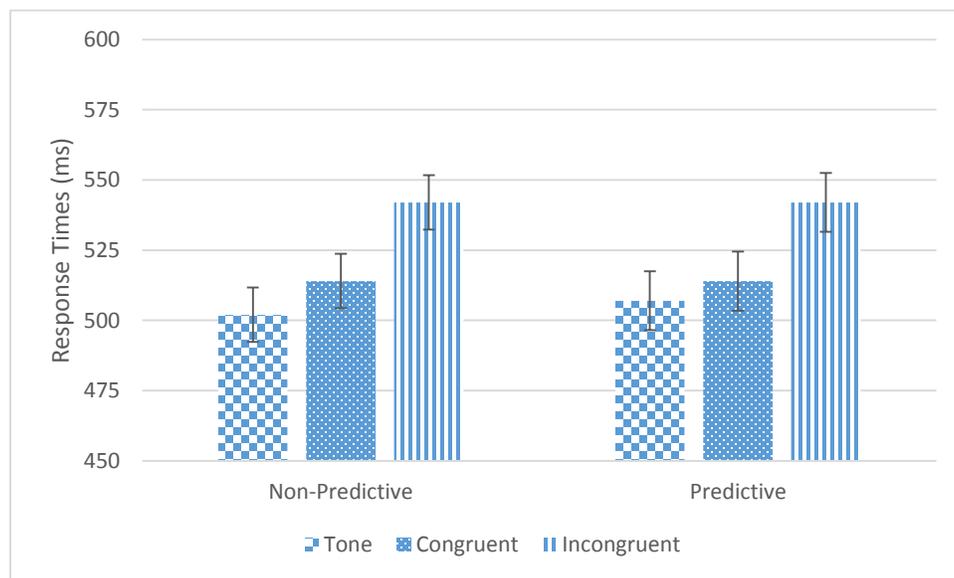


Figure 1: Experiment 1 response times for auditory distractor type by warning cue condition. Error bars represent within-subjects confidence intervals.

For errors, there was once again a significant main effect of auditory distraction,  $F(2, 122) = 10.77$ ,  $p < .01$ ,  $MSE = 5.24$ ,  $\eta^2_p = .15$ , but with congruent < incongruent, and tone not significantly different from either. There was no significant main effect of warning cue,  $F(1, 61) = 2.59$ ,  $p = .11$ ,  $MSE = 2.98$ ,  $\eta^2_p = .04$ , and no significant interaction,  $F(2, 122) = .51$ ,  $p = .60$ ,  $MSE = .25$ ,  $\eta^2_p = .01$  (see Table 2).

Table 2: Experiment 1 percentage of errors for each trial type by warning cue condition. Numbers in parentheses represent standard errors.

	Predictive Warning Cue	Non-predictive Warning Cue
Tone	0.92 (0.17)	0.56 (0.15)
Congruent	0.60 (0.12)	0.33 (0.11)
Incongruent	1.10 (0.18)	0.99 (0.17)

### Non-predictive Warning Cue Analyses

In addition to examining the impact of predictive and non-predictive cues overall, I was also interested in the specific pairings of warning cues and trial types. Thus, a 3 (warning cue) x 3 (auditory distractor) repeated-measures ANOVA was used to analyze this relationship. Given that there were slightly different conditions in this version of the experiment than overall, outliers and participants were re-examined. There were a total of 14 participants who displayed scores more than three standard deviations from the means and were, therefore, removed.

There was a significant main effect of auditory distractor,  $F(2, 48) = 5.13, p = .01, MSE = 6.84, \eta^2_p = .18$ , with congruent trials < incongruent trials with tone not different from either, and a nonsignificant main effect of warning cue,  $F(1.62, 38.80) = 2.56, p = .12, MSE = 2.60, \eta^2_p = .09$ . The interaction was, once again, not significant,  $F(2.94, 70.61) = 2.48, p = .07, MSE = 1.03, \eta^2_p = .09$  (see Figure 2).

### 2.3 Discussion

Overall, the results showed no evidence for attention capture playing a role in the cross-modal Stroop effect. Although there was no effect of the warning cues when they were predictive or non-predictive, it is possible that the warning cue manipulation simply was not strong enough to display clear effects. Moreover, the majority of the participants reported that they did not try

to use the cues to help them complete the task. Only 13 of the participants in the predictive cue condition (39.39%) reported trying to use the cues at least at some point in the experiment. Of these, five (38.46%) reported that the cues helped, four (30.77%) that they sometimes helped, and four (30.77%) that they made the task harder. Of the 26.32% in the non-predictive cue who reported attempting to use the warning cues, two reported that they helped (20%).

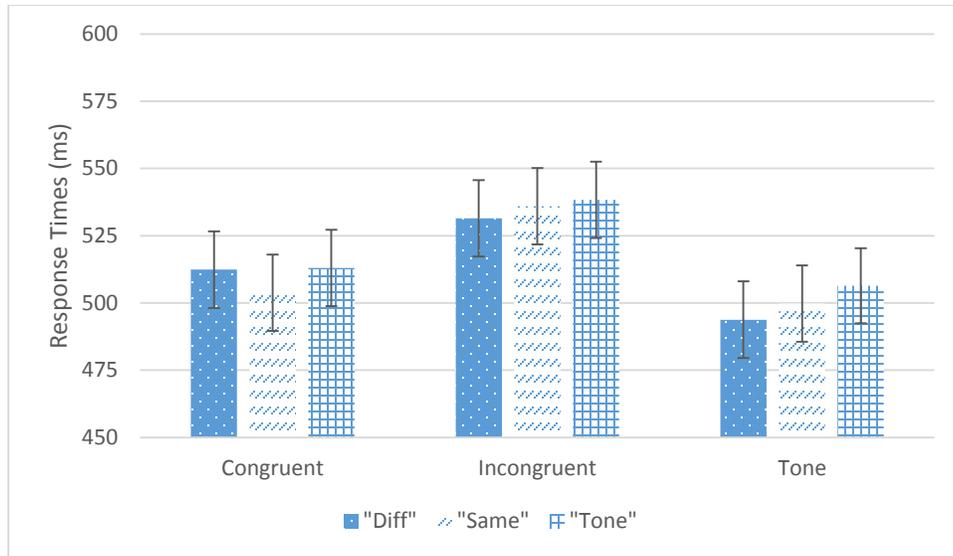


Figure 2: Experiment 1 response times for the non-predictive cues by auditory distractor condition. Error bars represent within-subjects confidence intervals.

Additional studies are needed to clarify the role of attention capture in the cross-modal Stroop effect. One solution would be to make it easier for participants to use the cues. To do this, one could provide the warning cues for a longer period of time. In this experiment the cues remained on the screen for 500ms, and some of the participants stated that they were almost too fast to use. Also, perhaps by encouraging participants to use the cues rather than providing them with the option to do so would lead to them having more of an impact. Lastly, some other research has shown that presenting participants with the exact distracting stimulus that they are about to experience as a distractor can mitigate distraction even when a general warning cue (e.g. a visual item signifying an oncoming trial with distractors) does not (Röer, Bell, & Buchner;

2015). R er et al. (2015) conducted a series of three experiments in which participants completed an ISE task in which they remembered visually-presented digits while ignoring auditory sentences. At times, participants heard and/or read the sentences that would be presented as the distracting stimuli before a trial started. R er et al. found that this pre-exposure helped to lessen the ISE and concluded that this finding supported a role for attention capture. Within the cross-modal Stroop paradigm, perhaps providing participants with the exact auditory distractor they are about to experience will help to lessen the effect (e.g. seeing the written word “Blue” before the trial begins when the word “Blue” will be the auditory distractor or even playing the auditory word “Blue” before the trial begins). Previous research has presented pre-exposure stimuli by either the class of color words, or the class of non-color words, but did not specifically pre-expose one item (see Experiment 3 of Elliott & Cowan, 2001).

It is also possible that even if attention capture is playing a small role in the cross-modal Stroop effect that general attentional resources are having an impact. For example, because participants are told to ignore the auditory distractors does not mean that they are actually doing so. Therefore, it is possible that participants are constantly attending to the sounds and/or switching back and forth, making the cross-modal Stroop task one of divided attention rather than selective attention. If this is the case, it would help to explain how attention capture could not play a large role in an effect that appears to habituate.

### Chapter 3: Experiment 2

As discussed above, it is possible that, at least at times, information that a researcher may view as being “irrelevant” (i.e. an auditory distractor) may actually be seen as “relevant” by participants and be used to help complete a task (Dalton & Hughes, 2014). For example, in the typical cross-modal Stroop paradigm, every time a distractor is heard, a target appears; thus participants may be using the sounds to alert themselves to the presence of a target (especially if they are not paying particularly close attention to the screen). In addition, some researchers have argued that the semantics of sounds are not analyzed unless they are first attended to (Li et al., 2013; Parmentier, 2008). If this assumption is correct, and the sounds are not “capturing attention,” it implies that the sounds are being monitored. If this were not the case, one would not expect to see an impact of semantics on the cross-modal Stroop effect as is seen. As such, cross-modal Stroop may be a divided attention task, not a selective attention one as is frequently assumed (however see Morey et al., 2012). If cross-modal Stroop were a divided attention task, it would help explain why attentional resources seem to be playing a role in the effect (i.e. habituation; Elliott & Cowan, 2001; Lutfi-Proctor et al., 2014) even though the role of attention capture appears to be minimal in the current Experiment 1.

In Experiment 2, the connection between the visual targets and auditory distractors was lessened by no longer having a target appear every time an auditory distractor was heard. By removing this “connection” between the auditory distractors and visual targets, participants should have been less likely to use the sounds in order to complete the task. Morey et al. (2012) conducted an experiment in which participants had to monitor the auditory channel for a specific sound (either a tone, non-color word, or a color word not in the response set—there were no differences among them) and press a key in addition to naming the color of the visual items on

these trials. Morey et al. found that the size of the cross-modal Stroop effect increased with this manipulation. Therefore, it would appear that by encouraging participants to monitor the auditory distractors, performance on the target task decreases. Is it possible to improve performance by encouraging participants to ignore the auditory distractors or, in other words, use top-down control to mitigate their impact?

If whether the auditory distractor is informative (i.e. provides information about the target) is unimportant, it would imply that cross-modal Stroop is a selective attention task and that participants truly are either not monitoring the auditory distractors or that this monitoring is not under top-down control. If the impact of the auditory stimuli is lessened when it no longer informs of the presence of the target, it would suggest that we monitor the auditory stimuli in an attempt to help complete the task and that cross-modal Stroop is a divided attention scenario, in which participants are using the experimental context to guide their behavior.

### **3.1 Method**

#### **Participants**

Eighty-five Louisiana State University undergraduates (19 males, age:  $M = 20.28$ ,  $SD = 1.78$ ) served as participants and received either course or extra credit. As in Experiment 1, participants were ineligible to participate if they had abnormal hearing, impaired color vision, and their first language was anything other than English (six participants were bilingual and were closely examined to see if they deviated from the monolingual speakers; based on RTs and errors, they did not). Six participants displayed results that were more than three standard deviations away from the mean for either the number of false starts, the number of errors produced, or the length of the response times. These participants were removed for a total of 79 in the final analyses (100% coupled,  $N = 42$ ; 50% coupled,  $N = 37$ ).

**Power analysis.** Experiment 2 consisted of a 3 (auditory distraction: incongruent, congruent, control) x 2 (coupled condition: 100% or 50%) mixed-factor design. Although the current experiment is similar to an existing one (Parmentier et al., 2014), the design of their experiment is unclear. Parmentier et al. conducted a 4 (sound condition: congruent deviant, incongruent deviant, noise deviant, and standard) x 2 (informative or coupled 100% vs. uninformative or coupled 50%) mixed-model design. Parmentier et al. reported a  $\eta^2_p = .03$  for the main effect of informative condition,  $\eta^2_p = .22$  for the main effect of sound condition, and a  $\eta^2_p = .08$  for the interaction. Given that Parmentier et al. provide confidence intervals rather than standard errors or standard deviations, I was unable to calculate Cohen's d in the same manner as the first two experiments. Nonetheless, Parmentier et al. ran 58 participants (29 in each group); thus, this number was used as a starting point, with an expectation to run 60-70 participants.

### **Materials, Design, and Procedure**

Participants were asked to name the color of the visual item as quickly and accurately as possible, and as in Experiment 1, the visual stimuli consisted of red, blue, and green color squares. The auditory stimuli comprised the auditory words *red*, *blue*, and *green* (the same auditory color word files used in Experiment 1), and silence was used as the control. Unlike in the first experiment, the auditory distractors (the color words) were not always accompanied by the visual targets. In addition, a control of silence was used to further disconnect the relationship between the auditory distractors and visual targets as there were now trials when a visual target appeared without a sound.

Whether the auditory distractors were always accompanied by a visual target was manipulated between subjects. In the 100% coupled condition, every time an auditory distractor was heard, a visual target was seen (participants still saw the visual target and heard no auditory

distractor on some trials). In the 50% coupled condition, 50% of the time the sound was presented no visual target appeared (again, participants saw the visual target without hearing an auditory distractor on some trials). Participants in both the 100% coupled and 50% coupled condition were told that if no visual stimulus appeared after the fixation cross (the screen was blank), they should say “none” (see Appendix A for the instructions given to the participants).

In both the 50% and 100% coupled conditions, there were 12 practice trials followed by 324 experimental trials. In the 50% coupled condition, there were 108 control trials (the visual target and silence), 108 coupled sound trials (54 congruent, 54 incongruent), and 108 uncoupled sound trials (an auditory color word with no accompanying visual target). However, in the 100% coupled condition, there were 108 control trials, and because all were coupled, there were 108 each of congruent and incongruent trials. Filler trials were randomly identified within both programs (there were no differences between filler trials and regular trials and neither the experimenter nor participant knew whether a particular trial was a filler or non-filler one) so that only 54 trials of each auditory distraction condition (congruent, incongruent, and control) could be analyzed for each coupled condition.

This experiment consisted of a 3 (auditory distractor) x 2 (coupled condition) mixed-factor design with auditory distractor as a within-subjects factor. Aside from the variations listed above, the exclusion of the warning cues, and the inclusion as “none” as a response option, the procedure was identical to that in Experiment 1.

### **3.2 Results**

Separate 2 (coupled condition: 50% or 100%) x 3 (auditory distractor: congruent, incongruent, silence) mixed-model ANOVAs were used to analyze the means of medians of RTs and the count of inaccurate trials or errors. A total of 1.71% of trials were removed due to

response errors, 1.59% because of false starts, and 0.08% for experimenter errors. All analyses reported below are with the filler trials excluded (there were no differences in the results when they were included).

### Response Times

A 2 (coupled condition) x 3 (auditory distraction condition) mixed-model ANOVA was used to analyze the means of medians of RTs. There was a main effect of auditory distraction,  $F(1.81, 139.49) = 154.58, p < .01, MSE = 76,666.85, \eta^2_p = .67$ , with silence < congruent < incongruent. However, there no significant main effect of coupled condition,  $F(1, 77) = 3.73, p = .06, MSE = 53,365.97, \eta^2_p = .05$  (see Figure 3), and no significant interaction,  $F(2, 154) = .7, p = .48, MSE = 332.62, \eta^2_p = .01$ . An examination of the interference scores (incongruent trials – silent/control trials) further showed that coupled condition had no impact on the amount of interference induced,  $t(157) = .38, p = .70$  (see Figure 4).

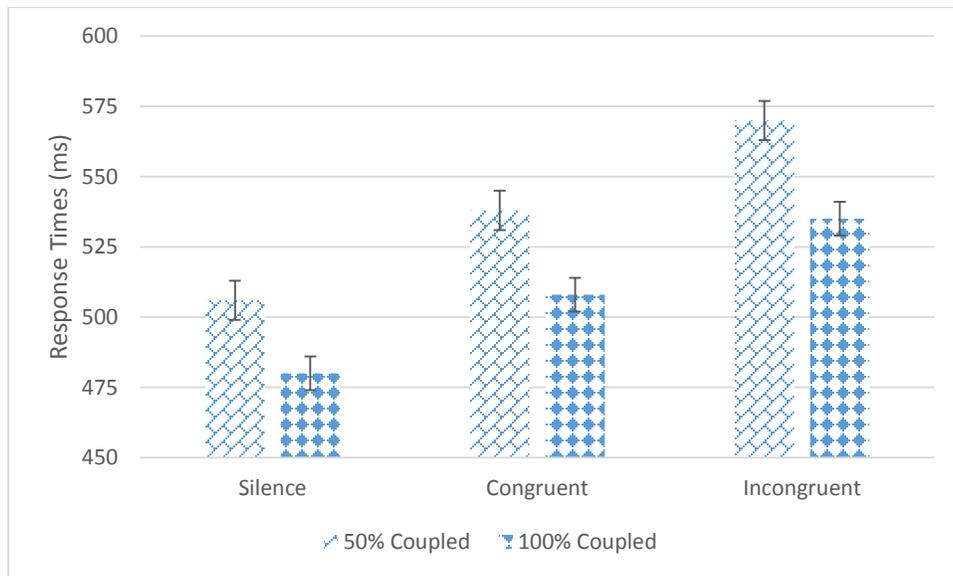


Figure 3: Experiment 2 response times for each trial type by version. Error bars represent within-subjects confidence intervals.

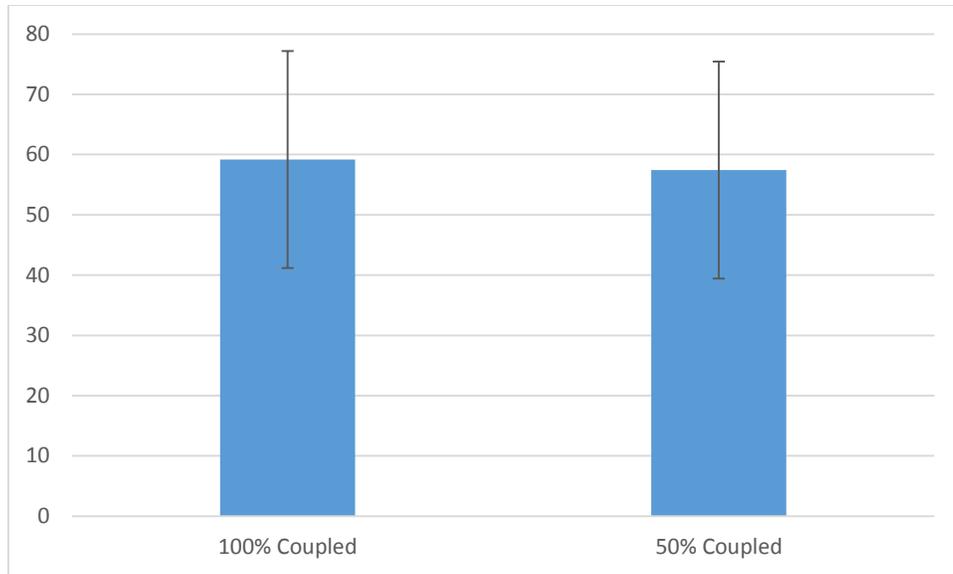


Figure 4: Experiment 2 interference scores (incongruent-silence) for the 100% and 50% coupled versions of the experiment. Error bars represent 95% confidence intervals.

### Errors

A 2 (coupled condition) x 3 (auditory distraction condition) mixed-model ANOVA was used to analyze the percentage of incorrect trials or errors. There was a main effect of auditory distraction,  $F(2, 154) = 3.61, p < .05, MSE = 7.06, \eta^2_p = .05$ , with incongruent > congruent (silence was not significantly different from either), but no main effect of coupled condition,  $F(1, 77) = 2.97, p = .09, MSE = 14.23, \eta^2_p = .04$ , with 50% > 100%. Once again, the interaction was not significant,  $F(2, 154) = .97, p = .38, MSE = 1.90, \eta^2_p = .01$  (see Table 3).

In terms of the “uncoupled” trials, they only led to significantly fewer errors than incongruent trials.

### Blocked Analyses

Due to the hypotheses related to top-down control, the response times were analyzed to see if there were any changes over the course of the experiment, due to a mechanism such as habituation. In order to do the block-level analyses, the first 108 trials were considered “Block 1,” the next 108 trials “Block 2,” and the last 108 trials “Block 3.” Due to the random

presentation of the trial types over all 324 trials, there were small variations in the number of each type of trial across each block. A 3 (block) x 4 (auditory distraction condition, this time including the “none” trials) repeated-measures ANOVA was run for the 50% coupled versions of the task, and a 3 (block) x 3 (auditory distraction condition) repeated-measures ANOVA was run for 100% coupled.

Table 3: Experiment 2 percentage of errors for each trial type by coupled condition. Numbers in parentheses represent standard errors.

	50% Coupled	100% Coupled
Silent	1.13 (0.24)	0.68 (0.23)
Congruent	1.23 (0.25)	0.41 (0.23)
Incongruent	1.48 (0.34)	1.28 (0.32)

In the 50% coupled version, there was a main effect of auditory distraction,  $F(1.43, 58.03) = 61.85, p < .01, MSE = 570411.20, \eta^2_p = .63$ , with none > incongruent > congruent > silence. There was also a significant main effect of block,  $F(1.57, 52.96) = 3.64, p < .05, MSE = 21801.96, \eta^2_p = .09$ , with block 1 > block 2 = block 3. Lastly, the auditory distraction by block interaction was significant,  $F(2.78, 102.78) = 61.845, p < .05, MSE = 13493.38, \eta^2_p = .10$  (see Figure 5a). In order to examine the interaction, each auditory distraction condition (congruent, incongruent, silence, and none) was examined by each block. Four separate repeated-measures ANOVAs with Bonferroni corrections were used to analyze the response times for each auditory distraction condition separately across the three blocks. There were no changes for incongruent, congruent, or silent trials across the three blocks, but for the “none” trials, participants got significantly faster from block 1 to block 2.

In the 100% coupled version of the task, there was a significant main effect of auditory distraction condition,  $F(1.70, 68.09) = 58.40, p < .01, MSE = 101214.33, \eta^2_p = .59$ , with incongruent > congruent > silence. However, neither the main effect of block,  $F(2, 80) = .474, p = .62, MSE = 1106.80, \eta^2_p = .01$ , nor the auditory distraction by block condition were significant,  $F(4, 160) = 1.23, p = .97, MSE = 77.8, \eta^2_p < .01$  (see Figure 5b).

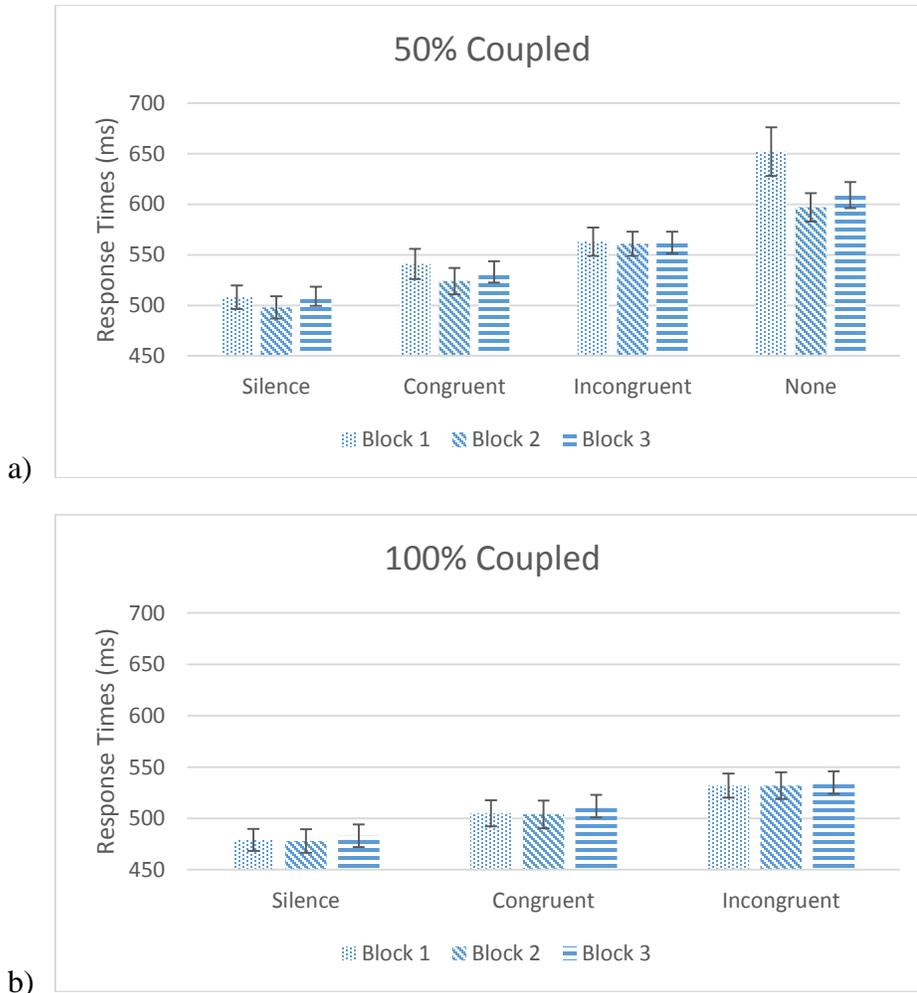


Figure 5: Experiment 2 response times for auditory distraction condition by block. Figure a displays the results from the 50% couple version of the task, Figure b displays the results from the 100% version. Error bars represent within-subjects confidence intervals.

### 3.3 Discussion

Experiment 2 examined whether or not participants were regularly attending to the auditory information in the cross-modal Stroop task even though it was irrelevant to the task. If participants do monitor the auditory information, it would imply that cross-modal Stroop can be a divided attention task rather than the selective attention one it is typically assumed to be (see also Morey et al., 2012). Moreover, if cross-modal Stroop were a divided attention task, it could potentially help to explain why the task habituates even though the evidence from Experiment 1 suggested that attention capture may be playing a minimal role.

It does not appear, however, that the informational value of the sounds in cross-modal Stroop had much of an impact on the size of the effect, as there were no differences when the auditory information was always related to completing the task (naming visual colors) versus when it was only available 50% of the time. While there was a difference in terms of the number of errors produced by the two versions of the task, with participants making more errors when the sounds were not always accompanied with a target, this seems to be driven by the fact that participants often said “none” in the 50% coupled version when a target did, indeed, appear (see Table 4). This suggests that participants may have been approaching the 50% version as a divided attention task (saying “none” versus naming the color), which implies that the mind-set employed was quite different from that used in the usual version of the task (i.e. 100% coupled version). Even if one were to view divided and selective attention tasks as a continuum rather than a dichotomy, this implies that the typical version of the cross-modal Stroop task is more on the selective than the divided end of the spectrum, although this can be altered by changing task instructions (see Morey et al., 2012). Moreover, the fact that even though the mental set was likely different in these two versions of the task with target always present versus target

sometimes absent, and still produced such similar results, shows a robust impact of the auditory color words on visual color naming.

Table 4: Experiment 2 percentage of each type of errors: saying the incorrect color on a congruent (Congruent), incongruent (Incongruent), and silent (Silent) trial, saying “none” on a trial where a color should have been named (None), and saying a color when the answer should have been “none” (Color).

	Means and Standard Errors
Silence	0.54 (0.17)
Incongruent	0.34 (0.25)
Congruent	0.34 (0.12)
None	1.53 (0.44)
Color	0.29 (0.07)

In addition, as mentioned earlier, recent research with cross-modal deviants has suggested that the informational value of a deviant is not as important as it was once thought to have been (Parmentier, 2016). Parmentier examined the informational impact of auditory deviants in more depth and determined that the fact that the deviant effect appears to “disappear” when the deviant is uninformative is really the combination of two opposite effects: distraction when a previous trial involved a target which needed to be responded to, and aiding when a deviant sound followed a trial involving no target and the withholding of a response as a result. In the current experiment, participants did not withhold their answers, but instead gave a different type of answer (saying none rather than naming the color). It is, therefore, necessary in the future to determine whether the same results would be found both in the cross-modal Stroop task if responses were withheld, and in the cross-modal deviant effect if participants responded “none” rather than not responding at all.

In summary, even if participants do attend to the auditory color words on some trials, thereby essentially making cross-modal Stroop a divided attention task, this division of attention does not appear to be under voluntary, top-down control. Moreover, while increasing the

attention paid to the auditory distractors appears to increase the size of the cross-modal Stroop effect (Morey et al., 2012), the current manipulation to decrease the degree to which the sounds were attended to had no impact. While it is possible this manipulation was not strong enough, more future research is needed to examine this in more depth. Lastly, this work expands upon that of Parmentier (2016) in that the informational value of a sound does not necessarily impact its ability to distract, and suggests that this can be extended beyond the go-no go paradigm Parmentier (2016) used.

### Chapter 4: Experiment 3

In contrast to Experiment 1 and 2, Experiment 3 sought to lessen the impact of interference-by-process on the cross-modal Stroop effect. According to the view of interference-by-process, interference is occurring because the processing of the semantics of the colored item and the semantics of the auditory word interfere. Thus, by removing the semantic relatedness of the auditory distractor, one should be able to lessen distraction from interference-by-process. This idea is supported by previous research which has shown that there is little to no difference between a control of silence and a control consisting of a non-speech tone (the tone has little additional effect beyond lessening the differences between congruent, incongruent, and control trials though the effect still remains significant; Lutfi-Proctor, Elliott, & Golob, in preparation). In addition, previous research has shown that rare non-color words habituate faster than more frequent color words during the cross-modal Stroop task (Elliott et al., 2014) and that words habituate faster than tones (there was a trend for non-color words habituating faster than color words, but this was not significant; Experiment 1, Elliott & Cowan, 2001). However, what impact non-color words and tones have on color naming does not appear to have been examined directly. Much of the work using non-color words has manipulated congruency proportions so that these particular types of trials were rare (Elliott et al., 2014). Thus Experiment 3 examined the role of semantic relatedness in the cross-modal Stroop paradigm by providing a direct comparison of the impact of color words and non-color words on color naming and was able to examine their rates of habituation over the course of the experiment (Elliott & Cowan, 2001 Experiment 3 conducted a similar experiment but was primarily focused on the effects of pre-exposing the stimuli).

## 4.1 Method

### Participants

Eighty Louisiana State University undergraduates served as participants and received either course or extra credit. Participants were ineligible to participate if they had abnormal hearing, impaired color vision, and their first language was anything other than English (four participants were bilingual, one of which was removed for displaying unusually slow response times). Seven participants displayed results that were more than three standard deviations away from the rest (four for RTs, two for false starts, and one was removed for errors). Error rates were so low that even two errors led to “extreme” scores that fell outside the range of three standard deviations. As such, only one person who produced errors in virtually every condition and had an accuracy level of less than 90% in some cases was removed (the results remained the same after exclusion). A total of 73 participants were included in the analyses (color first,  $N = 37$ ; non-color first,  $N = 36$ ).

**Power analysis.** Experiment 3 consisted of a 2 (semantically related and unrelated) x 2 (tone versus word) x 4 (block) within-subjects design. Once again, there were no clear prior comparisons, but by examining a number of studies, I was able to get a rough estimate of the number of participants I needed.

Elliott et al. (2014) conducted a cross-modal Stroop experiment consisting of incongruent and congruent color words, non-color words, and silence as a control. However, they also manipulated the congruency proportions so that 75% of the trials were control trials, meaning that the number of non-control trials was quite low. They conducted a 2 (block) x 4 (trial type: congruent, incongruent, control, non-color word) repeated-measures ANOVA. Elliott et al. found  $\eta^2_p = .47$  for the main effect of block,  $\eta^2_p = .70$  for the main effect of trial type, and  $\eta^2_p =$

.09 for the interaction. The color words in this experiment displayed minimal amounts of habituation and based on my interest in the habituation of non-color words, I estimated the means and standard errors of the non-color words in block one and two from the graph provided. I then converted the standard errors to standard deviations and calculated Cohen's  $d = .27$ .

Given that Cohen's  $d$  and partial eta squared are not equivalent and that I will be using four blocks instead of two, I halved the effect size calculated from Elliott et al. (2014) for an effect size of 0.135. Using this effect size in G\*Power 3 (Faul et al., 2009), I estimated that I would need approximately 77 participants total. I used the F-test family of tests and the repeated-measures, within factors a priori estimate in particular. The number of groups was input as 1, while the number of repetitions was 4 as I will be using four blocks ( $\beta = .80$  and  $\alpha = .05$ ).

Lutfi-Proctor et al. (2014) found evidence for habituation for incongruent and congruent trials (silence was used as the control) with incongruent trials seeming to habituate more than congruent ones ( $\eta^2_p = .28$ ). Again, this experiment is not quite the same, but it suggests that incongruent trials habituated more than congruent ones (and Elliott et al., 2014, suggests that non-color words habituated faster than color words), and I only used incongruent color words in the current design. Using the  $\eta^2_p = .28$ , I estimated that I would need to run 26 people to replicate the results of Lutfi-Proctor et al. If I halve the effect size (again I ran four blocks instead of two), this number goes up to 72 ( $\beta = .80$  and  $\alpha = .05$ ).

Elliott et al. (1998) compared color words (collapsed across auditory distraction condition) to non-color words and found a significant difference in terms of RTs (color words > non-color words). I was unable to calculate an effect size from the information provided in the article, but they had a final  $N = 24$ .

Lastly, Elliott and Cowan (2001; Experiment 1) examined trial by trial habituation of tones, non-color words, and color words (congruent and incongruent). They examined a series of 5 or 10 trials and found that tones habituated less than words (there was a trend in the difference between color words and non-color words, but it was not significant). However, I am once again unable to calculate a measure of effect size from the information given, but they used an  $N = 24$ . Based on all of this information, I believed a total of approximately 80 participants would be adequate.

### **Materials, Design, and Procedure**

The visual targets were once again red, green, and blue color squares, and the procedure was identical to that of Experiment 1 except that there were no predictive and non-predictive warning cues in this experiment. The auditory stimuli consisted of a tone (500ms 300 Hz) as the control, the auditory color words *red* (220ms), *blue* (300ms), and *green* (300ms), and three non-color words from the same category: *arch* (410ms), *dome* (280ms), and *maze* (360ms), which were matched for concreteness and imagability ratings on the MRC Psycholinguistic Database (Wilson, 1988). All of the verbal auditory stimuli were a recorded male voice.

This experiment had two parts. In one part (semantically related), participants named the color of squares while hearing either the tone or the auditory color words which were always incongruent (only incongruent trials were used as the non-color words do not match the visual targets). This served as a comparison for color naming when semantically similar words were present versus when they were not. In the other part (semantically unrelated), participants again named the color of squares, but this time they heard a tone and the three non-color words (see Appendix A for the instructions given to the participants).

Each of the two relatedness parts consisted of 12 practice trials and 288 experimental trials for a total of 24 practice and 576 experimental trials. Within each part, there were 144 control trials (tones) and 144 auditory word trials which were presented an equal number of times (there were three control combinations, six incongruent color word combinations, and nine non-color word combinations with each combination presented nine, six, and four times per block respectively). In each semantic part, there were 4 blocks of 60 experimental trials, 30 of which were control and 30 of which were auditory words (each of the three word options were heard 10 times per block). The two parts (semantically related and unrelated) were counterbalanced, and the experiment consisted of a 2 (task order) x 2 (semantically related and unrelated) x 2 (trial type: tone and word) x 4 (block) within-subjects design.

## 4.2 Results

Separate 2 x (task order: semantically related or unrelated first) x 2 (trial type: tones versus words) x 2 (part: semantically related versus unrelated) x 4 (block) mixed-model ANOVAs were used to analyze the means of medians of RTs and the count of inaccurate trials or errors separately. However, due to task order having no impact on the results for either RTs or errors, it was removed and the results of the 2 (trial type) x 2 (relatedness: semantically related versus unrelated) x 4 (block) repeated-measures ANOVAs are reported below. A total of 1.33% of trials contained a false start, 0.4% contained an error, while on only 0.2% of trials was an experimenter error reported.

### Response Times

A 2 (trial type: words versus tones) x 2 (relatedness: semantically related versus unrelated) x 4 (block) repeated-measures ANOVA was used to analyze the means of medians for RTs. There was a significant main effect of trial type,  $F(1, 72) = 81.31, p < .01, MSE =$

125485.85,  $\eta^2_p = .53$ , with words > tones. There was also a significant main effect of relatedness,  $F(1, 72) = 6.45, p < .05, MSE = 26187.01, \eta^2_p = .08$ , with the semantically related > semantically unrelated. The main effect of block was also significant,  $F(2.51, 180.90) = 4.67, p < .05, MSE = 7608.31, \eta^2_p = .06$ ; however, none of the follow-up tests were significantly different. A trend suggested that latency increased between blocks 2 and 3, with blocks 1 and 2 showing similar response times and blocks 3 and 4 being virtually identical (see Figure 6).

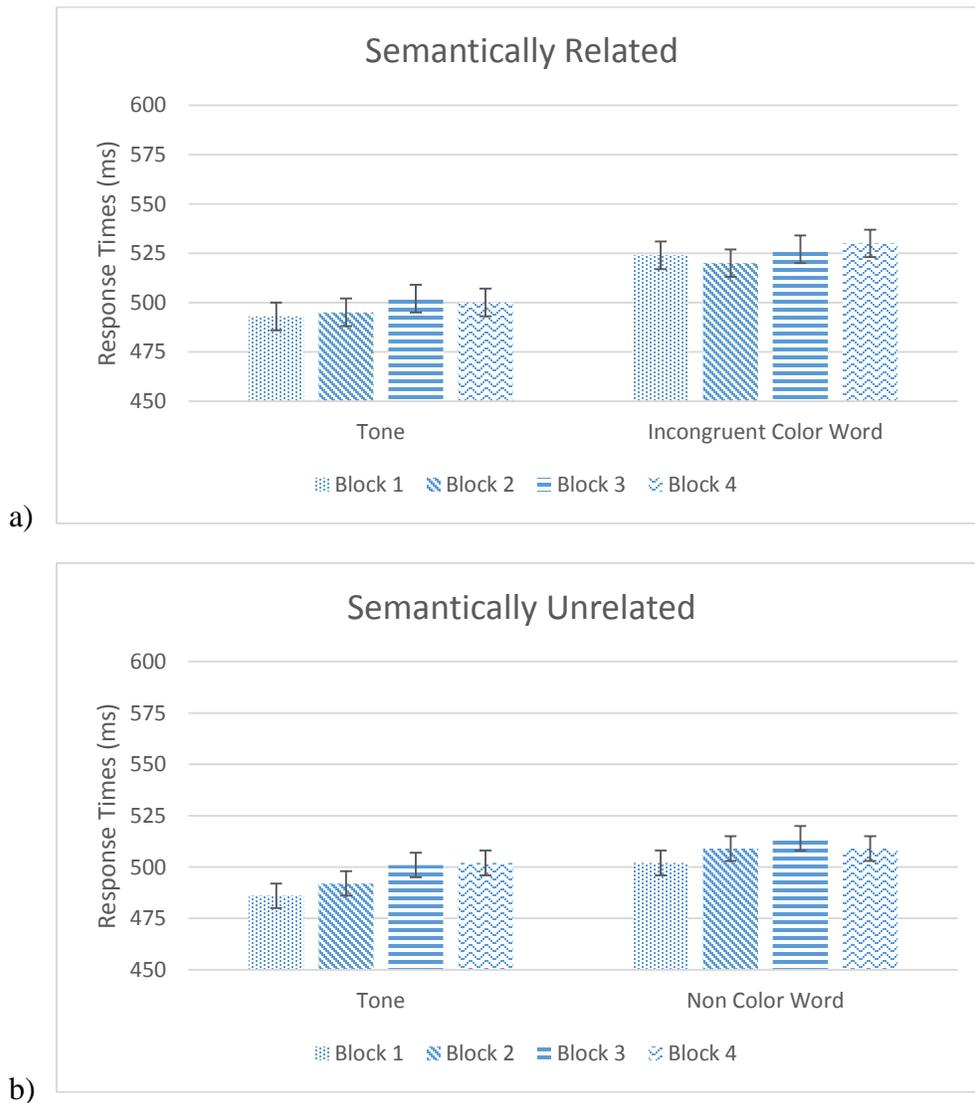


Figure 6: Experiment 3 for the for each auditory distraction condition by block in a) the semantically related b) and semantically unrelated. Error bars represent within-subjects confidence intervals.

There was also a significant interaction between trial type and relatedness,  $F(1, 72) = 32.64, p < .01, \text{MSE} = 15570.17, \eta^2_p = .31$  (this is examined in more depth below). The interaction between trial type and block was not significant,  $F(3, 216) = 1.14, p = .33, \text{MSE} = 399.08, \eta^2_p = .02$ , nor was the relatedness by block interaction  $F(3, 216) = 0.78, p = .51, \text{MSE} = 1008.01, \eta^2_p = .01$ . The three-way interaction (trial type by relatedness by block) was marginally significant,  $F(3, 216) = 2.60, p = .05, \text{MSE} = 767.12, \eta^2_p = .04$ .

In order to analyze the interaction between trial type and relatedness, the data were collapsed across blocks and interference scores were created for both the non-color words (non-color word trials – the tones trials in the semantically-unrelated part) and color words (color word trials – the tones trials in the semantically-related part). A paired samples t-test was then run to determine whether color words and non-color words led to different levels of interference. The test was significant,  $t(72) = -5.71, p < .01$ , with color words leading to significantly more interference than non-color words (see Figure 7).

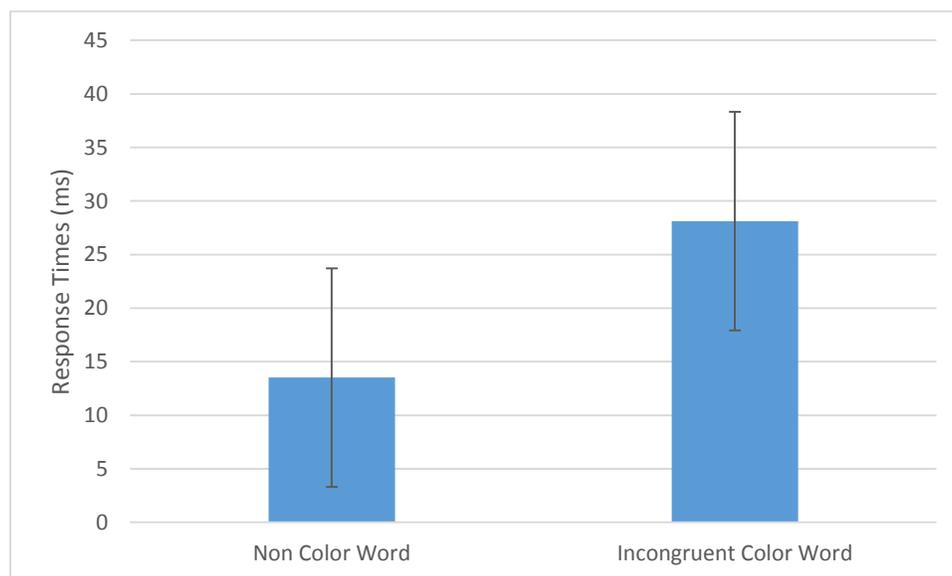


Figure 7: Experiment 3 interference scores for the semantically related and unrelated parts. Error bars represent 95% confidence intervals.

Lastly, as I was interested in the rate of habituation across the semantically related and unrelated words, the three-way interaction between trial type, relatedness, and block was analyzed in more depth despite not being significant. Separate 2 (trial type) x 4 (block) repeated measures ANOVAs were run for both the semantically-related and unrelated parts. In the semantically-related part, there was a significant main effect of trial type,  $F(1, 72) = 82.10, p < .01, MSE = 115474.22, \eta^2_p = .53$ , with color words being slower than tones. However, the main effect of block,  $F(3, 216) = 1.55, p = .21, MSE = 2223.87, \eta^2_p = .02$ , and the trial type by block interaction were not significant,  $F(3, 216) = 1.25, p = .29, MSE = 392.31, \eta^2_p = .02$  (see Figure 6a).

For the semantically-unrelated part, there was once again a main effect of trial type,  $F(1, 72) = 42.54, p < .01, MSE = 26682.80, \eta^2_p = .37$ , non-color words > tones. This time the main effect of block was also significant,  $F(2.51, 180.62) = 4.22, p < .05, MSE = 6166.38, \eta^2_p = .06$ . None of the follow-up tests were significant; however, the trend indicates that response times were slowing down over the course of the experiment. Lastly, the trial type by block interaction was not significant,  $F(3, 216) = 2.33, p = .08, MSE = 332.38, \eta^2_p = .03$  (see Figure 6b).

Table 5: Experiment 3 percentage of errors for words and tones for the four blocks and semantically related and unrelated parts. Numbers in parentheses represent standard errors.

	<u>Semantically Related</u>		<u>Semantically Unrelated</u>	
	Word	Tone	Word	Tone
Block 1	0.27 (0.10)	0.35 (0.12)	0.27 (0.11)	0.28 (0.10)
Block 2	0.44 (0.13)	0.40 (0.21)	0.33 (0.12)	0.51 (0.16)
Block 3	0.31 (0.12)	0.35 (0.13)	0.27 (0.10)	0.27 (0.10)
Block 4	0.26 (0.11)	0.46 (0.13)	0.43 (0.13)	0.23 (0.10)

## Errors

A 2 (trial type: words versus tones) x 2 (part: semantically related versus unrelated) x 4 (block) repeated-measures ANOVA was used to analyze proportion of incorrect trials, or errors (see Table 5). However, none of the main effects or interactions were significant (in all cases  $p > .1$  and  $\eta^2_p < .03$ ).

## 4.3 Discussion

Unlike in previous experiments, there was no evidence of habituation for any of the different trial types (non-color words, tones, and color words). It is possible that all habituation occurred within the first few trials and was, therefore, unable to be seen across blocks of 60; however, analyses of the first 10 trials<sup>1</sup> and the first 60 trials divided into six blocks of 10 showed no evidence of habituation either<sup>2</sup>. Lutfi-Proctor et al. (2014) found habituation across two blocks of trials with each block containing over 100 trials when only incongruent trials and silent control trials were used. It is therefore possible that the use of tones is responsible for the apparent lack of habituation. There appeared to be extremely high levels of fatigue over the course of this experiment as suggested by the slowing down of response times over the course of

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<sup>1</sup> A 2 (semantical relatedness) x 10 (trial number) repeated-measures ANOVA was used to analyze the first 10 trials for each participant. There was no significant main effect of trial number,  $F(9, 477) = 1.64, p = .10, \eta^2_p = .03$ , nor was the semantic relatedness by trial number interaction significant,  $F(9, 477) = 0.91, p = .52, \eta^2_p = .02$ . The order of the parts had no effect on the results.

<sup>2</sup> Separate 2 (trial type: word vs. non-word) x 6 (block) repeated-measures ANOVAs were used to analyze the first 60 trials divided into blocks of 10 for the semantically-related and unrelated parts. For the semantically-related part, there was no significant main effect of block,  $F(5, 355) = 0.60, p = .67, \eta^2_p = .01$ , nor was the trial type by block interaction significant,  $F(5, 355) = 0.32, p = .90, \eta^2_p = .01$ . For the semantically-unrelated part, there was, again, no significant main effect of block,  $F(5, 370) = 1.19, p = .32, \eta^2_p = .02$ , nor a significant block by trial type interaction,  $F(5, 370) = 2.07, p = .07, \eta^2_p = .03$ . However, given that the interaction was close to significant, it was examined in a little more depth. It would appear that the control trials stabilized in terms of their RTs faster than the non-color words. The order of parts had no impact on any of the results.

the experiment, with these levels being considerably higher than what is typically seen (generally response times improve or remain consistent throughout; Elliott et al., 2014, Lutfi-Proctor et al., 2014; Lutfi-Proctor et al., in preparation). Previous experiments have suggested that the use of tones as a control decreases the size of the cross-modal Stroop effect (Lutfi-Proctor et al., in preparation), and many participants stated that the constant barrage of sounds was tiring (something one does not typically hear when a control of silence is utilized). Thus, it is probable that any habituation was “washed out” by fatigue effects. If this is the case, it would also suggest that the habituation effects were not particularly strong to begin with (this will be discussed in more depth below).

Another important finding is that the non-color words led to interference above and beyond what was seen for tones. This suggests, as in the visual Stroop effect (Dalrymple-Alford, 1972; Klein, 1964), that the interference in cross-modal Stroop is not due purely to semantics and that hearing any word leads to a detriment in color naming (Elliott & Cowan, 2001; Elliott et al., 1998; this will be discussed in more depth in the general discussion). The fact that the non-color words continued to harm performance even after 100 trials also suggests that the words were not simply “capturing attention.” Research has consistently shown that distraction due to attention capture habituates (Cowan, 1995; Hughes et al., 2005; Hughes et al., 2007; Sokolov, 1963). The lack of clear habituation implies that this was not the case in this scenario.

In summary, the results suggested that while semantics do play a role in cross-modal Stroop, there is also an underlying “distraction” mechanism that seems to be more sensitive to words than tones. Perhaps this is similar to the role of acoustic complexity seen in the irrelevant sound effect (Macken & Jones, 1995; this will be discussed in depth in the general discussion).

Moreover, it would once again appear that attention capture or overall resources plays a small, if any role in the cross-modal Stroop effect.

## Chapter 5: General Discussion

Overall, there is very little evidence of attention capture playing a role in the cross-modal Stroop effect. Furthermore, if attention is responsible for the effect, then the attention involved seems to be outside the realm of top-down control. If attention capture was responsible for the effect, one would expect that various factors that manipulate top-down control, such as warning cues, would have an impact. This does not appear to be the case. Also, it does not appear that manipulating the connection between the auditory distractor and visual target had any effect on the impact of the sounds. Theoretically, one would expect participants to be less likely to monitor sounds when they provide no informational value to a primary task. This was not found, again implying that the attention involved in the effect, if it is playing a role, cannot be controlled. Furthermore, it would appear that participants are not, at least, explicitly, monitoring the auditory stimuli, and that the task is typically one of selective attention rather than divided attention, because whether attention is divided or not appears to have little impact on the size of the effect. Lastly, even though attention capture was not apparent across the three experiments, an interference-by-process mechanism based on some form of word processing interfering with color naming was. This implies that of the two auditory distraction mechanisms, interference-by-process is the mechanism primarily involved. Also, as of this time, there is no evidence suggesting that the two mechanisms can jointly lead to distraction effects.

### 5.1 Summary of Findings

In review, Experiment 1 was designed to ascertain whether or not attention capture plays a role in the cross-modal Stroop effect. Previous research has suggested that attention capture can be mitigated through top-down control, while interference-by-process cannot (Hughes et al., 2013). To explore this hypothesis, warning cues were provided in this experiment. If attention

capture were responsible for the effect, one would expect that the effect should be lessened when the warning cues were predictive and informed participants of what type of trial to expect. If the cues had no impact, it would imply that attention capture is not playing a large role, and that any potential attentional component involved in the cross-modal Stroop effect is not under top-down control.

As the warning cues had no impact on performance, the results implied that attention capture is not playing a large role in the effect. However, given the nature of null hypothesis testing, one cannot definitively rule out the possibility that the size of the cross-modal Stroop effect cannot be influenced through top-down factors. As mentioned above, it is also possible that the manipulation used was not strong or specific enough. It is, therefore, necessary in the future to examine the impact of warning cues in more depth and whether the specificity of the warning cue has an impact.

Experiment 2 was designed to determine whether participants are monitoring the auditory distractors during the cross-modal Stroop task. In cross-modal Stroop, whenever a distractor is heard, a target is also typically present. Furthermore, at times the distractor is the same as the target (i.e. congruent trials). Previous research has shown that decreasing the number of congruent trials or eliminating them altogether decreases the size of the cross-modal and classic Stroop effect—though it does not completely eliminate it (Kane & Engle, 2003; Elliott et al., 2014; Logan & Zbrodoff, 1979; Long & Pratt, 2002). Furthermore, by encouraging participants to monitor the auditory channel for targets that need to be responded to, one can increase the size of the cross-modal Stroop effect (Morey et al., 2012). Thus, it is possible that participants monitor the sounds in cross-modal Stroop in an attempt to complete the task (e.g. to alert them that a target has appeared if they are not staring at the screen). By allowing the distractors to

appear without the target, it was believed that perhaps the participants would monitor the auditory channel to a lesser degree, which in turn would lessen or eliminate the size of the cross-modal Stroop effect.

While changing the constraints of the task so that the target and distractor were not always presented together did slow down performance and increase errors overall, it had no impact on the size of the cross-modal Stroop effect. This finding implies that the cross-modal Stroop effect is extremely robust, and that participants do not seem to be explicitly monitoring the auditory words in order to complete the task. Also, it almost seemed as if adding in the “none” trials—when participants heard auditory distractors but no visual target appeared—made the task one of divided attention with participants now completing two separate tasks (saying “none” and naming colors). This adds to the growing evidence that distractors do not need to be informative in order to capture attention (Parmentier, 2016) and, again, that even if attention is playing a role in the effect, this attention is not able to be influenced through top-down control.

Experiment 3 was designed to examine the role of an interference-by-process like mechanism in the cross-modal Stroop effect. If the interference seen in the effect is due to the semantics of the words interfering with the semantics of the color square, removing the source of this conflict (the semantics of the auditory word) should lessen the effect. It was found that hearing a non-color word harmed performance less than receiving a color word. However, the fact that hearing a non-color word harmed performance at all is intriguing, as this suggests that the cross-modal Stroop effect is not due to purely “semantic” interference, and replicates previous work with this paradigm using non-color words as auditory distractors (Elliott et al., 1998; Elliott & Cowan, 2001).

Research with the visual Stroop task has suggested that semantics act like a continuum when it comes to the size of the visual Stroop effect: color words harm performance the most, then words with strong color associations (e.g. “rose” and “ice”), then non-color words, and non-words, etc. (Dalrymple-Alford, 1972; Klein, 1964). It may be the case that something similar is occurring here, though this has never been explicitly tested in the cross-modal Stroop paradigm. Why non-color word distractors impact the size of the visual Stroop effect has not been satisfactorily explained and is not well understood. It is possible the non-color words impacted performance in this experiment because they are “words” and the processing of any semantics leads to a detriment in performance or to attentional monitoring in general (this would be similar to the finding that any meaningful auditory word presented while participants are trying to generate category items harms performance while related meaningful words harm performance even more; Marsh et al., 2012). Another option is that more “complex” sounds (i.e. words) are processed and analyzed to a greater degree than less complex sounds (i.e. tones). The size of the serial recall irrelevant sound effect, for example, is greatly impacted by complexity of the auditory distractors, with “changing-state sounds” or sounds that change from one segment to the next have more of an impact than “steady-state” sounds or sounds that remain consistent (Colle & Welsh, 1976; Jones & Macken, 1995; Tremblay & Jones, 1999). In the serial recall ISE, the complexity of the sounds impacts performance due to the obligatorily processed order cues which appear to play no role in the cross-modal Stroop task; nonetheless, it is possible that complex sounds are processed more in other ways. This needs to be examined in more depth in order for a definitive answer to emerge.

The findings from the three experiments suggests that the interference-by-process and attention capture mechanisms are not working together in this paradigm to lead to distraction.

While it is possible that other auditory distraction paradigms are due to some combination of the two mechanisms, the lack of evidence here calls this in to doubt. However, the fact that the cross-modal Stroop effect has been shown to habituate in the past (Elliott & Cowan, 2001; Lutfi-Proctor et al., 2014) suggests that even though the attention involved in cross-modal Stroop does not appear to be under top-down control, there is some attentional aspect to the effect. However, the effect does not habituate completely as both the original and algorithm attention capture models would predict. Thus, the mechanism of attention capture, as it is currently defined, is unable to explain the cross-modal Stroop effect, especially without the aid of an additional underlying interference-by-process mechanism.

It may be the case that an additional mechanism or an expansion of the concept of “attention capture” is needed. As mentioned above, attention capture is typically viewed to be under top-down control. So far there is little evidence that the attentional process in the cross-modal Stroop effect can be mitigated by top-down factors, and yet the evidence suggests attention is indeed there and can have an impact, in at least some cases (Elliott & Cowan, 2001; Lutfi-Proctor et al., 2014; Morey et al., 2012). How exactly this attention is playing a role and to what extent it can be controlled still needs to be discovered.

## **5.2 Applications of Auditory Distraction Research**

If distraction is due attention capture, the research suggests that one can lessen distraction through top-down control (e.g. increasing concentration on the focal task and providing warnings that distracting stimuli will appear; Berti & Schröger, 2003; Horváth et al., 2011; Hughes et al., 2013; Parmentier & Hebrero, 2013; Shelton et al., 2009; Sörqvist & Marsh, 2015). Also, one can remove the distractions completely such as having participants turn off their phones during a lecture. At the same time, an understanding of attention capture and the underlying mental

models can give us an understanding when certain types of distractions will not be so detrimental. For instance, while a phone ringing during a lecture would harm performance because it is unexpected, a phone going off in a casino would most likely not harm performance as noises are consistent and varied in this environment.

In contrast to attention capture, as of this time, it would appear that the only way to mitigate distraction due to interference-by-process would be to remove the distracting process entirely. As can be imagined, there will always be certain instances in which this is not an option. In these cases, it may be possible to engage in some type of training to lessen this type of interference, though to my knowledge this has not been examined as of this time. Furthermore, research with the serial recall version of the ISE has shown that there is a large spread of effect sizes, and while most people have worse performance when distracting sounds are heard, some people actually show improved performance (Ellermeir & Zimmer, 1993). Therefore, taking into account individual differences in these types of scenarios may be extremely important for creating strategies to avoid interference.

Lastly, it is possible as mentioned above, that a type of attention that is not “attention capture” may lead to a detriments in performance and that this type of attention is not under top-down control. If this is the case, it would suggest that the only way to mitigate this type of distraction is to remove the distracting stimuli. However, as this potentially additional mechanism of distraction is little understood, and it is unclear at this time whether it exists, more research is needed to examine whether attention not under top-down control can indeed harm performance and whether there are any ways to lessen this form of distraction.

### 5.3 Conclusions

In conclusion, attention capture and perhaps attention in general (at least so far as it can be controlled by top-down mechanisms) are playing a small role in the size of the cross-modal Stroop effect, and a mechanism more like interference-by-process seems to be the contributing the most to the effect. Moreover, it is also possible that the interference-by-process involved in this effect comprises a number of facets (semantic interference plus general word interference or sound complexity). Overall, the manipulations reported in this dissertation have provided little evidence of both auditory distraction mechanisms interacting to lead to distraction jointly, and the role of divided attention and selective attention in terms of the activation of the two mechanisms is unclear. In addition, the results suggest that attention not under the control of top-down influences may be able to lead to distraction, an idea not consistent with the current concepts of attention capture. Future research is needed to continue to evaluate the underlying mechanisms of auditory distraction and to facilitate applications to reduce such distractions in the environment.

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## Appendix A

### Experiment 1

#### **Predictive Cue Condition:**

Participants will first be informed about what they will be doing in the task on a basic level:

*In the following experiment, you will see color squares and hear auditory color words. Your task is to name the color of the square as quickly and accurately as possible. Do not wait for the sound to finish unfolding before responding.*

Participants will then be given the warning cue instructions:

*Before each trial, you will see either the word "Same," "Diff," or "Tone." These words will let you know what type of trial is about to be seen.  
If you see "Same" the color of the square and auditory color word will match.  
If you see "Diff" the color of the square and auditory color word will NOT match.  
If you see "Tone" you will see a color square and hear a tone*

They will then receive additional warning cue instructions:

*Feel free to use the cues to help you complete the task.  
Again, if you see "Same" the visual and auditory colors will match.  
If you see "Diff" the visual and auditory colors will NOT match.  
If you see "Tone" you will see a color square and hear a tone.*

And then the instructor will give a mini-test to make sure the participant understands the cue instructions:

*If you see "Same"...*  
*If you see "Diff"...*  
*If you see "Tone"...*

If the participant still does not understand the instructions they will be reminded again and tested one last time. If they still cannot understand, they will be excluded from the study.

After the experiment is complete, the participant will be given a brief questionnaire to fill out which will ask the following questions:

1. Did you try to use the words "Same" "Diff" and "Tone" to help you prepare your response?
2. If you responded yes or sometimes to the question above, do you think these words helped you to make your response?

**Non-predictive Cue Condition:**

Participants will first be informed about what they will be doing in the task on a basic level:

*In the following experiment, you will see color squares and hear auditory color words. Your task is to name the color of the square as quickly and accurately as possible. Do not wait for the sound to finish unfolding before responding.*

Participants will then be given the warning cue instructions:

*Before each trial, you will see either the word "Same," "Diff," or "Tone." These words will NOT let you know what type of trial is about to be seen.*

After the experiment is complete, the participant will be given a brief questionnaire to fill out which will ask the following questions:

1. Did you try to use the words "Same" "Diff" and "Tone" to help you prepare your response?
2. If you responded yes or sometimes to the question above, do you think these words helped you to make your response?

## Experiment 2

**100% and 50% Coupled Conditions:**

In this experiments, participants in both conditions will receive identical instructions. First, they will be given basic task instructions:

*In this experiment, your task is to name the color of the square as quickly as possible. Occasionally you will hear auditory color words which you should ignore. Do not wait for these auditory words to finish unfolding before responding.*

Then, they will be given instructions about what to do if a color square does not appear:

*If you hear an auditory word but no color square appears, say "none."*

## Experiment 3

**Semantically Related and Unrelated Condition:**

In this experiments, participants will receive the same instructions in both parts.

*In the following experiment, you will see color squares and hear auditory words. Your task is to name the color of the square as quickly and accurately as possible. Do not wait for the sound to finish unfolding before responding.*

## Appendix B

### ACTION ON EXEMPTION CONTINUATION REQUEST



Institutional Review Board  
Dr. Dennis Landin, Chair  
130 David Boyd Hall  
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P: 225.578.8692  
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**TO:** Danielle Lufti-Proctor  
Psychology

**FROM:** Dennis Landin  
Chair, Institutional Review Board

**DATE:** August 25, 2015

**RE:** IRB# E6082

**TITLE:** Investigating Auditory and Visual Processes

**New Protocol/Modification/Continuation:** Continuation

**Review date:** 8/25/2015

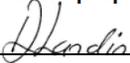
**Approved**  **Disapproved**

**Approval Date:** 8/25/2015 **Approval Expiration Date:** 8/24/2018

**Re-review frequency:** (three years unless otherwise stated)

**LSU Proposal Number** (if applicable):

**Protocol Matches Scope of Work in Grant proposal:** (if applicable) \_\_\_\_\_

**By:** Dennis Landin, Chairman 

**PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –**  
**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:** Please be aware that projects approved by exemption can be active for three years, after which time a renewal is needed.

*\*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/irb>*

### Consent to Serve as a Subject in Research.

I consent to serve as a participant in a research investigation that focuses on the processing of visual and auditory information in adults. The study is entitled “Investigating Auditory and Visual Processes” and is under the direction of Danielle Lutfi-Proctor and Emily Elliott.

I understand that the study will involve the following procedures: In the presence of one or more members of the research team, I will engage in a task involving visual stimuli (squares, words, numbers, arrows, and symbols) and/or auditory stimuli (words, sounds, noises). I will then be asked to indicate a response either verbally or nonverbally (e.g. through a computer key-press or mouse click).

All responses will be coded in a way that my name cannot be linked to my responses in any of the oral or written reports that are a result of this study. All scores will be kept strictly confidential and will not enter school records in any way. The entire session will take place in the Psychology Department at Louisiana State University and will be conducted in one hour or less. I understand that I may be asked to return for one or more additional sessions depending on the study I participate in; furthermore, I understand that my willingness to participate in one session does not obligate me to return for additional sessions.

This study is expected to help gain an understanding of how people process auditory and visual information when both the auditory and visual information are presented separately and when both types of information are presented simultaneously. Individuals are frequently presented with multiple sources of input during day-to-day life, and it is therefore important for some objects to be focused upon while others are ignored. How we process the information and focus upon it, however, is not fully understood. Thus, this research could generate practical suggestions for every life and especially so in classrooms and workspaces.

Refusal to consent to participate will not involve a penalty. I understand that I am free to withdraw my consent and to discontinue my participation in this study at any time without a 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 than those commonly encountered during daily life. I also understand that it is not possible to identify all of the possible risks in an experimental procedure, but that all reasonable precautions will be taken minimize the known and unknown potential risks.

This study has been discussed with me and all of my questions have been answered. I may direct additional questions regarding this study to Danielle Lutfi-Proctor ([dlutfi1@tigers.lsu.edu](mailto:dlutfi1@tigers.lsu.edu)) and Emily Elliott, (225) 578-7460. If I have questions regarding subjects’ rights or other concerns, I can contact Dennis Landin, Chairman, LSU Institutional Review Board, (225) 578-2916. I agree to participate in the study described above and acknowledge the researchers’ obligation to provide me with a copy of this consent form is signed by me.

Signature \_\_\_\_\_

Date \_\_\_\_\_

Print Name \_\_\_\_\_

## Vita

Danielle Lutfi-Proctor received a Bachelor of Arts in Psychology from Eckerd College, Saint Petersburg, Florida. She completed her Master's Degree in Cognitive Psychology at Louisiana State University, Baton Rouge, Louisiana, and anticipates graduating with a Doctor of Philosophy degree from Louisiana State University in August, 2016. Over the course of her time at Louisiana State University, Danielle has taught a number of courses and worked with many students on research. She looks forward to a career in psychology and the adventures to come.