Summer 2014

Match-to-Sample Stroop Task: A Systematic Manipulation of Sample and Response Option Onset

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MATCH-TO-SAMPLE STROOP TASK:

A SYSTEMATIC MANIPULATION OF SAMPLE AND RESPONSE OPTION ONSET

by

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(Under the Direction of Bradley R. Sturz, Ph.D.)

ABSTRACT

The Stroop task, in which participants identify the font color of a word which names an incongruent color, has long been used to investigate attentional processes; however, there is still debate concerning the source of the effects produced by the task. The s*emantic competition hypothesis* posits that interference results from competing semantic processes associated with the word and color dimensions of the stimulus prior to response selection. The *response competition hypothesis* posits that interference results from competing responses for articulating the word versus the color dimension at the time of response execution. Sturz, Green, Locker, and Boyer (2013) designed a Delayed Match-to-Sample Stroop task to differentiate between semantic and response based effects. Though the results supported a *semantic competition hypothesis,* it is still unclear whether the results globally supported semantic interference as the source of the Stroop effect or whether the effect was contextually driven by the DMTS task. In Experiment 1, a sequentially presented MTS task with no retention interval was implemented and the results replicated the findings of Sturz et al. Experiment 2 consisted of a simultaneously presented MTS task, where sample and response options onset concurrently for the duration of the trial. RT's on incongruent Stroop stimulus trials were significantly longer than neutral or congruent Stroop stimulus trials. Accuracy data indicated asynchronous interference of words on color matching and no interference of color on word matching. Together, these results provide converging evidence consistent with a semantic competition account and inconsistent with a response competition account.

INDEX WORDS: Stroop, Match-to-Sample, Semantic Competition, Response Competition

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B.S., Armstrong Atlantic State University, 2012

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial

Fulfillment of the Requirements for the Degree

Master of Science

Statesboro, Georgia

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Electronic Version Approved:
July 2014

DEDICATION

This manuscript is dedicated to my parents, Maurice and Candace Green.

ACKNOWLEDGEMENTS

I would like to thank Dr. Bradley R. Sturz for all his guidance throughout my academic training. I have learned that Academia can be quite a difficult game. To that I must reply, “But there are much worse games to play” (a quote from Collins, 2010). I would also like to thank Dr. Ty W. Boyer and Dr. Lawrence Locker, Jr. for the countless discussions, questions, (quips), reviews, and copious amounts of red ink on every page. I could not have reached this point without these three gentlemen.

I must also acknowledge the students who participated in my study. Truly, without them, there would not be anything written on these pages.

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CHAPTER ONE
INTRODUCTION

In 1935, J.R. Stroop designed what is colloquially called the Stroop task. The original Serial Color-Word task consisted of participants reading through a 10x10 list of color words which were either printed in colored ink or neutral black ink. This first experiment, however, did not yield any striking results: participants were just as fast to read a list printed in neutral black font as they were when reading a list printed in ink colored differently than that which the word named. It was the second experiment in which participants had to name the ink color of a 10x10 list of *color*-words or colored symbols, where Stroop found interference. Participants were much slower to name ink colors from the list when the words on the list named ink colors different than what the ink color represented. The asynchronous interference of word reading on color naming is the hallmark of the Stroop effect and has shaped theoretical accounts over the years.

Stroop's (1935) theoretical explanation of the interference was that associations between the word stimuli and the reading response were more effective than the associations between color stimuli and the naming response. In order to understand how Stroop arrived at this explanation, it may be useful to describe the experimental constructs as they were understood at the time of the original study as well as provide an example. First, interference and inhibition were considered interchangeable terms and were used in relation to events where a particularly strong association overrides another association even when that second association provided contrary information. For example, the behavior of checking your watch for the time contains a strong association of "watch" = "observe time"; however, the watch may malfunction, forming a new association of "watch" ≠ "observe time". Checking your watch for the time despite the malfunction would be an instance of a stronger association interfering with a weaker association. Similarly, Stroop (1935) suggested that reading a word was a strong one-process "to read" association and naming a color was associated with various responses such as “to name”, “to admire”, “to touch” (Stroop, 1935). When participants took longer to name ink colors of incompatible *color*-words versus non-word symbols, Stroop (1935) suggested that it was due to the superior effectiveness of the “to read” association relative to the “to name” association.

Although Stroop’s original explanation for the interference predicted the effects of learning and practice, it was not an adequate theory for explaining cognitive processes, though early cognitive theories of the Stroop effect were relatable (Fraisse, 1969; Treisman, 1969; see also MacLeod, 1991). Since that time, the relative speed-of-processing account was suggested to explain Stroop interference. Specifically, it posited that word reading was a faster, more automatic process compared to the processes involved in naming the color of an object. The advantage of this account was that it assumed a speed continuum of processing, setting the foundation for the response competition hypothesis of Stroop interference. In other words, the faster process of reading provided a potential response that competed with the other potential response provided by the slower naming process (Posner & Snyder, 1975, MacLeod, 1991).

To test the relative speed-of processing hypothesis, the Stroop effect can be examined via manipulating stimulus onset asynchrony (SOA). The logic behind an SOA manipulation is that assuming the total information processes involved in a reading task were faster compared to those involved in an identification task, and more time was allowed for identifying a target stimulus versus reading a conflicting irrelevant stimulus, then the interference effect should not be observed (Glaser & Glaser, 1982; MacLeod & Dunbar, 1988). A simple conception of a Stroop SOA experiment would consist of separating the Stroop stimuli into a word and color patch and then systematically manipulating the time between presentation of the relevant color patch and the irrelevant word. If color naming processes simply took longer than word reading processes, then an SOA of sufficient time should allow for completion of "naming" processes, thus eliminating the inference effect; however, results of SOA manipulations (see Glaser & Glaser, 1982) were shown to still produce, and even exacerbate, interference in the form of increased reaction times, leading to a rejection of the relative speed-of-processing account.

The main problems with the speed-of-processing account are that hypotheses required *a priori* knowledge of process speeds and the theory lacked an adequate incorporation of the role of attention (MacLeod, 1991). Relative speed-of-processing theory holds up under circumstances in which information is presented simultaneously, yet the results of SOA manipulations in Stroop tasks indicated that more recently attended information was able to interfere with older information regardless of task objective. Assuming that the processing of some information required more or less attention than processing of other information, the automaticity account was able to adequately explain problematic findings in the Stroop literature, such as SOA manipulation or priming (Priming involves a facilitation of responding by making the representative semantic content more active in semantic memory).

Process automaticity falls on a continuum related to the amount of attention required to perform a task. Reading processes are thought to be faster processes because reading requires less attention than other tasks, such as naming a color or an object. The automaticity account predicts the results of SOA manipulations because, though the task allows sufficient time for color identification prior to the word being presented, once the word is presented the automatic reading process locks in, resulting in interference with the task of responding to the color (Glaser & Glaser, 1982; MacLeod & Dunbar, 1988). The automaticity account is not without problems when addressing the Stroop effect. Similar to the difficulty of the relative speed-of-processing account, the great difficulty of testing the automaticity account is due to the requirement of knowing *a priori* which processes are more automatic; therefore, some have argued that the effects are more parsimoniously characterized as contextually controlled rather than automatic (Besner, Stolz, and Boutilier, 1997; Kahneman & Henik, 1981; see also MacLeod & Dunbar, 1988).

Controlled processes, such as selective attention, are thought to be voluntary and relatively slow, while automatic processes, such as spreading activation in semantic memory, are fast and do not require attention. In a two-experiment study, Besner, Stolz, and Boutilier (1997) manipulated the extent to which task level context allowed for semantic priming in the Stroop task. In experiment 1, Besner et al. (1997) attempted to minimize the extent to which the word dimension could interfere with the color dimension. By using single-letter coloring on half of trials and coloring the entire word on the other half of trials, and also by manipulating task context using color-words on half of trials and pseudohomophones (i.e., nonsense words which are similarly pronounceable to real words) on the other half of trials, the authors found that the Stroop effect was significantly reduced. In Experiment 2, the authors attempted to reduce semantic level processing even further by eliminating congruent stimuli and by replacing pseudohomophones with orthographically similar nonsense words. It was found that the Stroop effect was eliminated on single-letter colored trials.

Besner et al. (1997) concluded that task context drove semantic level processing and led to the Stroop effect. According to the automaticity account, semantic processes such as reading cannot be prevented from being set in motion because they are, by definition, automatic processes (Besner et al., 1997). When a word is attended to, it is thought that the reading processes cannot be prevented, and thus the semantic activation of irrelevant information cannot be inhibited. Since participants in the single-letter colored Stroop task attended to the word, then the automatic process of reading should have resulting in interference of color identification. The fact that Besner et al. (1997) did not find this result indicates that something else drives the extent to which semantic level processing is automatic; context is thought to mediate the automatic processes by controlling the extent to which stimuli is attended.

Therefore, what is known about the Stroop effect is that when an incongruent word and color stimuli are presented as a single bi-dimensional stimuli or closely in time and space, and the task is to identify only one dimension while ignoring the other, slowed responding and increased identification errors will occur. The speed-of-processing account and the automaticity hypothesis were both unable to adequately explain the results of Stroop research since both rely on *a priori* knowledge of stimulus processing speed or process automaticity, and neither can fully account for SOA manipulation, priming, or context effects.

CHAPTER TWO

THE STROOP EFFECT AND THE ROLE OF SEMANTIC MEMORY

One contemporary explanation is that incongruent Stroop stimuli activate semantic representations of both dimensions resulting in semantic competition between those dimensions prior to response selection (Lou, 1999). In other words, attending to both the color and the word dimension activates competing semantic representations. Suppression of one of the representations is required in order to make a response. This additional suppression slows processing and thus responding. When both of the dimensions represent the same semantic code, responding is not affected because suppression of the irrelevant semantic code is not required.

In the contrasting explanation, response competition posits that each dimension of the Stroop stimuli activates a potential response unit resulting in interference at the point of response output (Luo, 1999, DeHouwer, 2003). Similarly, response competition may more parsimoniously be described in terms of a bi-dimensional Stroop stimuli containing a dimension which is considered a ‘respond’ dimension as well as a dimension which is considered a ‘do not respond’ dimension (MacLeod, Chiappe, & Fox, 2002). Interference is thought to occur at response selection because there is both a ‘respond’ and a ‘do not respond’ attentional directive associated with the same bi-dimensional stimulus. By definition, response competition is located later in processing and places Stroop interference at the level of executive control. There is no assumption for a suppression mechanism, but rather the response can only be made by increasing attention to overcome the incompatible attentional directives.

According to Luo (1999), the semantic memory system is a knowledge base consisting of meanings and concepts of words and objects, and the verbal-lexical memory system is a knowledge base of orthographic and phonological (e.g., structure and sound of words respectively) features of words. Under the assumption that color identifying and word reading require the semantic and verbal-lexical systems respectively, Luo (1999) argued that a color activates a unit in the semantic system followed by activation of a unit in the verbal-lexical system (i.e., the name of the color), and a *color*-word activates a unit in the verbal-lexical system followed by activation of a unit in the semantic system (i.e., the color associate object; see also, Lachter, Remington, & Ruthruff, 2009). Luo (1999) posited that a response competition account of the Stroop effect must assume that the semantic unit of the color be matched to the verbal-lexical unit, and given that a verbal-lexical unit of the irrelevant dimension is already active, these two units then compete for response output. The problem with the response competition hypothesis is that it still assumes that one process is faster than another. Alternatively, Luo (1999) suggested that the processes are equally fast and that competing semantic units may inhibit, or suppress, each other resulting inevitably in the slowing of responding.

To examine this possibility, Luo (1999) devised a same/different matching task in which a colored bar was presented above a Stroop stimuli. Two groups performed this task with one instructed to respond according to the meaning (i.e., meaning decision) and the other according to the visual characteristic (i.e., visual decision). In other words, Luo (1999) worked under the assumption that the meaning decision group would respond based on whether or not the bar color (i.e., BC) matched the word meaning (i.e., WM) of the *color*-word stimulus. The visual decision group responded based on whether or not the BC visually matched the color of the *color*-word's font (i.e., word color, WC). This task was unique such that both the relatedness of the surface color of the bar and *color*-word, as well as the relatedness of the surface colors' and the *color*-words' color associate, could be manipulated. In a second study, Luo (1999) also manipulated a stimulus onset asynchrony (SOA) between the colored bar stimulus and the *color*-word stimulus for both groups, and hypothesized that increasing SOA's allowed for the semantic unit to map to its associate verbal-lexical unit reducing the opportunity of the *color*-words' semantic associate to compete.

Luo (1999) concluded that conflicting visual information led to interference in meaning decisions when the color bar and *color*-word were presented simultaneously (i.e., Exp. 1), and interference diminished as SOA increased (i.e., Exp. 2). Additionally, conflicting verbal information did not produce interference in visual decisions when the color bar and *color*-word were presented simultaneously (i.e., Exp. 1), but did produce interference when presented sequentially (i.e., Exp. 2). Luo (1999) interpreted these results as being more parsimoniously explained by a semantic competition hypothesis because of the experiment-wide task-level differences (i.e., meaning vs. visual decision groups) and the varying levels of interference as a function of SOA.

The results and conclusions put forth by Luo (1999) must be interpreted with caution. As was previously noted, the uniqueness of the design was that the surface color of the bar (i.e., BC) and Stroop stimulus could be manipulated with respect to WM and WC. In his analysis, Luo (1999) only included the congruency of variables relevant to the condition. For example, the meaning decision analyses addressed the congruency of WM and BC variables, but not WC. For visual decisions, the analyses addressed the congruency of WC and BC, but not WM. Luo (1999) argued that there were very clear task demands for attending to particular stimuli dimensions, and therefore the analyses need not incorporate a three level congruency construct. Alternatively, Goldfarb and Henik (2006) argued that, according to task-conflict theory (for review see MacLeod & MacDonald, 2000), when participants perform one task, such as Luo's (1999) surface color matching task, they are simultaneously performing a secondary irrelevant task (i.e., a WM matching task). Hence, when Luo (1999) found Stroop interference in the meaning decision group it was possible that the secondary irrelevant task contributed to the magnitude of the effect.

According to task-conflict theory and response competition hypothesis, Luo (1999) should have found that when the BC, WC, and WM were all incongruent, there should have been an additive effect resulting in a maximum amount of interference, but his analysis did not address this hypothesis. Goldfarb and Henik (2006) replicated Luo’s (1999) first experiment as well as conducted appropriate analyses, and indeed found the largest interference effect when BC, WC, and WM were incongruent. Subsequently, the authors argued that this finding did not support a semantic competition hypothesis, but rather a response competition hypothesis as well as support of task-conflict theory. Despite the limitations of the Luo (1999) analyses and interpretation, the attempt to disambiguate semantic competition and response competition was commendable due to the ongoing discussion concerning the locus of the Stroop effect (Augustinova, Flaudias, & Ferrand, 2010; DeHouwer, 2003; Schmidt & Cheesman, 2005; Stolz & Besner, 1999, Sturz et al., 2013).

CHAPTER THREE

STIMULUS CONGRUENCY EFFECTS

According to Egner (2007), congruency effects arise when different dimensions of stimuli or responses (or both) are highly similar with respect to perceptual, conceptual, or structural factors, but only when those factors are overlapping or incongruent. Regarding the Stroop effect, the perceptual and conceptual factors are the relevant or irrelevant dimensions of the color representations. In other words, the *color*-word is a representative concept and a hue is a particular percept which is likewise representative of its respective semantic associate. For an example in terms of Stroop stimuli, the color red and the word RED are representatively equivalent and thus, do not produce a congruency effect. In contrast, the color red and the word BLUE are not representatively equivalent producing a congruency effect, or the slowed processing of incongruent information relative to congruent information.

When one stimulus dimension is incongruent with the other dimension, the effect has been referred to as a Stimulus-Stimulus (S-S) congruency effect and is related to semantic conflict within the Stroop literature (Chen et al., 2013; DeHouwer, 2003; Egner, 2007; Schmidt & Cheesman, 2005; Zhang, Zhang & Kornblum, 1999). In any Stimulus-Response (S-R) choice based task, there are congruency effects which are attributable only to the response mapping (Egner, 2007). According to Egner (2007), there are two possible ways an S-R congruency effect can arise: a relevant S-R effect can stem from the overlap of the relevant stimulus dimension and a response option, and an irrelevant S-R effect can stem from the overlap of the irrelevant stimulus dimension and a response option. For example, in a typical manual response Stroop task, a relevant S-R effect occurs when the incorrect response option is incompatible with the relevant dimension. Likewise, an irrelevant S-R effect occurs when the correct response option is incompatible with the irrelevant response option.

The two separate effects have been carefully defined with respect to semantic and response competition, allowing for more adequate interpretations and for a more intuitive classification of Stroop tasks based on the Stroop stimuli and presentation paradigms. According to DeHouwer (2003), a Stimulus-Stimulus Compatibility (SSC) effect refers to facilitation or interference at the encoding or identification level (semantic competition). The presentation of an irrelevant word either facilitates (i.e., congruent trials) or interferes (i.e., incongruent trials) with identification of the relevant ink color. In contrast, a Stimulus-Response Compatibility (SRC) effect refers to interference at the response level due to the automatically activated response unit from the irrelevant word being incompatible with the response unit of the relevant color. In other words, the irrelevant word automatically activates a response with a similar meaning, facilitating responding on congruent trials, but interfering with responding on incongruent trials (e.g., response competition). Yet again, the important question is whether or not the irrelevant stimulus interferes by inhibiting identification early on or by producing a conflicting response option at response execution.

DeHouwer (2003) developed a task which allowed for the manipulation of response competition by controlling when the irrelevant Stroop dimension could compete with the target Stroop dimension. By allocating two color response options to a right key and two to a left key, this paradigm produced three types of trials: a). *identity trials*, in which target stimuli, irrelevant stimuli, and response were all the same, b). *same response trials*, in which the target and irrelevant stimuli were incongruent but the response option was the same, and c*). different response trials*, in which the target stimuli, irrelevant stimuli and response option were all incongruent. Note that this ability to manipulate the relatedness of the irrelevant dimension is similar to the Luo (1999) paradigm, yet the DeHouwer (2003) task also allowed for systematic manipulation of response option congruency. In one experiment, the researcher utilized color name triads all in one font color (e.g., white) where the middle word was the target surrounded by two flanker stimuli. This task is more appropriately a Flanker task with color names, but it nonetheless produces Stroop–like effects (for review, see MacLeod, 1991). In a second experiment, a true Stroop stimulus was utilized adding generalizability with past research. Results of both experiments were that responding on *different response trials* took longer than both *same response trials* and *identity trials* indicating an SRC effect (i.e., response competition). Importantly, responding on *same response trials* took longer than *identity trials* indicating an SSC effect (i.e., semantic competition). According to task-conflict theory, this additive effect suggests that, depending on the stimulus congruency within the trial, both response and semantic conflict contributed to the interference (MacLeod & MacDonald, 2000).

Similar to DeHouwer's (2003) conceptualization of the distinction between SSC and SRC effects, Schmidt and Cheesman (2005) suggested that an SRC (e.g., stimulus-response compatibility) effect alone is problematic because it essentially has two definitions which cannot be theoretically separated: 1) the strength of the relationship between a relevant stimulus and its assigned or learned response produces a relevant SRC effect, and 2) the strength of the relationship between the irrelevant stimulus and its assigned or learned response produces an irrelevant SRC effect. This conceptualization of relevant and irrelevant SRC effects mirrors the underlying components of Task Conflict Theory, which posits that multi-stimuli paradigms have the potential to create a context for multiple conflicting tasks (Goldfarb & Henik, 2006; MacLeod et al., 2002) Specifically, Schmidt and Cheesman (2005), replicated the DeHouwer (2003) study using color associate words (i.e., semantically color related, *sky*-blue*, money*-green*, or canary*-yellow) and found that interference from the color associate was restricted to an SSC effect. This finding is not only in line with studies specifically investigating the semantically based Stroop effect, which explicitly investigates color associate words such as *sky* or *money* (e.g., blue or green), but also suggests that Stroop tasks must incorporate both an input, or semantic interference measure, as well as a response competition measure (see also, Augustinova, Flaudias, & Ferrand, 2010; Augustinova & Ferrand, 2012; Augustinova & Ferrand, 2012).

CHAPTER FOUR

COMPUTATIONAL MODELLING OF THE STROOP EFFECT

Though a clear majority of studies addressing the topic of attention and interference via the Stroop effect have done so by carefully manipulating the manner in which subjects are presented Stroop stimuli, as well as varying response modality, others have attempted to construct computational models of the Stroop task (Cohen, Dunbar, & McClelland, 1990; Mewhort, Braun, & Heathcote, 1992; Zhang, Zhang, & Kornblum, 1999). Cohen et al. (1990) constructed a parallel distributed processing (PDP) model of the Stroop effect. Working upon the foundation of known interference effects and guided by the automaticity hypothesis, the researchers suggested that interference and automaticity in processing are continuous in nature and are closely related to practice. Given that previous tests of the automaticity hypothesis have provided evidence against such a strict account, this particular PDP model worked under the theoretical framework that interference effects and automaticity in processing were related to a common underlying variable referred to as *strength of processing* (Cohen et al., 1990; see also Kahneman & Henik, 1981).

The structure of the Cohen et al. (1990) PDP model consisted of a system of connected modules which likewise consisted of simple processing units. The basic system framework was a 12-module encoder network arranged in three layers: a 6-module input (stimulus) layer, a 4-module hidden (processing) layer, and a 2-module output (response) layer. In PDP network models, a hidden module processes information in-between input and output layers but more importantly allows for the computational model to incorporate non-linear processing, which is essential for the parallel framework. The units accumulate inputs which adjust outputs continuously in response to back-propagation of response feedback allowing for learning within the system. Input information is represented as a pattern of activation over the units in a module and the spread of activation within the units across the modules characterizes information processing. Thus, a particular process is represented by a pathway across the modules. The *strength of processing* parameter describes the weight allocated to a pathway based on the speed and accuracy of processing. Interference occurs within modules where intersections of dissimilar information converge, and facilitation occurs when that information is similar. The important features to note about this PDP model are the incorporation of a temporal component so that response times could be modeled, non-linear processing to account for attentional selection, and back-propagation of output units allowed for error reduction. Despite the use of running averages across input and hidden level modules, the Cohen et al. (1990) model accumulated additive effects at the response-selection mechanism. It was suggested later, by Mewhort et al. (1992), that this accumulation mechanism resulted in the processing components being too separated from the decision components.

Results of the model fared well in most of the simulations which were implemented into the system in much the way a task would be completed by a human participant (Cohen et al., 1990; Mewhort et al., 1992). The first simulation was that of the basic Stroop effect in which the model produced longer response times for color naming versus word reading, interference of word on color naming, and no effect of color on word reading. The second simulation was the only one which did not produce the hypothesized result. For this reason it will be discussed last. The third simulation showed that the system could handle the effects of practice according to the power law, which states that increases in speed of processing occur with practice. Additionally, the fourth simulation demonstrated the development of automaticity following sufficient practice by the system (i.e., back-propagation). In other words, as the system learned, the strength of the pathways increased leading to the development of faster processing along those pathways. This result supports the concept of automaticity though not the original strict interpretation (e.g., *speed of processing* versus *strength of processing*). The fifth simulation, which was characterized by introducing an attention allocation mechanism into the system, showed that, although processing can occur in the absence of attention, all the processes are affected by attention. Thus, the stronger and more automatic a process, the less susceptible it will be to attentional control and more likely to produce interference over the weaker controlled process. In the final sixth simulation, response set effects were produced following introduction of the attention allocation mechanism from the fifth simulation. A response set effect refers to increases in interference caused by attention to possible response options prior to response. The overall success of the model seemed to support the *strength of processing account* and, coupled with the additive response-selection design, supported the response competition hypothesis.

The simulation which did not produce the predicted results was the second simulation, in which the SOA was manipulated: the model was unable to account for interference when SOA's were increased (Cohen et al., 1990). This is a finding which has consistently been problematic for the automaticity hypothesis, and likewise, the response competition account of Stroop interference (Glaser & Glaser, 1982; Luo, 1999, MacLeod & Dunbar, 1988; Mewhort et al., 1992). Allowing the system enough time for the color unit to reach the response module should allow for elimination of interference given a long enough SOA. It appeared that the system locked in on the word unit and caused massive interference (Cohen et al., 1990). Mewhort et al. (1992) suggested that the Cohen, Dunbar and McClelland PDP model separated the processes from the response execution too much and eliminated the role of SSC effects in the system. In a subsequent replication of the model the researchers found that the model did indeed accurately simulate response time means across simulations; however, a more detailed analysis revealed that the model did not accurately simulate the shape of the distribution of response times. Since the mean is an ambiguous score when distributions are not similar, the model could not account for human subject performance on the Stroop task. The researchers concluded that the model must more effectively integrate SSC processing and the response component of the model.

In an effort to construct a PDP model that can produce more generalizable simulations of attention, as well as account for SSC and SRC effects, Zhang et al. (1999) integrated the model assumptions of the Cohen et al. (1990) model with those of the dimensional overlap (DO) model (see also Kornblum & Lee, 1995). The DO model was constructed to make ordinal predictions for performance in various tasks which contained multiple dimensions and the potential for dimensional compatibility effects, such as the Stroop task, and subsequently integrate those tasks under a systematic framework (Zhang et al., 1999). Using the principles of parallel distributed processing, a similar three level (input, hidden, and output) architecture, and incorporation of relevant SRC, irrelevant SRC, and SSC effects, the Zhang et al. (1999) model was able to simulate response times of compatibility effects of the Stroop task. To my knowledge this particular PDP model has not been replicated or re-tested by other researchers, though the incorporation of SSC effects, which are thought to be the source of semantic interference in Stroop tasks, was critically important.

CHAPTER FIVE

THE SOURCE OF STROOP CONFLICT

Brain Imaging Efforts to Dissociate Stroop Conflict

Despite numerous computational and task based attempts to dissociate S-S and S-R congruency effects, results from brain imaging studies have also suggested that separate neural mechanisms underlie semantic and response conflicts (Chen et al., 2013). In an fMRI study on practice-related effects within the Stroop task, Chen et al. (2013) hypothesized that brain regions associated with cognitive control may be correlated with semantically based and response based conflicts. Specifically, of interest were both the dorsolateral prefrontal cortex (DLPFC), associated with top-down biases of task demands, and the anterior cingulate cortex (ACC), associated with conflict monitoring and motivation based cognitive control. Also of interest was the posterior parietal cortex (PPC), which is associated with modulation of attentional orientation and supplementary motor areas (SMA's) which are associated with selection and execution of responses.

This Stroop task involved three stimulus-response types classified as congruent (CO), semantically incongruent (SI), and response incongruent (RI), and the resulting fMRI images were analyzed to produce representational contrasts of conflict. To isolate differing effects, contrasts of varying stimulus-response pairs were producing by subtracting fMRI images. For example, RI-CO contrast represented traditional Stroop interference, SI-CO contrast represented semantic conflict, and RI-SI contrast represented response conflict. Such that the goal of Chen et al. (2013) was to investigate practice effects, fMRI scans were taken early on, on the first trial block, and later in the last two trial blocks. The results of this study indicated that, at early stages of practice, RI and SI trials invoked more interference than CO trials. At late stages of practice, accuracy on CO and SI trials became more similar and, accuracy on RI trials increased but was still lower than accuracy on CO and SI trials overall. The DLPFC and PPC were shown to be active during response conflicts and AAC was shown to be active during semantic conflicts. Importantly, these areas were shown to be active in conjunction, indicating that SSC and SRC effects may not be fundamentally separate with respect to brain region activation; though, this was only the case following several practice trials. Since most Stroop paradigms involve many trials, this finding makes the task of dissociating SSC and SRC effects, as well as the use of subtractive logic in fMRI Stroop research, difficult to accomplish and interpret.

Overall, the most general consensus is that Stroop interference is due in part to the congruency of the dimensions of the stimulus (e.g., SSC effects), as well as in part to the relationship between the stimulus and response options (e.g., SRC effects). Stroop paradigms have been designed to dissociate the semantically based effect (i.e., SSC) from the response based effect (i.e., SRC) (DeHouwer, 2003; Luo, 1999; Schmidt & Cheesman, 2005). Additionally, it appears necessary for a computational model to include SSC effects in addition to SRC effects in order to sufficiently model Stroop performance (Zhang et al., 1999, see also, Cohen et al., 1990). Importantly though, brain imaging approaches to dissociating SSC and SRC effects show that the same brain regions may be active for both SSC and SRC conflicts, especially after experience with the task (Chen et al., 2013). What is still unclear, however, is the source of Stroop interference. To some extent the source appears to be semantic (i.e., SSC) and depends on whether or not conflicting information is attended; yet the source also appears to be based on an SRC effect in which the context of the task allows for dual stimulus-response options to compete for selection.

The Match-to-Sample Stroop Task

In a recent examination of the Stroop effect, Sturz, Green, Locker, and Boyer (2013) developed a delayed match-to-sample (DMTS) task. Unlike a standard DMTS task, in which a sample stimulus is presented followed by the presentation of match and foil targets after a predetermined retention interval, the researchers replaced the single dimensional sample stimulus with a Stroop stimulus. This caveat, coupled with the bi-dimensional nature of a Stroop stimuli, allowed for systematic manipulations of the relatedness of the foil response option to the irrelevant dimension of the sample. In addition, the task allowed for the possibility of probing either words or colors as response targets which provided a unique opportunity to probe each dimension independently during target presentation within the same task. For example, if the sample was the word blue in red font then, on color matching trials, the foil could be manipulated to either be related (e.g., color blue) or unrelated (e.g., color yellow) to the irrelevant word dimension, and on word matching trials the foil could likewise be manipulated to be related (e.g., word red) or unrelated (e.g., word yellow) to the irrelevant color dimension. Lastly, the DMTS task allowed for manipulation of the retention intervals between sample presentation and target presentation.

The importance of this task to the current understanding of Stroop interference and likewise, attentional processes, is in the way that it addresses several of the issues previously described. First, the match-to-sample task allowed for the ability to systematically manipulate the extent to which a Stroop stimulus produces SSC effects in the absence of S-R conflict (Luo, 1999; DeHouwer, 2003; Schmidt & Cheesman, 2005, Egner, 2007). Since the target response dimension was ambiguous prior to response option onset, the participants were required to attend to, and retain, both sample dimensions for the duration of the retention interval. This task demand differed from typical Stroop tasks, which require attending to only one dimension and to ignore the other dimension (Besner, Stolz, and Boutilier, 1997; Cohen, Dunbar, and McClelland, 1990). If the task demands are that both dimensions be attended to, and the target response dimension remains ambiguous prior to response selection, then the only congruency effect which can occur before response option presentation is an SSC effect. This hypothesis is based on the assumption that an incongruent SSC effect, with regards to Stroop stimuli, occurs when two semantic codes represent conflicting information requiring suppression of irrelevant information processing. In that regard, the semantic competition hypothesis predicts SSC effects.

Second, the match-to-sample task allows for the ability to manipulate the extent to which a response option can produce an incongruent SRC effect. Once response options are presented, and the target response dimension is revealed, then there is a potential for SRC effects, which occur when a potential response is incompatible with an attended stimulus and results delayed executive function. According to Egner (2007), when the irrelevant dimension is incompatible with the correct response, there is the potential for an irrelevant SRC effect. This phenomenon is inherently related to the dual task characteristic of tasks involving bi-dimensional Stroop stimuli, which contain color representations of both hue and name. While attending to and responding to the relevant dimension, there is always the potential for attending to the irrelevant dimension. Alternatively, in the Sturz et al. (2013) match-to-sample task, the task demand is not to attend to one dimension of the Stroop stimulus while ignoring the other, which necessarily creates the conditions for a secondary irrelevant task (i.e., irrelevant SRC), but rather to encode and retain both dimensions. Once the response options are presented, and the target dimension revealed, then SRC effects have the potential to emerge. Since the sample stimuli has already been encoded and retained in memory during the retention interval, then response options can only compete for stimulus-response mapping if they are related to the Stroop sample. Therefore, an SRC effect can only emerge under circumstances where a Stroop sample is incongruent and the foil response option is related to the irrelevant dimension. This hypothesis is based on the assumption that the relationship of the potential response options to the stimulus dimensions inherently provides the context for dual tasks, and these dual tasks result response competition.

The results of the Sturz et al. (2013) DMTS tasks were that responding was slowed on trials where the Stroop sample was incongruent. Additionally, a decrement in accuracy was found only on trials where the foil response was related to the irrelevant sample dimension. These findings suggest that the congruency of a bi-dimensional stimulus leads to competing semantic codes (e.g., SSC effect), as response times were longer even when the incorrect option was unrelated to the sample dimensions. Such that the context of the task allows for the emergence of a secondary task, as is the case when the incorrect response option is related to the irrelevant sample dimension, the result is competition between response options (e.g., SRC effects). Importantly, these results do not indicate that semantic effects are necessarily related to response times nor that response-based effects are necessarily related to accuracy; however, the conclusions drawn by Sturz et al. (2013) were that the source of Stroop interference must be located in semantic processing since interference was found when the stimulus was incongruent regardless of the irrelevant S-R relationship. Therefore, S-R based effects must be related to the context of the task. Given the novelty of the DMTS Stroop task, and the obvious differences when compared to more traditional Stroop tasks, it remains unclear whether or not the results found by Sturz et al. (2013) adequately generalize to typical Stroop research. Specifically of concern is the extent to which the retention interval resulted in SSC effects, and whether or not ambiguity about dimension relevancy, coupled with foil-to-sample relatedness, substantially eliminated S-R effects.

The Current Study

In the current study, two experiments were conducted to further extrapolate on the findings by Sturz et al. (2013) and to provide convergent support for the use of match-to-sample Stroop tasks for the study of attention. They consisted of systematically investigating whether or not the effects found by Sturz et al. (2013) can be replicated in a match-to-sample task with no retention interval as well as when sample and response options are presented simultaneously. The same word, color, and Stroop stimuli will used in the present experiments as were used by Sturz et al. (2013). Furthermore, the current study represents a further test of response competition and semantic competition accounts of the Stroop effect in the context of a match-to-sample task.

Hypotheses for the current study are derived from SSC and SRC effects and presented in terms of semantic competition and response competition respectively. Semantically based interference should occur when the Stroop sample contains conflicting information. Therefore, only incongruent sample trials will produce semantically based interference or, in terms of congruency effects, an SSC effect. On incongruent sample trials, response times should be longer compared to neutral and congruent sample trials because conflicting information requires suppression of irrelevant information to attend to relevant information. Regarding performance accuracy, since response options are not known prior to response option onset, levels of semantic activation for each dimension should be equal; however, once the response options become available and the target dimension revealed, activation of the incongruent Stroop sample with respect to the potential response options will depend on the relationship of the responses to the sample dimensions. When the foil response option is related to the irrelevant sample dimension, such that the irrelevant S-R relationship is semantically true, then accuracy is expected to be worse compared to when the foil is not related to the irrelevant dimension. Specifically, a decrement in accuracy is predicted when the sample is incongruent and the foil response option is related to the irrelevant dimension, but not when the sample is congruent or when the foil response option is unrelated to the irrelevant sample dimension of an incongruent sample.

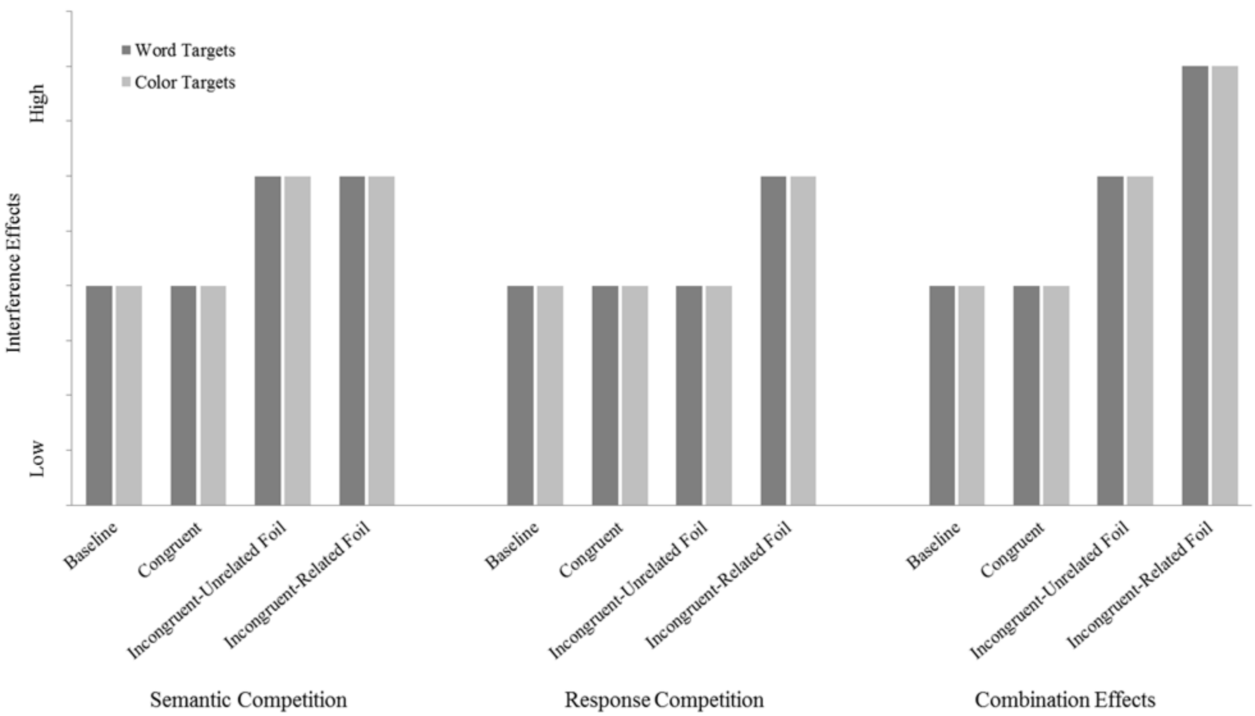

Figure 1. Experiment 1 Hypothetical Data. Predictions of Interference Effects plotted by Trial Type for Semantic Competition hypothesis, Response Competition hypothesis, and Combination Effects hypothesis. Word Targets are plotted in dark gray and Color Targets are plotted in light gray.

Response based interference should only occur when response options compete for selection at the stage of response execution. Therefore, only trials where the sample is incongruent and the foil is related to the irrelevant dimension will produce SRC based interference. That is, interference is a result of competition between two potential response options only when the irrelevant foil dimension is a potential response option (e.g., irrelevant S-R relationship) and the alternative response competes with the target response for selection. According to the response competition hypothesis, response times will only increase when the Stroop sample is incongruent and the foil response option is related to the irrelevant sample dimension. According to the *strength-of-processing* assumption of a speed-accuracy trade-off (Cohen et al., 1990), this increase in RT should also correspond with high accuracy. Therefore, trials in which the sample is incongruent and the foil response option is related to the irrelevant dimension should produce increased RT's and high accuracy. Alternatively, if participants are found to exhibit a decrement in accuracy performance on these trials, then there should not be any significant increase in RT's compared to trials in which the sample is neutral or congruent, or when the foil response option is unrelated to the irrelevant dimension of an incongruent sample.

Semantic and response competition could produce additive effects reflected in the response times. According to DeHouwer (2003; see also, Goldfarb & Henik, 2006), an SSC effect combined with an SRC effect would produce additive effects compared to the presence of only an SSC effect. Trials in which the sample is incongruent (e.g., SSC effect) would result in increased RT's compared to trials in which the sample is neutral or congruent; additionally, trials in which the foil response option is related to the irrelevant sample dimension would result in increased RT's compared to trials in which the sample is unrelated. A decrement in accuracy would only be seen in trials in which the sample is incongruent and the foil response option is related to the irrelevant dimension (e.g., irrelevant SRC effect). Importantly, Sturz et al. (2013) did not find additive effects consistent with a combination hypothesis of semantic and response competition. Instead, response times were identical on incongruent sample trial types and a decrement in accuracy performance was found only when the foil dimension was related to the irrelevant dimension. These combination effects are not anticipated, though given the differences between the current study and the study by Sturz et al. (2013), it is important to consider this possibility.

The first experiment will replicate the basic design used by Sturz et al. (2013) except that the retention interval will be eliminated. The match-to-sample (MTS) task will consist of Stroop sample presentation for 1 second followed immediately by response option presentation for 1.5 seconds. The purpose of this experiment is to eliminate the retention interval that was used by Sturz et al. (2013) while attempting to replicate the results. If the results successfully replicate Sturz et al. (2013), then responses on trials in which the Stroop sample is incongruent should be slower when compared to trials in which the sample is neutral or congruent. Additionally, a decrement in performance accuracy should only be seen when the foil response option is related to the irrelevant dimension.

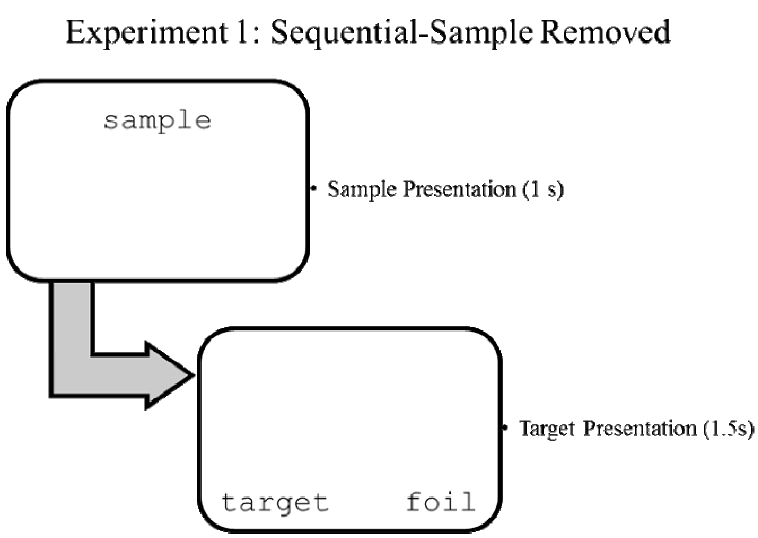

Figure 2. Experiment 1 Protocol. Experimental protocol for Experiment 1 is illustrated to represent all trial types. The Stroop sample is presented for 1 s and is then removed. At 1 s into the trial, response options are presented for 1.5 s. “Sample” represents the Stroop sample. “Target” represents the sample match and the correct response, and “foil” represents the incorrect response.

In the second experiment, a true simultaneous MTS task, the Stroop sample and response options will be presented simultaneously for 2.5 seconds. Most importantly, the relevant sample dimension will no longer be ambiguous prior to response option presentation, but rather, it will be concurrently salient with respect to the response option dimension of each particular trial.

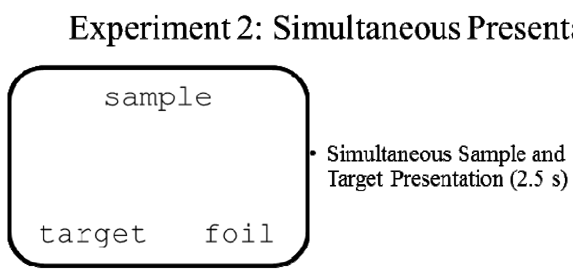

Figure 3. Experiment 2 Protocol. Experimental protocol for Experiment 2 is illustrated to represent all trial types. The Stroop sample and response options are presented simultaneously for 2.5 s. "Sample" represents the Stroop sample. "Target" represents the sample match and the correct response, and "foil" represents the incorrect response.

The purpose of Experiment 2 is to attempt to replicate the findings of Experiment 1, further extrapolate on the generalizability of the MTS task, and to provide convergent validity for the DMTS task used by Sturz et al. (2013). The predictions for Experiment 2 are the same as Experiment 1. According to a semantic competition hypothesis, responding on trials in which the Stroop sample is incongruent should take longer than trials in which the sample is neutral or congruent. RT's for both incongruent trial types should not differ. Since the sample and response options are available concurrently, it seems counterintuitive that there would be a decrement in accuracy; however, since the context of simultaneous presentation necessitates the formation of dual task conflict, then a decrement in accuracy should only be observed on trials in which the foil response option is related to the irrelevant dimension of an incongruent Stroop sample.

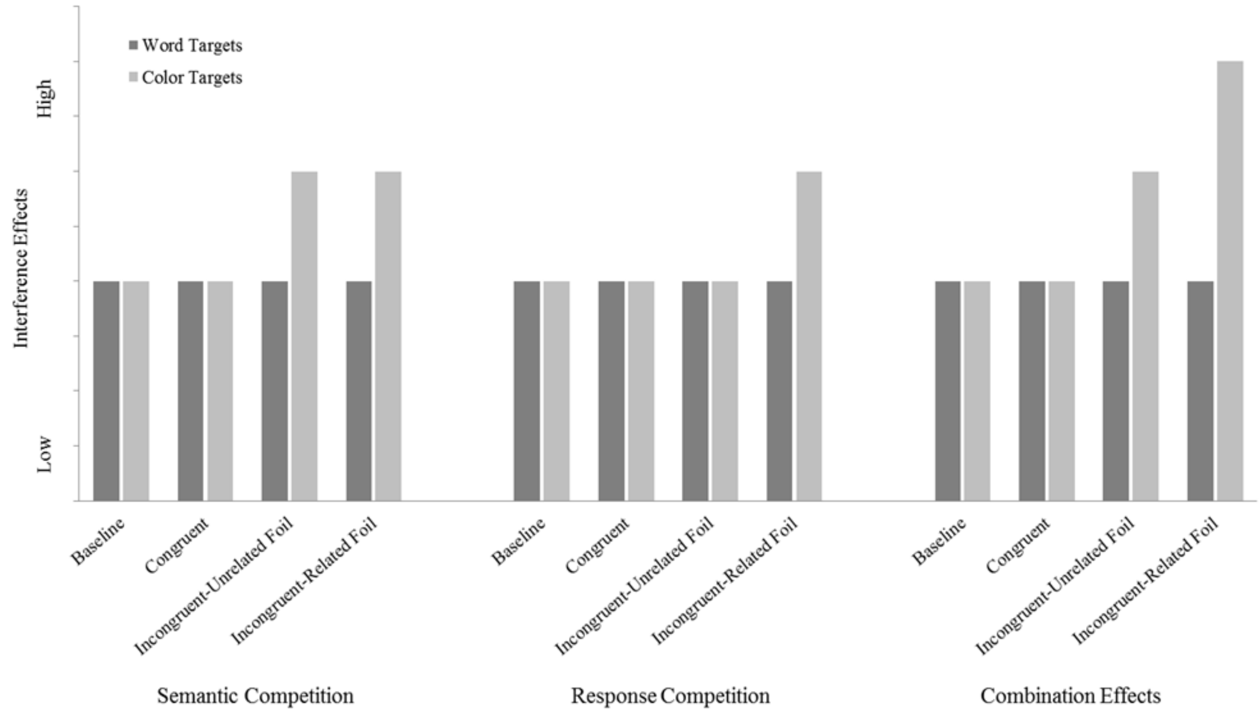

Figure 4. Experiment 2 Hypothetical Data. Predictions of Interference Effects plotted by Trial Type for Semantic Competition hypothesis, Response Competition hypothesis, and Combination Effects hypothesis. Word Targets are plotted in dark gray and Color Targets are plotted in light gray.

Given the differences between Experiment 1 and Experiment 2, it is necessary to make alternative predictions. A response competition hypothesis predicts that responses will be slower on trials in which the Stroop sample is incongruent and the foil response option is related to the irrelevant sample dimension, compared to when the sample is neutral or congruent, or when the foil response option is unrelated to the irrelevant sample dimension. A decrement in performance accuracy will also only be seen on those same critical trials. Secondly, a combination effect hypothesis predicts responses will be slower on trials in which the Stroop sample is incongruent compared to when the sample is neutral or congruent. Importantly, responses will be slower on trials in which the Stroop sample is incongruent and the foil is related to the irrelevant dimension compared to when the foil is unrelated to the irrelevant dimension.

Historically, Stroop tasks have revealed an asynchrony of effects such that colors do not appear to interfere with the reading of words yet, words interfere with the identification of colors (Sabri et al., 2001; see also, Stroop, 1935). Sturz et al. (2013) did not report any finding of asynchrony, and therefore the sequentially presented MTS task (i.e., Experiment 1) should not produce asynchronous effects. Since word reading is considered an automatic process (Besner et al., 1997), in Experiment 2 on trials in which the relevant dimension is the word dimension (i.e., word matching trials), participants should be highly accurate regardless of the relatedness of the foil to the irrelevant sample dimension. On trials in which the relevant dimension is the color dimension (i.e., color matching trials) participants should read the word automatically resulting in interference. This asynchrony is expected only in Experiment 2 because the word dimension of the Stroop sample is available during response option selection. The simultaneous match-to-sample context eliminates the requirement of encoding both sample dimensions since the relevant dimension is not ambiguous. Therefore, participants must attend to both sample dimensions whenever matching response option to sample, resulting in the word dimension being automatically read.

CHAPTER SIX

METHODOLGY

Experiment 1

Participants

Twenty participants (6 males, 14 females) were recruited from the Georgia Southern University population of undergraduate students and were randomly assigned to Experiment 1. According to Cohen (1992), approximately twenty participants were required for each experiment with an alpha level set at 0.05 and a large expected effect size (see MacLeod, 1991). Per the visual nature of this experiment, participants were required to have normal or corrected-to-normal vision. Participants were required to be age 18 or older. Compensation for participation consisted of course credit.

Apparatus

A match to sample (MTS) task was constructed on a personal computer with a 22-inch flat screen liquid crystal display (LCD) monitor (1,680 x 1,050 pixels). Responses were made by depressing the “c” (left index finger) and “m” (right index finger) keys on a standard keyboard. Experimental events were controlled and recorded using E-prime (Psychology Software Tools, Inc., www.pstnet.com). Up to 5 participants completed the task concurrently and were separated by partition within the research facility.

Stimuli

The two stimulus types were colors and words and were identical to those used by Sturz et al. (2013). Color stimuli were blue, red, and yellow color blotches represented as a 410 x 410 pixel filled diamond subtending a 9.6° visual angle horizontally and vertically. Word stimuli were “blue”, “red”, and “yellow” and were presented in black, blue, red, or yellow font color depending on trial type. Word stimuli was presented in bold 48 point Courier New font and was

149 (“blue”), 112 (“red”), or 228 (“yellow”) pixels in width, subtending 2.6° visual angle horizontally, and 40 (“blue” and “red”) or 52 (“yellow”) pixels in height, subtending 0.9° visual angle vertically. All stimuli were presented on a white background. Samples were presented in the center of the screen 25% down from its top edge. Targets were presented on opposite sides of the screen, 50% of screen width apart, and 25% up from its bottom edge.

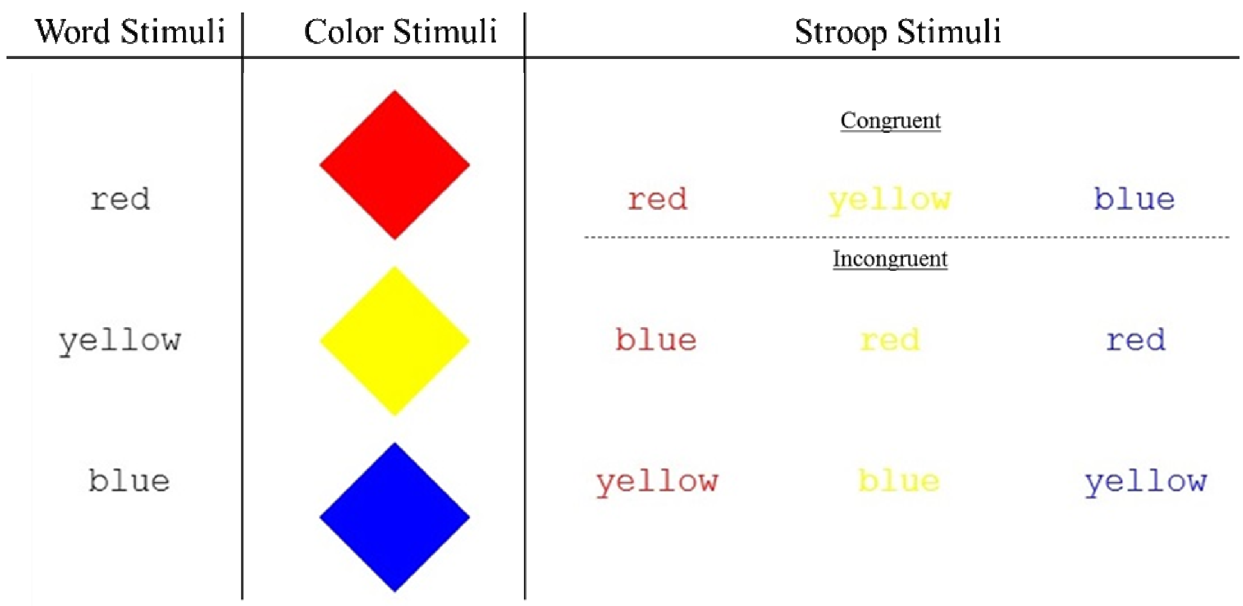

Figure 5. Stimuli. An illustration of the stimuli used in both Experiment 1 and Experiment 2. Word Stimuli consisted of “red”, “yellow”, and “blue” printed in 48 pt. Courier New in black font. Color stimuli consisted of red, yellow, and blue squares. Congruent and Incongruent Stroop stimuli were printed in 48 pt. Courier New in representative colored font (i.e., congruent), or in non-representative colored font (i.e., incongruent).

Procedure

Upon arrival at the research facility participants were provided with informed consent documentation and clarification of any information provided. Following informed consent protocol, participants were provided with an instruction page on the computer monitor. The instructions explained that they were completing a memory/matching test in which they would be presented with either colored shapes or words. Further, the participants were instructed to press the “c” key (left hand) if the matching word/color is on the left, and to press the “m” key (right hand) if the matching word/color is on the right. Pressing the space bar began the task. The experimenter ensured the comprehension of the printed directions by asking the participants, after the instructions were read and prior to beginning the task, if the instructions were understood. If affirmative, then the participants began the task. If not, then the experimenter provided the instructions verbally but did not elaborate on the instructions any more than what is provided on the screen.

Each of the following experiments consisted of 120 trials for each participant and was modeled after the Sturz et al. (2013) design. Training trials were provided first in order to familiarize participants with the MTS task. There were 24 training trials composed of two 12 trial blocks. One block consisted of 12 unique color training trials in which the sample presented was a diamond shaped color blotch and targets were two diamond shaped color blotches, one the match and one the foil. The second block consisted of 12 unique word training trials in which the sample was presented in black font only and the two targets were presented in black font only, one the match and one the foil. Training blocks order of presentation was counterbalanced. Testing consisted of 96 trials composed of twelve 8-trial blocks (24 Baseline, 24 Congruent trials, 24 Incongruent-Unrelated trials, and 24 Incongruent-Related trials).

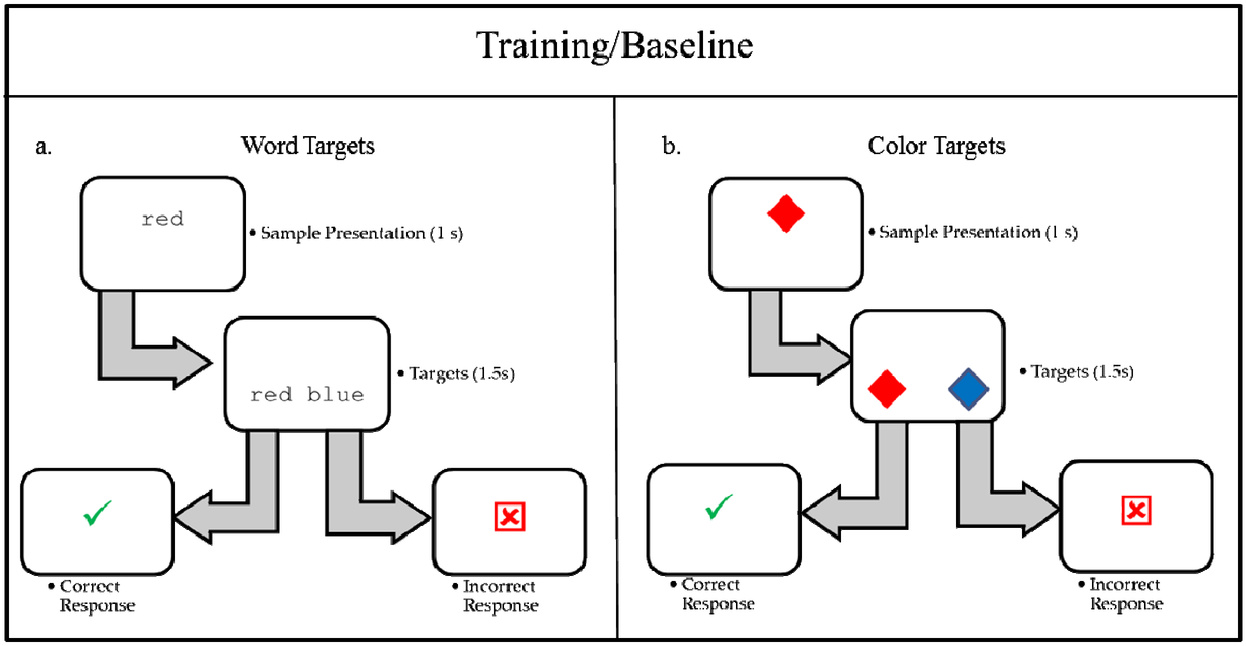

Figure 6. Training/Baseline Trial Types. One sample Training/Baseline trial is illustrated for Word Targets (a) and Color Targets (b).

For simplicity, Training type trials after the first 24 trials refers to the Baseline trials. On Congruent trials, the Stroop sample was one of the three word stimuli presented in its corresponding font color and target response options were the match or the foil. Incongruent-Unrelated Foil trials consisted of an incongruent Stroop sample (i.e. *color*-word in non-corresponding font color) and target response options was the match (i.e. word dimension match or color dimension match) or a foil which is semantically unrelated to the irrelevant dimension. For example, if the sample was the word “blue” written in red font color, then on Incongruent-Unrelated Foil word target trials the foil would be the word “yellow”. Incongruent-Related Foil trials were identical to Incongruent-Unrelated Foil trials except the foil was semantically related to the irrelevant dimension. For example, if the sample was the word “blue” written in red font color, then on Incongruent-Related color target trials the foil was the color red.

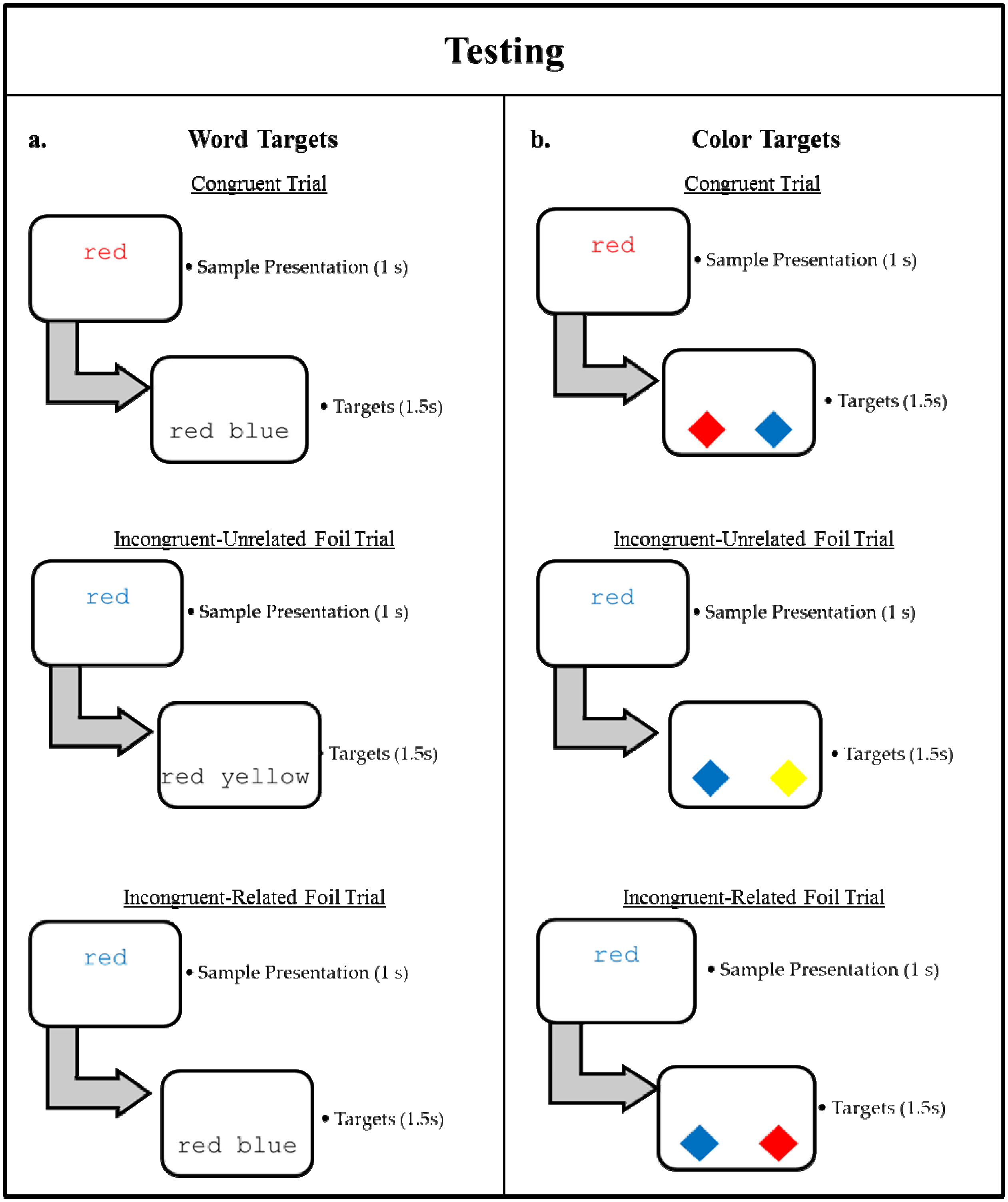

Figure 7. Testing Trial Types. One sample Congruent, Incongruent-Unrelated Foil, and Incongruent-Related Foil Trial is illustrated for Word Targets (a) and for Colors Targets (b). For illustrative purposes, all correct matches are shown as the left target. Target and Foil locations were balanced (see text for details).

One trial with color targets and one trial with word targets were presented for all trial types within each block. The sequence of the trial presentation was randomized within each block. The left/right location of the correct target (i.e. match) and incorrect target (i.e. foil) was counterbalanced resulting in a unique combination of each trial type being presented once without replacement resulting in a total of 96 test trials. On all trials, during a 500ms inter-trial interval (ITI), feedback was provided in the form of a green checkmark for correct responses, a red X-mark for incorrect responses, and “no response” for failing to make a response (see Figure 1). The experimental protocol resembled the Sturz et al. (2013) DMTS task with the exception that there was not a retention interval (i.e., Sequential-Sample Removed). A trial consisted of sample presentation for 1000ms, followed by target stimuli for 1500ms. Importantly, the sample was removed at the moment that targets were presented.

Results

Analyses were conducted on response times (RT’s) and proportion correct.

Response Time

Only the RT’s for correct trials were analyzed. Error trials and trials in which participants failed to respond were eliminated, resulting in the elimination of 37 of the total 1920 trials (1.9% total). A two-way repeated measures analysis of variance (ANOVA) with Target Type (Color Targets, Word Targets) and Trial Type (Baseline, Congruent, Incongruent-Unrelated Foil, Incongruent-Related Foil) as the within-subjects factors revealed a main effect of Target Type, $F_{(1, 19)} = 71.75$, $p < 0.05$, $\eta^2_p = 0.79$, and a main effect of Trial Type, $F_{(3, 57)} = 28.66$, $p < 0.05$, $\eta^2_p = 0.60$. The interaction was not significant, $F_{(3,57)} = 0.17$, $p = 0.91$. Participants were faster to respond to Color Targets compared to Word Targets. Fisher’s Least Significant Difference (LSD) *post hoc* tests on the Trial Type factor revealed that Baseline trials were significantly faster than Congruent trials, and Baseline and Congruent trials were significantly faster than both Incongruent-Unrelated Foil and Incongruent-Related Foil trials, *p*s < 0.05. Incongruent-Unrelated Foil and Incongruent-Related Foil trials were not significantly different from each other ($p = 0.26$).

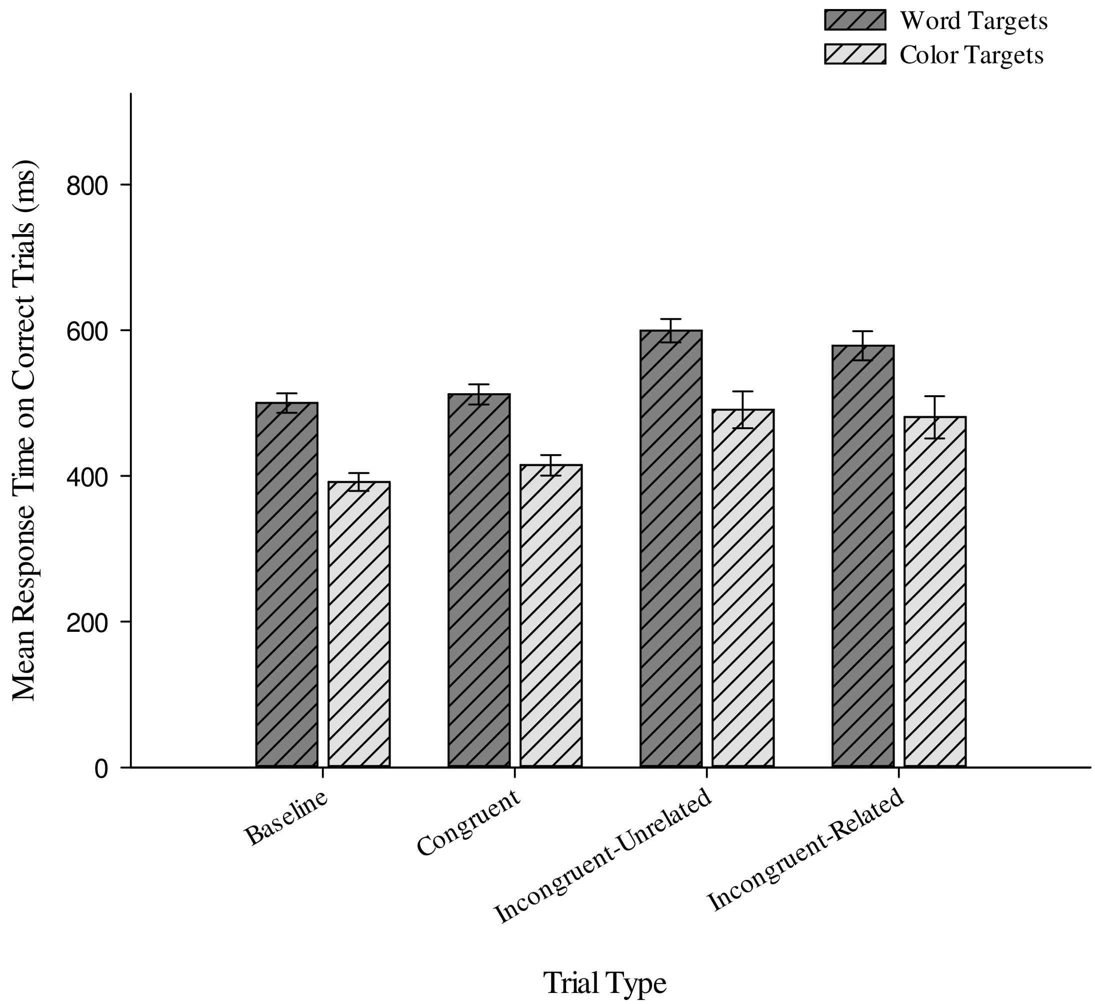

Figure 8. Experiment 1 Response Time Results. Mean response time on correct trials during Testing (in milliseconds) plotted by Trial Type for Word Targets (dark gray bars) and Color Targets (light gray bars). Error bars represent standard errors of the means.

Proportion Correct

Trials in which participants failed to respond were eliminated, resulting in the elimination of 15 of the total 1920 trials (0.8% total). Figure 8 shows the mean proportion correct plotted by Trial Type for Color and Word Targets. A two-way repeated measures ANOVA with Target Type (Color Targets, Word Targets) and Trial Type (Baseline, Congruent, Incongruent-Unrelated Foil, Incongruent-Related Foil) as the within-subjects factors revealed a main effect of Trial Type, $F_{(3,57)} = 75.11$, $p < 0.05$, $\eta^2_p = 0.80$. There was no main effect of Target Type ($F_{(1,19)} = 1.87$, $p = 0.19$). The interaction was significant, $F_{(3,57)} = 7.90$, $p < 0.05$, $\eta^2_p = 0.29$.

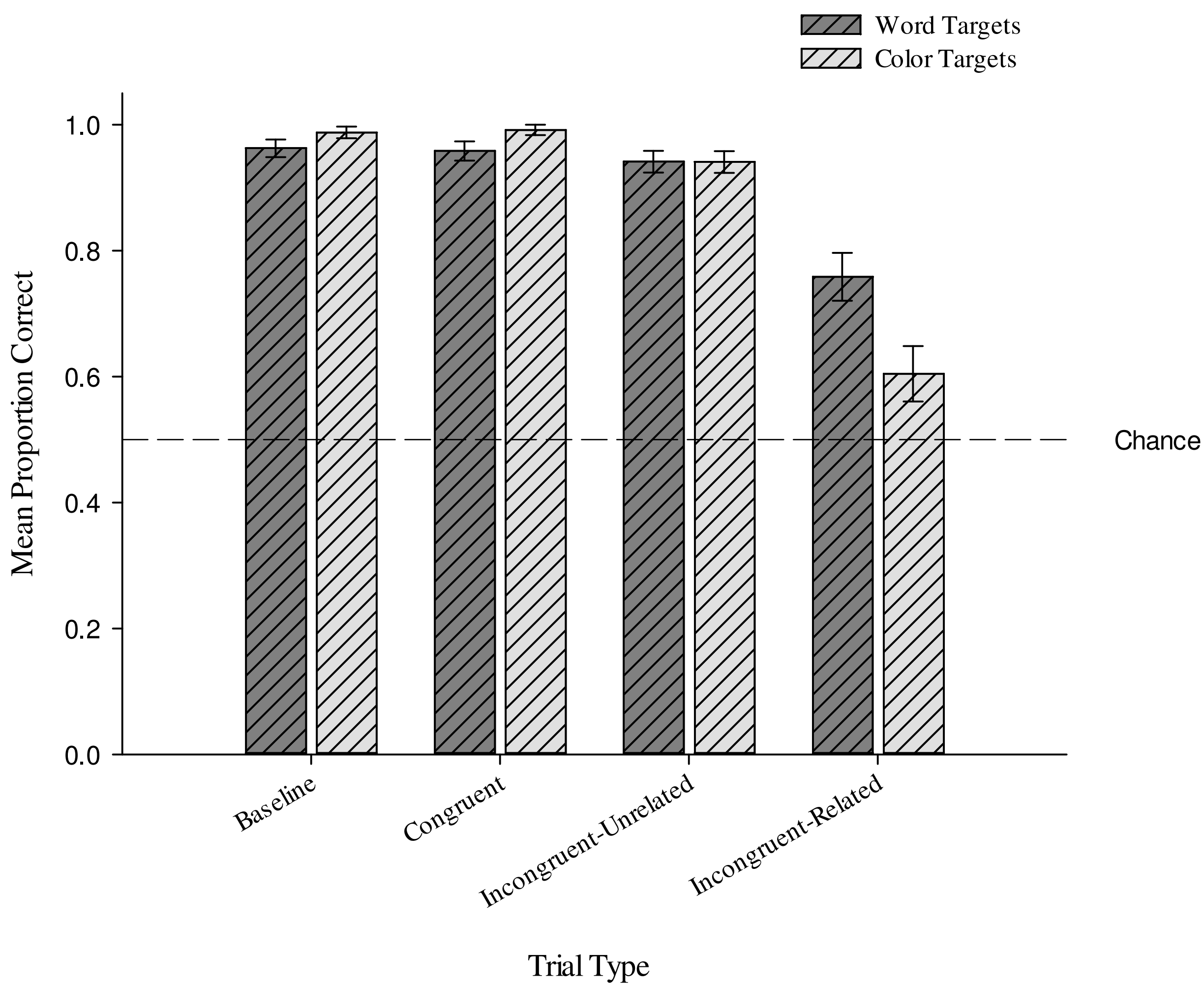

Figure 9. Experiment 1 Accuracy Results. Mean proportion correct during testing plotted by Trial Type for Word Targets (dark gray bars) and Color Targets (light gray bars). Dashed line represents chance performance (0.5). Error bars represent standard errors of the means.

To isolate the source of the Target Type x Trial Type interaction, separate one-way repeated measures ANOVA's with Trial Type as a factor were conducted for each Target Type. For Color Targets, there was a main effect of Trial Type, $F_{(3, 57)} = 66.67$, $p < 0.05$, $\eta^2_p = 0.78$. Post hoc tests revealed that Incongruent-Related Foil trials were significantly less accurate than Baseline, Congruent, and Incongruent-Unrelated Foil trials, $p < 0.05$. Incongruent-Unrelated Foil trials were significantly less accurate than Baseline and Congruent Foil trials, $p < 0.05$. Baseline and Congruent trials were not significantly different from one another, ps > 0.05. For Word targets, there was a main effect of Trial Type, $F_{(3, 57)} = 19.02$, $p < 0.05$, $\eta^2_p = 0.50$. Post hos tests revealed than Incongruent-Related Foil trials, were significantly less accurate than Baseline, Congruent, and Incongruent-Unrelated Foil trials, $p < 0.05$. Baseline, Congruent, and Incongruent-Unrelated Foil trials were not significantly different from one another, ps > 0.05.

To further determine to the source of the interaction, separate paired-samples *t*-tests were conducted for each Trial Type. On Baseline trials, Word Targets were significantly less accurate than Color Targets, $t_{(19)} = -2.85$, $p < 0.05$. On Congruent trials, Word Targets were significantly less accurate than Color Targets, $t_{(19)} = -2.99$, $p < 0.05$. On Incongruent-Unrelated Foil trials, Word Targets did not differ from Color Targets, $t_{(19)} = 0.02$, $p = 0.99$. On Incongruent-Related Foil trials, Word Targets were significantly more accurate than Color Targets, $t_{(19)} = 2.61$, $p < 0.05$. One-sample *t*-tests revealed that mean proportion correct was significantly greater than chance (0.5) for all Trial Types and Target Types, $ts_{(19)} > 2.37$, ps < 0.05.

Discussion

The RT analyses indicated that responses for Congruent trials took longer than Baseline trials, and that both incongruent trial types, unrelated and related foil trials, took longer than Baseline and Congruent trial types. This finding is consistent with those of Sturz, et al. (2013), with the exception that Congruent trials took longer than Baseline trials. While it is unclear why this difference was found, there are two possible explanations. First, the Fisher's LSD *post hoc* test may have been too powerful given that the effect sizes were quite large. Second, since Congruent trials contained a bi-dimensional stimulus, and since there was no retention interval to facilitate processing of two dimensions, Congruent trials may have taken longer compared to Baseline trials. This second explanation, however, is unlikely since past research has shown congruent Stroop stimuli to facilitate responding, and thus RT's on Congruent trials should have been faster than Baseline trials (MacLeod, 1991). A visual inspection of the data suggests that the former explanation is likely the case. Nonetheless, the important result indicated by the RT analyses is that Incongruent-Unrelated Foil and Incongruent-Related Foil trials were not significantly different from one another, suggesting that incompatible semantic content results in a slowing of processing regardless of the relatedness of the alternative response option (i.e., SSC effect).

The accuracy analyses indicated that there was a decrement in performance only for Incongruent-Related Foil trials. During these trials, the semantic content of the foil was related to the irrelevant dimension of the sample, and as such, an irrelevant S-R relationship produced a secondary viable response option. Although the response competition hypothesis predicts a decrement in accuracy due to competing response options, this hypothesis cannot account for the RT results. The response competition hypothesis does not predict increased response times on trials where the foil response option in unrelated to the irrelevant dimension. Additionally, the combined RT and accuracy results cannot be explained by a combination of semantic and response competition. A combination hypothesis predicts an additive effect in RT's, which would only be supported by evidence of a speed-accuracy trade-off on incongruent trials, and increased RT's on Incongruent-Related Foil trials compared to Incongruent-Unrelated Foil trials.

Consequentially, the results can only be explained by a semantic competition hypothesis because accuracy on Incongruent-Unrelated Foil trials was no different than Baseline and Congruent Trials, and there was no evidence for additive effects in the RT data (e.g., Luo, 1999; Sturz et al., 2013). Semantic activation of representations for both color and words cannot be prevented from being set in motion because they are, by definition, automatic processes (Besner et al., 1997). When incompatible semantic codes are activated with the semantic memory network, those codes have an inhibitory effect on spreading activation (Sturz et al., 2013). To make an accurate response to a stimulus, attentional resources must be allocated to suppress the irrelevant code, and since target dimension relevancy is unknown prior to response option onset, then only S-S based pathway suppression occurs. Under the assumptions of the *strength of processing* account, the speed and accuracy in which the semantic codes are processed specify the strength of the underlying semantic activation (Cohen et al., 1991). An incongruent stimulus-stimulus (e.g., S-S) pairing, therefore, activates two semantic codes which both have some network strength value that includes both the speed in which the code is processed and accuracy feedback (e.g., compatibility of pairing). Once the relevant target dimension is known, S-S based accuracy feedback allows for attentional resources to suppress the irrelevant semantic activation; however, when the foil response option is related to the irrelevant sample dimension, then there is increased chance that the relevant semantic code, rather than the irrelevant semantic code, is suppressed. Therefore, based on the context of the trial, there is an increased chance of making errors.

These results are consistent with the conclusions of Sturz et al. (2013). Using a Delayed MTS Stroop paradigm with a 5-second or a 10-second retention interval between sample offset and response option onset, the researchers found that participants were significantly slower to respond on incongruent Stroop stimulus trials compared to neutral and congruent Stroop stimulus trials. Importantly, response times for both incongruent trial types, unrelated foil and related foil trials, were no different from each other. A decrement in accuracy was only found on incongruent trials where the foil response option was related to the irrelevant sample dimension. The results appeared to be opposite a speed-accuracy trade-off and corroborated an interpretation consistent with semantic competition.

In summary, the purpose of Experiment 1 was to replicate the Sturz et al. (2013) delayed MTS paradigm while eliminating the retention interval. This replication allows for a more parsimonious comparison between MTS Stroop tasks and Stroop paradigms that do not utilize manipulations of stimulus and response onset, as well as those that do not utilize a brief SOA. Although the results of this task support those of Sturz et al. (2013), the full extent of generalizability to simultaneously presented Stroop-type tasks is not yet known. In Experiment 2, a simultaneous MTS task, in which the Stroop sample and response options are presented concurrently for the duration of a trial, will be used to further examine the generalizability of the MTS Stroop task. In most Stroop paradigms, the relevant target dimension is known at the same point in which the Stroop stimulus is presented (see MacLeod, 1991). A simultaneous MTS task, in which the sample and response options are concurrent, will immediately provide information about the relevant dimension. If conflicting semantic codes produce pathway inhibition in the semantic network, and suppression of an irrelevant semantic code is required to execute an appropriate response, then Experiment 2 should replicate the effect of Trial Type in Experiment 1 for both RT and accuracy measures of performance.

Experiment 2

In Experiment 2, the sample and the response options are presented simultaneously which is meant to most closely resemble Stroop tasks in which the relevant dimension is not ambiguous, but rather, known at the point of sample presentation. This context provides the means by which dual tasks can arise. In other words, both a relevant SRC effect and an irrelevant SRC effect have the potential to produce interference; however, since reading requires less attention than color identification, interference should only be seen for Color Targets. The color is identified more slowly than the word is read, and is thought to allow the word to interfere with color matching but not result in the color interfering with word reading. Evidence of Stroop asynchrony would provide convergent validity for the MTS task within the Stroop literature. Additionally, such that the match-to-sample task allows for the systematic manipulation of the semantic relatedness of the foil response option to the irrelevant sample dimension, then the same Trial Types can be designed while still in the context of simultaneous sample and response presentation. Therefore a comparison of Trial Types will determine whether a semantic competition hypothesis, a response competition hypothesis, or a combination effects hypothesis most parsimoniously explains the results.

Participants, Apparatus, Stimuli, and Procedure

Twenty participants (6 males, 14 females) were recruited from the Georgia Southern University population of undergraduate students and were randomly assigned to Experiment 2. Participants were required to have normal or corrected-to-normal vision. Participants were required to be age 18 or older. Compensation for participation consisted of course credit. The same apparatus and stimuli from Experiment 1 were used for Experiment 2.

The procedure for providing the informed consent and task instructions were identical to Experiment 1. Additionally, the same numbers of trials were presented to each participant in Experiment 2 (e.g., 120 total trials, 24 Training trials, 96 Test trials), and the trials were designed in the same way as Experiment 1 (e.g., Baseline, Congruent, Incongruent-Unrelated Foil, and Incongruent-Related Foil trials). The experimental protocol was different from Experiment 1 in that the sample and the response options were presented simultaneously for the duration of the trial (i.e., 2500ms). Participants were able to respond at any point during the trial.

Results

As in Experiment 1, analyses were conducted on response times (RT's) and proportion correct.

Response Time

Only the RT's for correct trials were analyzed. Error trials and trials in which participants failed to respond were eliminated, resulting in the elimination of 152 of the total 1920 trials (7.9% total). A two-way repeated measures ANOVA with Target Type (Color Targets, Word Targets) and Trial Type (Baseline, Congruent, Incongruent-Unrelated Foil, Incongruent-Related Foil) as the within-subjects factors revealed a main effect of Target Type, $F_{(1, 19)} = 4.38$, $p = 0.05$, $\eta^2_p = 0.19$, and a main effect of Trial Type, $F_{(3, 57)} = 32.25$, $p < 0.05$, $\eta^2_p = 0.63$. The interaction was also significant, $F_{(3,57)} = 13.70$, $p < 0.05$, $\eta^2_p = 0.42$.

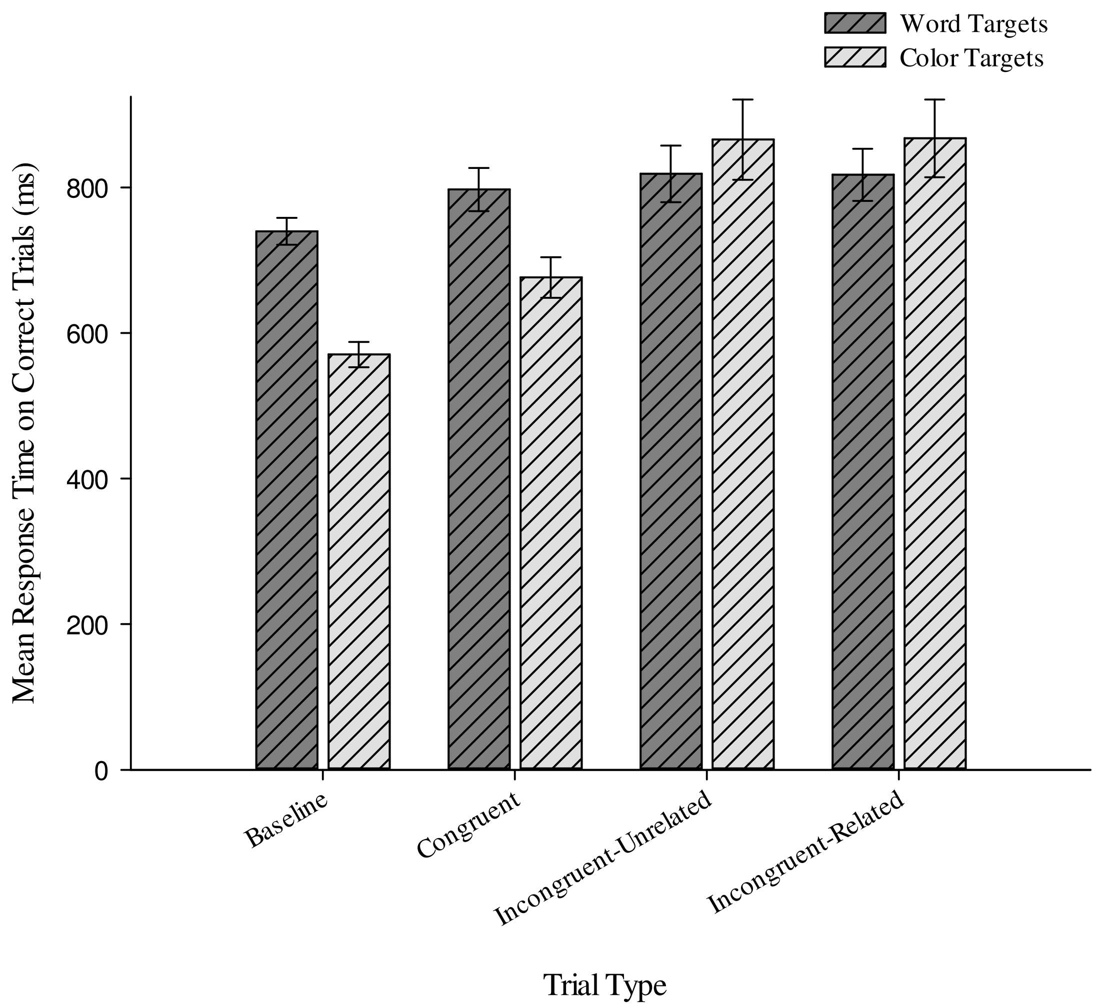

Figure 10. Experiment 2 Response Time Results. Mean response time on correct trials during Testing (in milliseconds) plotted by Trial Type for Word Targets (dark gray bars) and Color Targets (light gray bars). Error bars represent standard errors of the means.

To isolate the source of the Target Type x Trial Type interaction, separate one-way repeated measures ANOVAs with Trial Type as a factor were conducted for each Target Type. For Color Targets, there was a main effect of Trial Type ($F_{(3, 57)} = 35.13$, $p < 0.05$, $\eta^2_p = 0.65$). Post hoc tests revealed that Baseline trials were significantly faster than Congruent trials, and Baseline and Congruent trials were significantly faster than both Incongruent-Unrelated Foil and Incongruent-Related Foil trials, *p*s < 0.05. Incongruent-Unrelated Foil and Incongruent-Related

Foil trials were not significantly different from each other ($p = 0.94$). For Word Targets, there was a main effect of Trial Type, $F_{(3, 57)} = 3.74$, $p < 0.05$, $\eta^2_p = 0.16$. Post hoc tests revealed that Baseline trials were significantly faster than Congruent, Incongruent-Unrelated Foil, and Incongruent-Related Foil trials, *p*s < 0.05. Congruent, Incongruent-Unrelated Foil and Incongruent-Related Foil trials were not significantly different from each other, $p > 0.05$.

To further determine the source of the interaction, separate paired-samples *t*-tests were conducted for each Trial Type. On Baseline trials, Word Targets were significantly slower than Color Targets, $t_{(19)} = 9.52$, $p < 0.05$. On Congruent trials, Word Targets were significantly slower than Color Targets, $t_{(19)} = 4.85$, $p < 0.05$. On Incongruent-Unrelated Foil trials, Word Targets did not differ from Color Targets, $t_{(19)} = -0.97$, $p = 0.34$. On Incongruent-Related Foil trials, Word Targets did not differ from Color Targets, $t_{(19)} = -1.22$, $p = 0.24$.

Proportion Correct

Trials in which participants failed to respond were eliminated, resulting in the elimination of 7 of the total 1920 trials (0.4% total). Figure 8 shows the mean proportion correct plotted by Trial Type for Color and Word Targets. A two-way repeated measures ANOVA with Target Type (Color Targets, Word Targets) and Trial Type (Baseline, Congruent, Incongruent-Unrelated Foil, and Incongruent-Related Foil) as the within-subjects factors revealed a main effect of Target Type, $F_{(1, 19)} = 6.22$, $p < 0.05$, $\eta^2_p = 0.25$, and a main effect of Trial Type, $F_{(3, 57)} = 22.60$, $p < 0.05$, $\eta^2_p = 0.54$. The interaction was also significant, $F_{(57,17)} = 21.13$, $p < .05$, $\eta^2_p = 0.53$.

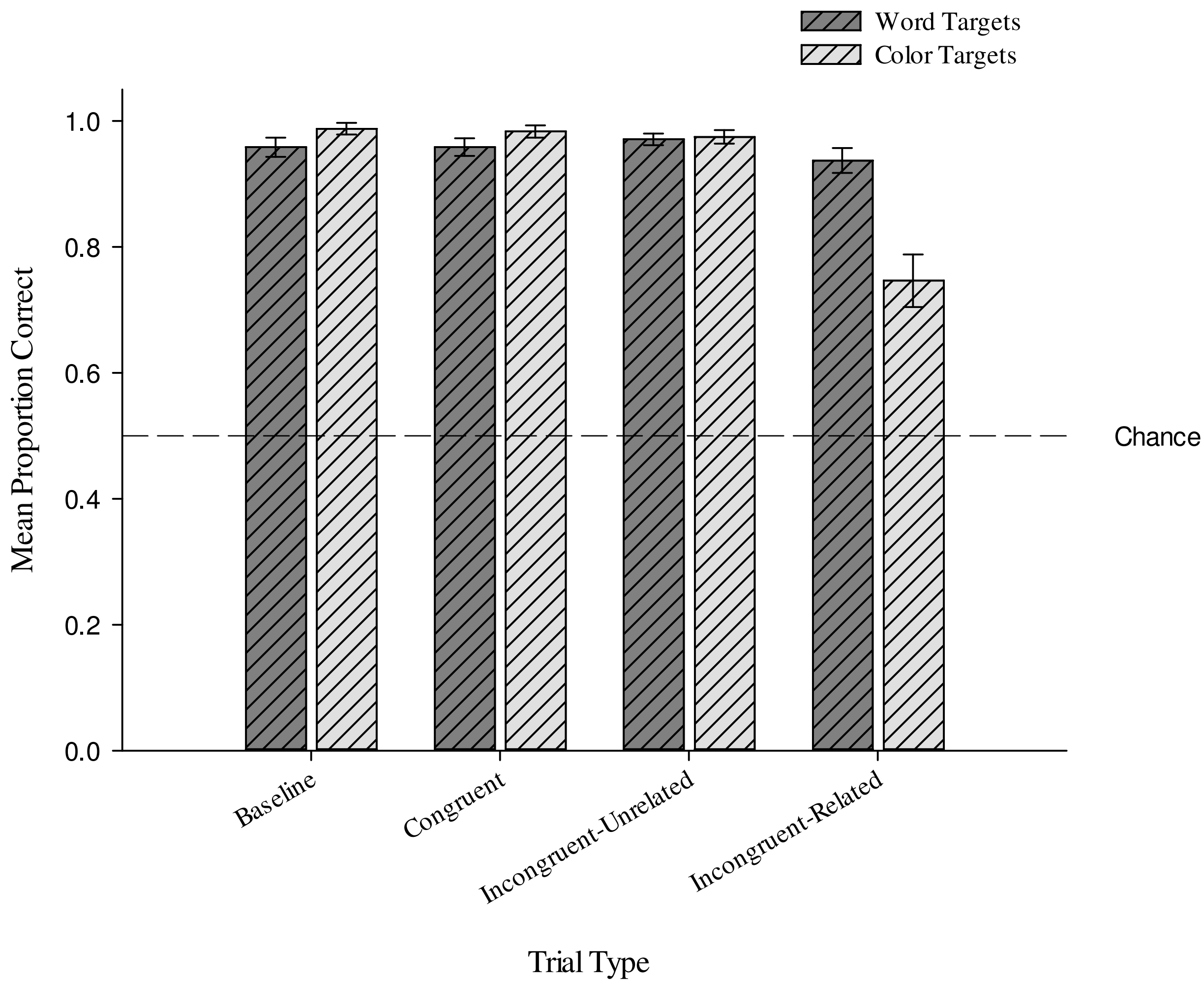

Figure 11. Experiment 2 Accuracy Results. Mean proportion correct during testing plotted by Trial Type for Word Targets (striped dark gray bars) and Color Targets (striped light gray bars). Dashed line represents chance performance (0.5). Error bars represent standard errors of the means.

To isolate the source of the Target Type x Trial Type interaction, separate one-way repeated measures ANOVAs with Trial Type as a factor were conducted for each Target Type. For Color Targets, there was a main effect of Trial Type, $F_{(3, 57)} = 29.33$, $p < 0.05$, $\eta^2_p = 0.61$. Post hoc tests revealed that Incongruent-Related Foil trials were significantly less accurate than Baseline, Congruent, and Incongruent-Unrelated Foil trials, $p < 0.05$. Baseline, Congruent, and Incongruent-Unrelated Foil trials were not significantly different from each other, $p > 0.05$. For Word targets, there was no main effect of Trial Type, $F_{(3, 57)} = 1.17$, $p = 0.33$, $\eta^2_p = 0.06$. One-sample *t*-tests revealed that mean proportion correct was significantly greater than chance (0.5) for all Trial Types and Target Types, $ts_{(19)} > 5.89$, $ps < 0.05$.

Discussion

Results of the RT analyses of Experiment 2 show that participants took longer to respond to Words Targets compared to Color Targets, but only on Baseline and Congruent trials. Responses to Word Targets and Color Targets did not differ on Incongruent trial types. Importantly, responding to Word and Color Targets on Incongruent-Unrelated Foil and Incongruent-Related Foil trials were not significantly different from one another. These results indicate that when sample and response options are presented simultaneously, and the sample is incongruent, it takes significantly longer to respond compared to when the sample is neutral or congruent.

The results from the accuracy analyses indicated a decrement in performance on Incongruent-Related Foil trials but only for Color Targets. Participants were equally accurate on all trial types for Word Targets. Additionally, participants were equally accurate on Baseline, Congruent, and Incongruent-Unrelated Foil trials for Color Targets. This asynchronous interaction effect of Trial Type and Target Type on accuracy performance indicates that when a Stroop stimulus and response option pair are presented simultaneously in a MTS task, interference is confined to color matching, and emulates the asynchronous interference associated with color identification of an incongruent Stroop stimulus in a typical Stroop task.

Although the results from Experiment 2 differ still from Experiment 1, the results are interpreted as supporting a semantic competition hypothesis. The overall pattern of the RT analyses was similar to the results of Experiment 1 and those of Sturz et al. (2013). When the Stroop sample is incongruent, a semantic code is activated for both dimensions. In order to make an accurate response, the irrelevant semantic code must be suppressed in the semantic memory network. Since the sample is incongruent, and subsequently requires suppression of the irrelevant semantic code to make an accurate response, then the suppression process slows responding. Such that the semantically based word reading process is considered a relatively automatic process, the accuracy results could potentially be reflective of the automaticity hypothesis. Although I do not suggest that the automaticity hypothesis is adequate on its own, due to the requirement of arbitrarily assuming one process is more automatic than another process, I alternatively suggest that the accuracy results of Experiment 2 indicate the power of context within a Stroop task. By presenting both the Stroop sample and word response options simultaneously, participants were able to match as accurately as when the neutral or congruent; however, when color response options were presented, massive interference in the form of a decrement in accuracy was observed.

In typical Stroop tasks, where the task is to identify a particular dimension, participants will unfailingly respond more slowly to incongruent Stroop stimuli and will make more errors compared to congruent or neutral stimuli (see MacLeod, 1991). Additionally, the Stroop effect in these paradigms consistently produces asynchronous effects (see Sabri et al., 2001). The irrelevant word interferes with color identification but the irrelevant color does not interfere with word reading. This pattern of results supports a response competition hypothesis which posits that one potential response unit will compete with another potential response unit for response output. The problem with typical Stroop paradigms, and conclusion derived from the results, is that the potential response options are either the relevant stimulus dimension (e.g., correct response) or are the irrelevant stimulus dimension (e.g., incorrect response). Therefore, the incorrect response option (e.g., equivalent to the foil response option in an MTS task) is always related to the irrelevant dimension. The results of Experiment 2, which revealed interference reflected in RT's when the Stroop sample was incongruent and asynchronous interference of color matching reflected in accuracy performance, support a semantic competition hypothesis (Luo, 1999; Sturz et al., 2013) and do not support a response competition hypothesis (Besner et al., 1997; Stolz & Besner, 1999).

CHAPTER SEVEN

GENERAL DISCUSSION

Results from Experiment 1 indicated that RT's for both incongruent trial types were longer than RT's for both Baseline and Congruent trial types. Additionally, both incongruent trial types did not differ from each other. These findings were identical to those found by Sturz et al. (2013) in a Delay MTS task with 5- and 10- second retention intervals. Dissimilar to Sturz et al. (2013), Congruent trials were slower than Baseline trials. The results from the accuracy data indicated that Incongruent-Unrelated Foil trials were less accurate than Baseline, Congruent, and Incongruent-Related Foil trials for both word and color targets. The majority of these results were identical to those found by Sturz et al. (2013).

Collectively, these results are interpreted as converging evidence that semantic memory is the source of the Stroop effect such that the matching of a response option to an incongruent Stroop sample involves suppression of semantic codes. The requirement of semantic code suppression on incongruent trial types leads to an increase in RT's compared to Baseline and Congruent Trial types. Since Baseline, Congruent, and Incongruent-Unrelated Foil trials did not require suppression of the semantic content of the irrelevant sample dimension, the increase in RT for incongruent trials types compared to Baseline and Congruent trials cannot be attributed to response competition. As a result, these findings are consistent with the semantic competition account (Luo, 1999; Sturz et al., 2013) and are inconsistent with a response competition account (Besner et al., 1997; Stolz & Besner, 1999).

Similar to Experiment 1, results from Experiment 2 indicated that RT's for both incongruent trials types were longer than RT's for both Baseline and Congruent trial types and likewise, both incongruent trials types did not differ from one another. These findings were also similar to those found by Sturz et al. (2013). Dissimilar to both Experiment 1 and the previous research conducted by Sturz et al. (2013), a decrement in accuracy was only found on Incongruent-Related Foil trials for Color Targets. Since the Stroop sample and the response options were presented simultaneously, and reading is thought to be a more automatic process than color identification (Besner et al., 1997), the result of asynchronous Stroop interference is not surprising. Rather, this result suggests that context plays a role in producing the asynchronous effects found in much of the Stroop literature (Sabri et al., 2001; see also MacLeod, 1991). Despite the difference in the accuracy results, since Baseline, Congruent, and Incongruent-Unrelated Foils did not require suppression of the semantic content of the irrelevant sample dimension, the increase in response times for incongruent trial types compared to Baseline and Congruent trials cannot be attributed to response competition. Again, these results are consistent with a semantic competition account and inconsistent with a response competition account.

According to the semantic competition hypothesis, the Stroop effect reflected in increased response times is caused by the suppression of the irrelevant dimension of an incongruent bi-dimensional stimulus prior to response selection. Each dimension activates a semantic representation, and thus, the irrelevant dimension must be suppressed before an accurate selection of a response option can be made. Under the assumption that semantic representations are activated for both sample dimensions, once the response options are presented, the irrelevant dimension must be suppressed in order to attend to and select the appropriate response. The semantic competition hypothesis posits that the effect associated with a decrement in accuracy is caused by the S-R relationship between the irrelevant stimulus dimension and a related response option. Since this irrelevant S-R relationship is semantically true, but only with regards to an irrelevant secondary task, then suppression of semantic content is more likely to result in errors compared to instances when the response option is unrelated to the irrelevant stimulus dimension. When the context of the task requires that both dimensions of the sample are encoded and retained (e.g., ambiguous relevant dimension, Experiment 1), then there is a decrement in performance accuracy when a response option is related to the irrelevant dimension for both color matching and word matching. When the context of the task does not require encoding and retention of both dimensions (e.g., Experiment 2), there is only a decrement in performance accuracy for color matching.

The accuracy differences between Experiment 1 and 2 can be described in terms of Stimulus-Response Compatibility effects. In Experiment 1, the sample is presented prior to response option onset and is informative about the relevant dimension at a trial level context. Therefore, since both dimensions must be encoded, and neither dimension suppressed prior to response option onset, then any congruency effect must, by definition, be an SSC effect. Once the response options are presented, SRC effects can potentially occur between the relevant sample dimension and the foil response option (e.g., relevant SRC effect), and the irrelevant sample dimension and the target response option (e.g., irrelevant SRC effect). The observed slowing of RT's in Experiment 1 are interpreted as an SSC effect (e.g., semantic competition) because the suppression of an irrelevant dimension is only required if a stimulus is incongruent. The decrement in performance accuracy in Experiment 1 is interpreted as an SRC effect (e.g., response competition) such that the relatedness of the foil to the irrelevant sample dimension produces an increased opportunity to erroneously suppress the relevant dimension versus the irrelevant dimension; however, response competition as an interference process underlying the Stroop effect is inadequate since such a process must, by definition, result in an S-R effect any time the foil response option is incompatible with either dimension of the sample (e.g., relevant or irrelevant SRC effect). Therefore, even on Congruent or Incongruent-Unrelated Foil trials, the foil response option will be incompatible with both dimensions of the sample. Such that this result was not observed, the most parsimonious explanation is such, that when both sample dimensions are encoded and the response dimension is unknown prior to response selection, then the resulting interference must be semantically based.

In Experiment 2, the sample and response options were presented simultaneously, and therefore, the dimension relevancy is revealed concurrently with the initial encoding of the sample. Therefore, semantic representations for both the dimensions of the sample, as well as both the response options, are activated and subsequently, there should be more information required to be suppressed. Both the irrelevant sample representation and the foil response representation would need to be suppressed to accurately respond. The results of Experiment 2 are interpreted as an indication that when the sample and response options are presented simultaneously, suppression of the irrelevant sample dimension and foil response option caused a slowing of responding not only on Incongruent-Unrelated Foil and Incongruent-Related Foil trials, but also on Congruent trials. Additionally, since the relevant dimension is revealed at the start of the trial there is no need to retain the irrelevant sample dimension past the point of initial encoding. A decrement in accuracy on Incongruent-Related Foil trials for Color Target trials provides converging evidence that S-R based Stroop interference is contextually driven. Since a response competition hypothesis is unable to account for all the results of the current MTS task, I propose that the semantic competition hypothesis can account for the current results and that semantic interference is a component of the Stroop effect in general. As the current results are understood, and in light of past research on the Stroop effect, the notion of an irrelevant response option competing with the relevant response option is directly related to the constraints of most paradigms which produce the context for dual tasks.

Returning to the computational models of the Stroop effect, one of the primary difficulties in designing a model that adequately models Stroop performance was whether or not to incorporate S-S compatibility effects (Zhang et al., 1999). In the Cohen et al. (1990) model, although accurate mean simulations were produced, the mean distributions did not fit human performance on the Stroop task. In a test of the model, Mewhort et al. (1992) concluded that eliminating S-S effects by separating response execution from stimulus processing resulted in the unrealistic response distributions. Zhang et al. (1999) built a new model based on framework and assumptions of the Cohen et al. (1990) model and incorporated relevant SRC, irrelevant SRC, and SSC effects, and were able to accurately simulate Stroop performance. Given the importance of incorporating these SSC and SRC effects into computer models to produce accurate simulations of Stroop task performance, it is important to design and test manual Stroop tasks which consider these very same effects.

DeHouwer (2003), for example, was able to systematically manipulate the congruency of the response option by allocating two color responses to two keys, resulting in three types of trials, *identity*, *same response*, and *different response* trials. Results of the study indicated that on *different response* trials, where both the correct and incorrect response keys were related to the relevant and irrelevant sample dimension respectively, RT's were longest. Additionally, on *same response* trials, where the correct response key was related to both the relevant and irrelevant response option, RT's were longer than *identity* trials in which the sample stimulus was congruent. DeHouwer (2003) interpreted this additive effect as evidence that *different response* trials produced both SSC and SRC effects, *same response* trials produced only SSC effects, and *different response* trial did not produce any SRC effects. According to MacLeod and MacDonald (2000), additive effects would support task-conflict theory, which assumes that both semantic and response competition contribute to the Stroop effect. It remains unclear then, why we were unable to produce additive effects in Experiment 1 and 2 and why Sturz et al. (2013) were unable to produce additive effects in a Delay MTS task.

The task used by Luo (1999) was designed to dissociate SSC and SRC effects. By asking participants to match stimuli based on either a word meaning decision or a visual decision, Luo (1999) concluded that the processing of conflicting semantic information was the source of Stroop interference. Alternatively, Goldfarb and Henik (2006) argued, since Luo (1999) only analyzed his results based on conditional level context (e.g., meaning decision versus visual decision), that an analysis based on experiment-wide stimulus congruency should have revealed additive effects. Upon replication and reanalysis, Goldfarb and Henik (2006) found additive effects based on the congruency of surface color, word meaning, and word color. These findings mirror DeHouwer (2003) and likewise support task-conflict theory.

Although it remains unclear why the additive effects associated with task-conflict theory are not found in the MTS task or the Sturz et al. (2013) delayed MTS task, the most parsimonious explanation is that these paradigms do not create the context for an irrelevant secondary task. In the Luo (1999) study, there was the potential to match stimuli based on both word meaning and surface color. In the DeHouwer (2003) task, there was the potential to match both the target stimuli and the irrelevant stimuli to the appropriate key. In MTS tasks, where the response dimension is randomly presented and subsequently denotes the relevant sample dimension to match, there is then no primary or secondary task. Strictly speaking, the task is to match based on the dimension of the response options. If there is no conflict of relevant and irrelevant task, then an additive effect based on an irrelevant SRC effect combined with an SSC effect would not be produced.

In conclusion, the results of this study support a semantic competition account of Stroop interference. A match-to-sample task, in which a response option is matched to a bi-dimensional Stroop sample, revealed that regardless of the relatedness of a foil response option, when the sample is incongruent, participants take longer to make a response. A decrement in accuracy only occurs when the sample is incongruent and the response option is related to the irrelevant dimension, and is partially a function of delay. These combined results rule out a speed-accuracy tradeoff, and the lack of additive effects do not support task-conflict theory, which posits that both semantic and response competition are a joint source of Stroop interference. Semantic competition, which posits that attending to both color and word dimensions result in the activation of competing semantic representations (Luo, 1999). In order to respond to a particular dimension, suppression of the irrelevant dimension is required. Importantly, both the conflict and the suppression occur prior to response selection. Alternatively, response competition posits that multiple response units compete for response output after semantic processing (Luo, 1999). In conclusion, the strength of the MTS Stroop task lies in the ability to systematically manipulate the relatedness of the foil response option. This approach not only allows for dissociating S-S and S-R effects, but also a means to investigate issues related to semantic and response competition, cognitive interference, and the mechanisms underlying cognitive and attentional processes.

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