Causal Relations Between Cognitive Control and Language: A Conflict Adaptation Study

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B.A. in Speech-Language-Hearing, January 2013, Temple University

A Thesis submitted to

The Faculty of
The Columbian College of Arts and Sciences
of The George Washington University
in partial fulfillment of the requirements
for the degree of Master of Arts

May 17, 2015

Thesis directed by

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Acknowledgments

I want to thank Dr. Malathi Thothathiri for her guidance, patience, and encouragement throughout the development of this thesis. Her mentorship from the beginning of this project through its completion has been invaluable – not only to the project itself, but to the strengthening of my research skills and intellectual development. I would also like to thank my thesis committee, Dr. Craig Linebaugh and Professor Michael Bamdad, both for their support and for taking the time to serve on my thesis committee. I am also grateful to Michelle Rattinger, Brooke Staveland, and the rest of the Neuroscience of Language Lab for their help with running participants, collating data, and providing feedback during my practice oral defense.

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Chapter 1: Introduction

Cognitive control is a network of components that are hypothesized to work together to support higher-level cognitive processes and allow for goal-directed behavior. Current models tend to describe interrelated but separable functions; for example, Miyake's diversity and unity model includes mental set shifting, information updating and monitoring, and inhibition of prepotent responses (Miyake et al., 2000. See also Banich, 2009; Miller & Cohen, 2001). Areas of the brain hypothesized to be important for cognitive control consist largely of prefrontal and frontal regions, which are involved in cognitive control as well as other functions, such as language. This raises the question of whether the underlying processes are shared across domains, or whether there are domain-specific sub-networks within these regions that are not shared. The domain-generality or –specificity of frontal cortex is a current topic of debate in the literature (see e.g., Fedorenko, Duncan, & Kanwisher, 2012). This thesis seeks to contribute to the discussion by examining whether there is behavioral evidence for shared neural substrates across disparate tasks requiring cognitive control.

We focus specifically on conflict resolution, which is the ability to choose an appropriate representation or response from a number of possible options. This process may include overriding prepotent but irrelevant options, choosing between equally permissible options, and/or correcting premature responses made before stimulus analysis was complete (Botvinick, Braver, Barch, Carter, & Cohen, 2001). This conflict can be present in tasks recruiting a variety of domains. For example, verbal color naming, perception of bistable figures, verb generation, and sentence interpretation have all been used to examine conflict (Kornmeier & Bach, 2005; Stroop, 1935; Thompson-Schill, D’Esposito, Aguirre, & Farah, 1997; Trueswell, Tanenhaus, & Kello, 1993), but involve mediating between activated representations in very different domains (i.e. visual-perceptual, semantic, syntactic, phonological). One of the most robustly researched indices of conflict resolution is the Stroop task (Stroop, 1935). This task requires participants to respond to the font color of a word, which may or may not be the same as the word itself. For example, a participant may have to indicate that the word “red” is written in blue font or that the word “blue” is written in blue font. Participants display an interference effect; that is, they are slower at responding when the font color and word are incongruent relative to when they are congruent. This difference is taken to reflect the need to override a prepotent bias to read the word instead of identifying the font color.

There are a variety of expressive and receptive language tasks that also involve overriding prepotent familiarity biases. For example, in language comprehension, plausibility refers to the influence of real-world knowledge on the interpretation of sentences. When sentences describe events that are less plausible, conflict occurs between semantics and syntax. Certain nouns are more frequently associated with a subject position or with an object position when paired with certain verbs. When nouns are placed in a relatively unusual subject/object pairing with a verb, conflict is induced. For example, “The cat chased the mouse,” is a sentence that is congruent between syntax and semantics. The verb “chase” occurs more commonly with the cat as the subject and the mouse as the object than the reverse according to real-world knowledge. In contrast, the sentence, “The mouse chased the cat,” creates a conflict between the syntax and semantics, as this pairing is less plausible. Plausibility violations have been shown to increase processing time or induce additional reanalysis (Garnsey, Pearlmutter, Meyers,

& Lotocky, 1997; Marslen-Wilson, Brown, & Tyler, 1988; Rayner, Carlson, & Frazier, 1983). Syntactic structure alone can also induce conflict. Passive voice is non-canonical in English, which primarily uses the active voice subject-verb-object construction. Comprehension of passive sentences is slower in neurotypical adults and causes activation in the left inferior frontal gyrus (LIFG), which is an area hypothesized to be important for conflict resolution (Mack, Meltzer-Asscher, Barbieri, & Thompson, 2013; but see Thothathiri, Schwartz, & Kimberg, 2012 for contradictory results). When sentences containing syntax-semantics conflict are formulated using a passive sentence structure (i.e. "The cat was chased by the mouse"), neurotypical adults resolve this conflict more slowly than active sentences with the same conflict (i.e. "The mouse chased the cat") (Gray, unpublished thesis, 2014).

In language production, selecting the appropriate word at the appropriate time is a necessary prerequisite for sentence production. Conflict arising from prepotent familiarity biases can also occur in this task. Thothathiri, Schwartz, & Thompson-Schill (2010) temporarily induced prepotent conflict in a multiword production task. They repeatedly primed the position of a noun in a conjoined noun phrase and then reversed that noun's position. For example, participants were presented with pictures of an apple and a sock, and were required to say "apple and sock." On the second trial, they were presented with a picture of an apple and a car, and were required to say "apple and car." On the third trial, "apple" stayed in the same first noun position (e.g., "apple and cloud") or moved to the second noun position (e.g., "cloud and apple"). The authors found marginally significant interference in neurotypical controls on trials where the position of the primed noun was changed, consistent with the hypothesized need for conflict resolution.

Additionally, they also found significant interference on trials that had an animate noun in the second position, which violates the dominant tendency of putting animates first in English.

While each of the tasks described above – Stroop, sentence interpretation, verbal word ordering – involve conflict, the relation between them (if any) as well as the underlying neural mechanisms are still being clarified. While each task involves some level of linguistic stimuli, the relevant representations, task structure, and task demands are vastly different. Whether conflict detection and resolution between representations elicited in different domains rely on separate or shared cognitive control mechanisms has researchers divided. Domain-specific theorists argue that conflict activated in different domains is subserved by separate cognitive control mechanisms for each domain (Ackay & Hazeltine, 2011; Egner, 2008). Proponents of a domain-general model argue that conflicting representations from these different domains recruit shared cognitive control mechanisms that detect and resolve conflict across a variety of domains (Miller & Cohen, 2001; Kan et al., 2013; Rajah, Ames, & D'Esposito, 2008). These domain-general theorists argue that contradictory findings in the research may not be due to specificity in the *domain* of conflict processing, but rather occur because of specificity in the *stage* of conflict processing (Kan, Teubner-Rhodes, Drummey, Nutile, Krupa, & Novick, 2013). Domain refers to the aforementioned type of conflicting representation – visual-perceptual, syntactic, semantic, phonological, etc. Stage refers to a distinction between representational conflict, or conflict at the level of the internal representation of the stimulus, and response conflict, or conflict at the level of the output response to a stimulus. For example, the Stroop task (and many other tasks) can elicit both of these stages of conflict processing. Consider an incongruent trial where the word “red” is written in blue font. Representational conflict occurs when both task-irrelevant but prepotent information (the word “red”) and task-relevant but less automatic information (the font color “blue”) are simultaneously activated. Response conflict occurs when both “red” and “blue” are output options, resulting in a competing motor response (Milham, et al., 2001). Domain-general theorists hypothesize different conflict resolution mechanisms for different stages (response vs. representational) of conflict processing, but argue for shared conflict resolution mechanisms in different domains occurring at the same stage of processing (i.e. a task eliciting visual representational conflict and a task eliciting semantic representational conflict). Current models of domain-general conflict processing account for this distinction. The Conflict Monitoring Theory was one of the first conflict processing theories and proposed a domain-general conflict detection mechanism that is responsible for monitoring the incoming sensory stream for conflict, which then triggers conflict resolution mechanisms (Botvinick, et al., 2001). Novick, Trueswell, & Thompson-Schill (2005) incorporated the aforementioned differences between stages of conflict processing and proposed a model where the anterior cingulate cortex (ACC) detects response-based conflict and then triggers resolution mechanisms in the left inferior frontal gyrus (LIFG). They theorize that the LIFG is responsible for both detection and resolution of domain-general representational conflict.

Current evidence for the domain-generality of conflict resolution mechanisms is largely correlational and comes from neuroimaging and lesion studies. Within the neuroimaging literature, a number of studies have noted LIFG activation in tasks eliciting conflicting representations in a variety of domains (Jonides, Smith, Marshuetz, Koeppe,

& Reuter-Lorenz, 1998; Nelson, Reuter-Lorenz, Sylvester, Jonides, & Smith, 2003; MacDonald, Cohen, Stenger, & Carter, 2000; Milham et al., 2001; Zhang, Feng, Fox, Gao, & Tan, 2004). More specifically, some studies have demonstrated co-localization, or fMRI activation in the same anatomical structures across tasks within subjects. For example, Rodd, Longe, Randall, & Tyler (2010) co-localized activity to the LIFG across semantic and syntactic ambiguities. While both tasks involved language production, they argued against a highly specific linguistic function of the LIFG as the linguistic representations differed across tasks. January, Trueswell, and Thompson-Schill (2009) co-localized neural responses between the Stroop task and a syntactically ambiguous sentence processing task. They found that both resulted in increased activation in the posterior LIFG. These tasks are vastly different in their structure, representational demands, and stimuli complexity. They argued that this showed evidence for a domain-general conflict resolution mechanism.

Within the lesion literature, several authors have argued that the linguistic deficits found in some patients with aphasia arise not from a linguistic deficit but from a more general cognitive control deficit. Specifically, patients with damage to the LIFG appear to present with specific difficulty in a wide variety of situations that involve prepotent biases or multiple activated representations. These impairments include tasks that are not overtly syntactic or semantic in nature, such as the Stroop task or proactive interference tasks that modulate familiarity of probes. Within language, these patients are *selectively* impaired on a variety of production and comprehension tasks involving mediating between multiple activated representations, such as naming semantically related pictures, verbal fluency tasks of semantically related items, naming pictures with multiple possible correct names, and resolving temporarily ambiguous sentences (Hamilton & Martin, 2005; Novick, Kan, Trueswell, & Thompson-Schill, 2009; Scott & Wilshire, 2010). Thothathiri et al. (2010) also found a subset of patients with LIFG damage – specifically to BA 44/6 – presented with exaggerated positional interference during the previously described multiword production task, increased production difficulty when the order of nouns did not match the predominant English pattern, and impaired comprehension of non-canonical reversible sentences. Taken together, these results suggest lesions to LIFG can impact performance on tasks involving representations in a variety of domains.

While the results described above suggest overlap between neuroanatomical substrates responsible for conflict resolution on a variety of tasks, the nature of this evidence is correlational and not causal. Activation studies can show that neural activity in a certain region is associated with a certain type of task, but not that it is necessary for performance of that task. Lesion studies also have interpretative limitations. Lesions to a specific area that result in disruptions of a cognitive control process do not necessarily indicate that area is responsible for that process. Instead, that area may have connections to or a supporting role with other cortical areas responsible for that process. Lesions in humans are also frequently large and irregular, so it is difficult to localize functions that may operate independently, but in anatomically adjacent areas. In other words, these results do not show that a single mechanism is responsible for the conflict resolution across these disparate tasks, but simply suggests that these deficits tend to occur together.

Causal evidence for domain-general cognitive control mechanisms can come from two avenues. One avenue is to provide training to participants in cognitive control using a specific task and show that they improve not only on the trained task but also on a structurally different task. Novick, Hussey, Teubner-Rhodes, Harbison, & Bunting (2014) trained neurotypical participants on an *n*-back with lures task. They presented participants with letters one at a time, and participants were required to determine whether a letter had appeared *n* presentations previously. Conflict was induced by including lure trials consisting of recent trials that occurred near the *n*-th trial. Participants who improved on this *n*-back task also improved on interpretation of garden-path sentences. As these garden-path sentences were untrained, this far transfer implies improvement in a shared cognitive resource required to perform both of these tasks.

Another more efficient avenue is to demonstrate conflict depletion or adaptation between disparate tasks. For example, Persson, Welsh, Jonides, and Reuter-Lorenz (2007) divided participants into two groups, and gave each one a version of the *n*-back task. One group was given an intensive session of a high-conflict version of the task with lures, and the other group was given a low-conflict version without lures. Performance on a verb-generation task that involved mediating between many possible permissible responses was impaired in the group that was given the high-conflict *n*-back with lures. This pattern of negative transfer implies that there is a shared, limited resource cognitive mechanism responsible for both of these tasks. Conflict adaptation is another type of causal behavioral interaction. Also referred to as the Gratton effect, conflict adaptation is the facilitation of performance on a task involving conflict when the previous task also involves conflict (Gratton, Coles, & Donchin, 1992). The original Gratton effect was discovered using Flanker stimuli, but the effect has since been shown on a number of other within-task paradigms (Clayson & Larson, 2011; Egner, Ely, & Grinband, 2010; Ullsperger, Bylsma, & Botvinick, 2005). However, evidence for a cross-task Gratton effect is still emerging. Facilitation of performance on a task in a different domain than the preceding task would indicate that a shared mechanism is responsible for the detection and subsequent resolution of conflict (Botvinick et al., 2001). Kan et al. (2013) explored this by performing two experiments examining Stroop adaptation from unambiguous versus temporarily ambiguous sentences and Stroop adaptation from unambiguous versus ambiguous Necker stimuli. They found that reaction times and accuracy on incongruent Stroop trials improved when they were preceded by 1) an ambiguous sentence compared to an unambiguous sentence and 2) Necker stimuli with a high number of perceived reversals compared to stable Necker stimuli and Necker stimuli with a low number of perceived reversals (implying less conflict experienced). Exploratory analyses examining the bidirectionality of the adaptation between Stroop and sentences were suggestive, albeit not significant.

The present study seeks to extend previous results by asking whether conflict adaptation occurs between Stroop (a non-syntactic task well-studied in the conflict resolution literature) and two different language tasks. Experiment 1 examines adaptation between Stroop and comprehension of sentences with both syntactic-semantic conflict and non-canonical sentence structure. Experiment 2 examines adaptation between Stroop and a multiword production task involving selection of nouns under conditions of positional interference. In both cases, we primarily examine adaptation from the language task to Stroop because Stroop measures are well-validated as being sensitive to conflict resolution demands and the language measures are less well characterized. However, we also tentatively examine adaptation in the opposite direction in order to see if the language measures show modulation depending on the previous Stroop trial type.

Chapter 2: Methods

2.1 *Experiment 1*

2.1.1 *Participants*

This study consisted of 16 healthy adults from the Washington, D.C. area (14 female; ages 22-33, mean=23.9). All participants were native English speakers. Participants signed a consent form under a protocol approved by The George Washington University.

2.1.2 *Stimuli*

Participants completed two tasks during the experiment. One task was a Stroop task and the other was a sentence comprehension task. Each task had a “congruent” condition without conflict and an “incongruent” condition that elicited conflict.

During the Stroop task, the congruent stimuli consisted of a written word and font color that were the same (i.e. the word “blue” was written in blue font). The incongruent stimuli consisted of a written word and font color that were different (i.e. the word “red” was written in blue font). Participants had a choice of three colors for the Stroop tasks (blue, green, yellow) and these were color-coded on the keyboard. In an effort to maximize representational instead of response conflict, incongruent trials contained words (red, orange, brown) that were not response options (Milham, et al., 2001).

During the sentence comprehension task, the congruent stimuli consisted of passive plausible sentences. The incongruent stimuli consisted of passive implausible sentences. There were also active voice filler trials. The sentence stimuli were pre-recorded by a female native English speaker. Practice items were also pre-recorded by another female native English speaker. Examples of sentence stimuli are as follows:

a. Passive plausible: The woman was bitten by the mosquito.

b. Passive implausible: The mosquito was bitten by the woman.

c. Active filler: The dog licked the treat.

For the sentence comprehension task, participants had a choice of four pictures as response options: a picture that matched the sentence, a role reversal picture with the agent and patient reversed, a distractor picture representing one correct element (agent, patient, or verb) with two incorrect elements, and an unrelated picture with a different agent, verb, and patient. Pictures were black and white line drawings. Example picture stimuli for the target sentence "The woman was bitten by the mosquito" are as follows:

a. Target picture: Mosquito biting woman

b. Role reversal: Woman biting mosquito

c. Distractor: FBI agent handcuffing woman

d. Unrelated: Cat tackling ball

<u>2.1.3 *Procedure*</u>

The experimental block consisted of 200 trials with 60 congruent Stroop trials, 60 incongruent Stroop trials, 20 passive plausible sentences, 20 passive implausible sentences, and 40 active filler sentences. The trials were pseudo-randomized in order to generate 10 in each of the following conditions:

<u>Stroop Trials:</u>

a. Congruent-Congruent Sentence-Stroop (CC-SeSt): a congruent Stroop trial preceded by a passive plausible sentence trial

b. Incongruent-Congruent Sentence-Stroop (IC-SeSt): a congruent Stroop trial preceded by a passive implausible trial

c. Incongruent-Incongruent Sentence-Stroop (II-SeSt): an incongruent Stroop trial preceded by a passive implausible trial
d. Congruent-Incongruent Sentence-Stroop (CI-SeSt): an incongruent Stroop trial preceded by a passive plausible trial

Sentence Trials:

a. Congruent-Congruent Stroop-Sentence (CC-StSe): a passive plausible sentence trial preceded by a congruent Stroop trial
b. Incongruent-Congruent Stroop-Sentence (IC-StSe): a passive plausible sentence trial preceded by an incongruent Stroop trial
c. Incongruent-Incongruent Stroop-Sentence (II-StSe): a passive implausible sentence trial preceded by an incongruent Stroop trial
d. Congruent-Incongruent Stroop-Sentence (CI-StSe): a passive implausible sentence trial preceded by a congruent Stroop trial

Each trial began with a 500 millisecond (ms) fixation in the center of the screen, followed by either a Stroop or sentence trial and then a 1000 ms blank screen. Stroop stimuli were presented for 1000 ms. Sentence trials were presented for a maximum of 5000 ms and advanced to the blank screen after a participant made a response. Both the audio and the pictures were presented concurrently at the beginning of the sentence trial. Mean sentence audio duration was 2462.91 ms, with a range from 2201.86 ms to 3154.65 ms.

Participants responded to Stroop trials by selecting from the adjacent color-coded 7-9 number keys with their right hand. Stroop stimuli were presented in the middle of the screen. Participants responded to sentence trials using the 1-4 number keys with their left hand. Pictures were arranged with picture 1 in the left upper quadrant, picture 2 in the right upper quadrant, picture 3 in the left lower quadrant, and picture 4 in the right lower quadrant. The pictures were numbered 1-4 to facilitate ease of response. Stimuli were counterbalanced so the target occurred in each quadrant an equal number of times.

Prior to the experimental block, all participants completed a Stroop practice block (10 trials), a sentence practice block (10 trials), a combined sentence-Stroop practice block (17 Stroop trials and 10 sentence trials, intermixed), and a Stroop baseline block. Sentences for all practice blocks were active sentences comparable to the filler sentences, and none of these sentences were used as targets or foils of the targets in the experiment. Participants were required to reach 80% accuracy on each of these practice blocks in order to continue. This allowed us to ensure that any differences were not influenced by difficulty understanding or executing the task.

All stimuli were presented and responses collected using E-Prime.

2.2 *Experiment 2*

2.2.1 *Participants*

This study consisted of 21 healthy adults from the Washington, D.C. area (14 female; ages 18-22, mean=19.7). All participants were native English speakers. All participants signed a consent form under a protocol approved by The George Washington University.

2.2.2 *Stimuli*

Participants completed two tasks during the experiment. One task was the previously described Stroop task. See section 2.1.2 for a description of the Stroop stimuli. The other task was a multiword production task. Again, each task had a "congruent" condition without conflict and an “incongruent” condition that elicited conflict. However, the language task used in Experiment 2 aimed to examine language production instead of language comprehension. It also examined conflict in overriding prepotent biases rather than conflict between two cues.

During the multiword production task, participants were presented with two color images of nouns. Images were displayed at the same screen height with one image on the left and one on the right. Participants were instructed to name the images with the conjunction “and.” For example, when shown a picture of an apple and a cloud, the participant would say “apple and cloud.”[1] Stimuli were arranged in groups of three trials. In these triads, one noun would remain the same across all three trials. In the first two trials, the constant noun would always be in the same position – either both first or both second. In the third trial, the constant noun would remain in the same position as the previous two trials for the congruent condition but would switch positions for the incongruent condition. Thothathiri et al. (2010) used this paradigm as a way to induce a prepotent familiarity bias by repeatedly priming the position of a noun. Examples of the stimuli are as follows:

a. Congruent multiword:

1. grapes and cloud
   grapes and pen
   grapes and zebra
2. snake and carrot
   chair and carrot

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[1] Three participants produced “noun noun” responses omitting “and”. However, they did so consistently and were therefore included in the analyses.

bottle and carrot

b. Incongruent multiword:

1. belt and heart
   belt and pen
   eye and belt
2. star and nose
   apple and nose
   nose and saw

Nouns were organized into 8 semantic categories (i.e. food, clothing) with five items per category. Within an experimental triad, no two nouns shared a semantic category. Within an individual trial, there was no phonological overlap. This was done to reduce possible interference or facilitation effects in naming.

The pictures for the multiword tasks were color line drawings adapted from Snodgrass & Vanderwart's drawings (Roisson & Pourtois, 2004).

2.2.3 *Procedure*

The experiment consisted of two blocks with a break in the middle. Across both blocks, there were 400 trials. There were 120 Stroop trials, which consisted of 40 filler trials, 40 priming trials used to examine adaptation from Stroop to multiword production, and 40 experimental trials used to examine adaptation from multiword production to Stroop. These were split evenly in each condition between congruent and incongruent.

There were 280 multiword naming trials, which consisted of 40 individual filler trials and 80 experimental triads of three trials. The experimental triads consisted of 40 priming triads used to examine adaptation from multiword production to Stroop and 40 experimental triads used to examine adaptation from Stroop to multiword production. The experimental trials were split evenly in each condition between congruent and incongruent. Filler trials had no congruency. Fillers used the same nouns as the experimental trials. Each noun occurred in two filler trials. No noun pairs were repeated within the experiment.

In order to examine adaptation from multiword production to Stroop, a Stroop trial was placed immediately after a multiword triad. However, to examine adaptation from Stroop to multiword production, the Stroop trial was placed after the first two trials of an experimental triad, but before the third trial where the noun was either reversed or remained constant. See Table 1 for an example.

Table 1: Examples of Stimuli for Multiword to Stroop and Stroop to Multiword trials

Multiword to Stroop *(Example of CC-MwSt)*	**Stroop to Multiword** *(Example of II-StMw)*
Trial 1: apple, shoe Trial 2: apple, cat Trial 3: apple, chair Trial 4: ("blue" written in blue font)	Trial 1: shoe, apple Trial 2: cat, apple Trial 3: ("orange" written in blue font) Trial 4: apple, chair

The trials were pseudorandomized in order to generate 10 in each of the following conditions:

Stroop Trials:

e. Congruent-Congruent Multiword-Stroop (CC-MwSt): a congruent Stroop trial preceded by a consistent multiword trial

f. Incongruent-Congruent Sentence-Stroop (IC- MwSt): a congruent Stroop trial preceded by a reversed multiword trial
g. Incongruent-Incongruent Multiword -Stroop (II- MwSt): an incongruent Stroop trial preceded by a reversed multiword trial
h. Congruent-Incongruent Multiword -Stroop (CI- MwSt): an incongruent Stroop trial preceded by a consistent multiword trial

<u>Sentence Trials:</u>

e. Congruent-Congruent Stroop- Multiword (CC- StMw): a consistent multiword trial preceded by a congruent Stroop trial
f. Incongruent-Congruent Stroop- Multiword (IC- StMw): a consistent multiword trial preceded by an incongruent Stroop trial
g. Incongruent-Incongruent Stroop- Multiword (II- StMw): a reversed multiword trial preceded by an incongruent Stroop trial
h. Congruent-Incongruent Stroop- Multiword (CI- StMw): a reversed multiword trial preceded by a congruent Stroop trial

Four experimental lists were used and pseudorandomly assigned to participants. These lists were balanced so that each triad of noun pairs occurred in each condition. This was done to control for any potential effects of phonological properties on onset time. For an example, see Table 2.

Table 2: Examples of balanced multiword production lists

	Congruent Trials	**Incongruent Trials**
3rd trial with constant noun as noun 1	apple, shoe apple, cat apple, chair	shoe, apple cat, apple apple, chair
3rd trial with constant noun as noun 2	shoe, apple cat, apple chair, apple	apple, shoe apple, cat chair, apple

Following the results of experiment 1, discussed below, we wanted to see whether a reduction in interstimulus interval had an impact on adaptation, particularly from the Stroop task to the language task. As a result, we eliminated the fixation and 1000 ms blank slide. However, during trial runs of the task with research assistants, we found that entirely eliminating the inter-stimulus interval made the task subjectively difficult to perform. As a result, we included a 500 ms blank slide before each individual multiword naming trial. Multiword naming slides with two images appeared for 3000 ms, during which participants' responses were audio recorded. Stroop trials were not preceded by a blank. Participants were allowed a maximum of 1000 ms to respond to Stroop trials, and the slide would advance to the next trial following a response. After the first 200 experimental blocks, participants were allowed to take a short break before finishing the experiment.

Participants responded to Stroop trials in the same manner as described in Section 2.1.3. Participants verbally responded to multiword trials by saying the name of the pictures with the conjunction "and." Responses were recorded via USB microphone.

Prior to the experimental block, all participants completed a Stroop practice block, a single word naming practice block, and a multiword naming practice block. The Stroop baseline block was eliminated during this experiment for time constraints as this experimental design necessitated many more trials. The Stroop practice block required 90% accuracy to continue. The single word naming practice block was included to ensure that participants were familiar with the pictures. Participants named the 40 nouns that were included in the subsequent experimental trials. The experimenter provided feedback if participants were unable to name a picture or named it incorrectly. Participants then practiced multiword naming; however, this did not have an accuracy criterion as accuracy was analyzed post-hoc during audio transcription. However, the experimenter monitored performance and would provide feedback if the participant had difficulty naming objects or did not use the conjunction “and.”

All stimuli were presented and responses collected using E-Prime.

Chapter 3: Results

3.1 *Experiment 1*

3.1.1 *Accuracy*

We computed the mean accuracy for Stroop and sentence comprehension target trials in each possible condition. Average percent accuracy for Stroop experimental trials was as follows: CC= 96.25%, IC= 92.5%, CI= 95%, and II= 95.625% (Figure 1) Repeated measures ANOVA revealed no significant effects of previous trial type [F(1,15)=2.05, p>.1], current trial type [F(1,15)=.41, p>.5], or an interaction [F(1,15)=2.56, p>.1].

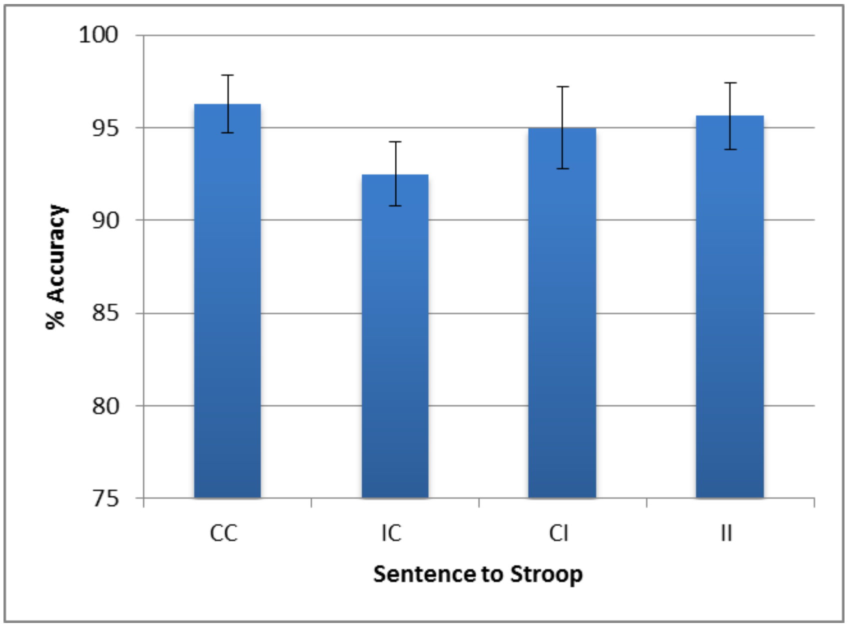

Figure 1: Participants' mean accuracy on sentence to Stroop trials. Error bars denote standard error here and on following figures.

Average percent accuracy for sentence comprehension trials was as follows: CC= 90%, IC= 85%, CI= 93.75%, and II= 81.25% (Figure 2). For the sentence trials, previous trial type was significant [F(1,15)=23.71, p<.001] with lower accuracy for sentence trials following incongruent Stroop trials. There were no significant effects for current trial type [F(1,15)=0, p=1]. There was also no interaction between previous and current trial type [F(1,15)=2.14, p>.1].

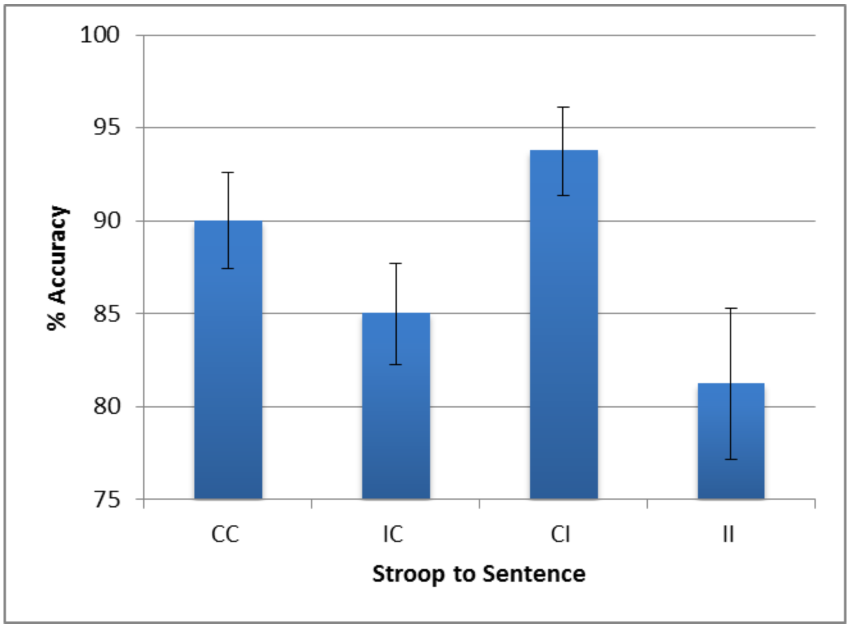

Figure 2: Participants' mean accuracy on Stroop to sentence trials

3.1.2 *Reaction Times*

Participants' reaction times were recorded using E-Prime. Inaccurate responses and reaction times more than 2 SD from the individual participants' means were excluded from data analysis.

Average reaction times for Stroop experimental trials were as follows: CC= 707.56, IC= 725.34, CI= 739.18, and II= 726.12 (Figure 3). We performed a 2x2 (previous trial type x current trial type) repeated measures ANOVA on reaction times. There was no effect of previous trial type [F(1,15)=.14, p>.7]. There was a significant effect of current trial type [F(1,15)=5.69, p<.04] resulting from longer reaction times on incongruent Stroop trials. There was a significant interaction between previous and current trial types [F(1,15)=5.28, p<.04]. This interaction resulted from shorter reaction times on CC trials than IC trials [F(1,15)=6.25, p<.026]. There was no significant difference between CI and II trials [F(1,15)=1.448, p>.247].

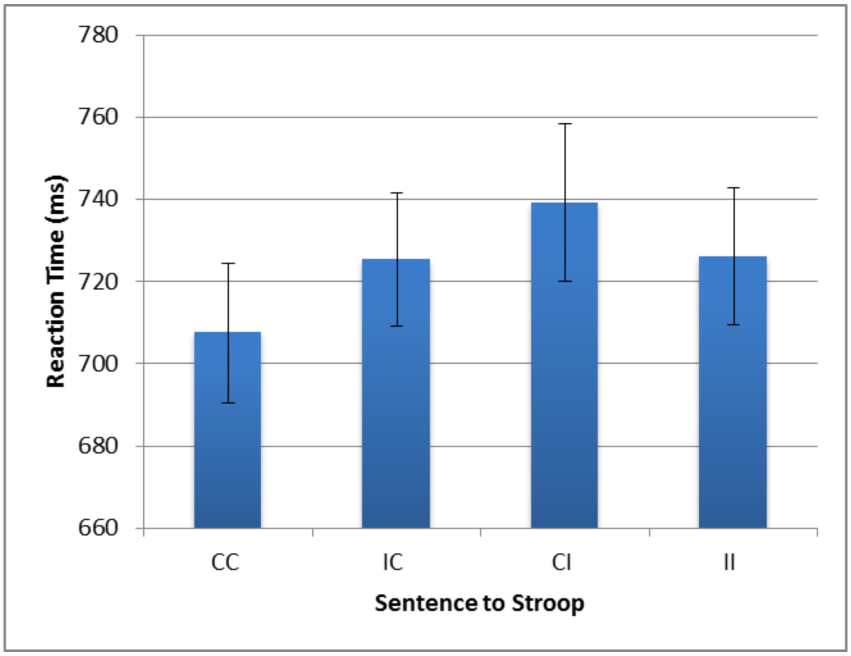

Figure 3: Participants' mean reaction times on sentence to Stroop trials

Average reaction times for sentence trials were as follows: CC= 3005.14, IC= 3064.63, CI= 3091.35, II= 3279.28 (Figure 4). There was a significant effect of previous trial type [F(1,15)=9.22, p<.01] resulting from longer reaction times from a preceding incongruent Stroop trial. There was also a significant effect of current trial type [F(1,15)=15.12, p<.01] resulting from longer reaction times on a current incongruent trial. There was no significant interaction effect between previous and current trial [F(1,15)=1.32, p>.2].

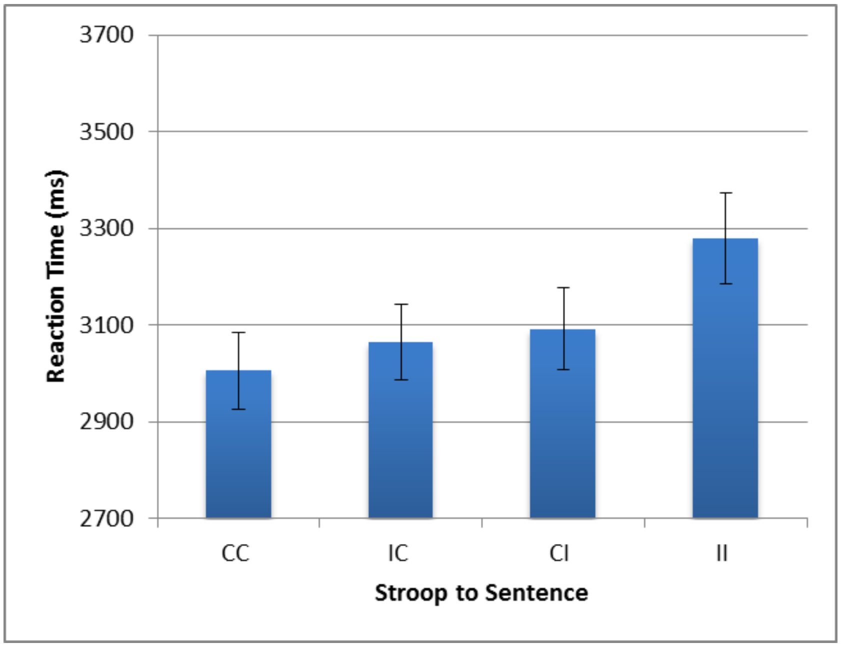

Figure 4: Participants' mean reaction times on Stroop to sentence trials

3.1.3 *Exploratory Analysis*

We also computed statistics for the first and second halves of the data separately as an exploratory analysis to examine whether stronger effects were seen in the first half of the experiment. Given findings of resource depletion in cognitive control processes (Persson et al., 2007), we wanted to see whether performance would change over the course of the experiment.

On the Stroop trials in the first half of the experiment, average reaction times were as follows: CC= 696.16, IC=728.19, CI=755.75, and II=718.33 (Figure 5). We again used repeated measures ANOVA. Previous trial type was not significant [F(1,15)=.08, p>.7]. There was no significant effect of current trial type [F(1,15)=2.52, p>.1]. However, there was a significant interaction effect [F(1,15)=9.63, p<.01].Upon further analysis, this interaction resulted from faster reaction times on CC trials compared to IC trials [F(1,15)=5.08, p<.05] and faster reaction times on II trials compared to CI trials [F(1,15)=5.99, p<.03], reflecting a conflict adaptation effect.

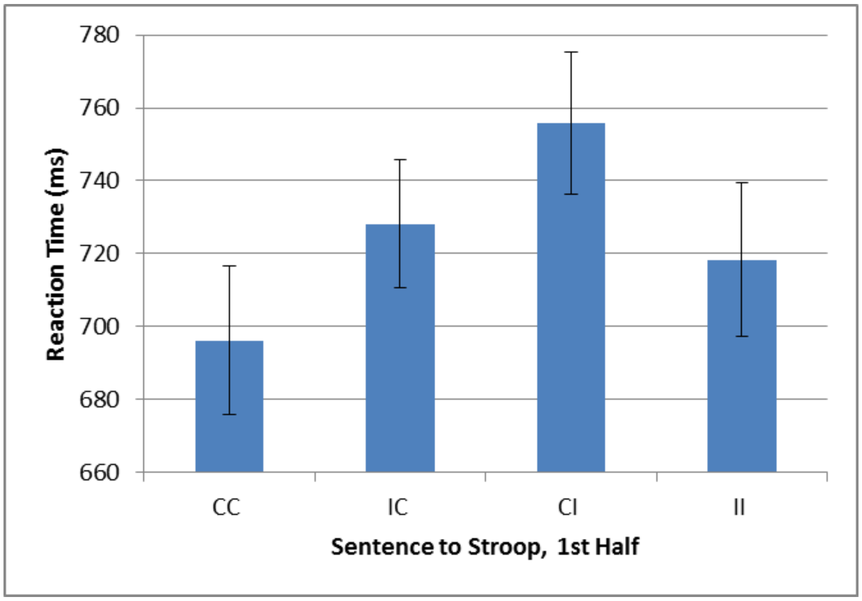

Figure 5: Participants' mean reaction times on the first half of sentence to Stroop trials

During the second half of the experiment, the average reaction times were as follows: CC=713.70, IC=717.74, CI=715.55, and II=734.46 (Figure 6). There was no significant effect of previous trial type [F(1,15)=1.23, p>.2]. Current trial type was also not significant [F(1,15)=0.46, p>.5]. There was no interaction effect [F(1,15)=0.45, p>.5].

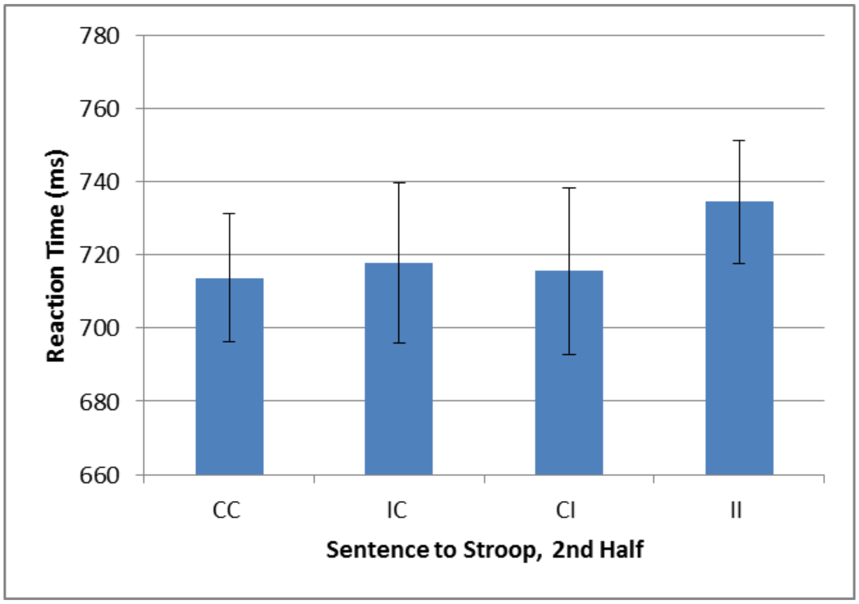

Figure 6: Participants' mean reaction times on the second half of sentence to Stroop trials

On sentence trials from the first half of the data, average reaction times are as follows: CC= 3154.83, IC= 3138.49, CI= 3095.37, and II= 3069.32 (Figure 7). In the first half of the experiment, there was no significant effect of previous trial type [F(1,15)=0.17, p>.6]. Current trial type was also not significant [F(1,15)=1.97, p>.1]. There was no interaction effect [F(1,15)=.003, p>.9].

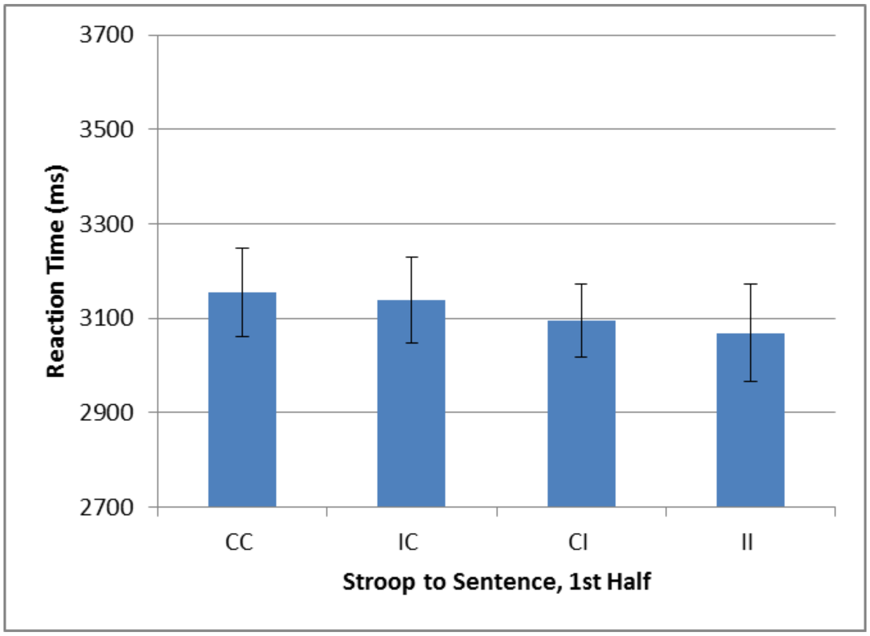

Figure 7: Participants' mean reaction times on the first half of Stroop to sentence trials

During the second half of the experiment, average reaction times were as follows: CC= 2899.788, IC= 2948.078, CI= 3071.667, and II= 3556.385 (Figure 8). Previous trial type was significant [F(1,15)=23.44, p<.001] with longer reaction times following incongruent trials. Current trial type was also significant [F(1,15)=32.57, p<.001] with longer reaction times on incongruent trials. There was also a strong interaction effect [F(1,15)=23.68, p<.001]. Upon further analysis, this interaction results from no effect for CC vs IC reaction times [F(1,15)=.693, p>.4] and strong effects for II > CI reaction times [F(1,15)=34.98, p<.001].

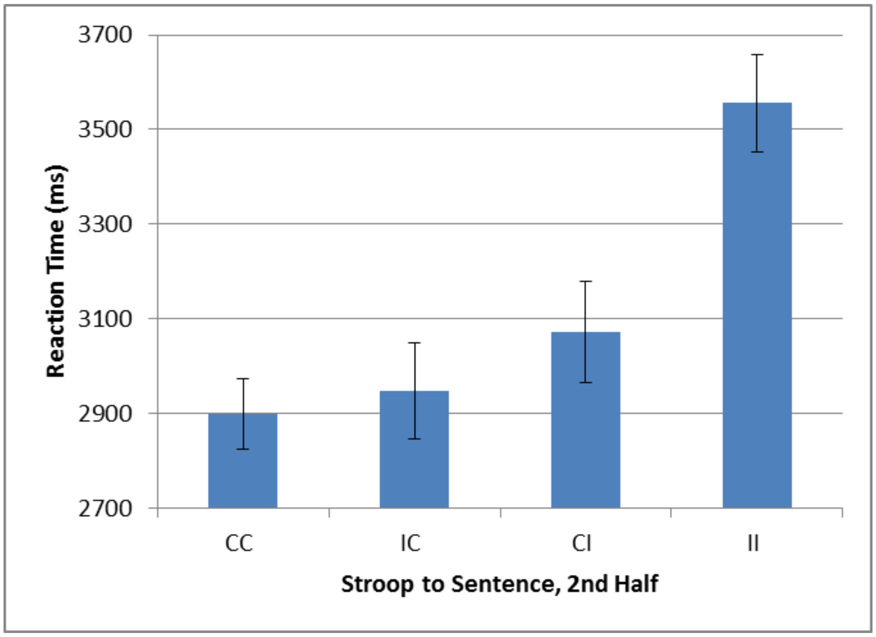

Figure 8: Participants' mean reaction times on the second half of Stroop to sentence trials

3.1.4 *Interstimulus Intervals*

We also calculated interstimulus intervals for each task. Egner et al. (2010) showed that conflict adaptation deteriorates over a relatively short time interval, specifically after interstimulus intervals (ISIs) longer than 4,000 ms. For our ISI calculations, we attempted to measure the duration from the onset of the location of conflict on the previous trial to the location of conflict on the current trial. For our sentence stimuli, we reasoned that conflict first occurs at the verb offset (time from the beginning of the sentence to the time when the verb ends). For example, in the sentence "The mosquito was bitten by the woman," we hypothesized that conflict would occur approximately at the end of the word "bitten," as this is the first indication that there is a plausibility conflict (mosquito is getting bitten rather than biting). We measured verb offset for each sentence using Praat speech analysis software. For Stroop stimuli, we reasoned that conflict occurs as soon as the stimulus is shown.

For sentence to Stroop trials, ISI was the duration from conflict on the sentence trial to conflict on the Stroop trial. Thus, ISI = time from verb offset to end of sentence trial + blank screen duration + fixation duration. The mean ISI for sentence to Stroop trials was 3044.8 ms. For Stroop to sentence trials, ISI was the duration from conflict on the Stroop trial to conflict on the sentence trial. Thus, ISI = Stroop trial duration + blank screen duration + fixation duration + verb offset. The mean ISI for Stroop to sentence trials was 4064.95.

3.2 *Experiment 2*

3.2.1 *Accuracy*

We computed the mean accuracy for Stroop and multiword production target trials in each condition. Multiword trials were considered inaccurate if any nouns were missing, if the order of the nouns was incorrect, if there were extraneous phonemes or syllables before the onset of a noun, or there were extraneous words. Fillers such as "um" or different morphological forms of the words (i.e. "grape" instead of "grapes") were not considered errors. Average percent accuracy for Stroop experimental trials was as follows: CC=87%, IC=83.5%, CI=79.5%, II=82.5% (Figure 9). Repeated measures ANOVA revealed no significant effect of previous trial type. Current trial type was marginally significant [F(1,19)=4.13, p=.06] for the classic Stroop interference effect. There was no significant interaction effect [F(1,19)=2.34, p>.1].

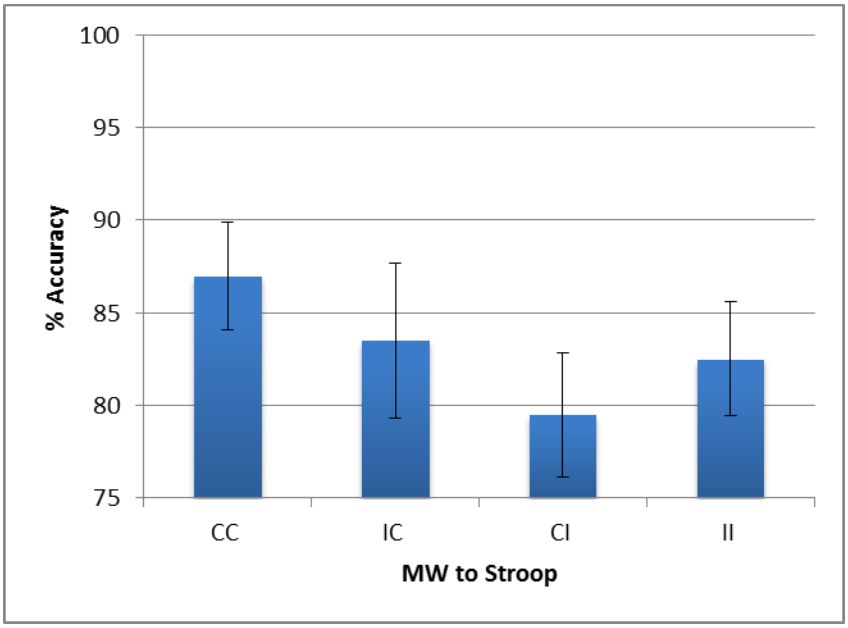

Figure 9: Participants' mean accuracy on multiword production to Stroop trials

Average percent accuracy for multiword production trials was as follows: CC= 95%, IC= 96%, CI= 96%, II= 94% (Figure 10). For multiword trials, there was no significant effect of previous trial [F(1,19)=.08, p>.7], current trial [F(1,19)=.14, p>.7], or interaction [F(1,19)=1.69, p>.2].

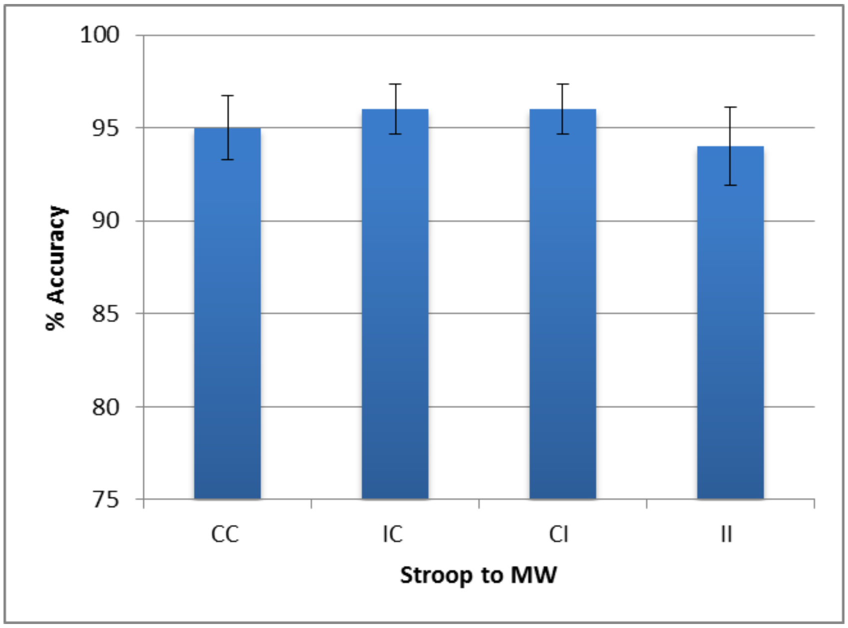

Figure 10: Participants' mean accuracy on multiword production to Stroop trials

3.2.2 *Reaction Times*

Participants' Stroop reaction times were recorded using E-Prime. Verbal responses to the multiword naming task were recorded via microphone. Voice onset time was considered the reaction time for these trials. Inaccurate responses and reaction times more than 2 SD from the individual participants' means were excluded from data analysis.

Average reaction times for Stroop trials were as follows: CC= 745.47, IC= 760.71, CI= 778.53, and II= 782.84 (Figure 11). A 2x2 repeated measures ANOVA was performed. There was no significant effect of previous trial type [F(1,19)=1.25, p>.2]. Current trial type was significant [F(1,19)=9.71, p<.01], demonstrating the classic Stroop interference effect. There was no significant interaction effect [F(1,19)=.55, p>.4].

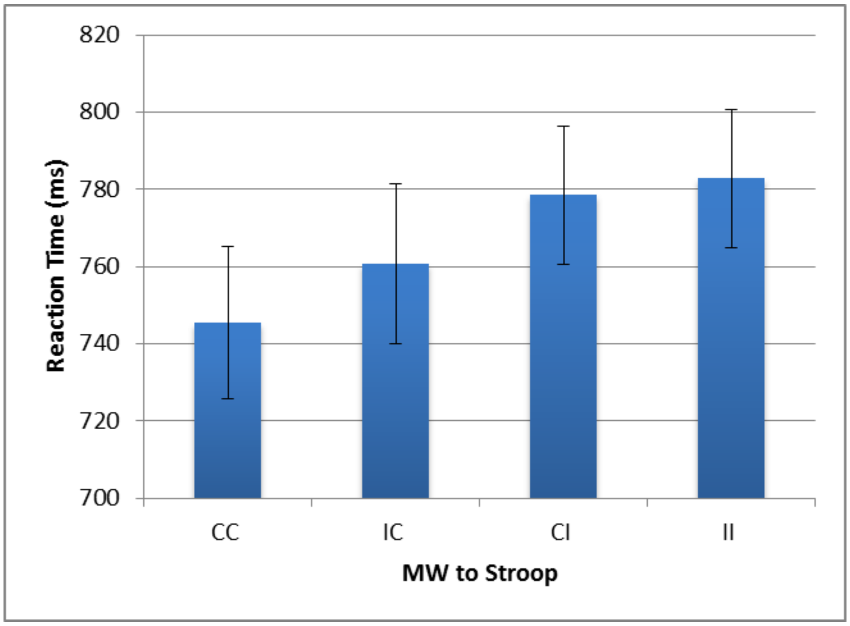

Figure 11: Participants' mean reaction times on multiword production to Stroop trials

Average reaction times for multiword trials were as follows: CC= 813.67, IC= 833.04, CI= 857.88, and II= 875.44 (Figure 12). There was no significant effect of previous trial type [F(1,19)=2.8, p>.1] on multiword reaction times. Current trial type was significant [F(1,19)=12.99, p<.01] demonstrating positional interference on reversed trials. There was no significant interaction effect [F(1,19)=.006, p>.9].

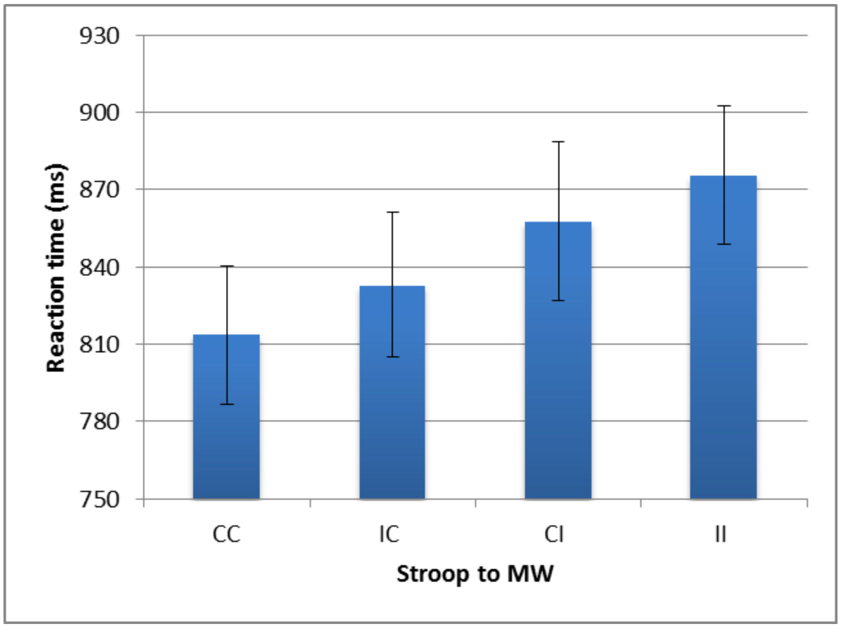

Figure 12: Participants' mean reaction times on Stroop to multiword production trials

3.2.3 *Exploratory Analysis*

We again examined the first half of the data separately from the second half of the data to see if the effects changed over the course of the experiment. On the first half of Stroop trials, average reaction times were as follows: CC= 743.98, IC= 770.99, CI= 771.52, and II= 782.45 (Figure 13). The first half of Stroop trials revealed no significant effect of previous trial type [F(1,19)=2.12, p>.1]. The Stroop incongruence effect was marginally significant [F(1,19)=3.47, p=.08]. There was no interaction effect [F(1,19)=.40, p>.5].

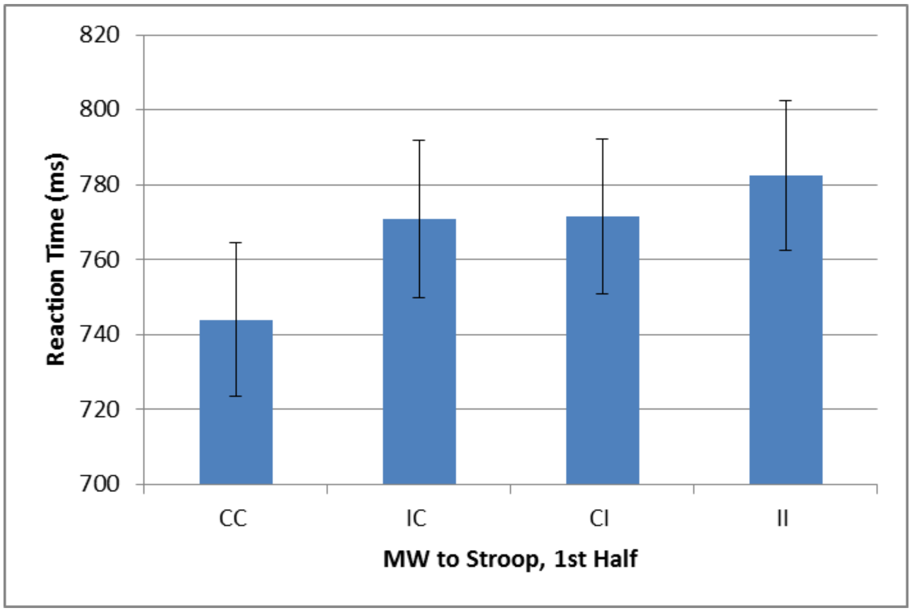

Figure 13: Participants' mean reaction times on first half of multiword production to Stroop trials

For Stroop trials in the second half of the experiment, average reaction times were as follows: CC= 746.68, IC= 750.97, CI= 783.15, and II= 782.27 (Figure 14). There was no significant effect of previous trial type [F(1,19)=0.04, p>.8]. The current trial type was significant for the Stroop incongruence effect [F(1,19)=7.09, p<.05]. There was no significant interaction [F(1,19)=.12, p>.7].

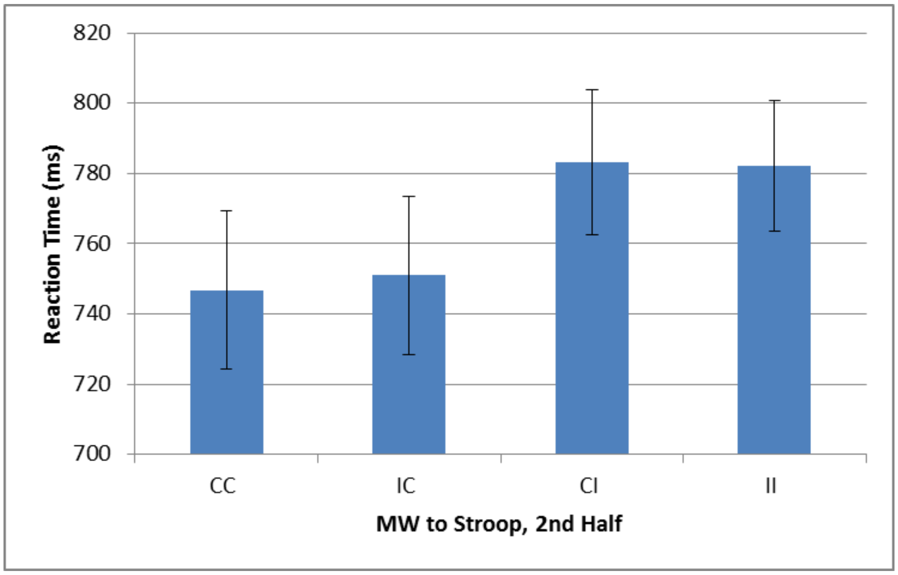

Figure 14: Participants' mean reaction times on second half of multiword production to Stroop trials

For the multiword production trials in the first half of the experiment, average reaction times were as follows: CC= 788.15, IC= 855.54, CI= 854.02, and II= 889.96 (Figure 15). During the first half of the experiment, the previous trial type was significant [F(1,19)=6.55, p<.02] for general depletion from a previous I trial. The current trial type was significant for the multiword incongruence effect [F(1,19)=10.2, p<.006]. There was no significant interaction effect [F(1,19)=.8, p>.3].

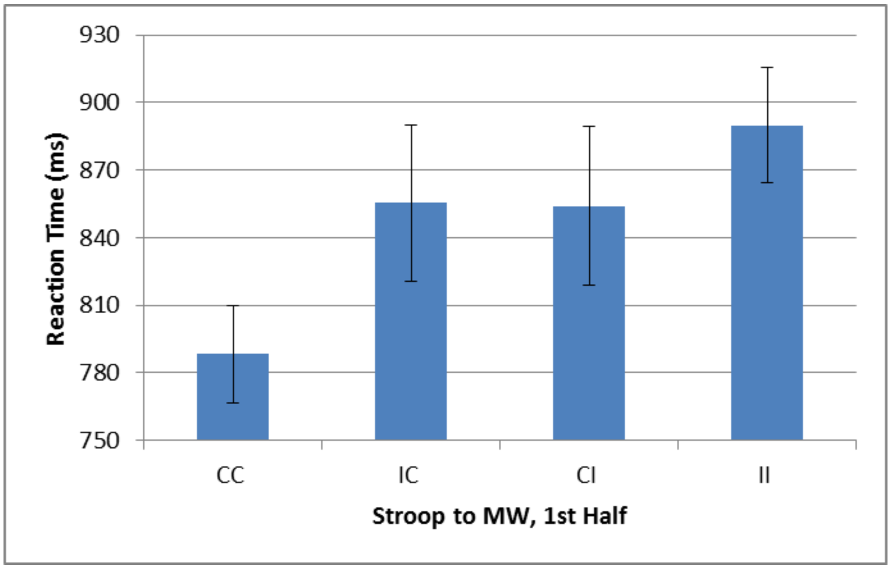

Figure 15: Participants' mean reaction times on the first half of the multiword production to Stroop trials

During the second half of the experiment, average reaction times for multiword trials were as follows: CC= 845.50, IC= 809.26, CI= 862.10, and II=860.90 (Figure 16). Previous trial type was not significant [F(1,19)=1.83, p>.1]. The current trial type was marginally significant for the multiword incongruence effect [F(1,19)=3.47, p>.08]. There was no significant interaction effect [F(1,19)=.99, p>.3].

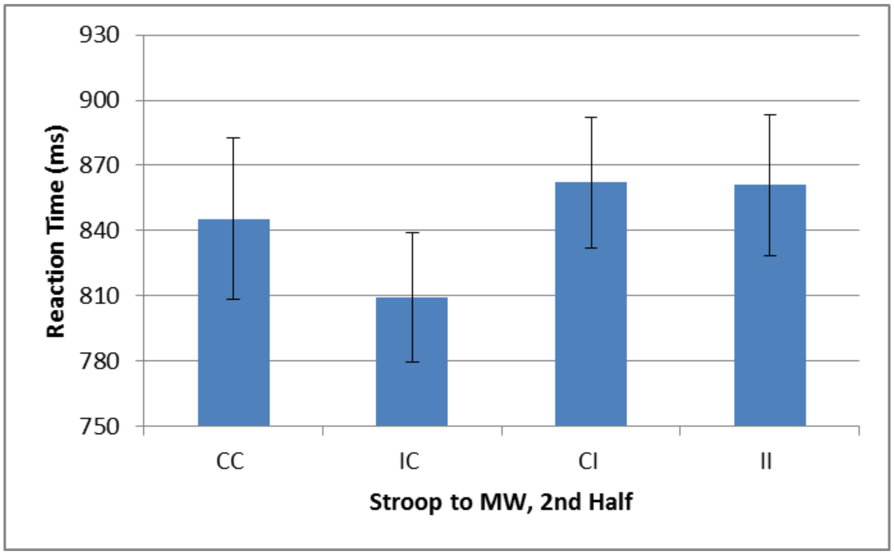

Figure 16: Participants' mean reaction times on the second half of the multiword production to Stroop trials

3.1.4 *Interstimulus Intervals*

We again calculated ISIs for each task. For both the Stroop and the multiword trials, we considered conflict to occur at the beginning of each trial. For multiword to Stroop trials, there were no intervening blank or fixation screens in this experiment. As a result, the ISI was simply the duration of the multiword stimuli, which was 3000 ms. For Stroop to multiword trials, the ISI included Stroop trial duration and blank screen duration. The mean ISI was 1266.25 ms.

Chapter 4: Discussion

4.1 *Experiment 1*

Experiment 1 aimed to 1) examine whether conflict adaptation occurs from a sentence task with both syntactic-semantic conflict and non-canonical sentence structure to a non-syntactic (Stroop) task and 2) tentatively explore effects in the opposite direction.

4.1.1 Sentence Comprehension to Stroop

4.1.1a: All Trials

In the first analysis, we examined all trials across the entire experiment. This revealed no significant effects for accuracy. For reaction times, participants demonstrated longer reaction times on current incongruent Stroop trials, reflecting the Stroop incongruence effect. There was also a significant interaction between previous and current trial type, as IC trials were slower than CC trials; however, there was no such difference between II and CI trials. Although this is not the classic conflict adaptation pattern wherein II trials are expected to be faster than CI trials, the interaction indicates that the effect of the previous trial on the current trial was not general, affecting all trials across the board, but more specific. Namely, incongruent sentence trials triggered some process that adversely affected congruent Stroop trials but not incongruent Stroop trials. We speculate that an incongruent trial may activate networks designed to resolve conflict, and when this conflict does *not* occur on a subsequent trial, the activation of these networks could impair performance.

4.1.1b: Halves

Previous studies have shown that conflict resolution abilities can be depleted after sessions of intensive conflict resolution tasks (Persson et al., 2007). Therefore, we decided to analyze data from the first half of the experiment separately from the second half. In the first half of the experiment, there were no effects of previous and current trial type. However, there was a significant interaction showing longer reaction times on IC trials than CC trials, but shorter reaction times for II than CI trials. This second finding – that II trials were *faster* than CI trials – reflects the classic conflict adaptation pattern. This is consistent with the idea that conflict detected during a previous incongruent sentence trial triggered conflict resolution processes, which then facilitated performance on an incongruent Stroop trial. This demonstrates a causal relationship between cognitive control employed during a sentence comprehension task and that employed during the Stroop task.

In the second half of the experiment, there were no significant main effects or interaction. We speculated that the disappearance of conflict adaptation may reflect participants experiencing less conflict on incongruent sentence trials over the course of the experiment. It is possible that participants were able to adapt to these sentences, perhaps by adopting a strategy for interpretation, resulting in less conflict experienced. If conflict detection mechanisms are not sufficiently triggered, conflict adaptation would not occur. In our data, there was no way to independently measure the amount of sentence conflict experienced over time as all passive sentences served as both targets and primes. However, we analyzed data from a previous study that used the exact same picture and sentence stimuli but did not examine conflict adaptation (Gray, unpublished thesis, 2014). We ran a 2 x 2 (half x type) repeated measures ANOVA on the incongruent and congruent passive sentences in the first and second halves of the study. There was a significant interaction [F(1,15)=6.742, p<.021] resulting from longer reaction times on incongruent passive sentences relative to congruent ones in the first half [F(1,15)=16.911, p<.002] but not the second half of the experiment [F(1,15)=.031, p>.861]. These results suggest that conflict during incongruent passive sentences dissipated in the second half of the experiment. They are consistent with our speculation that conflict adaptation did not occur in the second half of the adaptation experiment because conflict sentence trials did not effectively trigger conflict detection and resolution mechanisms and therefore did not influence subsequent Stroop trials.

4.1.1c: Summary

These data provide evidence for causal behavioral adaptations across disparate tasks and domains. They are consistent with domain-general theories of cognitive control. However, the results also highlight the need to verify that the tasks employed consistently trigger conflict detection and resolution. They raise the possibility that some previous results against domain-generality could instead be explained by experimental artifacts.

4.1.2 Stroop to Sentence Comprehension

4.1.2a All Trials

Analysis of adaptation from Stroop to sentence comprehension was exploratory because behavioral measures from sentence-picture matching likely include many component processes such as processing and selecting a picture and it is unclear whether these measures are sensitive enough for detecting conflict adaptation. For accuracy, the only significant finding was that participants performed less accurately on sentence trials that were preceded by an incongruent Stroop trial. Because there was no interaction between previous and current trial type, this can be interpreted as showing potential fatigue after performing a difficult task (incongruent Stroop) and not as evidence for any specific shared processes between the Stroop and sentence comprehension tasks. For reaction times, participants responded slower to trials following an incongruent Stroop (effect of previous trial type). They also responded slower on incongruent sentence trials (effect of current trial type). As with accuracy, there was no interaction and therefore no evidence for a specific influence of Stroop trials on sentence trials.

4.1.2b Halves

As before, we analyzed reaction times from the two halves of the experiment separately. In the first half of the experiment, there were no significant effects. In the second half of the experiment, participants were slower on trials following an incongruent Stroop (effect of previous trial type) and slower on incongruent sentence trials (effect of current trial type). There was also a significant interaction resulting from no difference between IC and CC trials but *slower* reaction times on II trials than CI trials. This is an interesting and unexpected finding. The interaction demonstrates a causal influence of Stroop trials on subsequent sentence trials. However, the direction of the effect suggests depletion rather than adaptation. Having completed an incongruent Stroop trial made participants slower on subsequent incongruent sentence trials. Below, we speculate on possible explanations for this pattern.

4.1.2b Summary

In the first half analysis, we found no effects of the previous Stroop trial on the current sentence comprehension trial. This is different from the results for the reverse direction (sentence to Stroop). One possible explanation for the difference between the two directions could be the different ISIs. For sentence to Stroop, the mean ISI was 3044.8 ms. For Stroop to sentence, the mean ISI was 4064.95. Thus, there was a longer gap between Stroop to sentence than sentence to Stroop. Previous research suggests that these temporal factors are critical for detecting conflict adaptation. Egner, Ely, & Grinband (2010) found that adaptation deteriorates rapidly after conflict detection and may not be present after ISIs of longer than 4000 ms. Since our average ISIs for Stroop to sentence comprehension trials were greater than this, any possible facilitative effects may have dissipated before the onset of the current trial.

In the second half analysis, we found a significant interaction resulting from longer reaction times on II than CI trials. This is suggestive of conflict depletion rather than adaptation. We did not expect this result and can only speculate with respect to a possible explanation. We suggest that this result may reflect a refractory period of conflict detection and/or resolution that becomes longer as subserving neural mechanisms become fatigued. Over time, an incongruent Stroop trial may trigger conflict detection and resolution, which stay active for a while but then undergo a refractory period when they cannot be reactivated. If this is true, then following an incongruent Stroop trial, there may be a waiting period until conflict resolution can be retriggered on an incongruent sentence trial, leading to slower reaction times on II trials relative to CI trials. Critically for our purposes, any interaction between previous and current tasks, whether depletion or adaptation, is logically consistent with shared resources between the two tasks and is therefore supportive of the domain-general view.

4.2 *Experiment 2*

Experiment 2 aimed to 1) examine whether conflict adaptation occurs from a verbal production task involving selection of nouns under conditions of positional interference to a non-syntactic (Stroop) task and 2) tentatively explore effects in the opposite direction.

4.2.1 Multiword Production to Stroop

4.2.1a All Trials

In the first analysis, we examined all trials. This revealed marginally increased reaction times on current incongruent Stroop trials, reflecting the Stroop incongruence effect. There were no other significant results. These results provide no evidence for shared conflict processing resources between these two tasks.

4.2.1b Halves

We again analyzed the data from the first half of the experiment separately from the data from the second half of the experiment. In the first half, the only significant finding was marginally significant increased reaction times on current incongruent Stroop trials, reflecting the Stroop incongruence effect. In the second half, there was a significant effect of increased reaction times on current incongruent Stroop trials, again reflecting the Stroop incongruence effect. Again, these results do not support shared conflict processing resources between these two tasks.

4.2.1c Summary

These results do not provide any support for domain-general conflict detection and resolution mechanisms. No interaction was present between the previous and current trial type. As a result, there was no evident causal behavioral influence of one trial type on the other. We consider two possible explanations for this null effect. First, as previously discussed in Chapter 1, there is a difference between level of processing and domain of processing. Even in a domain-general model, levels of processing of conflict – response versus representational – are not expected to share a conflict detection mechanism. As a result, two tasks that differentially activate one level of conflict processing over the other would not show adaptation. Our Stroop task was modeled after Milham et al. (2001) in order to differentially activate representational conflict. However, the extent to which incongruent multiword production trials recruit response versus representational conflict is unknown. Conflict processing that requires response via verbal production invariably recruits at least some level of response conflict. As a comparison, in the Stroop task, responses could be constrained so that the task irrelevant but prepotent activation (the written word) was response ineligible (no button on the keyboard). However, verbal productions cannot be constrained in this manner. Thus, it is possible that the multiword production task elicited a high level of response conflict relative to representational conflict, triggering different conflict detection mechanisms than those triggered in the Stroop task.

A second possibility is that there is some degree of domain-specificity within cognitive control. In the Stroop task, the competing representations were different color names, which may primarily activate competing semantic representations. However, in the multiword production task, competition may have occurred between putting the sounds of the primed word in the location of noun 1 versus noun 2, and thus primarily activated conflict in a phonological domain. Several studies have linked activation during phonological tasks to more posterior portions of the LIFG and activation during semantic tasks to more anterior portions of the LIFG (Bodke, Tagamets, Friedman, & Horwitz, 2001; Poldrack, Wagner, Prull, Desmond, Glover, & Gabrieli, 1999; Thothathiri, Gagliardi, & Schwartz, 2012). The significant findings of conflict adaptation and depletion from Experiment 1 would then have to be interpreted in a domain-specific context. The sentence stimuli contained conflicting information from syntax *and* semantics while the Stroop is clearly non-syntactic. However, as both putatively elicit semantic conflict, albeit in vastly different tasks, these findings could be interpreted as recruiting a shared domain-specific semantic conflict detection/resolution mechanism. Regardless of whether the results of Experiment 1 are interpreted in a domain-specific or domain-general framework, they do demonstrate conflict processing mechanisms that are task-general and that are recruited across very structurally different tasks with varying levels of demands.

4.2.2 Stroop to Multiword Production

4.2.2a All Trials

Analysis of adaptation from Stroop to multiword production was exploratory because the extent to which behavioral measures of verbal multiword production reflect cognitive control versus other component processes has not been studied systematically. In the first analysis, we examined all trials. The current trial type was significant for longer reaction times on incongruent multiword production trials, reflecting positional interference, but there were no other significant findings. There was no evidence for behavioral interactions between multiword production and Stroop.

4.2.2b Halves

We again analyzed the first half and the second half of the data separately. In the first half, reaction times were significantly increased on multiword trials following a previous incongruent Stroop trial. This reflects potential fatigue from performing a difficult task (incongruent Stroop) on the previous trial. Reaction times were also significantly increased on a current incongruent multiword trial, reflecting positional interference. In the second half of the experiment, current trial was marginally significant for increased reaction times on a current incongruent multiword trial, again reflecting positional interference. There were no interactions in either half and therefore no evidence for shared conflict processing resources between these two tasks.

4.2.2c Summary

These results provide no evidence for domain-general conflict processing, as there was no interaction between previous and current trial types. The results from the analysis of Stroop to multiword production are consistent with the two possible explanations outlined in Section 4.2.1c.

4.3 *General Discussion*

To summarize, this study examined conflict adaptation between two different language tasks and the Stroop task. Evidence of bidirectional behavioral interaction between sentence processing and Stroop was found in Experiment 1, which suggests that these two disparate tasks recruit common conflict processing resources. However, results from Experiment 2 showed no behavioral interactions between multiword production and Stroop. The difference between these two studies could be consistent with either a domain-general or domain-specific model of conflict processing, as it is unclear whether interactions were not found due to differences in levels of conflict processing or differences in domains of conflict processing. Further research should focus on better distinguishing between these two possibilities. Finally, we also suggest that future research should better characterize the time course of conflict processing. Specifically, we suggest our results were potentially modulated by changes in the amount of conflict experienced over time, length of cross-task ISIs, and possible refractory periods following triggering of conflict detection mechanisms. These factors must be better clarified so that future experiments do not inadvertently confound experimental design artifacts with domain-generality or specificity.

Research into the relationship between conflict processing mechanisms and various language tasks will allow for a better understanding of language processing in both neurotypical and clinical populations. Determining whether conflict processing mechanisms are domain-general or domain-specific will help clinicians better characterize patients' deficits. This will also have implications for treatment, as training tasks and/or compensatory mechanisms may be developed to improve outcomes in patients who present with impaired conflict processing.

References

Akcay, C. & Hazeltine, E. (2011). Domain-specific conflict adaptation without feature repetitions. *Psychonomic Bulletin & Review, 18*, 505-511.

Banich, M.T. (2009). Executive function: The search for an integrated account. *Current Directions in Psychological Science: A Journal of the American Psychological Society, 18*(2), 89-94.

Bodke, A.L.W., Tagamets, M.A., Friedman, R.B., & Horwitz, B. (2001). Functional interactions of the inferior frontal cortex during the processing of words and word-like stimuli. *Neuron, 30,* 609-617.

Botvinick, M.M., Braver, T.S., Barch, D.M., Carter, C.S., & Cohen, J.D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 8*(3), 624-652.

Clayson, P.E. & Larson, M.J. (2011). Conflict adaptation and sequential trial effects: Support for the conflict monitoring theory. *Neuropsychologia, 49*(7), 1953-1961.

Egner, T. (2008). Multiple conflict-driven control mechanisms in the human brain. *Trends in Cognitive Sciences, 12*(10), 374-380.

Egner, T., Ely, S., & Grinband, J. (2010). Going, going, gone: Characterizing the time-course of congruency sequence effects. *Frontiers in Psychology, 1,* 1-8.

Fedorenko, E., Duncan, J., & Kanwisher, N. (2012). Language-selective and domain-general regions lie side by side within Broca's area. *Current Biology, 22,* 2059-2062.

Garnsey, S.M., Pearlmutter, N.J., Meyers, E., & Lotocky, M.A. (1997). The contributions of verb bias and plausibility to the comprehension of temporarily ambiguous sentences. *Journal of Memory and Language, 37,* 58-93.

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General, 121,* 480–506

Gray, H., (2014). *The role of the left inferior frontal cortex in resolving syntactic-semantic conflict: A neuropsychological study.* (Unpublished masters thesis). George Washington University, Washington DC.

Hamilton, A.C. & Martin, R.C. (2005). Dissociations among tasks involving inhibition: A single-case study. *Cognitive, Affective, & Behavioral Neuroscience, 5*(1), 1-13.

January, D., Trueswell, J. C., & Thompson-Schill, S. (2009). Co-localization of stroop and syntactic ambiguity resolution in Broca's area: Implications for the neural basis of sentence processing. Journal of Cognitive Neuroscience, 21(12), 2434-2444.

Jonides, J., Smith, E.E., Marshuetz, C., Koeppe, R.A., & Reuter-Lorenz, P.A. (1998). Inhibition in verbal working memory revealed by brain activation. *Proceedings of the National Academy of Sciences of the United States of America, 95,* 8410-8413.

Kan, I.P., Teubner-Rhodes, S., Drummey, A.B., Nutile, L., Krupa, L., & Novick, J.M. (2013). To adapt or not to adapt: The question of domain-general cognitive control. *Cognition, 129,* 637-651.

Kornmeier, J. & Bach, M. (2005). The Necker cube – An ambiguous figure disambiguated in early visual processing. *Vision Research, 45,* 955-960.

MacDonald, A.W., Cohen, J.D., Stenger, V.A., & Carter, C.S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288*(5472), 1835-1838.

Mack, J.E., Meltzer-Asscher, A., Barbieri, E., Thompson, C.K. (2013). Neural correlates of processing passive sentences. *Brain Sciences*, 3, 1198-1214.

Marslen-Wilson, W., Brown, C.M., & Typer, L.K. (1988). Lexical representations in spoken language comprehension. *Language and Cognitive Processes, 3*(1), 1-16.

Milham, M.P., Banich, M.T., Webb, A., Barad, V., Cohen, N. J., Wszalek, T., Kramer, A.F. (2001). The relative involvement of anterior cingulate and prefrontal cortex in attentional control depends on nature of conflict. *Cognitive Brain Research, 12*(3), 467–473.

Miller, E.K. & Cohen, J.D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24,* 167-202.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., & Wagner, T.D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Nelson, J.K., Reuter-Lorenz, P.A., Sylvester, C.C., Jonides, J., & Smith, E.E. (2003). Dissociable neural mechanisms underlying response-based and familiarity based conflict in working memory. *Proceedings of the National Academy of Sciences of the United States of America, 100*(19), 11171-11175.

Novick, J.M., Hussey, E., Teubner-Rhodes, S., Harbison, J.I., & Bunting, M. (2014). Clearing the garden-path: Improving sentence processing through cognitive control training. *Language, Cognition, and Neuroscience, 29*(2), 186-217.

Novick, J.M., Kan, I.P., Trueswell, J.C., & Thompson-Schill, S.L. (2009). A case for conflict across multiple domains: Memory and language impairments following damage to ventrolateral prefrontal cortex. *Cognitive Neuropsychology, 26*(6), 527-567.

Novick, J.M., Trueswell, J.C., & Thompson-Schill, S. (2005). Cognitive control and parsing: Reesamining the role of Broca's area in sentence comprehension. *Cognitive, Affective, & Behavioral Neuroscience, 5*(3), 263-281.

Persson, J., Welsh, K.M., Jonides, J., Reuter-Lorenz, P.A. (2006). Cognitive fatigue of executive processes: Interaction between interference resolution tasks. *Neuropsychologia, 45,* 1571-1579.

Poldrack, R.A., Wagner, A.D., Prull, M.W., Desmond, J.E., Glover, G.H., & Gabrieli, J.D.E. (1999). Functional specialization for semantic and phonological processing in the left inferior prefrontal cortex. *Neuroimage, 10,* 15-35.

Rajah, M.N., Ames, B., & D'Esposito, M. (2008). Prefrontal contributions to domain-general executive control processes during temporal context retrieval. *Neuropsychologia, 46,* 1088-1103.

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing. *Journal of Verbal learning and Verbal Behavior, 22*(3), 358-374.

Rodd, J.M., Longe, O.A., Randall, B., & Tyler, L.K. (2010). The functional organisation of the fronto-temporal language system: Evidence from syntactic and semantic ambiguity. *Neuropsychologia, 48,* 1324-1335.

Roisson, B. & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwort's object pictorial set: The role of surface detail in basic-level object recognition. *Perception, 33,* 217-236.

Scott, R.M. & Wilshire, C.E. (2010). Lexical competition for production in a case of nonfluent aphasia: Converging evidence from four different tasks. *Cognitive Neuropsychology, 27*(6), 505-538.

Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 635-662.

Thompson-Schill, S.L., D'Esposito, M., Aguirre, G.K., & Farah, M.J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences of the United States of America, 94*(26), 14792-14797.

Thothathiri, M., Kimberg, D.Y., & Schwartz, M.F. (2012). The neural basis of reversible sentence comprehension: Evidence from voxel-based lesion symptom mapping in aphasia. *Journal of Cognitive Neuroscience, 18*(1), 212-222.

Thothathiri, M., Schwartz, M., & Thompson-Schill, S.L. (2010). Selection for position: The role of left vetrolateral prefrontal cortex in sequencing language. *Brain & Language, 113,* 28-38.

Trueswell, J.C., Tanenhaus, M.K., & Kello, C. (1993). Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden paths. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(3), 528-553.

Ullsperger, M., Bylsma, L.M., & Botvinick, M.M. (2005). The conflict adaptation effect: It's not just priming. *Cognitive, Affective, & Behavioral Neuroscience, 5*(4), 467-472.

Zhang, J.X., Feng, C.M., Fox, P.T., Gao, J.H., & Tan, L.H. (2004). Is left inferior frontal gyrus a general mechanism for selection? *Neuroimage, 23,* 596-603.