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EXAMINING THE BOUNDARY CONDITIONS BETWEEN COGNITIVE CONTROL AND INTERFERENCE DERIVED FROM STIMULUS-BASED AND RESPONSE-BASED CONFLICT

A Dissertation

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Abstract

Cognitive control is a broad construct that defines a set of processes involved in maintaining task goals in response to interference. Working memory capacity (WMC) is a similarly defined construct that shares many overlapping functions with cognitive control. The studies presented used controlled forms of interference to identify limits, or boundary conditions, that could help clarify the relationship between cognitive control and WMC. Experiment 1 used context effects to manipulate how interference and cognitive control could overlap. A spatial Stroop/Simon task was used in which proportion congruency for each subset (e.g., Simon or spatial Stroop) was manipulated to produce a 2 x 2 arrangement. Error rates, reaction times (RT), post-error slowing, and conflict adaptation were measured. A composite WMC score was formed from multiple working memory tasks. The results demonstrate that WMC is recruited globally by proactive control processes to help maintain context-specific control and that conflict adaptation effects are not always context-specific. Experiment 2 used isolated forms of interference to examine cognitive control responses in a more structured, but limited, task. The spatial Stroop and Simon components were separated and assessed 48hrs apart. The same variables were measured. Results showed that Simon and spatial Stroop differ in proactive control, but not reactive control measures. No correlation with WMC was found in Experiment 2.

Introduction

Cognitive control refers to the set of systems that are engaged when one is trying to focus on relevant task features while inhibiting irrelevant information. Exerting cognitive control during a task serves to redirect information more efficiently along task goals. Overriding a pre-potent or habitual response would be an example of how cognitive control could shift the processing of information. Some of the processing performed by cognitive control overlap with aspects typically attributed to working memory, such as directing/focusing attention, maintaining active representations in memory, and limiting the influence of interference, among other things. This is not surprising since working memory is limited resource system that temporarily stores information for processing and is described as a subset of systems that are linked to higher-order cognitive functions like intelligence (Conway, Jarrold, Kane, Miyake, & Towse, 2007; Kane, Conway, Hambrick, & Engle, 2007; Engle & Kane, 2004).

This link between cognitive control and working memory is strengthened by theories of working memory capacity that describe individual differences in higher-order cognitive abilities as being derived, in part, from variations in one's aptitude at effectively utilizing cognitive control processes within a task (Braver, Gray, and Burgess, 2007; for a related view see Kane et al., 2007)[1]. These theories divide control processes into two distinct mechanisms: proactive and reactive. Proactive control is important for maintaining task-relevant information such as goal representations. It is typically initiated in the first few trials and must be actively maintained throughout the task (Braver et al., 2007; Botvinick, Braver, Barch, Carter, & Cohen, 2001). On the other hand, reactive control is typically transient in nature, and activates as a conflict

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[1] The executive attention model of working memory uses the term "*executive attention* to emphasize a debt and family resemblance to other theories of executive function, executive control, and executive attention (e.g., Baddeley & Logie, 1999; Norman & Shallice, 1986; O'Reilly, Braver, & Cohen, 1999; Posner & DiGirolamo, 1998)" and therefore shares many similarities to cognitive control (Kane, Poole, Tuholski, & Engle, 2006).

resolution process (Braver et al., 2007; Botvinick et al., 2001; Funes, Lupiáñez, & Humphreys, 2010b). Taken together, these two mechanisms should account for most of the individual differences in control functions, such as in mitigating interference. If so, what features of the task environment cue these mechanisms to activate or deactivate? And, can we use the conditions under which these mechanisms activate to identify situations that begin to separate and clarify cognitive control processes that do not overlap with working memory capacity? Identification of the boundary conditions associated with cognitive control, and its relation to working memory, is important for advancing our knowledge within each domain (Kane et al., 2006; Egner, 2007; Meier & Kane, 2013).

Therefore, the present research examined the relationship between interference, cognitive control, and working memory capacity, a measure of working memory abilities as assessed by complex-span tasks. The goal was to identify limits, boundary conditions, in which features in the task environment like interference result in changes to how cognitive control operates. Furthermore, it aimed to identify similar conditions with which cognitive control and working memory capacity operate. Taken together, these goals could help resolve some of the ambiguity under which these broad concepts overlap.

Dual Mechanisms of Control

Proactive Control. Like working memory capacity, cognitive control consists of a limited amount of resources in a top-down manner (Braver et al., 2007; Kane et al., 2007). Proactive control is the primary means by which limited attentional resources are distributed. It is useful for creating more strategic, global policies within which resources are used (Braver et al., 2007). For example, proactive control is used to maintain active goal representations. Metaphorically, goal maintenance can be thought of as acting like the conveyor system at a parcel service like Fed-Ex. Information, like a package, is taken in and redirected along different conveyors based upon the goal representation, the shipping address. This filtering process serves to bias incoming information so that it is rerouted to the most efficient pathway. In the example, this would be represented by the computers routing the package onto the most relevant conveyors in order to quickly and efficiently get the package to the correct delivery truck. Outside of the metaphor, this can be viewed as processes that bias incoming information to an appropriate stimulus-response (S-R) mapping. In other words, these processes enhance activation of the appropriate response mappings based on stimulus features. In each descriptive case, it is the goal information (shipping address/task goal) that is used to redirect incoming information (package/stimulus). Therefore, by maintaining the goal information in an activated state during a task, one can more quickly and easily trigger the required response based upon a given trial's stimulus features.

However, proactive control can be a costly process to maintain. Proactive control is believed to require sustained deployment of attentional resources (Braver et al., 2007; Kane & Engle, 2003; Soutschek, Strobach, & Schubert, 2012). This process can prove difficult to keep up, especially in individuals that may already be limited in their overall amount of resources (Kane & Engle, 2003). Competition for resources from a limited resource system means that control may not always be effectively maintained. Failure to maintain the goal in a highly active state, called goal neglect, can lead to inefficient processing of the information. The earlier descriptive examples used the goal representation to bias the incoming information along the most effective channels. Without having the goal maintained in an active state, there is little or no biasing of that information towards the appropriate channels. While it is not necessarily the case that goal neglect leads to errors, goal neglect does produce more "noise" due to ineffectively routed information. This increased noise can result in extended processing times, and, when the task contains significant levels of interference, can also result in errors.

The use of attentional resources by proactive control creates an area in which cognitive control and working memory capacity should overlap. Conceptually, both concepts are defined as recruiting these resources. Neurophysiologically, tasks believed to recruit cognitive control and working memory capacity also recruit the same brain region, the dorsolateral prefrontal cortex (DLPFC). The DLPFC is argued to be the center of attentional control, and is attributed to being the primary area involved in proactive cognitive control and goal maintenance (Kane et al., 2007; Braver et al., 2007; Botvinick, et al., 2001; Miller & Cohen, 2001). Studies have shown this brain region to be more active during maintenance and updating in working memory (Sylvester, Wager, Hernandez, Nichols, Smith, & Jonides, 2003; Owen, Evans, & Petrides, 1996) and in tasks that require top-down cognitive control, such as the Stroop and Simon tasks (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Peterson, Kane, Alexander, Lacadie, Skudlarski, Leung, May, & Gore, 2002; Liu, Banich, Jacobson, & Tanabe 2004). Thus, they are believed to share a similar process for recruiting attentional resources.

Reactive Control. In contrast to proactive control's sustained activation, reactive control processes are more reflexive. They are activated, briefly, at a more local level in response to inter-trial changes to serve as a late correction mechanism (Braver et al., 2007). When a failure of proactive control misroutes information, reactive control can attempt to redirect it back to the desired location. For example, imagine the information is a package, again. Proactive control is required to make sure the package is delivered quickly and efficiently. A failure of proactive control might result in the package being put on the wrong truck, and potentially misdelivered. Reactive control acts as a dispatcher that reroutes the wrong truck to the correct location, albeit at the expense of a later delivery time. The idea, here, is that these reactive processes are time-consuming, on-the-fly corrections in response to detected conflict.

Reactive control mechanisms are believed to be driven by both top-down and bottom-up processes (Braver et al, 2007; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Notebaert & Verguts, 2011, for a review see Egner, 2007, but also Schmidt, 2013). Conceptually, this line of thinking has been derived from the inability for either top-down or bottom-up views to account for most of the data, as well as their lack of being mutually exclusive. To briefly elaborate, the conflict monitoring account (Botvinick et al., 2001) argues that conflict is first detected by the anterior cingulate cortex (ACC), which then signals the DLPFC to enact the processes required to top-down override erroneous behavior. Basically, the ACC serves to estimate task difficulty and triggers the DLPFC adjust the level of top-down control exerted. Alternatively, feature repetition views have been put forward which argue that the evidence for some of these cognitive control measures, in particular the reactive control measures, can be attributed to complete repetitions or complete alternations of stimulus and response features (Mayr, Awh, and Laurey, 2003; Hommel, Proctor, & Vu, 2004). When both the stimulus and response features overlap, a significant speeding can be found due to reactivation of the same pathway. For example, if the previous trial contained a green circle and the present trial contains a green circle, then the stimulus features of shape and color repeat, as does the response feature, the corresponding keypress associated with that stimulus. Therefore, the same information pathways are reactivated which produces a speeding. In contrast, complete alternations of features require activation of a completely new pathway, and thus exhibit significant slowing. If instead of a green circle, the second stimulus were a red triangle, then there would be no overlap of shape, color, or response features from the previous trial, which requires the activation of a new pathway. This pattern of trade-offs in bottom-up processing can produce the observed “control effects.”

It should be noted that a feature repetition view does not necessarily change the complete interpretation of the underlying neurophysiological response associated with reactive control. For example, it has been shown with both imaging and single-neuron recordings that the ACC activity correlates with behavior adjustments, like expedited processing when the current trial matches the difficulty of the previous trial (Sheth, Mian, Patel, Asaad, Williams, Dougherty, Bush, & Eskandar, 2012). Therefore, the ACC would still be expected to trigger in a similar fashion whether it is “detecting conflict” or “detecting feature mismatch.” This means that in some cases, ACC modulation and bottom-up processing alone can account for the data, while in other instances, such modulation might be deemed inefficient and overridden in a top-down manner and further study is needed to identify exactly how much and when each process contributes (Egner, 2007).

One possible avenue of addressing this issue relates to recent work involving micro-adjustments of control (Ridderinkhof, 2002). Micro-adjustments of control refer to the minor alterations in the control processes by the PFC. These changes stem from conflict that is detected in the ACC. The ACC then signals the PFC to adjust control processes for the current trial or to more globally increase proactive control for future trials in the task (Braver et al., 2007). This separation of function between transient, trial-by-trial changes and more global strategic shifts across trials might help us to understand more about the dual nature of reactive control processes. The effects of these two types of micro-adjustments are seen in post-error slowing and conflict adaptation effects.

Post-error slowing refers to the tendency for responses to be much slower and accurate following an erroneous response than when following a correct response (Laming, 1979; Rabbitt, 1966). Post-error slowing is argued to result from the ACC detecting a conflict on the previous trial which likely resulted in the erroneous response. The ACC then signals the PFC to be more vigilant on the subsequent trial, which results in slowing across several trials. The amount of slowing that occurs has been shown to be related to the amount of increased activation in the DLPFC (Kerns, Cohen, MacDonald, Cho, Stenger, & Carter, 2004). Furthermore, the amount of activation in the DLPFC has been linked to the amount of increased activation in the ACC (Debener, Ullsperger, Siegel, Fiehler, von Cramon, & Engel, 2005). Thus, the neurological evidence suggests that control processes can respond to the magnitude of conflict encountered on a particular trial, and use trigger appropriate global adjustments in control (Braver et al., 2007).

Conflict adaptation effects reflect a similar, but separate form of reactive control. Conflict adaptation effects refer to the difference in performance between congruent and incongruent trials based upon whether the trial preceding them was itself congruent or incongruent (Gratton, Coles, & Donchin, 1992). Congruent trials represent trials in which both the relevant and irrelevant dimensions of the task overlap, so that each dimension cues the same correct response. Incongruent trials, in contrast, represent more challenging trials where the relevant stimulus dimension is in conflict with other dimensions, which cue alternate responses. Conflict adaptation effects reveal how changes between these trial types can shape performance. For example, when a congruent trial follows another congruent trial (cC), reaction times (RTs) are shorter and accuracy improves, since the processing demands of the current trial match the processing demands used on the previous trial. This holds true for two back-to-back incongruent trials as well (iI), in which the conflict arising from the incongruent trial is lessened because of the processing match across trials. The opposite holds true (e.g., longer RTs) when the two trials mismatch, such as an incongruent trial preceding a congruent one (iC) or vice versa (cI). The typical pattern of RTs for conflict adaptation is that cC < iC < iI < cI. This pattern emerges because congruent trials tend to be faster than incongruent trials, and trial pairs involving conflict are slower than trial pairs with repetitions.

Conflict adaptation effects are like post-error slowing, in that ACC activation has been shown to be greatest during cI trials (Egner & Hirsch, 2005; Kerns, 2006) and ACC activation is indicative of activation in the PFC, as well as performance effects (Kerns et al., 2004). But unlike post-error slowing which can last for several trials and result in more global changes, conflict adaptation effects are more momentary, trial-to-trial changes in control.

Notebaert and Verguts (2011) illustrated these differences in an experiment that combined a Simon effect with a SNARC (spatial numerical association of response codes) effect. To put briefly, the Simon effect is produced when there is interference between response and stimuli locations (Simon & Small, 1969). Participants respond to stimuli faster when the stimulus and response are on the same side and slower when they are on opposite sides. For example, if the tasks involves responding to the color of shapes, then a green object on the left side of the screen will produce a faster response if the response button for green is also on the left. In contrast, the same green circle on the left side of the screen produces a slowed response if the response button for green is on the right side. In the SNARC effect, participants respond differently based on button location and the magnitude of numbers, smaller numbers get faster responses from the left hand while larger numbers get faster right hand responses (Dehaene, Bossini, & Giraux, 1993). In this case, the task may involve responding to the color of numbers. If a green “3” is presented, then participants will be faster to make the green response when the response button is on the left side. In contrast, a green “9” would produce slower responses from that same left response button.

Notebaert and Verguts (2011) manipulated features of the stimuli across two conditions. In one condition, participants responded to the same stimulus feature, italic or upright font, for both the Simon and SNARC trials. In the second condition, participants again responded to the font for SNARC stimuli, but responded to color for the Simon stimuli. The results of the experiment showed that in the same condition, both conflict adaptation and post-error slowing effects were unaffected by changes to the task. That is, reactive control was unaffected by the change in stimuli when the goal focused on the same feature in each task. However, when the responses depended on different features, post-error slowing was unaffected by task changes, while conflict adaptation was only present for trials where the previous and current trial were from the same task. This dissociation reinforces theoretical claims that post-error slowing is more global, and conflict adaptation is local. It also suggests that the two forms of reactive control may tap different processes, with conflict adaptation being sensitive to feature overlap.

Dissociating between the two forms of reactive control could also be informative about top-down and bottom-up influences. It is possible that working memory capacity only correlates with cognitive control when top-down processes are required, such as with global changes. Bottom-up processes like feature integration could then account for other situations in which there is an overlap between task dimensions, such as in the Notebaert and Verguts’ (2011) “same” condition. Alternatively, Kerns et al. (2004) found that activation in the ACC correlated in magnitude with activation in DLPFC, a region known for working memory updating and maintenance. Furthermore, the magnitude of the activation was related to the amount of conflict encountered in the task. So, it is also possible that top-down processes, and thus working memory, might only be utilized once conflict has crossed a particular threshold. Clarification of these boundary conditions are therefore an important empirical question that needs further study.

Interference Taxonomy

In theoretical discussions, conflict and interference are not always clearly defined terms. In order to understand how control mechanisms might be affected by interference in an on-going task, it is necessary to first examine a few of the ways in which interference can arise from the stimuli presented in a task. An excellent illustration of interfering effects can be found in the dimensional overlap (DO) model (Kornblum, Hasbroucq, & Osman, 1990; Kornblum, 1994; Kornblum & Lee, 1995; Kornblum, Stevens, Whipple, & Requin, 1999). In this model, there are different types of interactions that can occur due to the compatibility of stimulus dimensions and responses. To put briefly, the manner in which irrelevant stimulus or response dimensions overlap with relevant dimensions determines the type of interference that one will encounter. These interactions focus on the fact that there is usually a key stimulus dimension that is task-relevant (e.g., color or shape). Additionally, there can be stimulus dimensions that are irrelevant to the task, such as the stimulus location. It is the irrelevant dimension that can create conflict, or facilitation, in performing a task based upon whether it is inconsistent with the relevant task dimension or the response.

For example, suppose one is performing a task in which the goal is to judge the orientation of a colored vertical arrow, and then respond with a left key press for UP and a right key press for DOWN (Figure 1). Suppose further that the arrow appears in the center of the screen on each trial. For each trial, there is a relevant dimension, the arrow’s orientation, and irrelevant dimensions that are neutral. Color has no bearing on an UP or DOWN judgment and the stimulus location, center screen, offers no enhancement or handicap. To put it another way,

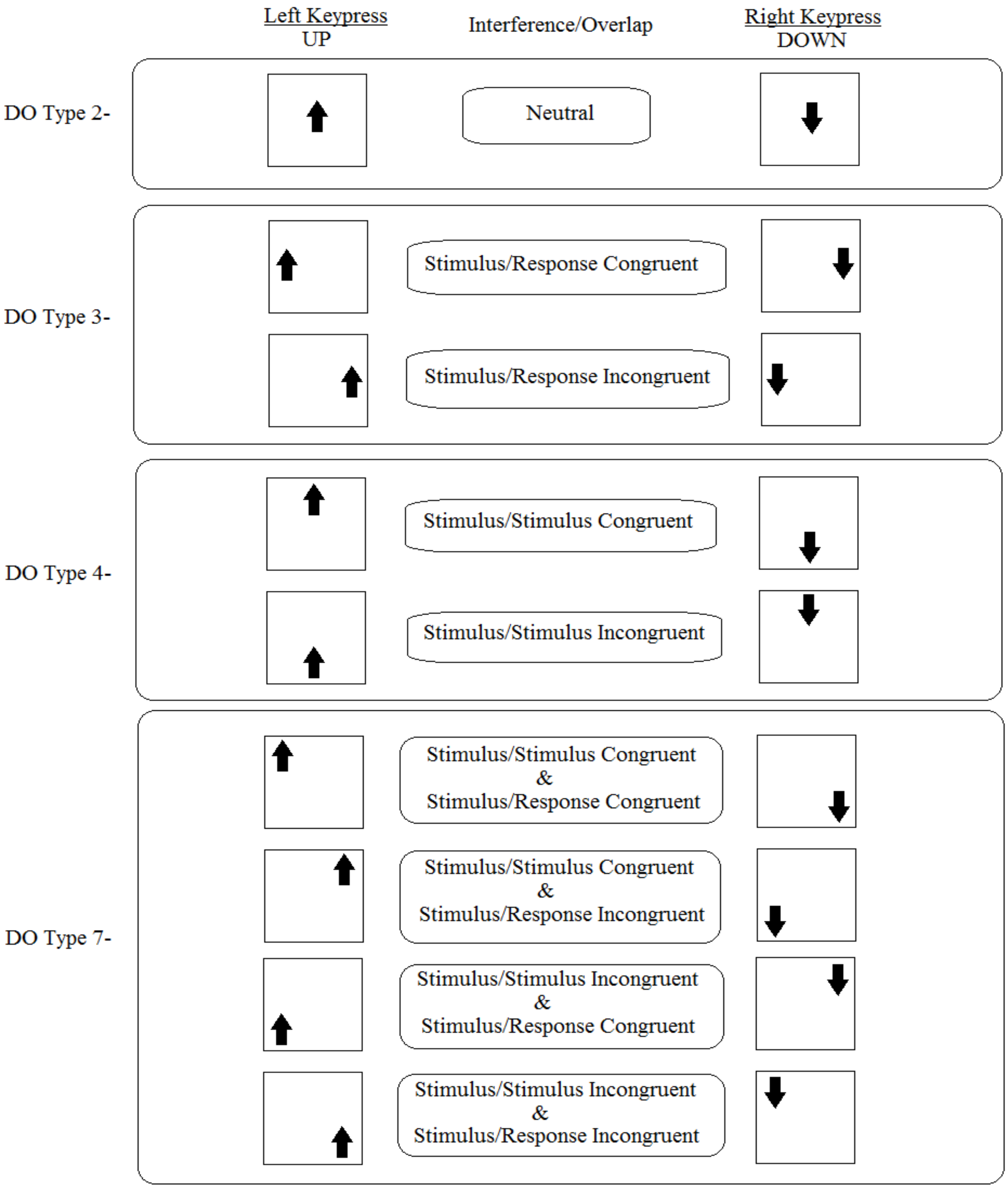

Figure 1. Examples of the Dimensional Overlap taxonomy. The left and right columns represent example stimuli screenshots. The screenshots are intended to demonstrate congruent and incongruent examples of the 4 DO types described in this paper. The left column shows stimuli relative to a left key press (UP) and the right column illustrates stimuli relative to a right key press (DOWN).

one cannot effectively perform the task by using any of the irrelevant dimensions as a cue for the proper response. Neither of the irrelevant dimensions carry any predictive value of the expected response, and can simply be ignored. Under this scenario, the task would have a DO Type 2 situation and there would be no conflict of irrelevant dimensions, since the only overlap occurs between the relevant stimulus dimension and the response (Figure 1).

Now let us change it such that the arrow might appear on the left or right side of the screen instead of in the center. In this situation, the irrelevant dimension of location begins to play a role. While it is still neutral with respect to the UP or DOWN judgment itself, the location information can interfere at the response level. When the UP arrow is on the left side of the screen, it is compatible with the UP key press (e.g., a left key press) and would facilitate processing of that response. This occurs because one can rely on either the orientation, the relevant stimulus dimension, or the location, the irrelevant stimulus dimension, as a cue to the proper response. In this case, the stimulus location information (e.g., left side) maps onto the response location, since the UP response involves a "left" key press. Since both the relevant and irrelevant stimulus information cue the same correct response, there will be a speeding of the response, facilitation, due to lack of conflict.

However, when the UP arrow is on the right side of the screen, it is incompatible with the UP key press (e.g., left key press) and would create interference like those mentioned previously in Simon tasks. Examination of the irrelevant stimulus dimension would reveal a different stimulus-response mapping. The irrelevant location information of the stimulus, right side, would predict the response to be a right key press, or DOWN response. Under these conditions, two competing response pathways are cued, and the conflict between them must be mitigated by control processes. Resolving this interference produces a slowing of the response. This is an example of a DO Type 3 situation in which the overlap between the stimulus location and response location forms a Stimulus-Response (S-R) compatibility issue (Figure 1).

Instead of having the arrow appear on the right or left side of the screen, suppose the stimuli were to appear above and below the center of the screen. Here, the location information no longer overlaps with the response locations. The stimuli have upward or downward location information while the response locations are left and right. This configuration removes any compatibility issues associated with the irrelevant stimulus dimension, location, and the irrelevant response dimension, also location. However, the stimulus location information now overlaps with the relevant stimulus dimension, arrow orientation. An UP arrow that appears at the top of the screen will be processed more effectively since the overlapping dimensions are consistent (e.g., UP arrow and "up" location). Again, both the irrelevant and relevant stimulus serve as effective cues to the correct UP response.

Similar to the previous DO type, an UP arrow that appears at the bottom of the screen would create interference from the conflicting response pathway activations. The irrelevant stimulus dimension would predict a DOWN key press, since the arrow is located "down." This would need to be inhibited in favor of the goal directed UP key press to the arrow's orientation. Since the conflicting dimensions are both part of the stimulus (e.g., a task-relevant and a task-irrelevant dimension), this is a DO Type 4 situation in which the interference comes from a Stimulus-Stimulus (S-S) compatibility problem (Figure 1).

One final situation to note involves a combination of the conflict from the previous two scenarios. The caveat this time is that the arrows appear in one of the 4 corners of the screen. This would create a DO Type 7 situation in which the irrelevant stimulus dimension overlaps with both stimulus (S-S) and response (S-R) dimensions (Figure 1). The irrelevant stimulus dimension of location is creating conflict between both the relevant stimulus and the irrelevant response locations. Each stimulus location contains both “up”/”down” information as well as “left”/”right” information. The pattern of conflict that arises is more intricate than the previous two situations, since conflict can arise from one or both overlaps at the same time. For example, an UP arrow that is in the top right corner would not produce any S-S conflict, but would still produce S-R conflict. An UP arrow in the bottom right corner would produce conflict along both dimensions. In this situation (S-S/S-R), the irrelevant stimulus dimension, location, can be consistent with both stimulus and response, inconsistent with both, or inconsistent with respect to one, but not the other. And, it demonstrates some of the complexity that can be derived due to interference from irrelevant stimulus dimensions.

It should be noted that Kornblum (1994) gives a comprehensive breakdown of all 8 DO Types (see also, Kornblum and Lee, 1995). However, DO Types 1, 5, 6, & 8 refer to situations that are beyond the scope of the present paper. DO Type 1 refers to situations in which there is no overlap, such as the number of objects on the screen. In a task like this, none of the stimulus dimensions map onto response dimensions. DO Types 5 & 6 refer to unique situations that have rarely occurred in the literature, and are primarily conceptual. Finally, DO Type 8 refers to complex situations that arise when you combine a DO Type 5 & 6.

Despite restricting the present discussion to only a few types, the taxonomy still presents an invaluable tool for bringing clarity to discussing and manipulating interference in a range of situations. It provides a means by which we can use precise operational definitions of interference with which to examine the effects on cognitive control. More specifically, does S-R (DO Type 3) and S-S (DO Type 4) engage cognitive control in the same way? If not, can their differences identify boundary conditions within cognitive control or between cognitive control and working memory capacity that will help to refine our theoretical understanding of the two broad constructs?

The Simon Task

Simon interference was first demonstrated in a study by Simon and Small (1969) in which auditory tones were presented in either the left or right ear. Participants were asked to respond to low-pitch tones with a left key press, and high-pitch tones with a right key press. The results showed that participants were slower to respond when the ear in which the stimulus was presented (e.g., low tone in right ear) and the response button (e.g., left button for low tone) mismatched, rather than when the same stimulus was presented in the other ear, such as low tone in left ear. This slowing is called Simon interference, and tasks designed to produce this type of interference are called Simon tasks.

Simon interference has since been shown to arise when stimuli are visually represented in a number of stimulus and response configurations (for reviews, see Lu & Proctor, 1995; Hommel, 2011). The common theme is that there is always a facilitation (or speeding) of responses when the stimulus and response locations match, and likewise a significant slowing when they do not. Simon tasks, at least conceptually, also share another interesting feature. They all produce S-R interference (DO Type 3). If we consider the original Simon task, we see that the irrelevant location information, the ear in which the tone is presented, produces interference when it creates response competition. That is, the tone signifies one response button, while the ear the tone was heard in signifies another button.

To be clear, the matching of stimulus and response locations that produces as Simon effect is tied to spatial codes that are applied to the context and not necessarily to strict “locations.” This means that the effect depends on how information is represented and the “location” information can be inferred. For example, Hommel and Lippa (1995) found a meager, but significant, amount of facilitation in a task where information was presented in one of 2 vertical locations, while the response configuration had horizontal location information. The stimuli consisted of an image of Marilyn Monroe’s face rotated 90 degrees to the left or right, and a black dot was placed over one of her eyes. Participants were told to use left and right key presses for “Top” and “Bottom” responses, respectively. The buttons were counterbalanced across participants. Therefore, the only left or right location information came from the eye that the dot was covering, since the dot was always above or below center. Hommel and Lippa found a very small amount of facilitation in which responses were faster if the dot was over the same eye as the button location, such as the dot being over the left eye, when the left eye was on top, and the left button was the “top” response key. Information about the intrinsic location of the dot, “left eye”, was being used despite being irrelevant and inconsequential to the task.

Another example comes from Hommel (1993) in which participants were instructed to respond to high- and low-pitch tones. There were 3 groups: 1 in which response key presses caused a small LED to light up on the same side as the response key, and 2 groups in which the response keys caused the LED to light on the opposite side. Of particular importance are the last two groups, since one group was instructed to press the key in response to a tone, such as the left key for a low tone. The other group however was instructed to light up a particular LED in response to a tone, such as light up the right LED for a low tone. It should be noted that these two groups are making the exact same response to the exact same stimuli. However, their *perceived action* is different. Both groups are pressing the left key to a low tone, for example, but one of them intends to press the key as a designated response, while the other intends to light up the right LED as the response. The data from the study showed that they produced opposite

Simon effects. That is, the key press group was faster if the tone was presented on the side that corresponded to the key press, while the other group was fast if the tone was presented to the side that the LED was on. Thus, the effect was being driven entirely by how the response was represented.

How exactly these codes are used is unclear. For example, according to a feature repetition account, these codes can develop from bottom-up processes. The mapping between the stimulus and response creates a binding in episodic memory. These bindings can then be recalled to facilitate processing on similar trials. However, other researchers have argued that these codes are used within working memory representations (Ansorge & Wühr, 2004; Wühr, Biebl, & Asorage, 2008; Wühr & Biebl, 2011). The response-discrimination account claims that the stimulus location codes must enter working memory and interact with response representations that are being maintained as part of the task goals. Therefore, there is some disagreement as to the role of top-down influences in the Simon effect, and identification of extent to which bottom-up and top-down processes influence the effect would be informative for both theories of cognitive control and our understanding of S-R effects.

The Stroop Task

The Stroop task consists of color words (e.g., BLUE) presented in colored ink (Stroop, 1935). The goal of the task is to name the color of the ink, and to ignore the printed word. The general finding is that, like the Simon task, there is a facilitation of responding when the printed color word and ink color match. And again like the Simon task, there is a significant slowing that accompanies a mismatch, such as the word “BLUE” in red ink. Unlike the Simon task, the Stroop task tends to correlate with measures of working memory and measures of cognitive control (Kane & Engle, 2003).

Kane and Engle (2003) showed that one could dissociate between proactive control (e.g., goal maintenance) and reactive control (e.g., conflict resolution) within the Stroop task. Their experiment tested participants' performance in various versions of a Stroop task, as well as their working memory capacity. Working memory capacity is a measure of the participant's working memory abilities as assessed using complex span tasks that involve a processing component and a short term storage component. Participants must maintain a particular accuracy on the processing portion, while simultaneously trying to remember things like letters in serial order. The span score is the result of their ability to perform the task. Therefore, high span individuals tend to be able to efficiently juggle the processing demands while maintaining most of the letters correctly, while low span individuals have considerable trouble. Kane and Engle (2003) found that when the Stroop list consisted of mostly congruent trials (e.g., the word "BLUE" in blue font), participants with low working memory capacity were faster to respond to these congruent trials. Additionally, low capacity participants made more errors on the infrequent incongruent trials in which the word and ink do not match. This supports the hypothesis that these low capacity individuals have difficulty with goal maintenance (proactive control). After all, not having the goal in a highly activated state would limit one's ability to inhibit the dominant, and in this case reinforced, response of word naming that suffices for most of the task. To put it another way, participants that have lower capacity do not have the resources to sustain top-down activation of the task goal. Since incongruent trials are infrequent, slips of goal maintenance do not incur regular penalties, and thus the ink naming goal is rarely reinforced.

To demonstrate the influence of the reactive component, they gave participants a Stroop task in which the lists were mostly incongruent. Under these conditions, one should not expect goal maintenance to be a factor, since most of the trials reinforce active maintenance of the goal of ink color naming by keeping the goal conflict present. Instead, the researchers were looking for differences in the resolving of this conflict on a trial-to-trial basis. The results showed that when most of the trials were incongruent, low capacity individuals were much slower to respond to incongruent trials regardless of whether they were correct or not. The overall slowing was taken to show that the lower capacity participants were processing the task goal on each trial. Since the trials were frequently incongruent, any goal neglect slips were quickly met with a task goal reinforcer, another incongruent trial. So, while they were not globally sustaining the task goal, the trial-to-trial reinforcements kept the goal activated and processed resulting in much longer reaction times. This demonstrates that even when they were able to accurately perform the task, their inefficient reactive control caused processing delays when resolving the conflict.

Despite being able to demonstrate a relationship between interference, cognitive control, and working memory capacity, the Stroop task has a shortcoming in that direct comparisons between the Stroop task and other forms of interference are a bit challenging. For example, the basic Stroop task is inherently linguistic. This has been demonstrated by Glaser and Glaser (1989) who showed that there is greater interference from words with semantic color meaning than from neutral words. For example, “sky” carries a semantic meaning of blue, whereas the word “purpose” carries no color meaning with it and would be neutral. “Sky” would be more likely to produce facilitation with blue and interference with other colors, though not as strong the word “blue” would. “Purpose” would neither create facilitation, nor interference with any color. These results demonstrate that it is not simply the overlap between the stimulus dimensions and response dimensions (e.g., color word stimuli and color word response), but rather the act of reading and semantic meaning play some role. Thus, the picture of how interference occurs within the basic Stroop task is messy.

Shor, Hatch, Hudson, Landrigan, and Shaffer (1972) conducted an experiment that showed Stroop effects in a slightly different context. They showed participants an arrow that was pointing either up, down, left or right. Concurrent with the drawing of the arrow was a word: UP, DOWN, LEFT, or RIGHT. Participants were much slower at naming the direction of the arrow when the concurrent word mismatched. Moreover, the pattern of results mirrored that of the classic Stroop paradigm, and were robust even after 10 sessions. While this task still contains a reading element, it was one of the earliest studies to demonstrate the effect spatially.

Clark and Brownell (1975) expanded on the “spatial Stroop” paradigm by containing the information to a single stimulus. In their experiment, they asked participants to judge the orientation of an arrow. They used one key press to indicate UP and another to indicate DOWN. The stimuli could be presented in 1 of 6 locations on the screen. 3 above the center and 3 below. The results were that congruent stimuli, upward arrows above center, were responded to much quicker than incongruent arrows. Their findings did not map as cleanly onto color Stroop performance as Shor and colleagues (1970), but they did succeed in creating Stroop-like results that were not contaminated by linguistics.

Unfortunately, the results of Clark and Brownell (1975) had a different problem. Their task employed 6 spatial locations, which resulted in two types of interference. The location that was directly above the center and the location directly below the center were S-S interference trials (DO Type 4). The other 4 locations were S-S/S-R interference trials (DO Type 7).

More recently, versions of the spatial Stroop task have employed the simpler S-S (DO Type 4) format as the analogue for Stroop interference (Liu et al., 2004; Funes, Lupiáñez, & Humphreys, 2010a; Funes et al., 2010b; Torres-Quesada, Funes, & Lupiáñez, 2013; Meier & Kane, 2011). This simplification of the task has allowed for better comparisons between interference types, such as being able to compare Simon (S-R) and Stroop (S-S) interference more directly. Such direct comparisons have enabled insights into neurological task-related areas (Liu et al., 2004), as well as task-specific and task-general contributions of cognitive control processes (Funes et al., 2010a, 201b; Torres-Quesada et al., 2013), but have only been used once with working memory tasks (Meier & Kane, 2011).

Task Comparisons

As mentioned previously, comparisons between the Simon and Stroop tasks have been met with methodological challenges. Peterson et al., (2002) employed a direct comparison that was designed to highlight the relevant brain regions associated with the two tasks. In their experiment, participants performed a basic color version of the Stroop task that consisted of predominantly congruent trials. They also performed and interesting version of the Simon task in which they judged the orientation of arrows that were pointing either left or right. The arrows appeared to the left or right of the center of the screen and participants responded with left and right key presses. The imaging results showed a remarkable similarity between the two tasks, with little variation separating them. These results are interesting insofar as the color word version of the task showed such remarkable relationship with a spatial task. However, the results also contain a methodological flaw. By having the Simon task arrows pointing to the left and right, they inadvertently created a situation in which S-S interference overlapped with S-R. To be clear, a left arrow on the left side of the screen carried irrelevant location information that corresponded with the relevant stimulus, the relevant response, and irrelevant response dimensions. The arrow was pointing left in a left location that required a left response via a left key press. In contrast, a right arrow on the left side had irrelevant location information that conflicted with the relevant stimulus dimension on a semantic level (e.g., S-S interference).

Moreover, the irrelevant location information conflicted with the relevant response dimension (e.g., S-R interference). Therefore, each of the trials consisted of either full S-S/S-R congruence or full S-S/S-R incongruence, and this served to increase the complexity of the Simon task to that of the color Stroop task.

Liu and colleagues (2004) improved upon the comparison by using a spatial version of the Stroop task in which only S-S interference was employed. This task was interleaved with a version of the Simon task that matched all characteristics except it created S-R interference only. The stimuli sets were combined into one seamless, uniform task. That is, the underlying design was similar to task-switching paradigms in which one trial could be Simon, and the following trial could spatial Stroop. However, the overarching goal of the task, to respond to the arrows, made this “switching” invisible to the participants. This allows the participant to perceive it was a single, uniform task. In this combined spatial Stroop/Simon task, participants responded to the orientation of a vertical arrow by using a left or right key press to indicate UP or DOWN. Interestingly, both tasks were found to tap similar brain regions such as the DLPFC. This is expected since it is believed to be the source of attentional control. However, the anterior cingulate cortex (ACC) was activated in the Simon task, but not the Stroop. This area is commonly thought to handle response conflict and selection. In contrast, the Stroop task had higher activation in the inferior parietal cortex, an area that combines sensory information. They argue that this area is more important for “biasing processing toward the task-relevant attribute” (Liu et al., 2004). These results suggest that there are potential differences in the underlying interference produced by these two tasks. More importantly for the present research, this suggests that the two types of interference may not recruit cognitive control processes in the same way.

Meier and Kane (2011) used a similar design, but included a comparison with working memory capacity. Their study compared spatial Stroop and Simon effects using the same setup of S-S and S-R arrow locations. Additionally, they allowed the arrows to appear at the 4 corners of the screen, S-S/S-R interference. All of the stimuli sets were combined into one seamless, uniform task. Their results showed working memory to only be related to trials that contained S-S interference. This finding is theoretically interesting since it shows a relationship between working memory capacity and spatial Stroop interference, and because it provides a direct comparison of working memory capacity between S-S and S-R interference.

Unfortunately, the task design also introduces some unaccounted for complexity. This procedure assumes that any effects are processed at the trial level. That is, it operates under one of two assumptions. It assumes that there is no carry-over effects between an S-S trial and an S-R trial. Any interference encountered on one trial has no effect on the next trial, if the trials change types from S-S to S-R or vice versa. Under this assumption, one can reasonably isolate trial types (e.g., S-R only), analyze them, and make inferences about "pure" effects, since no inter-trial effects are expected. Alternatively, the procedure assumes that any carry-over effects are equal. In this case, any interference from processing an S-S trial is similar to that processed by an S-R trial. Again, the trial types may be isolated, examined, and inferences about "pure" effects made, since inter-trial effects are equivalent. However, if the two interferences are not equal, then one might expect that effects of effectively resolving on form of conflict (e.g., S-S) might carry over to the other type of conflict's trials (e.g., S-R). For example, S-R trials following another S-R trial may produce one pattern of results, while S-R trials following S-S trials produce a different pattern. When all of the S-R trials are collapsed, these patterns are jumbled. Because of this, it is possible for the actual levels of interference in the experiment to be masked and it would be difficult to accurately determine their relation, if any, to working memory capacity. It is, therefore, an empirical question that requires more experimental control over the relative influence of each interference type to disentangle.

Context Effects

One way to frame the previous criticism more appropriately is to discuss the role of context effects. The most familiar context effect in the literature is proportion congruency (Logan & Zbrodoff, 1979; Kane & Engle, 2003). Proportion congruency refers to the relative number of items that are congruent within a stimuli list versus those that are incongruent. As mentioned earlier, lists that are primarily congruent require active goal maintenance, while lists that are primarily incongruent do not. The differences in congruency proportions can affect the overall, global approach to the task, and facilitate different patterns of performance.

More recently, researchers have begun to question the extent to which the global effects are really *global* at all. In other words, are the global effects observed actually attributable to overall shifts in behavior, or can they be accounted for more locally. For example, Bugg, Jacoby, and Toth (2008) conducted a series of experiments that they claim shows that participants can respond to item-level congruency, and that these local effects can drive performance in interference tasks. In their experiment, they created two separate stimuli lists. They then manipulated the congruency of the two lists, individually, to create the desired congruency proportions. For instance, in two of the conditions, one list remained a constant 50% congruency, while the other list was created to be either highly congruent or highly incongruent. This allowed them to have a similar reference set of stimuli, the 50% set, while manipulating the overall task congruence to be either 67% congruent or 33% congruent. The two lists were then intermixed randomly in the task. Any significant differences in the reference set would be indicative of list-wide, global, effects, while a null finding would suggest participants are learning specific congruency information about the individual items. They found that only the congruency proportion of the sub-list affected the outcome. That is, in the two 50% sets, it did not matter whether the secondary list that it was mixed with was highly congruent or incongruent. The results were the same. Therefore, they argued that control could be enacted at multiple levels, list and item.

Schmidt and Besner (2008) countered this claim by demonstrating that the same pattern of results can be accounted for by contingency learning alone. Participants can recognize that particular items appear with an expected contingency associated with them. In a mostly incongruent list, one can quickly give the expected incongruent response. To illustrate, assume that the word BLUE occurs predominantly in yellow ink and only a few times in green, blue, and red, while the word GREEN frequently appears in green ink, and rarely in blue, red, and yellow. The contingency hypothesis suggests that one uses the expected pattern to predict the response that they are going to give. The participant expects the response to the word BLUE is yellow and thus is able to give that response more quickly when encountering the word. Thus, item-level congruency has less to do with adjustments of control, and more to do with automatic learning of expected correlations.

Hutchison (2011) clarified list-wide and item-wide effects in a Stroop study in which the two effects were not confounded with one another. In his study, he created two sets of items. One set of items was made of words that had a manipulated associative value. Some incongruent stimuli were repeated many times (e.g., the word RED in black ink seen 16 times), while other incongruent stimuli were seen rarely (e.g., the word RED in blue ink 1 time). This created situations in which the word RED had high contingency, such as when seen in black ink, and situations in which the word RED had a low contingency, the unique presentations of RED in any color other than red or black. The second set of items used was considered filler and were either mostly congruent or incongruent. This allowed for the critical items and filler items to be combined into mostly congruent and mostly incongruent lists. More importantly, the combination of items into a larger list allowed for the separation of item-based (contingency-based) and list-wide (congruency-based) effects.

The results Hutchison's (2011) experiment demonstrated that item-based and list-based effects are related to one another, but separable. This means that one cannot rely on either alone as an explanation for the effects observed within a context. He also argued that individuals that had low working memory capacity, as determined from being in the bottom quartile of a complex span task (Operation span), have more difficulty with goal maintenance and more heavily rely upon reactive control, while individuals that had high working memory capacity (top quartile) were better able to maintain the goal in a highly active state and were more insensitive to list congruency characteristics.

Crump, Gong, and Milliken (2006) conducted an interesting study in which they revealed another level at which items could be processed. In their study, they used color words to cue a stimulus. The stimuli were colored shapes that could appear either above or below fixation. The goal of the task was to name the color of the shape. Unlike in typical congruency experiments, the congruency proportion was not tied to items specifically, nor were they assigned at the list-level. Instead, the location that the stimulus appeared in conveyed the congruency. Items that appeared in one location were likely to be congruent, while in the other location they would be incongruent. They showed across experiments that participants could identify congruency proportions based on context-specific dimensions such as shape or location. This *context-specific* *proportion congruency* could not be reduced to the item level since the same items appeared in both contexts. That is, the color word prime and the colored shape were seen with regular congruency, and thus as items, they had no contingency associated with them. In contrast, the location in which the items appeared dictated congruency such that items appearing above fixation might be predominantly incongruent, while those below fixation are always congruent, regardless of what item appeared in that location. Participants were able to identify a feature that indicated was predictive of congruency that was neither at the task level (since each location had different congruency), but was also not at the item level (since the items appeared equally across locations). Therefore, the results indicate that participants can exert control at levels that fall between list- and item-levels.

To relate this back to the previous criticism of the spatial Stroop/Simon task, it is unclear the degree to which some control processes are treated as *global*, that is they apply at the level of the task, while others are *context-specific* and can operate at the level of individual task lists. For example, Funes et al. (2010b) used a version of the spatial Stroop/Simon task to try and separate sustained global processes from more transient, local processing. In their task, they kept the spatial Stroop (S-S) trials at a constant 50% congruency, while manipulating the Simon (S-R) trials to be either mostly congruent or mostly incongruent. Their results showed that participants adopted global policies based on the overall congruence level. That is, participants responded differently to the 50% congruent/incongruent S-S trials based on the proportion congruency of the S-R trials. If the S-R trials were mostly congruent, then participants shifted responses on the S-S list as if it were mostly congruent, e.g., faster RT on congruent trials. This speeding of S-S trials based on S-R trials is a demonstration of a global response to the proportion congruency manipulation, since trial type, S-S or S-R, did not matter. They then analyzed conflict adaptation effects and found them to be significant only when the conflict type repeated. That is, participants were not treating an S-S trial preceded by another S-S trial as equivalent to an S-S trial preceded by an S-R trial. Participants were thus able to use the location cues, which define S-S and S-R, to respond specifically to the S-S and S-R trials as being part of separate lists. Conflict adaptation, unlike proportion congruency, appears to responding at a context-specific level of the list, and are sensitive to local, trial-by-trial changes.

These findings are interesting because unlike Crump et al. (2006) and Bugg et al. (2008), the information here was not used to shift congruence responding. Participants did not use the location information to treat S-S and S-R as separate contexts for the purposes of the proportion congruency. Since the location information was used to abolish conflict adaptation effects, it is unlikely that the location dimension was not specific enough to warrant context-specific proportion congruency. It is unclear why conflict adaptation was able to partition contexts at the local, trial-by-trial level, while proportion congruency was not able to do it at the task level.

In a related experiment, Torres-Quesada et al. (2013) used the spatial Stroop/Simon task to examine the persistence of global effects across task blocks. In their study, they had a pre-training phase that consisted of one block of 50% congruent spatial Stroop/Simon stimuli. This was followed by a training phase made up of 2 blocks with either mostly congruent or mostly incongruent *S-R trials only*. Then a post-training phase was conducted using 4 blocks of 50% congruent spatial Stroop/Simon stimuli. Participants were allowed to briefly rest between each block. The results of this experiment showed that the S-R training affected both the S-R and S-S trials in the post-training phase for 2 blocks. These results are similar to the finding by Kane and Engle (2003) in which low working memory capacity individuals performed much better in a 75% congruent Stroop condition after performing a 0% congruent Stroop condition.

Additionally, they replicated Funes et al. (2010b) finding that global congruency effects can transfer from one stimulus type to another. Finally, it should be noted that they failed to find conflict adaptation effects when the task trials alternated, suggesting that again location information was being effectively used in one control process (conflict adaptation), but not in another (proportion congruency). These findings support the hypotheses that context effects can influence performance on unrelated trials and that different measures of cognitive control can be used to tap separate underlying processes. Hence, controlled manipulation of context can be used to assist in identifying boundary conditions in which cognitive control utilizes different processes.

Present Experiments

With these issues in mind, the goal of the present series of studies was to examine the relationship between S-S (Stroop) and S-R (Simon) interference, cognitive control, and working memory with the purpose of identifying boundary conditions. Boundary conditions in which the type of interference differentially affects measures of cognitive control would be informative to both theoretical understanding of the tasks from which the interference is derived, as well as cognitive control. Finding limiting conditions for cognitive control measures could help facilitate our understanding of how bottom-up and top-down processes contribute to control functions. Furthermore, identification of such limits with respect to cognitive control and working memory would assist in clarifying the grey area in which these concepts overlap, thereby allowing each area to refine its theoretical understanding.

To this end, interference, in these experiments, was manipulated while measures of proactive control, reactive control, and working memory capacity were assessed. The aim was to identify situations in which: 1) Interference caused cognitive control to respond differently, and

2) working memory capacity responded to support changes in cognitive control. More specifically, can changes in the type of interference result in differences in how cognitive control is used? And, can the processes identified by working memory tasks interact with changes in cognitive control? These situations would be fruitful for refining our understanding of cognitive control, and how it is related to another broad construct, working memory. In Experiment 1, the issue was addressed by examining the effects of S-S (Stroop) and S-R (Simon) within the same task. Unlike previous research, Experiment 1 used different congruency proportions for each type of interference within the combined spatial Stroop/Simon task to reveal differences that arose from dimensional overlap within a task context. That is, the separate congruency proportions for each interference type allowed us to see the relative influence of one type of interference (e.g., S-R), both globally and locally, on the other type of interference (e.g., S-S). Since this experiment did not rely on the use of a 50% congruent test list, we were able to look for effects that might be restricted to context, such as only affecting a mostly congruent or incongruent list.

Experiment 2 expanded upon the findings of Experiment 1 by conducting the spatial Stroop and Simon tasks in isolation from one another on different days. The separation of the two tasks afforded a more precise measure of each task's interference in a pure environment, while still managing to keep the tasks virtually identical. Of importance here, previous research has either combined the tasks (Liu et al., 2004; Meier & Kane, 2011; Funes et al., 2010a; 2010b, Torres-Quesada et al., 2013; Egner et al., 2007; Verbruggan, Liefooghe, Notebaert, & Vandierendonck, 2005) or used methodologically different versions (Peterson et al., 2002; Stins, Polderman, Boomsma, & de Geus, 2005). The goal of Experiment 2 was to examine each task in a directly comparable, but isolated, form so that the effects can be assessed more "purely."

Experiment 1

Experiment 1 was designed to examine the role of each type of interference on the other through context effects. For example, a response to S-S interference might employ a higher degree of interference control than S-R interference. This might cause S-R differences to be much smaller and harder to detect, which could result in the underestimation of any links between cognitive control measures and working memory. The goal of Experiment 1 was to extend the findings of previous research by controlling for context effects through the systematical manipulation of the congruency portion of each interference type (Table 1). The carry-over effects from one interference type to the other could be effectively measured by comparing across conditions that differed in their respective congruency proportions: 75% S-S congruent and 75% S-R congruent (75s/75r); 75% S-S congruent and 25% S-R congruent (75s/25r); 25% S-S congruent and 75% S-R congruent (25s/75r); 25% S-S congruent and 25% S-R congruent (25s/25r).

Table 1. Experiment 1 manipulation.

	S-R 25% congruent	**S-R 75% congruent**
S-S 25% congruent	25s/25r	25s/75r
S-S 75% congruent	75s/25r	75s/75r

By combining congruency proportions in this way, the experiment allowed the comparison of changes in one interference congruency (e.g., 75% congruent S-R vs. 25% congruent S-R), to another congruency proportion that was held constant (e.g., 75% congruent S-S or 25% congruent S-S). Furthermore, by not limiting the comparison group to 50% congruence, we can evaluate this carry-over influence while control processes are being employed by the “transferred to” group. To clarify, 50% congruent lists offer an effective baseline for evaluating whether an influential effect shifts behavior. However, these lists do not necessarily engage control processes in the same way that mostly congruent or incongruent lists do (Logan & Zbrodoff, 1979; Kane & Engle, 2003). For example, Kane and Engle (2003) showed that the effect of proactive control was more dominant in highly congruent lists where goal maintenance is required, and reactive control was more indicative of individual differences in highly incongruent lists where the task goal is regularly reinforced. Therefore, it is an empirical question whether any carry-over effects are differentially affected by situations that rely more heavily on one form of control over the other. Such questions cannot be answered when the baseline congruence is 50% because the 50% congruency does not engage control processes to bias information in accordance with congruency. Thus, the present experiment created situations in which the baseline was either 75% or 25% congruent with the purpose of looking for such limits.

Under these conditions, it is predicted that context should have an effect in one of 2 ways. If local context information is used by control processes, then those measures would exhibit little disruption from the paired influence. That is, it is expected that the 75% S-R congruent trials would show the same interference pattern whether they were paired with 25% S-S congruent trials (e.g., 50% overall list-wide congruence) or with 75% S-S congruent trials (e.g., 75% overall list-wide congruence). The results would show main effects for each interference type, but there would not be interactions with the other type. In other words, 75% S-S groups would be different than 25% S-S groups on S-S trials regardless of S-R congruency.

However, it is possible that the two interferences are not completely independent and can have effects that mesh together. Recall, Hutchison (2011) demonstrated that item-based and list-wide congruency proportions were separate but related to one another. Under this interpretation, the overall congruency proportions would affect the individual interference list, and this effect should be most noticeable in low working memory individuals since they are highly susceptible to interference (Hutchison, 2011; Kane & Engle, 2003). This perspective would predict both main effects for interference type, but also an interaction. For example, 75% S-S groups would differ from one another based on S-R congruence, and provide main effects for both S-S and S-R congruency. However, they may not be influenced equally. The 75% S-S condition may respond strongly to 25% S-R interference, while the 25% S-S condition may only have a weak impact from the 25% S-R condition. A mismatch like this would produce interactions beyond main effects of each.

Methods

Participants. 284 undergraduate students from LSU volunteered to participate in the study. In exchange for participation, the students received partial course credit. The participants were run in groups of up to 8 at a time, and were randomly assigned to conditions based on their subject number. Therefore, any given session would contain at most 2 participants from each condition. Unfortunately, a number of participants had to be cut prior to analysis. 20 were removed for failing to respond on more than 10% of the trials. 6 were removed for error rates in excess of 25% on neutral trials. 44 participants did not maintain sufficient accuracy on one of the three working memory tasks, and a final 18 were removed for having individual working memory task scores that were 2.5 standard deviations or more apart. The remaining 196 participants were in the 4 conditions as follows: 56 in the 75s/75r, 49 in the 75s/25r, 42 in the 25s/75r, and 49 in the 25s/25r.

Materials. Participants were seated in front of a desktop computer that ran each of the required tasks. The participants were first asked to perform a modified version of the spatial Stroop/Simon task. After that, they were given a working memory battery consisting of reading span (Rspan), operation span (Ospan), and symmetry span (Symspan). The order of the working memory tasks was always Ospan, then Symspan, then Rspan.

Modified Simon/Stroop Task. In this version, participants responded to the vertical orientation of an arrow. The arrows could appear in the center, left of center, right of center, top of center, or bottom of center. The participant was instructed to respond to the arrow's orientation by pressing the 'F' key and the 'J' key for 'Up' and 'Down'. The button assignment was counterbalanced across participants.

Working Memory Tasks. The three working memory assessments used in this study were: The Operation span task (Ospan), the Symmetry span (Symspan) task, the Reading span (Rspan). The purpose of using three tasks was to form a composite working memory score that should limit any task-specific sources of variance. To that end, a spatial task (SymSpan) and a verbal task (Rspan) were added to the traditionally used working memory task, the Ospan. These tasks were performed on the computer in their automated format (Unsworth, Heitz, Schrock, & Engle, 2005). In the Operation span task, participants were shown simple math problems that they must solve (e.g., 2 + 8/2 = ?). Then, they were shown an answer to the problem and must indicate whether or not it was the correct answer. Finally, they were given a letter to remember. This repeated 3-7 times, after which, they were required to select the recalled letters in serial order.

In the Symmetry span, participants determined whether the pattern they were shown is symmetrical along the vertical axis. After making their symmetry judgment, they were shown a location on the spatial grid to remember. This only repeated 2-5 times since capacity limits in this task are typically smaller than those of Rspan or Ospan. Afterward, they were required to recall the spatial locations in serial order.

Finally, in the Reading span, participants judged whether or not a sentence that they were presented with made sense. The non-sense sentences were all made from sentences that were grammatically correct with a key noun replaced with another noun that did not fit. After making the sentence judgment, participants were given a letter to remember, as in the Ospan. Also similar to the Ospan, this sequence repeated 3-7 times, and then they were asked to recall the letters in serial order. Additionally, it should be noted that each of the tasks required the participants to perform the judgment task (e.g., math problem for Ospan) with at least an 85% overall accuracy. This was to ensure that an appropriate amount of effort was devoted to the processing component of the 3 tasks, and not neglected in favor of recalling the memory items.

Procedure. Participants came into the lab and filled out the appropriate consent form. They were then randomly assigned to one of the 4 groups: 75s/75r, 75s/25r, 25s/75r, 25s/25r. Afterwards, instructions for the modified Simon/Stroop task was presented on the computer screen in front of them while also being simultaneously read by the experimenter. The participants conducted a brief practice block that covered all 10 possible arrow/location configurations twice (e.g., 20 trials), before being taken into the main test block. This block consisted of 360 trials. Of these 360 trials, 40 trials were always neutral (in the center). The remaining trials were divided by the particular grouping. For example, the 75s/25r group had 40 S-S trials that were incongruent, 120 S-S trials that were congruent, 40 S-R trials that were congruent, and 120 S-S trials that were incongruent. This breakdown of trials resulted in 75% congruence for the two S-S locations, and 25% congruence for the S-R locations. After completing the modified Simon/Stroop, participants completed the Ospan, followed by the Symspan, and finally the Rspan.

Results

Prior to analysis, the working memory totals were converted into z-scores. These scores were then averaged into a composite working memory total. The means and standard deviations for the working memory tasks can be found in Table 2, while the correlations between working memory tasks can be found in Table 3. When all participants were taken together, all 3 groups displayed the expected correlations. However, it should be noted that one of the groups did not share the same significant correlation between all 3 tasks as the other conditions. It is unclear why the 25s/75r condition showed such poor correlations between the Ospan and other measures. Therefore, the working memory capacity score used in the analyses below was formed from a composite which consisted only of the SymSpan and Rspan, as these tasks were correlated within all 3 groups.

Table 2. Experiment 1 working memory task totals. Values reflect total correct items recalled. Standard deviation in parentheses.

	Ospan total	**SymSpan total**	**Rspan total**
All participants	55.10 (14.80)	27.24 (7.64)	48.48 (16.07)
75s/75r	58.45 (12.83)	28.91 (8.00)	47.88 (14.38)
75s/25r	54.35 (13.86)	27.88 (7.49)	53.98 (13.56)
25s/75r	56.02 (12.59)	26.45 (6.73)	46.93 (16.93)
25s/25r	51.24 (18.57)	25.37 (7.83)	45.00 (18.39)

Table 3. Experiment 1 working memory correlations. Values represent Pearson correlation values. *P*-value is provided in parentheses.

	Ospan_SymSpan	**Ospan_Rspan**	**SymSpan_Rspan**
All participants	.425 (.000)	.497 (.000)	.549 (.000)
75s/75r	.368 (.005)	.528 (.000)	.487 (.000)
75s/25r	.379 (.007)	.402 (.004)	.324 (.023)
25s/75r	.071 (.654)	.068 (.667)	.745 (.000)
25s/25r	.651 (.000)	.806 (.000)	.656 (.000)

Unless otherwise stated, all analyses in Experiment 1 were conducted using a General Linear Model in which S-S congruency and S-R congruency were between-subjects factors, and working memory capacity was entered as a covariate. Due to the complexity of the experimental design, the custom model that was specified examined main effects of each, as well as, interactions between the factors. The resulting model thus contained 7 tests: S-S, S-R, WMC, S-S x S-R, S-S x WMC, S-R x WMC, and S-S x S-R x WMC. This full model was necessary to uncover relationships that might occur between the contexts, such as S-S or S-R, and other factors. The main effects are sufficient for separating a global effect (main effect of both S-S and S-R) from a context effect (main effect of S-S only when evaluating S-S trials). However, the interactions are important for examining the extent to which relationships extend between the variables and working memory capacity.

S-R Influence on S-S. For these analyses, all of the S-R trials were removed to restrict focus to only the S-S trials. Analysis is broken down by control type, proactive vs. reactive.

Proactive Control Analyses. First, error rates for the 4 conditions were analyzed. The analyses were conducted for the congruent trials and incongruent trials separately, since they differed in overall proportion across groups. The means and standard deviations for the congruent error rates can be found in Table 4. The results indicated that the S-S congruency manipulation was significant for congruent errors, $F(3, 188) = 4.07$, $p = .045$, $\eta_p^2 = .021$, which demonstrates that the manipulation worked. Participants in the 75% congruent S-S conditions, where these trials were common, made fewer errors than those in the 25% congruent S-S conditions in which these trials were infrequent. The S-R congruency manipulation did not have a significant effect on the S-S trials, $F(3, 188) = 1.08$, $p = .300$, $\eta_p^2 = .006$, nor was the S-S x S-R interaction significant, $F(3, 188) = .953$, $p = .330$, $\eta_p^2 = .005$. This pattern is expected if control is being exerted at a context-specific level (Crump et al., 2006). That is, control processes are being engaged specifically to the S-S trials, regardless of when these trials occur, and the effects, if any, of processing the S-R trials are not altering the control exerted on these S-S trials.

Table 4. Experiment 1 S-S congruent error means. Values reflect percentages. Standard deviation is in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	2.32 (2.13)	3.00 (3.05)
S-S 25%	3.83 (3.61)	4.02 (4.60)

There was also a significant effect of working memory capacity, *F*(3, 188) = 12.03, *p* = .001, η_p^2 = .060. However, there was not an interaction with the other factors: S-S x WMC, *F*(3, 188) = .600 *p* = .439, η_p^2 = .003, S-R x WMC, *F*(3, 188) = .025 , *p* = .875, η_p^2 = .000, or S-S x S-R x WMC, *F*(3, 188) = 1.34, *p* = .248, η_p^2 = .007. A linear regression was conducted on the S-S congruent error rate with working memory capacity as a predictor which showed that higher-capacity individuals were less likely to make errors that lower-capacity individuals, *b* = -.011, *t*(194) = -3.78, *p* < .001. At this point in the analyses, it is unclear whether working memory capacity is being supportive at the global (task) level, or that of the S-S trials context. The insignificant interaction between WMC and the other factors appears to imply global. It is worth noting that previous research using Stroop tasks have shown that working memory capacity is usually related to error rates in mostly congruent lists only (Kane & Engle, 2003; Hutchison, 2011; Meier & Kane, 2013). Thus, the present lack of sensitivity of working memory capacity and the S-S congruency manipulation seems anomalous. However, Meier & Kane (2013) argue that the goal neglect that is believed to drive the relationship between working memory capacity and errors can be triggered by situations that produce a repetition of stimulus features across trials. Because the present experiment was designed to minimize the differences between the S-S and S-R trials, a repetition of some stimulus features was likely to occur between nearly any two trials. For example, 50% of the trials are made up of upward pointing arrows regardless of whether the trial is S-S, S-R, or neutral. Orientation is the only relevant feature for task goals, and it is easily possible for this feature to repeat, not to mention the other irrelevant feature. It is unclear how often stimulus features need to repeat in order to produce a relationship with working memory capacity, however, the ample possibility of at least one feature repeating (either stimulus location or orientation) allows these results to still be reconciled with the goal neglect account, despite the contrast to previous research. Such reconciliation would require further research involving more control over which features repeat as well as, when and how often they do.

The results from the incongruent error rates were similar to the congruent ones. The means and standard deviations can be found in Table 5. There was a main effect of the S-S congruency manipulation, $F(3, 188) = 18.53$, $p < .001$, $\eta_p^2 = .090$. This again showed that the manipulation was working as there were lower error rates in the 25% congruent conditions which encountered these trials more frequently than the 75% congruent conditions. The S-R congruency manipulation again did not have a significant effect on the S-S trials, $F(3, 188) = .004$, $p = .949$, $\eta_p^2 = .000$, nor was there a significant S-S x S-R interaction, $F(3, 188) = .460$, $p = .50$, $\eta_p^2 = .002$. As with the congruent trials, this pattern reflects context-specific control. Participants were able to respond to the S-S trials without significant influence of the S-R congruency.

Table 5. Experiment 1 S-S incongruent error means. Values reflect percentages. Standard deviation is in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	7.48 (6.00)	7.38 (4.99)
S-S 25%	4.74 (5.44)	4.31 (3.91)

Working memory capacity was significant for the incongruent error rates like with the congruent trials, $F(3, 188) = 5.38$, $p = .021$, $\eta_p^2 = .028$. And again, there was not an interaction with the other measures: S-S x WMC, $F(3, 188) = .247$ $p = .620$, $\eta_p^2 = .001$, S-R x WMC, $F(3, 188) = .028$, $p = .868$, $\eta_p^2 = .000$, or S-S x S-R x WMC, $F(3, 188) = 1.69$, $p = .195$, $\eta_p^2 = .009$. A linear regression was conducted on the S-S incongruent error rate with working memory capacity as a predictor, but it was not significant, $b = -.006$, $t(194) = -1.20$, $p = .231$. Thus, the relationship between working memory capacity and the incongruent S-S errors that created the effect in the GLM analysis is unclear.

Next, analysis is turned from error rates to reaction times. For these analyses, reaction times below 200ms or greater than 1000ms were excluded from analysis. Facilitation effects were examined first. Facilitation scores were created for each individual by subtracting their mean correct congruent trial RT from the mean correct neutral trial RT. Positive numbers indicate increased amounts of facilitation. The means and standard deviations can be found in Table 6. The analysis revealed that S-S congruency was significant for facilitation effects, $F(3, 188) = 29.35$, $p < .001$, $\eta_p^2 = .135$. This was to be expected, since it again verifies that our S-S congruency manipulation effecting performance. Participants were having faster responses in the 75% congruent S-S condition than the 25% congruent condition. As with previous analyses, the S-R congruency manipulation again did not have a significant effect on the S-S trials, $F(3, 188) = 2.38$ $p = .125$, $\eta_p^2 = .012$, nor was there a significant S-S x S-R interaction, $F(3, 188) = 2.69$, $p = .103$, $\eta_p^2 = .014$. This is consistent with the previous 2 error rate analyses which demonstrated that participants were responding at a context-specific level.

Table 6. Experiment 1 S-S facilitation. Values reflect differences in RT (msec). Standard deviation is in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	.76 (20.64)	1.90 (20.78)
S-S 25%	-24.76 (27.13)	-12.85 (29.50)

There was no effect of working memory capacity, $F(3, 188) = .40$, $p = .528$, $\eta_p^2 = .002$, nor were there any interactions between working memory capacity and either S-S congruency, $F(3, 188) = 1.41$, $p = .237$, $\eta_p^2 = .007$ or S-R congruency, $F(3, 188) = 1.29$, $p = .258$, $\eta_p^2 = .007$

or both, $F(3, 188) = .055$ $p = .815$, $\eta_p^2 = .000$. It is curious that working memory differences did not yield any significance here given that facilitation effects, like interference effects, tend to be tied to error rates. Unfortunately, the task design does not permit a more detailed reaction time analysis, as has been used recently with the Stroop task (Unsworth, Redick, Spillers, & Brewer, 2012). In their analysis, Unsworth et al. (2012) divided RTs into quintile bins based on fastest to slowest. The relationship between working memory capacity and a Stroop, antisaccade, and four-choice RT task were limited to those RTs in the slowest end of the distribution. It is therefore possible that the relationship could be masked within the present data set if it only appears in 20% or less of the trials. Therefore, conclusive interpretation of the present results is not possible beyond the stating of the finding.

Interference effects were examined next. The means and standard deviations for the interference effects can be found in Table 7. Interference effects are derived from subtracting the mean correct incongruent trial RT from the mean correct neutral RT. As with facilitation effects, this leads to positive numbers indicating more amounts of interference. In looking at the interference effects, it was found that the S-S congruency manipulation continued to influence the pattern of results with participants exhibiting much slower responses in the 75% congruent condition, $F(3, 188) = 43.07$, $p < .001$, $\eta_p^2 = .186$. Also remaining consistent with the previous analyses, the S-R congruency manipulation again did not have a significant effect on the S-S trials, $F(3, 188) = 1.86$, $p = .174$, $\eta_p^2 = .010$, nor was there a significant S-S x S-R interaction, $F(3, 188) = .258$, $p = .612$, $\eta_p^2 = .001$. These results provide consistent evidence across all 4 proactive control measures that participants were engaging control at the specific level of the S-S trial context. All were sensitive to the S-S congruency manipulation, while none of the 4 measures showed significant influence of the S-R trials, nor an interaction.

Table 7. Experiment 1 S-S interference. Values reflect differences in RT (msec). Standard deviation is in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	56.75 (24.61)	47.34 (30.06)
S-S 25%	30.33 (22.19)	26.44 (27.03)

The results from the analyses involving working memory capacity are a little different. There was not a main effect of working memory capacity, as was observed in the previous error analyses, $F(3, 188) = .005$, $p = .941$, $\eta_p^2 = .000$. Working memory capacity did not interact with S-R, $F(3, 188) = 1.15$, $p = .284$, $\eta_p^2 = .006$, or S-S x S-R, $F(3, 188) = .010$, $p = .919$, $\eta_p^2 = .000$ either. There was an interaction, however, with S-S congruency and WMC, $F(3, 188) = 8.79$, $p = .003$, $\eta_p^2 = .045$. Linear regressions were conducted on S-S interference with working memory capacity as a predictor separately for the 25% and 75% congruent S-S groups. The results showed that 75% congruent S-S groups had lower interference scores as working memory capacity increased, $b = -7.68$, $t(194) = -2.05$, $p = .042$. In contrast, the 25% congruent S-S groups had *higher* error rates as working memory increased, $b = 6.26$, $t(194) = 2.21$, $p = .030$. This finding is intriguing as it shows that participants in the 25% congruent S-S conditions are exhibiting a *reversal* of their advantage in the 75% condition. To foreshadow later results, a similar reversal only appears one other time across both experiments and was not significant.

Reactive Control Analyses. Since all reactive control measures are based on RT, the trimming procedure was maintained in which all RTs were cut if they were faster than 200ms or longer than 1000ms. Post-error slowing rates were analyzed first. For this analysis, mean RT from correct trials in which the previous trial was correct were subtracted from the mean RT from correct trials in which the previous trial was incorrect. This means that positive numbers indicate greater levels of slowing. The means and standard deviations for post-error slowing can be found in Table 8. Neither S-S congruency, $F(3, 188) = .016$, $p = .899$, $\eta_p^2 = .000$, S-R congruency, F(3,

188) = .367, p = .545, η_p^2 = .002, or an S-S x S-R interaction, $F(3, 188)$ = .282, p = .596, η_p^2 = .001, were significant of post-error slowing which would seem to support the argument that it is a global process that is relatively unaffected by task dimensions, and fits with previous research which has shown that post-error slowing is not affected by task changes, nor task goal changes (Notebaert et al., 2011).

Table 8. Experiment 1 S-S post-error slowing. Values reflect differences in RT (msec) and larger values indicate more slowing. Standard deviations are in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	31.27 (37.10)	37.80 (31.43)
S-S 25%	34.74 (33.57)	35.96 (42.01)

The amount of post-error slowing similarly did not draw any relationship with working memory capacity, whether as a main effect, $F(3, 188)$ = 1.54, p = .216, η_p^2 = .008, or with any possible interaction: S-S x WMC, $F(3, 188)$ = .727, p = .395, η_p^2 = .004, S-R x WMC, $F(3, 188)$ = .003, p = .96, η_p^2 = .000 or S-S x S-R x WMC, $F(3, 188)$ = 1.64, p = .202, η_p^2 = .009. The lack of a relationship with working memory suggests that the control exerted for post-error slowing does not require additional processing resources despite being a global process. That is, this form of control is a low-cost process that is sensitive to task performance, but not task goals.

Finally, conflict adaptation effects were examined. All 4 conflict types, cC, iC, iI, and cI, were analyzed only if the participant answered correctly. Initially, only the trials in which the S-S trials repeated were examined. For these analyses, participants were removed if they did not have at least 1 trial RT for each of the 4 conflict types. This trimming resulted in only 2 participants being removed from these analyses. The mean RT for the 4 conflict types are graphed by group in Figures 2, 3, 4 & 5. To test for conflict adaptation effects, a 2 factor within-subjects variable was added to the GLM model for previous trial congruency type. Current congruent and current incongruent trials were run in separate analyses.

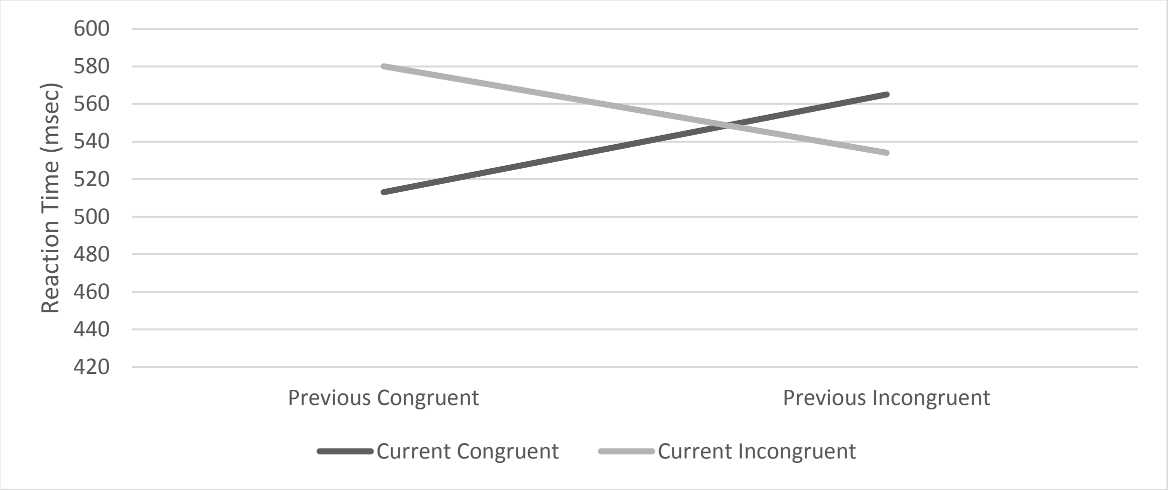

Figure 2. 25s/25r S-S repeating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

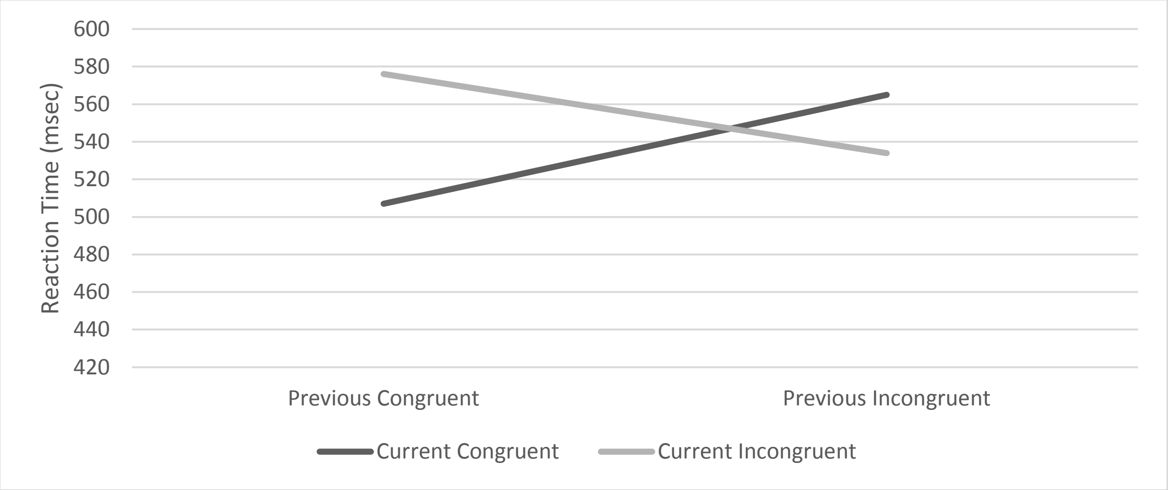

Figure 3. 25s/75r S-S repeating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

For the current incongruent trials (soft grey line in the Figures), the results showed a main effect of previous congruency type, *F*(3, 186) = 79.74, $p < .001$, $\eta_p^2 = .300$. Thus, incongruent trials are significantly slower when the previous trial was congruent (cI) than when the preceding trial was also incongruent (iI). This slowing due to congruency mismatch is the conflict adaptation effect and is reliable when the trial type repeats (Funes et al., 2010a; Funes et al., 2010b; Notebaert et al., 2011; Torres-Quesada et al., 2013). The previous trial congruency did not interact with any of the between-subjects factors: S-S x Previous, *F*(3, 186) = .015, *p* = .903, $\eta_p^2 = .000$, S-R x Previous, *F*(3, 186) = .361, *p* = .548, $\eta_p^2 = .002$, or WMC x Previous, *F*(3, 186) = 1.91, *p* = .169, $\eta_p^2 = .010$. Previous trial congruency also did not interact with any of the between-subjects interactions either: S-S x S-R x Previous, *F*(3, 186) = .145, *p* = .704, $\eta_p^2 = .001$, S-S x WMC x Previous, *F*(3, 186) = 1.78, *p* = .184, $\eta_p^2 = .009$, S-R x WMC x Previous, *F*(3, 186) = 1.95, *p* = .164, $\eta_p^2 = .010$, S-S x S-R x WMC x Previous, *F*(3, 186) = .518, *p* = .472, $\eta_p^2 = .003$. The lack of interaction between previous trial congruency and S-R congruency was not surprising since the analysis was restricted to S-S trial repeats, and conflict adaptation effects go away when task trials alternate.

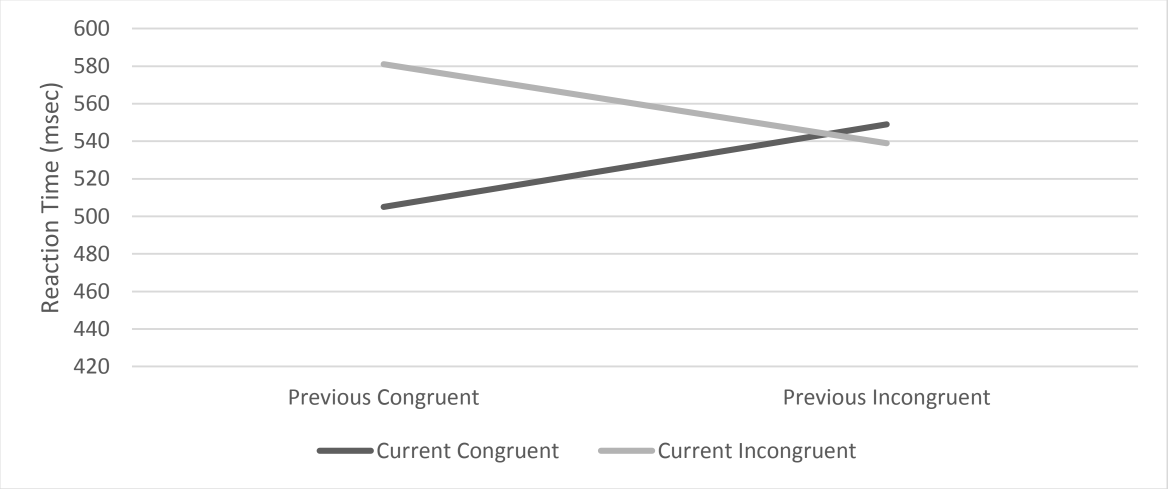

Figure 4. 75s/25r S-S repeating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

The analysis also yielded largely insignificant effects for the between-subjects factors outside of any interaction with previous trial congruency: S-S, *F*(3, 186) = .866, *p* = .353, $\eta_p^2 = .005$, S-R, *F*(3, 186) = .179, *p* = .673, $\eta_p^2 = .001$, S-S x S-R, *F*(3, 186) = .142, *p* = .707, $\eta_p^2 = .001$, S-S x WMC, *F*(3, 186) = 1.74, *p* = .189, $\eta_p^2 = .009$, S-R x WMC, *F*(3, 186) = .434, *p* = .511, $\eta_p^2 = .002$, S-S x S-R x WMC, *F*(3, 186) = .617, *p* = .433, $\eta_p^2 = .003$. The lack of a main effect of S-S congruency was slightly disconcerting since it was expected that participants would respond more quickly in the 25% S-S congruency condition to the incongruent trials regardless of previous trial type. This is further confusing by the fact that interference effects, which are derived from these RTs, were found to be sensitive to the S-S manipulation. It is unclear why the present results do not mirror those analyses.

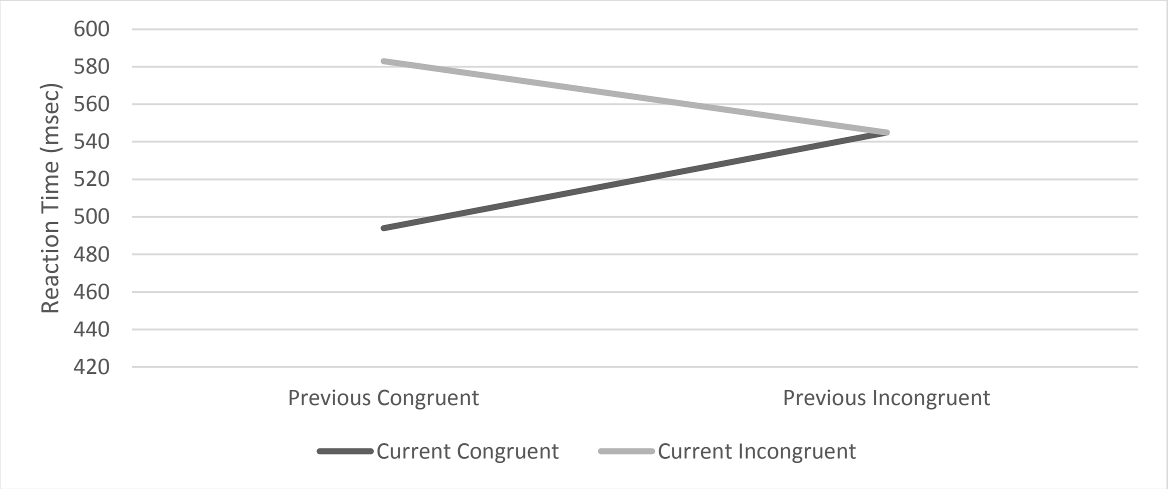

Figure 5. 75s/75r S-S repeating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

There was one between-subjects factor that pulled a barely significant effect, WMC, $F(3, 186) = 3.88$, $p = .050$, $\eta_p^2 = .02$. While unrelated to conflict adaptation, this effect was examined further by averaging the incongruent trials across previous congruency types and entering them into a linear regression with WMC as the predictor. The results showed that higher-span individuals had overall faster RT than lower-span individuals, $b = -10.69$, $t(192) = -2.27$, $p = .024$. This link with working memory capacity is interesting because of the other variable involved. Working memory capacity is significant at the level of *incongruent trial RT*. It did not interact with previous congruency type, and therefore did not reveal itself to interact with conflict adaptation effects. Moreover, working memory capacity did not have a main effect for the interference effect variable in the proactive control analyses above which consisted of incongruent trial RT – neutral trial RT. These results might indicate that there may be a stronger underlying relationship between WMC and RTs that is restricted to the slower RTs in the distribution, and therefore being masked in the present analyses (Unsworth et al., 2012).

The same analyses were performed on the congruent trials (dark grey line in Figures) to examine them for conflict adaptation effects as well. The results showed a main effect of previous congruency type, $F(3, 186) = 143.03$, $p < .001$, $\eta_p^2 = .435$. Thus, congruent trials are significantly slower when the previous trial was incongruent (iC) than when the preceding trials was also congruent (cC). As in the incongruent analyses, the previous trial congruency did not interact with any of the between-subjects factors: S-S x Previous, $F(3, 186) = .487$, $p = .486$, $\eta_p^2 = .003$, S-R x Previous, $F(3, 186) = .267$, $p = .61$, $\eta_p^2 = .001$, or WMC x Previous, $F(3, 186) = .023$, $p = .881$, $\eta_p^2 = .001$. Previous trial congruency also did not interact with any of the between-subjects interactions either: S-S x S-R x Previous, $F(3, 186) = .000$, $p = .985$, $\eta_p^2 = .000$, S-S x WMC x Previous, $F(3, 186) = .205$, $p = .651$, $\eta_p^2 = .001$, S-R x WMC x Previous, $F(3, 186) = .122$, $p = .727$, $\eta_p^2 = .001$, S-S x S-R x WMC x Previous, $F(3, 186) = .147$, $p = .702$, $\eta_p^2 = .001$. Again, the lack of an interaction with S-R was not surprising since these are repeat S-S trials.

With respect to the between-subjects factors outside of any interaction, the analysis showed no significant effects: S-S, $F(3, 186) = 2.76$, $p = .099$, $\eta_p^2 = .015$, S-R, $F(3, 186) = .135$, $p = .714$, $\eta_p^2 = .001$, WMC, $F(3, 186) = .447$, $p = .504$, $\eta_p^2 = .002$, S-S x S-R, $F(3, 186) = .002$, $p = .961$, $\eta_p^2 = .000$, S-S x WMC, $F(3, 186) = 2.36$, $p = .127$, $\eta_p^2 = .013$, S-R x WMC, $F(3, 186) = .647$, $p = .422$, $\eta_p^2 = .003$, S-S x S-R x WMC, $F(3, 186) = .274$, $p = .601$, $\eta_p^2 = .001$. Again, there is a lack of a main effect of S-S congruency which would indicate that participants in the 75% congruent S-S conditions were responding faster to these congruent trials regardless of previous congruent trial type. It is unclear why this effect was not observed here or in the incongruent trials in the previous analyses.

Finally, the same analyses were conducted on the alternation trials in which the previous trial was S-R, but the current trial is S-S. Participants were removed if they did not have at least 1 trial RT for each of the 4 conflict types. This trimming resulted in 4 participants being removed from these analyses. The mean RT for the 4 conflict types are graphed by group in Figures 6, 7, 8 & 9.

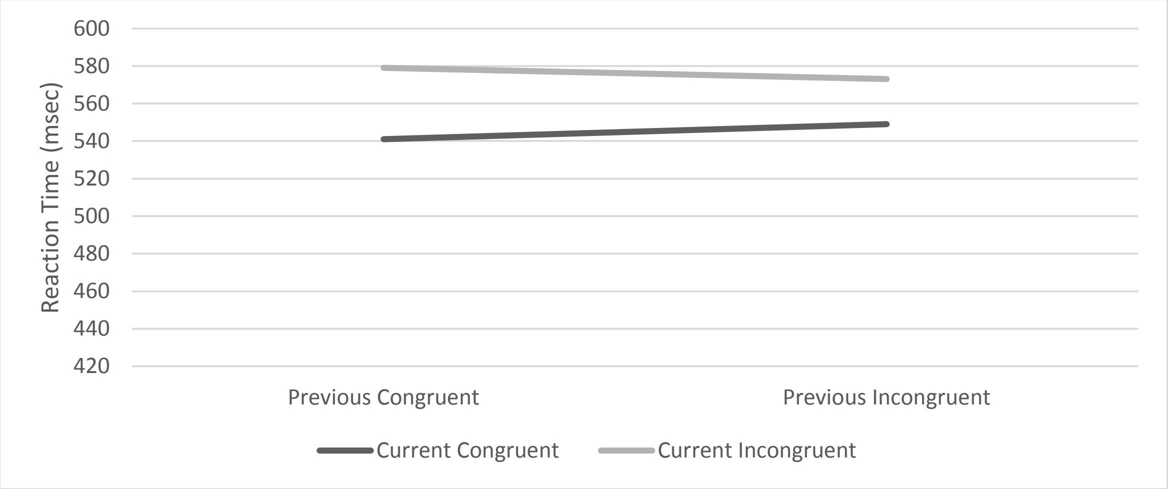

Figure 6. 25s/25r S-S alternating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

The results begin with the incongruent trials (soft grey line in Figures). In this case, there was not a significant effect of previous trial congruency, $F(3, 184) = 1.88$, $p = .172$, $\eta_p^2 = .010$. The lack of an effect here means that there was no conflict adaptation when the trials alternated. This finding is in line with previous research that has demonstrated that conflict adaptation effects go away when context (task) trials change (Funes et al., 2010a; Funes et al., 2010b; Notebaert et al., 2011; Torres-Quesada et al., 2013). There was nearly an interaction between previous trial congruency and S-R congruency, $F(3, 184) = 3.76$, $p = .054$, $\eta_p^2 = .020$, because the 75% S-R congruent were faster on cI trials (562ms) but slow on iI trials (574ms), as compared to the 25% congruent S-R conditions (571ms and 570ms respecitively). On the cI trials, the 75% congruent S-R conditions were following a frequently encountered congruent S-R trial. On the iI trials, they were following the infrequently encountered incongruent trial. This minor difference may be what underlies the trending to significance.

Previous trial congruency was not found to interact with any of the other effects or interactions: S-S x Previous, $F(3, 184) = .481$, $p = .489$, $\eta_p^2 = .003$, WMC x Previous, $F(3, 184) = .023$, $p = .880$, $\eta_p^2 = .000$, S-S x S-R x Previous, $F(3, 184) = .072$, $p = .788$, $\eta_p^2 = .000$, S-S x WMC x Previous, $F(3, 184) = .817$ $p = .367$, $\eta_p^2 = .004$, S-R x WMC x Previous, $F(3, 184) = 1.97$, $p = .162$, $\eta_p^2 = .011$, S-S x S-R x WMC x Previous, $F(3, 184) = .002$, $p = .969$, $\eta_p^2 = .000$.

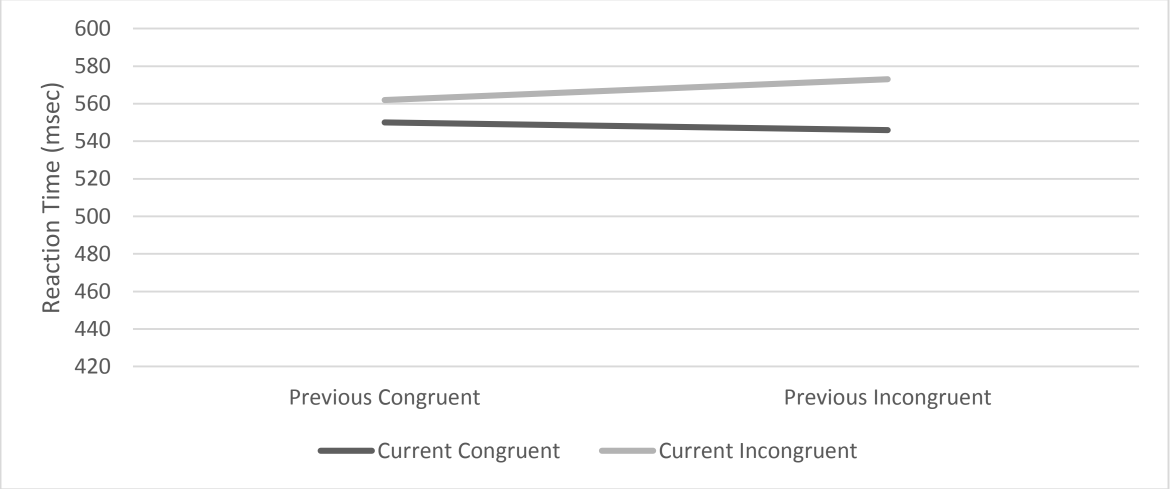

Figure 7. 25s/75r S-S alternating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

With respect to the between-subjects factors outside of any interaction, the analysis showed no significant effects: S-S x Previous, $F(3, 184) = .227$, $p = .634$, $\eta_p^2 = .001$, S-R x Previous, $F(3, 184) = .001$, $p = .975$, $\eta_p^2 = .000$, WMC x Previous, $F(3, 184) = 2.20$, $p = .139$, $\eta_p^2 = .012$, S-S x S-R x Previous, $F(3, 184) = .621$, $p = .432$, $\eta_p^2 = .003$, S-S x WMC x Previous, $F(3, 184) = 1.07$, $p = .301$, $\eta_p^2 = .006$, S-R x WMC x Previous, $F(3, 184) = 1.26$, $p = .262$, $\eta_p^2 = .007$, S-S x S-R x WMC x Previous, $F(3, 184) = .543$, $p = .462$, $\eta_p^2 = .003$.

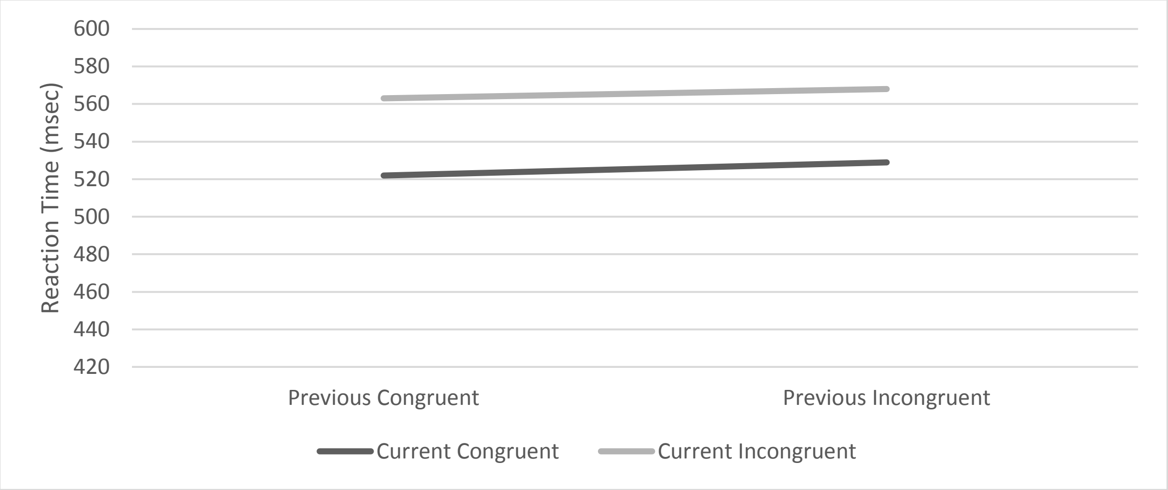

Figure 8. 75s/25r S-S alternating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

In turning to the congruent trials (dark grey line in Figures), there was again no significant effect of previous trial congruency, *F*(3, 184) = 1.49, *p* = .224, η_p^2 = .008. This further demonstrates that the conflict adaptation effects observed with the repeat trials disappear when the context (task) alternates. Previous trial congruency also did not interact with nearly any of the other effects or interactions: S-S x Previous, *F*(3, 184) = .473, *p* = .492, η_p^2 = .003, S-R x Previous, *F*(3, 184) = 1.96, *p* = .164, η_p^2 = .011, WMC x Previous, *F*(3, 184) = .771, *p* = .381, η_p^2 = .004, S-S x S-R x Previous, *F*(3, 184) = .049, *p* = .825, η_p^2 = .000, S-S x WMC x Previous, *F*(3, 184) = .030, *p* = .864, η_p^2 = .000, S-R x WMC x Previous, *F*(3, 184) = .017, *p* = .897, η_p^2 = .000. The exception was a significant 4-way interaction between previous trial congruency, S-S congruency, S-R congruency, and WMC, *F*(3, 184) = 7.71, *p* = .006, η_p^2 = .040. To examine this complex interaction, separate linear regressions were conducted for the cC and iC trials with WMC as the predictor. These linear regressions were conducted for each of the 4 conditions separately.

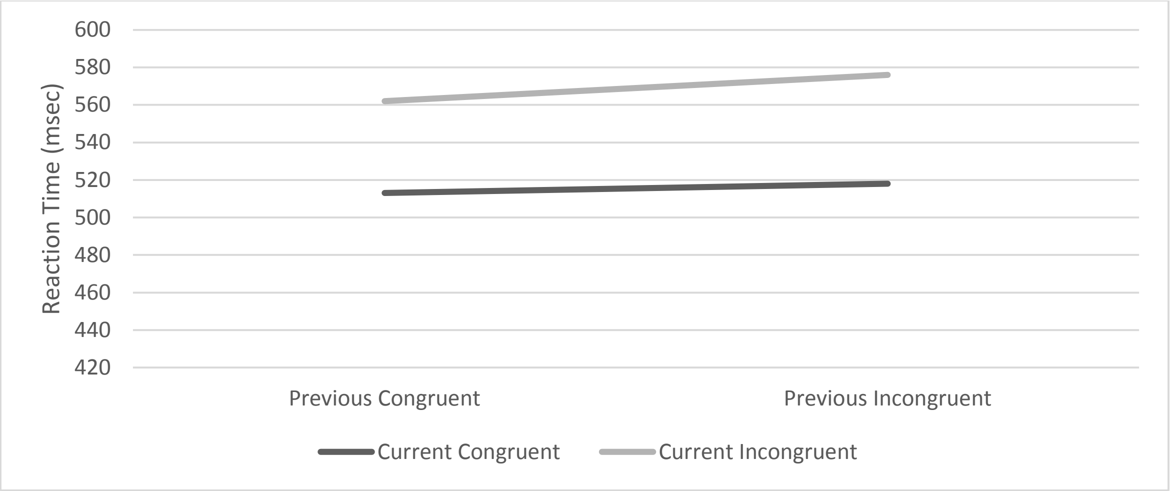

Figure 9. 75s/75r S-S alternating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

For the cC trials, the 25s/25r condition showed the only significant relationship with working memory capacity such that higher-span individuals had faster RT, *b* = -24.13, *t*(45) = -2.04, *p* = .047. The 75s/25r condition was trending towards significance, but in the opposite direction, *b* = 23.10, *t*(47) = 1.78, *p* = .082. The 25s/75r and 75s/75r conditions were simply non-significant, *b* = -16.13, *t*(40) = -1.07, *p* = .290 and *b* = -4.27, *t*(52) = -.382, *p* = .704, respectively.

For the iC trials, the 25s/25r condition was nearly significant, *b* = -15.75, *t*(45) = -1.95, *p* = .057, as was the 25s/75r condition, , *b* = -35.52, *t*(40) = -1.87, *p* = .068. The 75s/25r condition and the 75s/75r condition were not, *b* = 4.16, *t*(47) = .36, *p* = .72 and *b* = 7.27, *t*(52) = .57, *p* = .569, respectively.

These results are somewhat challenging to explain as they are neither predicted, nor easily explained by present theories. First, the only significant effect comes from the 25s/25r condition on cC trials. However, the two 25% congruent conditions were nearly significant in the same way for the iC trials. This would seem to suggest a difficulty in low span individuals to make the transition from the S-R trials (another task) to an infrequent congruent trial as indicated by their additional slowing. It is unknown how many of these trials involved repeats of stimulus features, or whether the relationship with working memory capacity is strengthened when either stimulus features repeat or don’t. Since finding working memory capacity relationships with conflict adaptation processes has not been done, uncovering the conditions that lead to these effects can be informative for the literature.

With respect to the between-subjects factors outside of any interaction, the analysis showed no significant effects: S-S , $F(3, 184) = 8.04$, $p = .005$, $\eta_p^2 = .042$, S-R , $F(3, 184) = .000$, $p = .992$, $\eta_p^2 = .000$, WMC , $F(3, 184) = 1.64$, $p = .202$, $\eta_p^2 = .009$, S-S x S-R , $F(3, 184) = .500$, $p = .481$, $\eta_p^2 = .003$, S-S x WMC , $F(3, 184) = 6.48$, $p = .012$, $\eta_p^2 = .034$, S-R x WMC , $F(3, 184) = .566$, $p = .453$, $\eta_p^2 = .003$, S-S x S-R x WMC , $F(3, 184) = .068$, $p = .794$, $\eta_p^2 = .000$.

S-S Influence on S-R. In line with the previous analyses, the S-S trials were excluded so that S-R could be examined. The analyses are again divided by control type: proactive and reactive.

Proactive Control Analyses. First, error rates for the 4 conditions were analyzed. The analyses were, again, conducted for the congruent trials and incongruent trials separately, since they differed in overall proportion across groups. The means and standard deviations for the congruent error rates can be found in Table 9. The results indicated that the S-R congruency manipulation was significant for congruent errors, $F(3, 188) = 23.01$, $p < .001$, $\eta_p^2 = .109$. This is what would be expected from the manipulation itself, as it shows that participants in the mostly congruent S-R conditions were committing less errors on the congruent trials than the participants in the conditions that rarely encountered these trials.

The S-S congruency manipulation was non-significant, $F(3, 188) = .845$, $p = .359$, $\eta_p^2 =$ .004, indicating that errors were not going up based on global task congruency. However, there was a significant S-R x S-S congruency interaction, *F*(3, 188) = 3.93, $p = .049$, $\eta_p^2 = .020$. This interaction shows that effort on the S-R trials was not specific to the context of those trials. Rather, participants were showing a weak influence of the S-S congruency. In this case, the results showed that participants were more likely to commit an error when the two contexts, that of S-S and S-R, did not match. Errors rose from 1.23% to 1.76% when shifting from 75s/75r to 25s/75r, and similarly, errors rose from 3.12% to 3.52% when moving from the 25s/25r to the 75s/25r. Because errors increased based on context mismatch and not because of a general, overall increase across conditions, we get this interaction and not also a main effect of S-S congruency. This finding is novel in this respect. Previous research has demonstrated congruency effects to be either globally determined or context-specific (at the item-level). These results are neither. They are not context-specific insofar as they allow for influence of S-S trial congruency on S-R trials. Further, they are not globally determined because the means do not move linearly with overall task congruency, from 75% overall congruency (75s/75r) to 50% overall congruency (75s/25r and 25s/75r) to 25% overall congruency (25s/25r). Instead, the pattern of results suggest a competition between the dominant S-R context and the weaker S-S context (as interference).

Table 9. Experiment 1 S-R congruent error means. Values reflect percentages. Standard deviation is in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	1.23 (1.36)	3.52 (4.45)
S-S 25%	1.76 (2.40)	3.12 (3.38)

In examining working memory capacity, there was a significant effect in the S-R trials, *F*(3, 188) = 17.71, $p < .001$, $\eta_p^2 = .086$, as well as 2 nearly significant interactions: S-R x WMC, *F*(3, 188) = 3.78, $p = .053$, $\eta_p^2 = .020$, and S-R x S-S x WMC, *F*(3, 188) = 3.68, $p = .057$, $\eta_p^2 = .019$. But, the S-S x WMC interaction was not significant, *F*(3, 188) = 1.02, $p = .313$, $\eta_p^2 = .005$.

A linear regression was conducted on the error rate of congruent S-R trials which showed the significant effect of working memory capacity was due to higher-span individuals committing less errors, $b = -.010$, $t(194) = -3.56$, $p < .001$. The two nearly significant interactions with working memory were with the two other effects observed above: S-R congruency and S-R x S-S congruency. It is possible that working memory capacity is being used to differently in these situations of context congruency mismatch. However, the present results do not speak clearly to this, which may or may not be an artifact of the differences between groups on the working memory tasks in the present study.

The incongruent trials showed a far simpler pattern. The means and standard deviations for the incongruent error rates can be found in Table 10. The results indicated that the S-R congruency manipulation was again significant for incongruent errors, $F(3, 188) = 37.55$, $p < .001$, $\eta_p^2 = .166$. Neither the S-S congruency manipulation, $F(3, 188) = .024$, $p = .876$, $\eta_p^2 = .000$, nor the S-S x S-R congruency interaction was significant, $F(3, 188) = 1.85$, $p = .175$, $\eta_p^2 = .010$. These results show the expected pattern if one presumes that control is exerted at a context-specific level. Participants made more errors to the incongruent trials in the S-R conditions in which those trials were infrequent. There were no global task effects, since the main effect of S-S congruency and the S-R x S-S interaction were not significant.

Table 10. Experiment 1 S-R incongruent error means. Values reflect percentages. Standard deviation is in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	11.22 (6.75)	6.41 (5.31)
S-S 25%	12.90 (8.52)	5.96 (4.36)

There was a significant effect of working memory capacity, $F(3, 188) = 5.64$, $p = .019$, $\eta_p^2 = .029$. However, none of the interactions were significant: S-R x WMC, $F(3, 188) = .130$, $p = .719$, $\eta_p^2 = .001$, S-S x WMC, $F(3, 188) = 2.52$, $p = .114$, $\eta_p^2 = .013$, and S-R x S-S x WMC, *F*(3, 188) = .045, $p = .831$, $\eta_p^2 = .000$. This again was followed by a linear regression in which higher-span individuals were nearly significantly less likely to make errors on the S-R trials regardless of condition, $b = -.012$, $t(194) = -1.90$, $p = .059$.

Analysis was then shifted from error rates to reaction times. For these analyses, reaction times below 200ms or greater than 1000ms were excluded from analysis. Facilitation effects were examined first. Facilitation scores were created for each individual by subtracting their mean correct congruent trial RT from the mean correct neutral trial RT. The means and standard deviations can be found in Table 11. The analysis revealed that S-R congruency was significant for facilitation effects, *F*(3, 188) = 36.61, $p < .001$, $\eta_p^2 = .163$. This was to be expected, since it again verifies that our S-R congruency manipulation was working, and participants are sensitive to the differences. Participants were having faster responses in the mostly congruent S-R condition. As with previous analyses, the S-S congruency manipulation again did not have a significant effect on the S-R trials, *F*(3, 188) = .013, $p = .910$, $\eta_p^2 = .000$, nor was there a significant S-S x S-R interaction, *F*(3, 188) = 3.18, $p = .076$, $\eta_p^2 = .017$, though it was trending. This means that the increase in error rates observed when the contexts mismatched did not translate into a significant effect here within RT, despite a similar pattern being observed in Table 11.

Table 11. Experiment 1 S-R facilitation. Values reflect differences in RT (msec). Standard deviation is in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	12.35 (21.11)	-12.88 (28.33)
S-S 25%	6.52 (18.69)	-7.81 (24.02)

There was also no effect of working memory capacity, *F*(3, 188) = .050, $p = .824$, $\eta_p^2 = .000$, nor were there any interactions between working memory capacity and either S-R congruency, $F(3, 188) = .319$, $p = .573$, $\eta_p^2 = .002$, S-S congruency, $F(3, 188) = 1.88$, $p = .172$, $\eta_p^2 = .010$, or both, $F(3, 188) = .793$, $p = .374$, $\eta_p^2 = .004$.

Interference scores were created for each individual by subtracting their mean correct incongruent trial RT from the mean correct neutral trial RT. The means and standard deviations can be found in Table 12. The analysis revealed that S-R congruency was significant for interference effects, $F(3, 188) = 61.87$, $p < .001$, $\eta_p^2 = .248$. This again displays the expected pattern in which interference effects are much larger for the conditions in which these trials are seen less frequently. As with previous analyses, the S-S congruency manipulation again did not have a significant effect on the S-R trials, $F(3, 188) = .229$, $p = .633$, $\eta_p^2 = .001$, nor was there a significant S-S x S-R interaction, $F(3, 188) = .001$, $p = .973$, $\eta_p^2 = .000$. This time, the pattern of data fit cleanly with context-specific level of control.

Table 12. Experiment 1 S-R interference. Values reflect differences in RT (msec). Standard deviation is in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	63.58 (26.81)	28.54 (26.15)
S-S 25%	61.24 (32.47)	28.99 (24.35)

There was again no effect of working memory capacity, $F(3, 188) = .026$, $p = .871$, $\eta_p^2 = .000$, nor were there any interactions between working memory capacity and either S-R congruency, $F(3, 188) = 1.49$, $p = .224$, $\eta_p^2 = .008$, S-S congruency, $F(3, 188) = 2.52$, $p = .114$, $\eta_p^2 = .013$, or both, $F(3, 188) = 1.44$, $p = .232$, $\eta_p^2 = .008$.

Reactive Control Analyses. Post-error slowing rates were analyzed first. For this analysis, mean RT from correct trials in which the previous trial was correct were subtracted from the mean RT from correct trials in which the previous trial was incorrect. The means and standard deviations for post-error slowing can be found in Table 13. Neither S-R congruency, $F(3, 188) = 1.48$, $p = .226$, $\eta_p^2 = .001$, S-S congruency, $F(3, 188) = 2.28$, $p = .133$, $\eta_p^2 = .012$, or an S-S x S-R interaction, *F*(3, 188) = .000, *p* = .996, η_p^2 = .000 were significant of post-error slowing which would seem to support the argument that it is a global process that is relatively unaffected by task dimensions. This was a little surprising since the means resemble a pattern expected by global task congruency effects. Slowing is the least in the 75% overall condition, roughly equal in the 50% overall conditions, and finally the most slowing is occurring in the 25% congruent condition. The lack of significance in the two main effects clearly counters this "illusion" of an effect.

Table 13. Experiment 1 S-R post-error slowing. Values reflect differences in RT (msec) and larger values indicate more slowing. Standard deviations are in parentheses.

	S-R 75%	**S-R 25%**
S-S 75%	21.18 (29.37)	27.14 (33.35)
S-S 25%	28.57 (45.14)	34.67 (33.85)

The amount of post-error slowing similarly did not draw any relationship with working memory capacity, whether as a main effect, *F*(3, 188) = 1.30, *p* = .256, η_p^2 = .007, or with any possible interaction: S-R x WMC, *F*(3, 188) = 1.90, *p* = .170, η_p^2 = .010, S-S x WMC, *F*(3, 188) = 2.60, *p* = .109, η_p^2 = .014 or S-S x S-R x WMC, *F*(3, 188) = 3.37, *p* = .068, η_p^2 = .018. The latter was approaching significance, but since this was for an interaction and not main effects, it is unclear what was underlying this trending.

Finally, conflict adaptation effects were examined. All 4 conflict types, cC, iC, iI, and cI, were analyzed only if the participant answered correctly. In these initial analyses, only the trials in which the S-R trials repeated were examined. For these analyses, participants were removed if they did not have at least 1 trial RT of each of the 4 conflict types. This trimming resulted in 4 participants being removed. The mean RT for the 4 conflict types are graphed by group in Figures 10, 11, 12 & 13. To test for conflict adaptation effects, a 2 factor within-subjects variable was added to the GLM model for previous trial congruency type. Current congruent and current incongruent trials were run in separate analyses.

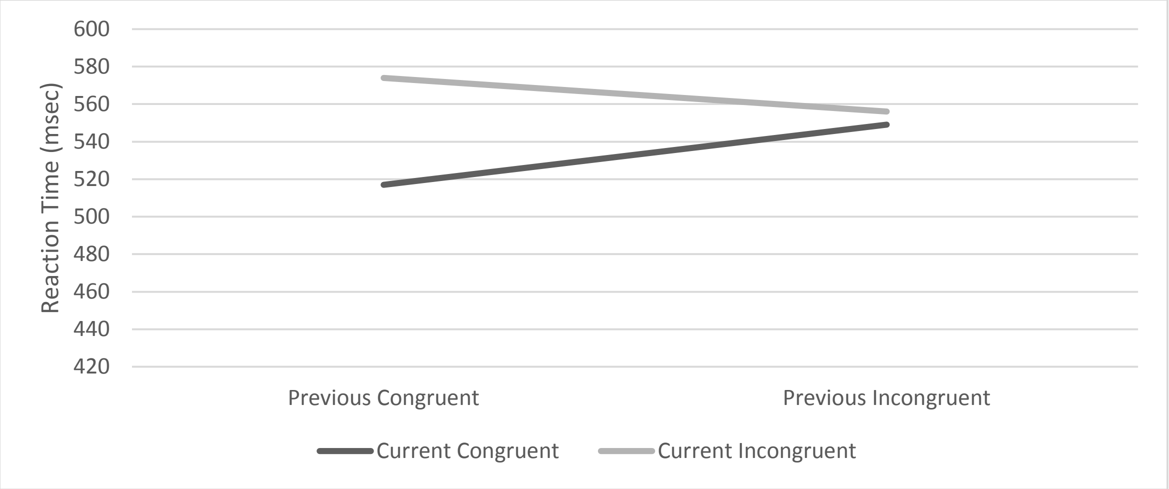

Figure 10. 25s/25r S-R repeating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

For the current incongruent trials (soft grey line in Figures), the results showed a main effect of previous congruency type, *F*(3, 184) = 37.05, *p* < .001, η_p^2 = .168. Thus, incongruent trials are significantly slower when the previous trial was congruent (cI) than when the preceding trials was also incongruent (iI). This slowing is consistent with conflict adaptation effects. The previous trial congruency did not interact with either of the congruency factors: Previous x S-S, *F*(3, 184) = .447, *p* = .505, η_p^2 = .002 and Previous x S-R, *F*(3, 184) = .004, *p* = .949, η_p^2 = .000. Though, there was an interaction with working memory capacity, *F*(3, 184) = 4.28, *p* = .040, η_p^2 = .023. Follow-up linear regressions on cI and iI revealed this interaction to be driven by WMC being a significant predictor of cI, *b* = -14.21, *t*(190) = -2.57, *p* = .011, but not for the iI trials, *b* = -4.63, *t*(190) = -.802, *p* = .424. Here, we again have a novel finding of working memory capacity interacting with conflict adaptation in contrast to previous research (Unworth et al, 2012; Meier & Kane, 2011). This time, it is occurring when the trial type repeats, rather than alternates. Therefore, these trials more closely resemble the single task designs used in previous research in which no relationship was found. Moreover, the hypothesis that working memory capacity is recruited when stimulus features repeat also needs supplementation to apply here, since a relationship was not found in the S-S trials when they repeat. It is not apparent why the relationship pulls significant for this set of trials.

Previous trial congruency did not interact with any of the between-subjects interactions either: Previous x S-S x S-R, *F*(3, 184) = 1.23, $p = .262$, $\eta_p^2 = .007$, Previous x S-S x WMC, *F*(3, 184) = 2.14, $p = .145$, $\eta_p^2 = .011$, Previous x S-R x WMC, *F*(3, 184) = .021, $p = .885$, $\eta_p^2 = .000$, and Previous x S-S x S-R x WMC, *F*(3, 184) = .055, $p = .815$, $\eta_p^2 = .000$.

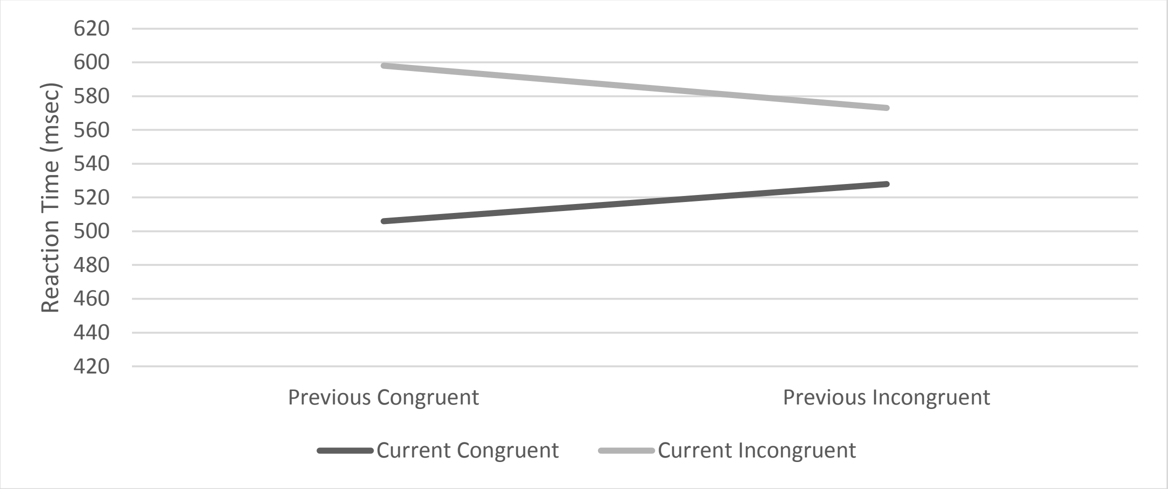

Figure 11. 25s/75r S-R repeating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

The between-subjects portion of the analyses revealed main effect of S-R congruency, *F*(3, 184) = 5.60, $p = .019$ $\eta_p^2 = .030$. This means that participants responded slower to these incongruent trials when they were in the mostly congruent condition and fits with expectations as well as the results from the error rate and interference effects analyses. The analyses also yielded two trending effects: S-S, *F*(3, 184) = 3.04, $p = .083$, $\eta_p^2 = .016$, and S-S x WMC, *F*(3, 184) = 3.57, $p = .060$, $\eta_p^2 = .019$. RTs were slightly faster for the 75% congruent SS condition (561ms) than the 25% congruent S-S condition (574ms), but the relationship with WMC is not clear. The last of the analyses produced insignificant effects for the remaining between-subjects factors outside of any interaction with previous trial congruency:, S-S x S-R, *F*(3, 184) = .055, *p* = .814, η_p^2 = .000, S-R x WMC, *F*(3, 184) = .246, *p* = .620, η_p^2 = .001, S-S x S-R x WMC, *F*(3, 184) = .275, *p* = .600, η_p^2 = .001.

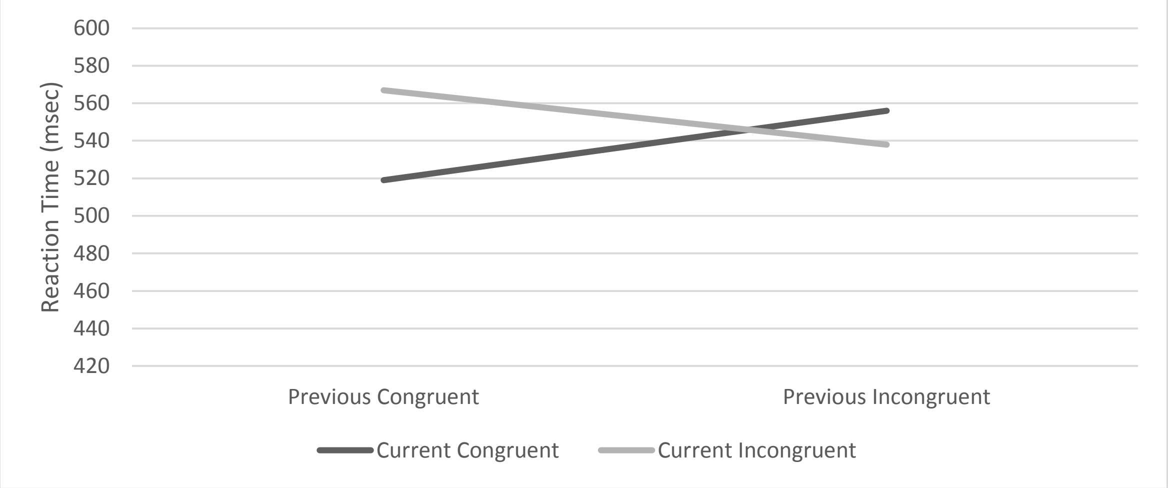

Figure 12. 75s/25r S-R repeating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

For the current congruent trials (dark grey line in Figures), the results showed a main effect of previous congruency type, *F*(3, 184) = 69.34, *p* < .001, η_p^2 = .274. Here, we again find the expected conflict adaptation effect in which the trials in which the congruency changes (iC) are slower than when the congruency remains the same (cC). The previous trial congruency did not interact with any of the between-subjects factors: Previous x S-S, *F*(3, 184) = .502, *p* = .480, η_p^2 = .003, Previous x S-R, *F*(3, 184) = .042, *p* = .838, η_p^2 = .000, or Previous x WMC, *F*(3, 184) = .104, *p* = .747, η_p^2 = .001. Previous trial congruency did not interact with any of the between-subjects interactions either: Previous x S-S x S-R, *F*(3, 184) = .179, *p* = .673, η_p^2 = .001, Previous x S-S x WMC, *F*(3, 184) = .005, *p* = .945, η_p^2 = .000, Previous x S-R x WMC, *F*(3, 184) = 1.64, *p* = .202, η_p^2 = .009, Previous x S-S x S-R x WMC, *F*(3, 184) = .746, *p* = .389, η_p^2 = .004. Thus, the trials, and hence the stimulus features, should overlap in this set just as well as the incongruent trials, yet we do not find a significant relationship with working memory here, adding further murkiness to the interpretations of the earlier findings.

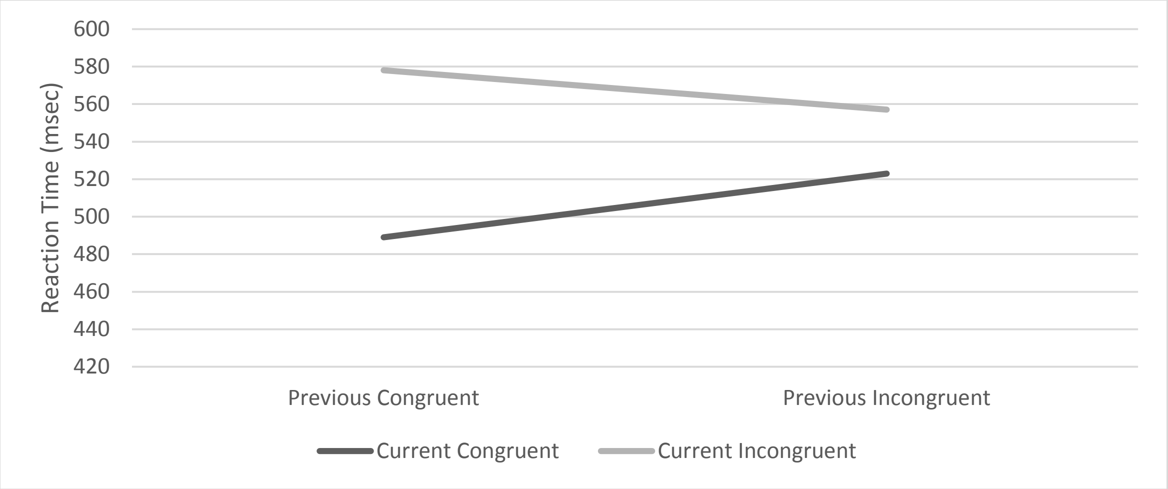

Figure 13. 75s/75r S-R repeating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

The analysis also yielded largely insignificant effects for the between-subjects factors outside of any interaction with previous trial congruency: S-S, $F(3, 184) = .275$, $p = .601$ $\eta_p^2 = .001$, WMC, $F(3, 184) = 2.94$, $p = .088$, $\eta_p^2 = .016$, $\eta_p^2 = .030$, S-S x S-R, $F(3, 184) = .970$, $p = .326$, $\eta_p^2 = .005$, S-S x WMC, $F(3, 184) = 2.58$, $p = .110$, $\eta_p^2 = .014$, S-R x WMC, $F(3, 184) = 2.44$, $p = .120$, $\eta_p^2 = .013$, S-S x S-R x WMC, $F(3, 184) = .283$, $p = .595$, $\eta_p^2 = .002$. The one exception to this was the barely significant effect of S-R, $F(3, 184) = 5.73$, $p = .018$. This significant effect merely demonstrates that participants were faster on these congruent trials when they were in a mostly congruent condition which validates the manipulation and previous results from the S-R conflict adaptation, error rates, and RT analyses.

Next, the same analyses were conducted on the alternation trials in which the previous trial was S-R, but the current trial is S-S. Participants were removed if they did not have at least 1 trial RT of each of the 4 conflict types. No participants were removed for these analyses. The mean RT for the 4 conflict types are graphed by group in Figures 14, 15, 16 & 17.

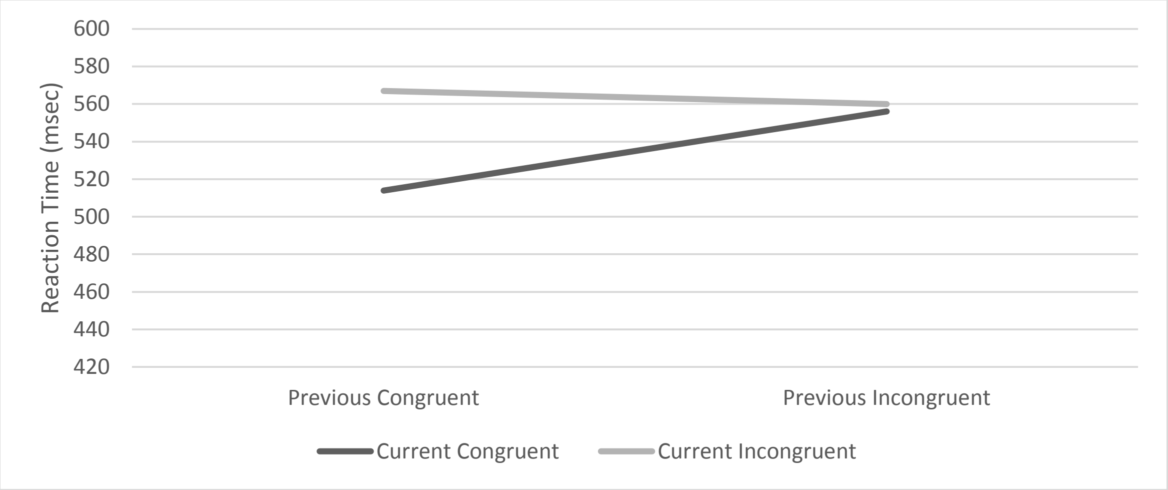

Figure 14. 25s/25r S-R alternating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

The results begin with the incongruent trials (soft grey line in Figures). Unlike the S-S alternating analysis, there was a significant effect of previous trial congruency, $F(3, 188) = 17.78$, $p < .000$, $\eta_p^2 = .086$. This effect is important because it is the first time that conflict adaption has been shown when the task context changes. In previous research, conflict adaptation has been assessed by collapsing alternating trials across tasks. Here, the two tasks have had their alternating trials examined separately. These results challenge the view that conflict adaptation effects are context-specific. Instead, conflict adaptation effects may go away under certain instances of change, such as moving from S-R to S-S, but may function normally under others, such as the S-S to S-R in this analysis. It is not immediately clear what features are being relied on more when making S-R judgments rather than S-S that would cause a shift (or lack thereof since the effect *does not* go away). However, it provides evidence that the tasks should not be collapsed across because information about when and why conflict adaptation effects go away is being lost.

Further examination shows that previous congruency did not interact and any of the other factors: Previous x S-S, $F(3, 188) = .554$, $p = .458$ $\eta_p^2 = .003$, Previous x S-R, $F(3, 188) = 1.32$, p

= .252, η_p^2 = .007, Previous x WMC, *F*(3, 188) = .190, *p* = .663, η_p^2 = .001, Previous x S-S x S-R, *F*(3, 188) = .328, *p* = .567, η_p^2 = .002, Previous x S-S x WMC, *F*(3, 188) = .381, *p* = .538, η_p^2 = .002, Previous x S-R x WMC, *F*(3, 188) = .832, *p* = .363, η_p^2 = .004, Previous x S-S x S-R x WMC, *F*(3, 188) = .000, *p* = .991, η_p^2 = .000. In this case, we have trial alternations, but they resemble trial repeats, and the unique working memory relationships from before do not appear here.

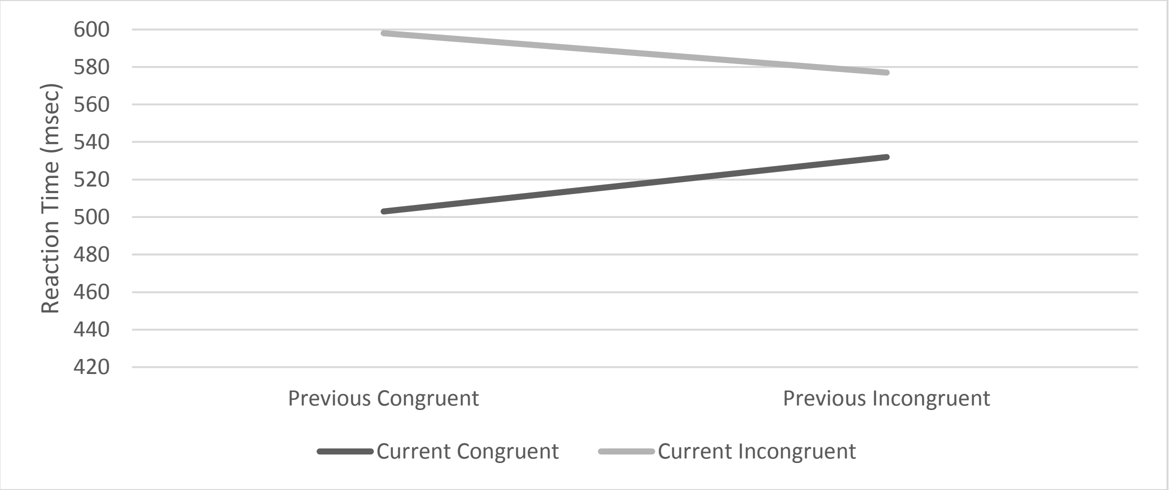

Figure 15. 25s/75r S-R alternating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

With respect to the between-subjects factors outside of any interaction, the analysis again showed a main effect of S-R congruency, *F*(3, 188) = 7.61, *p* = .006, η_p^2 = .039, but no other significant effects: S-S, *F*(3, 188) = .910, *p* = .341, η_p^2 = .005, WMC, *F*(3, 188) = 2.21, *p* = .139, η_p^2 = .012, S-S x S-R, *F*(3, 188) = .022, *p* = .883, η_p^2 = .000, S-S x WMC, *F*(3, 188) = .928, *p* = .337, η_p^2 = .005, S-R x WMC, *F*(3, 188) = 1.00, *p* = .318, η_p^2 = .005, S-S x S-R x WMC, *F*(3, 188) = .034, *p* = .854, η_p^2 = .000. Therefore, only the effect of the manipulation in which incongruent trial RTs are slower for the mostly congruent condition was observed outside of the novel finding of the conflict adaptation effect.

When turning to the congruent trials (dark grey line in Figures), there was again a significant effect of previous trial congruency, *F*(3, 188) = 89.03, *p* = .000, η_p^2 = .321. This critical finding compliments the conflict adaptation effect observed in the incongruent trials by demonstrating that the iC trials are slower than the cC trials *even though the context alternates*. This finding shows that with respect to the S-R trials, there is no difference between task-repeat and task-alternation trials.

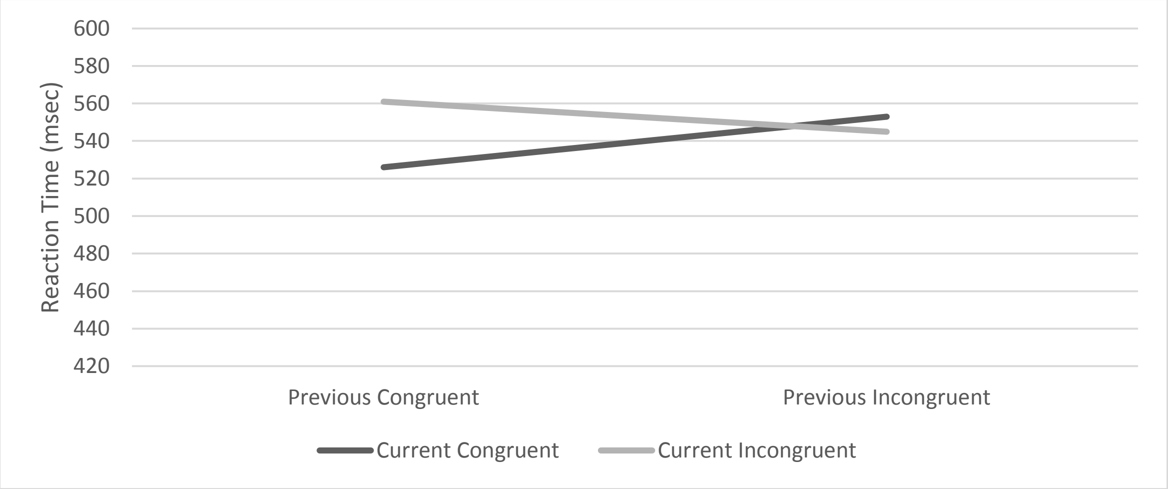

Figure 16. 75s/25r S-R alternating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

This time, there was another significant interaction, Previous x S-S x WMC, *F*(3, 188) = 4.39, *p* = .037, η_p^2 = .023. Separate linear regressions were conducted on each of the previous trial types for each S-S congruency. The results revealed that higher-span individuals had faster RTs for the cC trials in the 25% congruent S-S conditions, *b* = -14.31, *t*(89) = -1.98, *p* = .050. This was not observed for the iC trials, *b* = -8.68, *t*(89) = -1.20, *p* = .232, neither was it found for either cC or iC in the 75% congruent S-S conditions, *b* = 9.10, *t*(103) = 1.16, *p* = .248 and *b* = -4.01, *t*(103) = -.436, *p* = .664, respectively. In the 25% congruent S-S conditions, the congruent S-S trial that precedes the congruent S-R trial is infrequent. However, it does not interact with S-R congruency. It is not intuitive why this particular transition would be distinctly more challenging than other transitions, and thus require additional processing. It should be noted that in the analysis of conflict adaptation in the 25% congruent S-S trials; they showed a similar relationship to working memory capacity insofar as higher-spans were significantly (or nearly significantly) faster in RTs when the tasks alternated. There is not a significant amount of commonalities between the 3 findings of significant working memory capacity relationships in this experiment, so precise interpretation of these results cannot be performed.

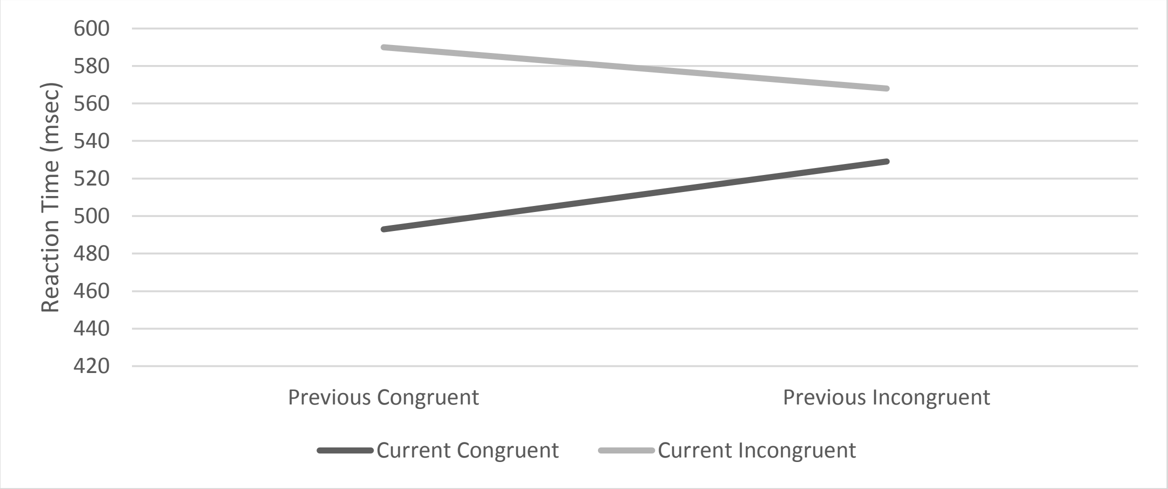

Figure 17. 75s/75r S-R alternating conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R trials. The lines x-axis is the previous trial type, while the line represents the current trial type.

Previous trial congruency was not found to interact with any of the other effects or interactions: Previous x S-S, $F(3, 188) = .003$, $p = .956$, $\eta_p^2 = .000$, Previous x S-R, $F(3, 188) = .118$, $p = .731$, $\eta_p^2 = .001$, Previous x WMC, $F(3, 188) = .464$, $p = .497$, $\eta_p^2 = .002$, Previous x S-S x S-R, $F(3, 188) = 1.39$, $p = .239$, $\eta_p^2 = .007$, Previous x S-R x WMC, $F(3, 188) = .234$, $p = .629$, $\eta_p^2 = .001$, Previous x S-S x S-R x WMC, $F(3, 188) = .026$, $p = .872$, $\eta_p^2 = .000$.

With respect to the between-subjects factors outside of any interaction, the analysis showed a main effect of S-R, $F(3, 188) = 5.73$, $p = .018$, $\eta_p^2 = .030$, but no other significant effects: S-S, $F(3, 188) = .007$, $p = .935$, $\eta_p^2 = .000$, WMC, $F(3, 188) = 1.02$, $p = .314$, $\eta_p^2 = .005$, S-S x S-R, $F(3, 188) = .324$, $p = .570$, $\eta_p^2 = .002$, S-S x WMC, $F(3, 188) = 1.64$, $p = .202$, $\eta_p^2 =$

.009, S-R x WMC, $F(3, 188) = 1.44$, $p = .232$, $\eta_p^2 = .008$, S-S x S-R x WMC, $F(3, 188) = .231$, $p = .631$, $\eta_p^2 = .001$. It was again nice to see the main effect of S-R congruency reinforcing that the manipulation worked. These results again show that participants are faster on congruent trials when in the mostly congruent condition.

Discussion

To summarize the findings of Experiment 1, proactive control was found to operate at a context-specific level. That is, error rates, facilitation effects, and interference effects were generally found to not be influenced across tasks, and only responded to the proportion congruency of their context. This finding is revealing because it suggests that once cognitive control is established for a context (e.g., S-R trials), it is robust towards other forms of interference. For example, the one bit of influence observed across contexts was in the congruent S-R trials error rate, and it suggested a competition, not a global change in behavior. Participants were not responding to global congruency proportions but rather were disrupted by the other trials. These results do not support previous findings in which congruency effects led to global congruency responding (Hutchison, 2011; Funes et al., 2010b; Torres-Quesada et al., 2013).

Interestingly, working memory variation was predictive of error rates in both the S-S and S-R trials. This finding implies that working memory resources were operating at a global level. This seems somewhat strange since the behavior it was predicting was context-specific. It is possible that the resources recruited from working memory capacity could have been operating globally to either flexibly maintain context-specific goals, inhibit the interfering aspect of the "other" context, or both.

More oddities emerged with the analyses of the reactive control measures. Post-error slowing was further demonstrated to be a global, task-general process. However, it too was unaffected by global congruency effects. It should be noted that it was unaffected by context-specific effects as well, so it could be the case that it is robust to congruency effects in general. Moreover, it did not interact with working memory capacity suggesting that it may be a self-contained task-general process that does not require significant resources to operate.

The most insightful results came from the conflict adaptation trials in which the typical pattern of conflict adaptation emerged when the trials types repeated (e.g., S-S followed by S-S). However, there was a dissociation found when trials alternated. Conflict adaptation effects have been shown to go away when the task trials alternate (e.g., S-R to S-S), but in those studies, both types are collapsed together. That is, both S-S and S-R repetitions form the repetition analysis and both S-S and S-R alternations form the alternation analysis. The present results suggest that this collapsing could be masking the limits of conflict adaptation.

Most curious of all were the few bits of interaction between working memory capacity and conflict adaptation. Unfortunately, there were not sufficient commonalities between them. The findings occurred in both repeated and alternating conditions and in both current congruent and current incongruent trials. However, they provide a starting ground from which future supplementation of the stimulus repetition hypothesis can be tested (Meier & Kane, 2013).

Experiment 2

Experiment 1 was effective at highlighting some boundary conditions between interference and cognitive control. However, the primary goal of the task was to examine these conditions with respect to context effects that were not controlled for in previous research. The aim of Experiment 2 was to extend the findings of Experiment 1 by examining the relationship between S-S and S-R interference individually. Like the previous experiment, it also looked at how they might be affected by individual differences in resources available for cognitive control from working memory capacity. Participants performed separate Simon and spatial Stroop tasks, as well as the battery of working memory measures from Experiment 1. Because context effects are not the focus of this experiment, both the Simon (S-R) and spatial Stroop (S-S) tasks contained mostly congruent items. This is because previous research has shown that in mostly congruent lists participants employ both proactive control in the form of goal maintenance (Kane and Engle, 2003), and reactive control in the form of post-error slowing and conflict adaptation effects. Therefore, 75% congruent lists were selected to maximize the impact of cognitive control measures and thus draw a more complete picture of their function.

It is expected that S-S interference will be related to working memory capacity. That is, it is expected that span differences should predict differences in S-S interference in both the proactive and reactive measures according to executive attention/control theories of working memory (Braver et al., 2007; Kane et al., 2007). Alternatively, it can be argued that working memory capacity will only be related to control processes that require global changes. The presumption here is that working memory resources are tied to top-down processes that tend to have global effects. Under these circumstances, it would also be expected that both S-S and S-R would likely engage the reactive control processes in a similar way. These findings would suggest that these reactive processes may be more automatic responses, or bottom-up processes (see Unsworth, et al., 2012).

Methods

Participants. 219 undergraduate students from LSU volunteered to participate in the study in exchange for partial course credit. Of these 219, 18 failed to appear for the 2nd testing session. 28 participants failed to maintain the 85% accuracy requirement on at least one of the working memory tasks. 35 were removed for failure to follow directions. These participants either did not respond on over 10% of the trials, or did not follow the button associations on the S-R task. Since congruency in the S-R task is based on button and stimulus locations, failure to follow the assigned button mapping changes the task congruency from 75% to 25% congruent trials. Therefore, they performed a fundamentally different task. Finally, 5 people were removed for excessive errors on the neutral trials (over 25%), and 4 were removed for having individual working memory task scores that were 2.5 standard deviations apart or larger. This left only 129 participants in the following analyses.

Materials. The materials are the same as the previous experiment except the Simon and spatial Stroop tasks have been separated from the modified Simon/Stroop task.

Simon Task. In this task, participants responded to a vertical arrow that appeared on the computer screen. The arrows appeared in either the center, left of center, or right of center positions. There was a fixation cross in the center of the screen between trials. The participant was instructed to respond to the arrow’s orientation by pressing the ‘F’ key and the ‘J’ key for UP and DOWN, respectively. The button assignment was counterbalanced across participants.

Spatial Stroop Task. Participants also responded to a vertical arrow in this task. However, the arrows appeared in either the center, top of center, or bottom of center positions.

There was a fixation cross in the center of the screen between trials and the participants were again instructed to respond to the arrow's orientation by pressing the 'F' key and the 'J' key for UP and DOWN, respectively. The button assignment was counterbalanced across participants.

Procedure. Participants came into the lab and performed the tasks across 2 days. On each day, they filled out the appropriate consent form. Afterwards, the instructions appeared on the computer screen. Both the Simon and the spatial Stroop tasks utilized the same instructions. The order of the tasks was however counterbalanced, so that some received Simon on Day 1, while others began with the spatial Stroop. The instructions were also simultaneously read aloud by the experimenter. The participants were taken to a brief practice block that covered all 6 possible arrow/location configurations twice (e.g., 12 trials), then they began the main test block. This block consisted of 180 trials. Of these 180 trials, 20 trials were neutral (in the center), 40 trials were incongruent, and 120 trials were congruent. This breakdown of trials resulted in 75% congruence for the two non-center locations, and a 67% congruence overall. After completing the primary task, participants completed the working memory tasks. On Day 1, all participants completed the Rspan, while on Day 2, they completed the Symspan and Ospan. Instructions for the working memory tasks were presented on the screen as well as read aloud by the experimenter. They completed a few brief practice blocks to orient them with the task, before being taken to the main testing block.

Results

Prior to analysis, the working memory totals were converted into z-scores. These scores were then averaged into a composite working memory total, as in Experiment 1. Unlike Experiment 1, there were good correlations between all three working memory tasks, and the full composite could be used. The working memory totals can be found in Table 14, while the correlations between working memory tasks are listed in Table 15.

Table 14. Experiment 2 working memory task totals. Values reflect total correct items recalled. Standard deviation in parentheses.

	Ospan	**SymSpan**	**Rspan**
Totals	56.57 (15.27)	28.58 (7.75)	55.68 (11.99)

Table 15. Experiment 2 working memory correlations. Values represent Pearson correlation values. $p < .001$ in all 3 cases.

	Ospan_SymSpan	**Ospan_Rspan**	**SymSpan_Rspan**
Correlation	.654	.652	.464

As in Experiment 1, analyses are divided according to control type, with the proactive measures coming first.

Proactive Control. First, the error rates were analyzed. Even though both tasks shared 75% congruency, congruent and incongruent error rates were separated to provide a better analogue to Experiment 1. The means and standard deviations for the error rates can be found in Table 16. The analyses will be conducted using a General Liner Model that includes task type (S-S or S-R) and congruency (congruent or incongruent) as a within-subjects measures and WMC as a covariate. The model looks for a main effect of task type and congruency, as well as the following interactions: Task x Congruency, Task x WMC, Congruency x WMC, and Task x Congruency x WMC.

Table 16. Experiment 2 error means. Values represent percentages. Standard deviation in parentheses.

	S-S	**S-R**
Congruent	1.63 (1.75)	0.76 (1.17)
Incongruent	7.04 (5.44)	12.13 (6.60)

The results found significant effects of task, $F(1, 127) = 46.32$, $p < .001$, $\eta_p^2 = .267$, and congruency, $F(1, 127) = 407.71$, $p < .001$, $\eta_p^2 = .762$. There was also a significant Task x Congruency interaction, $F(1, 127) = 87.92$, $p < .001$, $\eta_p^2 = .409$. The congruency main effect was to be expected, in that, error rates were higher for the rare, incongruent trials than the frequent congruent trials in each task. It was also expected for the tasks to differ from one another. However, the nature of the interaction was not expected. The S-R task showed fewer error rates for congruent trials and more for the incongruent trials. This pattern is indicative of participants suffering more heavily from goal neglect in the S-R condition. They more readily slipped into a habit of responding based upon the irrelevant stimulus feature which predicted the frequent congruent trials.

Unfortunately, there were no interactions with working memory capacity: Congruency x WMC, $F(1, 127) = 1.69$, $p = .196$, $\eta_p^2 = .013$, Task x WMC, $F(1, 127) = .008$, $p = .928$, $\eta_p^2 = .000$, and Task x Congruency x WMC, $F(1, 127) = .283$, $p = .596$, $\eta_p^2 = .002$. This means that the less frequent slips of goal maintenance in the S-S task does not appear to be related to working memory capacity.

Next, facilitation and interference effects replaced the congruent and incongruent error rates. Recall that facilitation is an RT score that is derived from subtracting the mean correct congruent RT from the mean correct neutral RT. Similarly, interference scores are derived from subtracting the mean correct neutral RT from the mean correct incongruent RT. Therefore, this analysis is an RT variant of the previous analysis. The means and standard deviations for facilitation and interference can be found in Table 17.

Table 17. Experiment 2 facilitation and interference. Values represent differences in RT (msec). Standard deviation in parentheses.

	S-S	**S-R**
Facilitation	19.97 (27.49)	34.09 (28.51)
Interference	49.14 (30.73)	47.05 (32.86)

The results showed the same pattern as before. There was a main effect of congruency indicating that facilitation and interference effects were different, $F(1, 127) = 34.46$, $p < .001$, η_p^2

= .213, and there was a main effect of task showing that the two tasks did not respond equally, $F(1, 127) = 20.25$, $p < .001$, $\eta_p^2 = .138$. This was again clarified by a Task x Congruency interaction which suggests the two tasks have comparable interference, but S-R has considerably more facilitation than S-S, $F(1, 127) = 7.13$, $p = .009$, $\eta_p^2 = .053$. The ample facilitation exhibited in the S-R task provides further support for the argument that participants more easily fall into goal neglect, since the expectation would be that they would be quicker and near perfect on the congruent trials. However, the lack of a difference in interference was unexpected. Both tasks are causing slowing to the same degree regardless of the level of goal maintenance being employed.

With respect to WMC, there was nearly a Congruency x WMC interaction, $F(1, 127) = 3.45$, $p = .066$, $\eta_p^2 = .026$. However, neither of the other interactions were near significance: Task x WMC, $F(1, 127) = 2.03$, $p = .157$, $\eta_p^2 = .016$, and Task x Congruency x WMC, $F(1, 127) = .351$, $p = .554$, $\eta_p^2 = .003$.

Reactive Control. Post-error slowing rates will be analyzed next. Post-error slowing is derived from the mean correct RT of trials in which the previous trial was correct subtracted from the mean correct RT of trials that followed an error. The means and standard deviations are listed in Table 18. For this analysis, only task as a within-subjects variable and WMC as a covariate was used in the model.

Table 18. Experiment 2 post-error slowing. Values represent differences in RT (msec). Standard deviation in parentheses.

	S-S	**S-R**
Post-error Slowing	30.43 (35.83)	36.58 (34.36)

Both tasks exhibited the same degree of post-error slowing, and the comparison between the 2 tasks was not significant, $F(1, 127) = 2.34$, $p = .128$, $\eta_p^2 = .018$. The interaction between the tasks and working memory was also not significant, $F(1, 127) = 1.11$, $p = .295$, $\eta_p^2 = .009$. These null findings provide further support for the growing evidence suggesting that post-error processes are a domain general process that is not sensitive to task features (Notebaert & Verguts, 2011).

Finally, conflict adaptation effects were compared and the results are displayed in Figures 18 & 19. As in Experiment 1, the congruent and incongruent trials were analyzed separately. A GLM was conducted with task and previous trial congruency as the within-subjects measures, while working memory was again a covariate. The model specified main effects of task and previous trial congruency, as well as the following interactions: Task x Previous, Task x WMC, Previous x WMC, and Task x Previous x WMC.

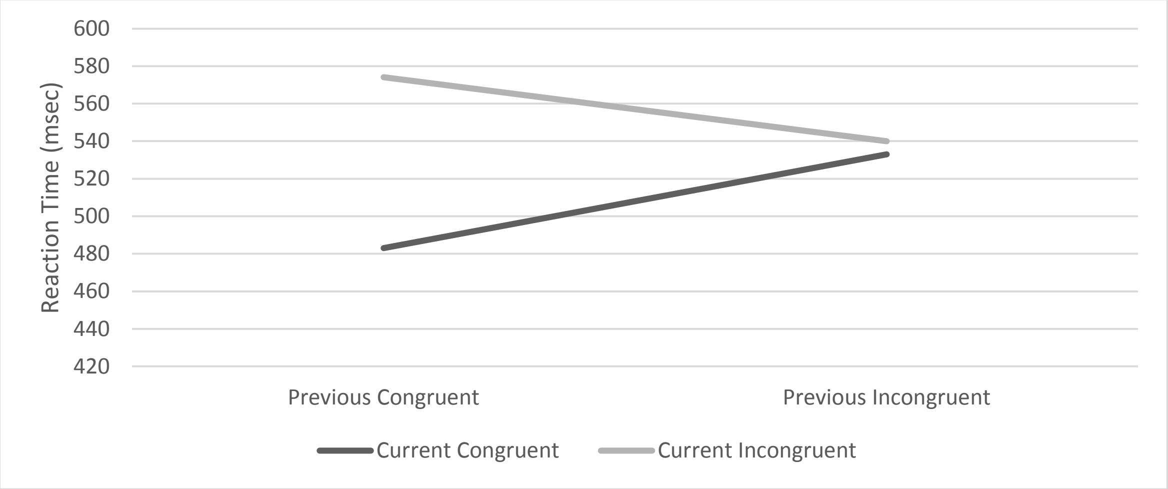

Figure 18. S-S conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-S task. The lines x-axis is the previous trial type, while the line represents the current trial type.

The results for the incongruent trials (soft grey line in Figures 18 & 19) showed a significant effect of previous trial type, $F(1, 127) = 144.39$, $p < .001$, $\eta_p^2 = .534$. This demonstrates a robust conflict adaptation effect. The main effect of task was insignificant suggesting that the two tasks do not differ in conflict adaptation for these incongruent trials, $F(1, 127) = 1.48$, $p = .226$, $\eta_p^2 = .012$. There was however a nearly significant Task x Previous interaction, $F(1, 127) = 3.70$, $p = .057$, $\eta_p^2 = .029$, which highlights that the S-R task and S-S primarily differed in the how slow they were following a congruent trial. That is, participants were taking more time to respond to a cI trial in the S-R condition than in the S-S condition, though this failed to reach significance.

Working memory capacity was not found to interact with any of the variables: Task x WMC, $F(1, 127) = .416$, $p = .520$ $\eta_p^2 = .003$, Previous x WMC, $F(1, 127) = 1,17$, $p = .282$, $\eta_p^2 = .009$, and Task x Previous x WMC, $F(1, 127) = 1.27$, $p = .261$, $\eta_p^2 = .010$.

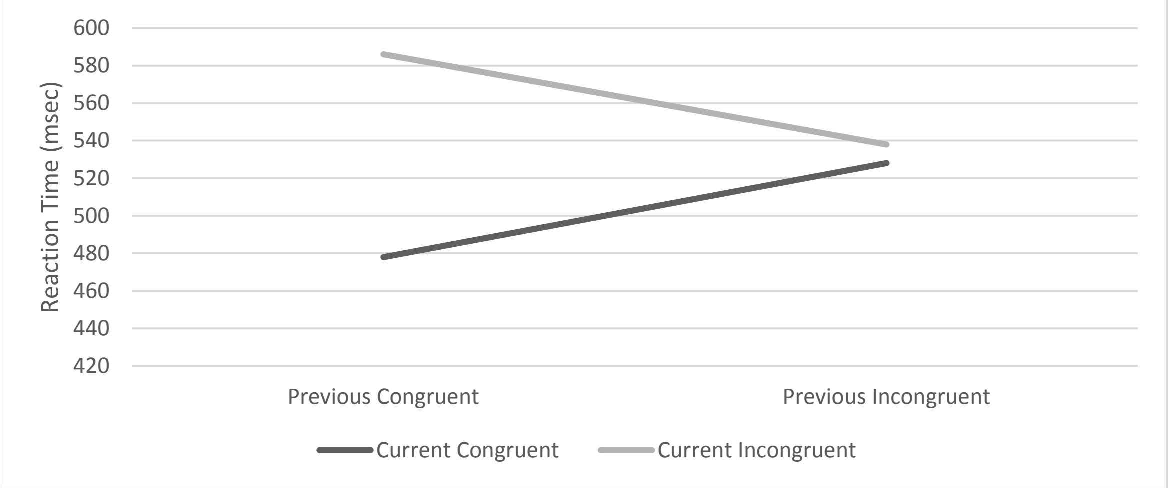

Figure 19. S-R conflict adaptation. This graph represents the reaction times (msec) for the 4 conflict adaptation measures cC, iC, iI, and cI in the S-R task. The lines x-axis is the previous trial type, while the line represents the current trial type.

The results for the congruent trials (dark grey line in Figures 18 & 19) showed a similar pattern in that there was only a significant main effect of previous trial type, $F(1, 127) = 664.22$, $p < .001$, $\eta_p^2 = .841$. This demonstrates a profound conflict adaptation effect in the congruent trials of both tasks. Again, the main effect of task was insignificant suggesting that the two tasks do not differ in conflict adaptation for these congruent trials, $F(1, 127) = .891$, $p = .347$, $\eta_p^2 = .007$. There were no significant effects in any of the interactions: Task x Previous, $F(1, 127) = .294$, $p = .588$, $\eta_p^2 = .002$, Task x WMC, $F(1, 127) = .879$, $p = .350$ $\eta_p^2 = .007$, Previous x WMC, $F(1, 127) = .679$, $p = .412$, $\eta_p^2 = .005$, and Task x Previous x WMC, $F(1, 127) = 1.30$, $p = .256$, $\eta_p^2 = .010$. The lack of task differences in both components of the conflict adaptation effect suggest that both tasks are processing the information similarly. The analyses on the repeat trials in Experiment 1 demonstrated that the two types of interference were producing similar conflict adaptation effects. These results add to that by showing that those are indeed the same. This makes the question about why they differed on task alternation trials in Experiment 1 much more interesting and difficult.

Discussion

The goal of the present experiment was to illuminate areas in which S-S interference and S-R interference trigger cognitive control differently in the absence of context effects. The results shared a common theme: S-S interference triggers more of a response from cognitive control than S-R interference. The initial analyses demonstrated that S-R interference produced larger facilitation effects, fewer errors on the congruent trials, and higher error rates for the infrequent incongruent trials. This suggests that participants are very unlikely to engage in proactive monitoring in response to S-R interference. It was a little strange that post-error slowing was not different between the groups. After all, one might expect that the increased frequency of errors in the S-R task would result in more slowing. This was not the case. It is still interesting in that evidence continues to mount that post-error slowing is a domain general process, yet, it does not appear to bear a relationship with working memory capacity, also proposed to be only related to global processes. But it should be noted that working memory capacity was not related to either the expected effects, or those found in Experiment 1. It is possible that the complexity of the task in Experiment 1 was necessary to elicit supplemental working memory resources. Some of those S-S specific effects have been demonstrated in a complex version of the task previously (Meier & Kane, 2011). However, they have not been demonstrated in isolated versions of the task, so the lack of a finding here may not be unusual.

General Discussion

The present series of studies sought to inform two research questions: 1) Can we identify conditions in which interference causes cognitive control mechanisms to respond differently, and 2) Can we identify situations in which working memory capacity supported changes in cognitive control. The answer to the first question was yes. Experiment 1 demonstrated that conflict adaptation effects occur differently in response to S-S and S-R interference when trials alternate. That is, an S-S trial followed by an S-R trial produces typical conflict adaptation effects for alternations, while the converse order does not. This dissociation, therefore, represents a situation in which reactive control processes are responding differently to the two sources of interference.

With respect to the second question, the answer is, hesitantly, yes. In Experiment 1, working memory capacity was related to different aspects of S-S and S-R trials. Working memory was predictive of the congruent S-S trials for the 25% congruent S-S condition when the overall conflict adaptation effects were abolished. For the S-R trials, working memory capacity was related to particular situations in both repeated and alternating conflict adaptation. It should be pointed out that conflict adaptation effects do not go away for S-R when trials alternate. Therefore, the differences between repeating and alternating are lessened. Since it is unclear what mechanism led to these differences with respect to working memory capacity and interference, it is difficult to conclude that working memory capacity was responding to changes in cognitive control, *per se*.

Implications

Outside of the evidence for the research questions, the results from these experiments provide several useful additions to the literature. First, the dissociation in conflict adaptation mentioned above challenges the assumption in the literature that conflict adaptation effects are task-specific (Notebaert et al., 2011; Funes et al., 2010a; 2010b; Torres-Quesada et al., 2013). This finding is novel, in that, previous researchers have not separated their trials by type. Rather, they report collapsed data that simply compares alternations on the one hand with repetitions on the other. The present results suggest that these should be separated as they can be informative about differences in cognitive control as well as the two sources of interference. In this case, separating the two tasks before examining alternations and repetitions revealed a dissociation that is suggestive of a limit for the bottom-up processes, and is not predicted by feature repetition explanations (Mayr et al., 2003; Hommel et al., 2004). It is difficult to conceive of why an S-S trial preceding an S-R trial can produce conflict adaptation, while the converse is not true. It is possible that S-R trials encourage more reliance on bottom-up feature matching with little effort on top-down control. Such an explanation would explain the increased goal neglect in Experiment 2, since they would be less likely to engage in any proactive control. The explanation would also fit with the interference from the S-S trials observed in the error rates for the congruent S-R trials in Experiment 1. But the question remains, how?

The answer to that question may lie in the time-course of activation. If S-R facilitation and interference are processed more quickly, then response patterns may be activated for S-R trials faster than S-S trials, and likely faster, at times, than the effect of control processes. Therefore, one might come to rely on this more “heuristic” approach to S-R trials. In contrast, S-S interference may be more difficult to process. As such, the extra time in processing the relevant information can allow for control processes to take effect on many S-S trials. Future research using these tasks and event-related potentials can look for these hypothesized differences in either the N2 or lateralized readiness potentials (Folstein & Van Petten, 2008; Coles, Gratton, Bashore, Eriksen, & Donchin).

Second, it was found that proactive control measures appeared to be driven by context-specific effects (Crump et al., 2006). Error rates and facilitation for S-S trials were determined by the congruency proportion of the S-S trials, and remained unaffected by the congruency of the S-R trials, and vice versa. This pattern showed that participants were using the "irrelevant" location information to identify the "relevant" congruency of each trial type despite the similarities in the relevant features (e.g., the stimulus itself and the response). This fails to replicate other findings in the literature in which significant global effects were found independent of the context-specific effects (Hutchison, 2011). This failure to replicate could be due to differences within the trial types. In Hutchison (2011), all of the items were typical Stroop items (e.g., Color words) that were merely presented at different congruencies to separate one "list" from another. Each of his stimuli relied on the same type of interference, since they only differed in congruency and/or contingency. In the present study, the difference between "lists" represented changes to the type of interference encountered in the task: S-S vs. S-R. Therefore, the pattern of control here could be accounted for by task-specific processing. To the extent that other research has shown that some aspects of cognitive control are task specific (Notebaert et al., 2011; Funes et al., 2010a; 2010b; Torres-Quesada et al., 2013), this is not an unreasonable assumption. However, in those studies, conflict adaptation was shown to be local and task-specific, while other measures like proportion congruency and post-error slowing were shown to be global and task-general. This makes the present results unique in that proactive control is recruiting resources globally, e.g., working memory capacity, but operating more locally at the context level.

While not addressing the two research questions, this finding is still relevant since it challenges contingency learning accounts of congruency effects (Schmidt et al., 2007, Schmidt & Besner, 2008). That is, automatic learning of contingencies would not predict a relationship with working memory like the ones observed here. To put this in perspective, proactive control is theorized to be a global process (Braver et al., 2007; Kane et al., 2007). The results support this, in so far as, working memory capacity was predictive of error rates. Individuals that scored higher in working memory capacity exhibited lower error rates. The relationship between working memory capacity and each of the error rates suggests that participants were using these resources irrespective of condition or trial type (as evidenced by a lack of interactions), and thus they were globally recruited. In contrast, "global" control was being enacted at a level lower than the overall task. That is, participants were using the location information to respond to proportion congruency effects that were context-specific.

This conflicts with the findings of both Funes et al. (2010b) and Torres-Quesada et al. (2013) in which proportion congruency was shown to transfer across tasks. In each of those experiments, they used version of the spatial Stroop/Simon task similar to the present studies, and proportion congruency was shown to transfer across tasks from 75% or 25% congruent S-R trials to 50% congruent S-S trials. The present results compared the effects on 75% and 25% S-S congruent lists, as well as S-S on S-R. The congruency difference of the "transferred to" trials between experiments is important because highly congruent and highly incongruent lists do not use control processes in the same way (Kane & Engle, 2003; Logan & Zbrodoff, 1979). It is therefore possible that the transfer observed in those earlier studies was due to the control processes not biasing information in accordance with congruency for that trial type since there was not a dominant congruency. The lack of engagement of control processes one way or another could have left the trials open to the overall task congruency, and thus a transfer effect. The present studies compared transfer to lists that would, in theory, have already engaged control processes in a particular way. These results then suggest that once these processes are engaged, they can be fairly robust to global congruency influences.

Limitations

There were a few areas in which this study provided a context that was less than ideal. First, the lack of global proportion congruency effects could have been bolstered by including 4 additional conditions that used a 50% baseline, such as: 75s/50r, 25s/50r, 50s/75r, and 50s/25r. These conditions would have provided and ideal complement to the 4 groups tested in Experiment 1 and allowed for more concrete assertions about the role of context-specific control biases.

Second, the working memory groups in Experiment 1 were far from desirable. The restriction to only 2 of the working memory tasks from the full composite due to uneven group differences opens the door for questions over the validity of the working memory relationships observed. However, two points should be noted. 1) In only one case did the problematic group ever reach a significance level beyond that of the other groups. That is, the working memory results were significant across multiple groups, not just that particular one, which would not be expected if the relationship was erroneous. 2) Experiment 2 had much more ideal working memory relationships, and failed to find interactions with S-S interference or error rates. Therefore, there relationship between the interference types, control, and working memory may be much more delicate and complicated than the picture that has emerged. Regardless, neither of these points undercut the difficulty in drawing firm conclusions about the role of working memory capacity and therefore, more research is needed.

Finally, trials in this experiment were randomly assigned for each participant. This creates a problem in which it is impossible to produce a controlled amount of trials for some of the analyses, such as those involved in conflict adaptation. While there will always be some degree of variability based upon the number of correct responses given, having a more precise set of predetermined conflict trials would have been useful. This level of control would also have helped in developing hypotheses for some of the differences that were observed, since each participant would have been exposed to the same amount of feature repetitions within each condition. This lack of control burdens future research with clarifying some of the results here in terms of feature repetitions.

Conclusions

The results of the present experiments provided evidence that can help shape our understanding of cognitive control and working memory. For example, there is need for more specification when comparing the transfer of conflict adaptation effects. The findings here, suggest that collapsing across tasks is masking effects that would otherwise show boundary conditions between tasks and conflict adaptation. Future research should be sure to separate out task types when making comparisons of conflict adaptation so that a more representative picture can be developed. Next, the finding that proactive control recruits working memory resources in a global, sustained fashion fits with current theories (Braver et al., 2007; Kane et al., 2007), and adds to the evidence in support of them. However, the demonstration that these global processes can act in a more localized, task-specific manner was unexpected. These results imply that cognitive control processes may be recruiting working memory resources to maintain, and flexibly switch between, context-specific task representations, as well as to inhibit cross-context interference.

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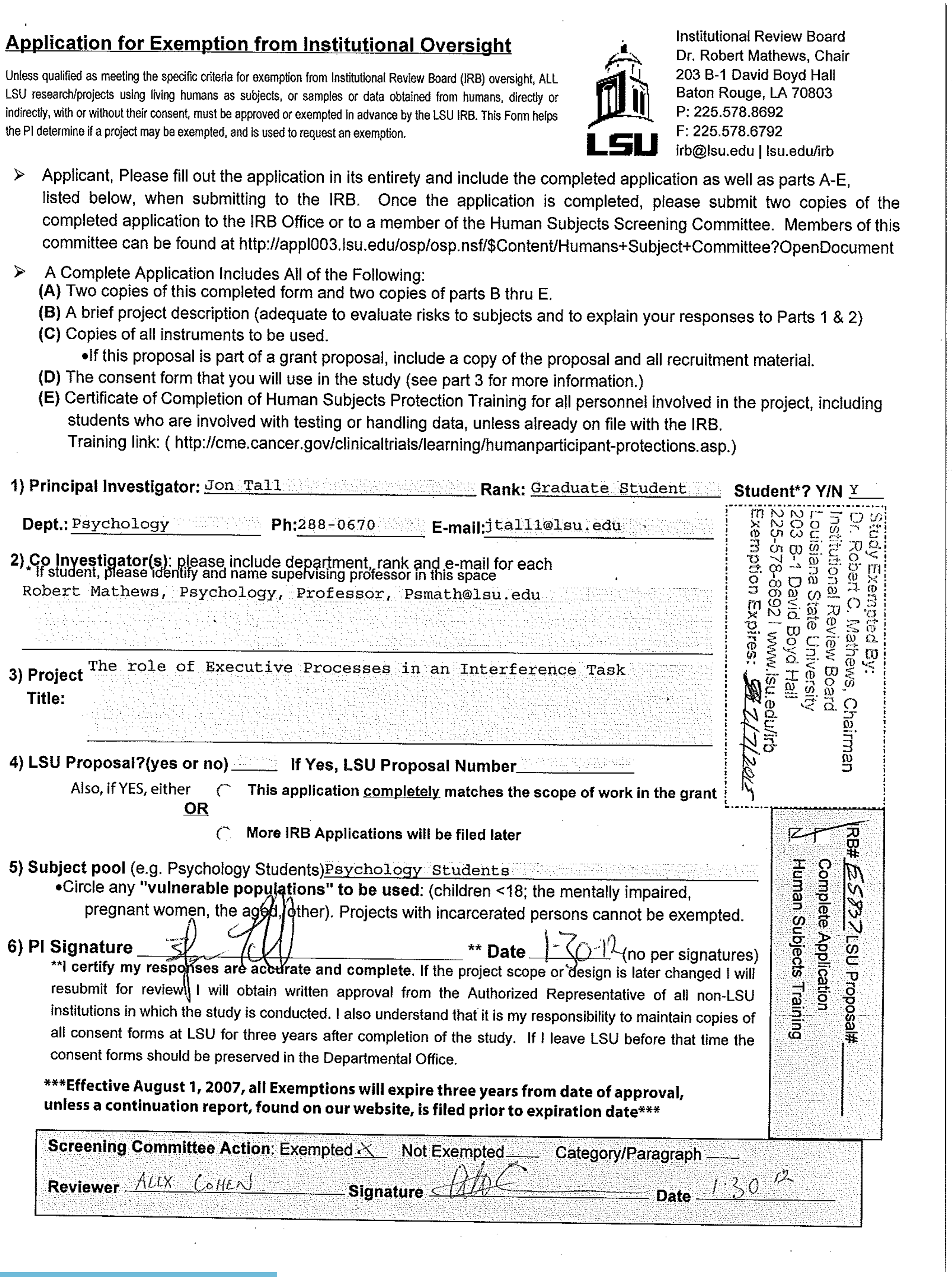
Appendix

IRB Form



Application for Exemption from Institutional Oversight

Unless qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

LSU

Institutional Review Board
Dr. Robert Mathews, Chair
203 B-1 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
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irb@lsu.edu | lsu.edu/irb

- Applicant, Please fill out the application in its entirety and include the completed application as well as parts A-E, listed below, when submitting to the IRB. Once the application is completed, please submit two copies of the completed application to the IRB Office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at http://appl003.lsu.edu/osp/osp.nsf/$Content/Humans+Subject+Committee?OpenDocument
- A Complete Application Includes All of the Following:
  (A) Two copies of this completed form and two copies of parts B thru E.
  (B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1 & 2)
  (C) Copies of all instruments to be used.
    •If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment material.
  (D) The consent form that you will use in the study (see part 3 for more information.)
  (E) Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB.
  Training link: (http://cme.cancer.gov/clinicaltrials/learning/humanparticipant-protections.asp.)

1) Principal Investigator: Jon Tall **Rank:** Graduate Student **Student*? Y/N** Y

Dept.: Psychology **Ph:**288-0670 **E-mail:**jtall1@lsu.edu

2) Co Investigator(s): please include department, rank and e-mail for each
* If student, please identify and name supervising professor in this space
Robert Mathews, Psychology, Professor, Psmath@lsu.edu

3) Project Title: The role of Executive Processes in an Interference Task

4) LSU Proposal?(yes or no) ______ **If Yes, LSU Proposal Number**______

Also, if YES, either ○ **This application completely matches the scope of work in the grant**
OR
○ **More IRB Applications will be filed later**

5) Subject pool (e.g. Psychology Students)Psychology Students
•Circle any **"vulnerable populations" to be used**: (children <18; the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted.

6) PI Signature ______ **** Date** 1-30-12 (no per signatures)
****I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at LSU for three years after completion of the study. If I leave LSU before that time the consent forms should be preserved in the Departmental Office.**

*****Effective August 1, 2007, all Exemptions will expire three years from date of approval, unless a continuation report, found on our website, is filed prior to expiration date*****

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Exemption Expires: 1/27/2015

IRB# E5937 LSU Proposal# ______
☑ Complete Application
☑ Human Subjects Training

Screening Committee Action: Exempted X Not Exempted ___ Category/Paragraph ___
Reviewer Alex Cohen **Signature** ______ **Date** 1.30.12

Consent Form- Experiment 1

Study Approved By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
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225-578-8692 | www.lsu.edu/irb
Approval Expires: 2/7/2015

Written Confirmation of Informed Consent

Performance Sites: B3, Audubon Hall, Louisiana State University
210a, Audubon Hall, Louisiana State University

Researchers: Jon Tall, M.A. Dr. Robert Mathews
Dr. Sean Lane

Institutional Review Board:
Dr. Robert Mathews, Chair
Louisiana State University 203 B-1 David Boyd Hall, Baton Rouge, La
225-578-8692

Procedure: In this study, you will be tested on your ability to handle interference. You will complete 4 tasks. The first will require you to designate the orientation of an arrow on a computer monitor. The second will test your ability to remember letters after solving simple mathematical problems. The third will assess your spatial reasoning ability. And, the final will test your reading comprehension.

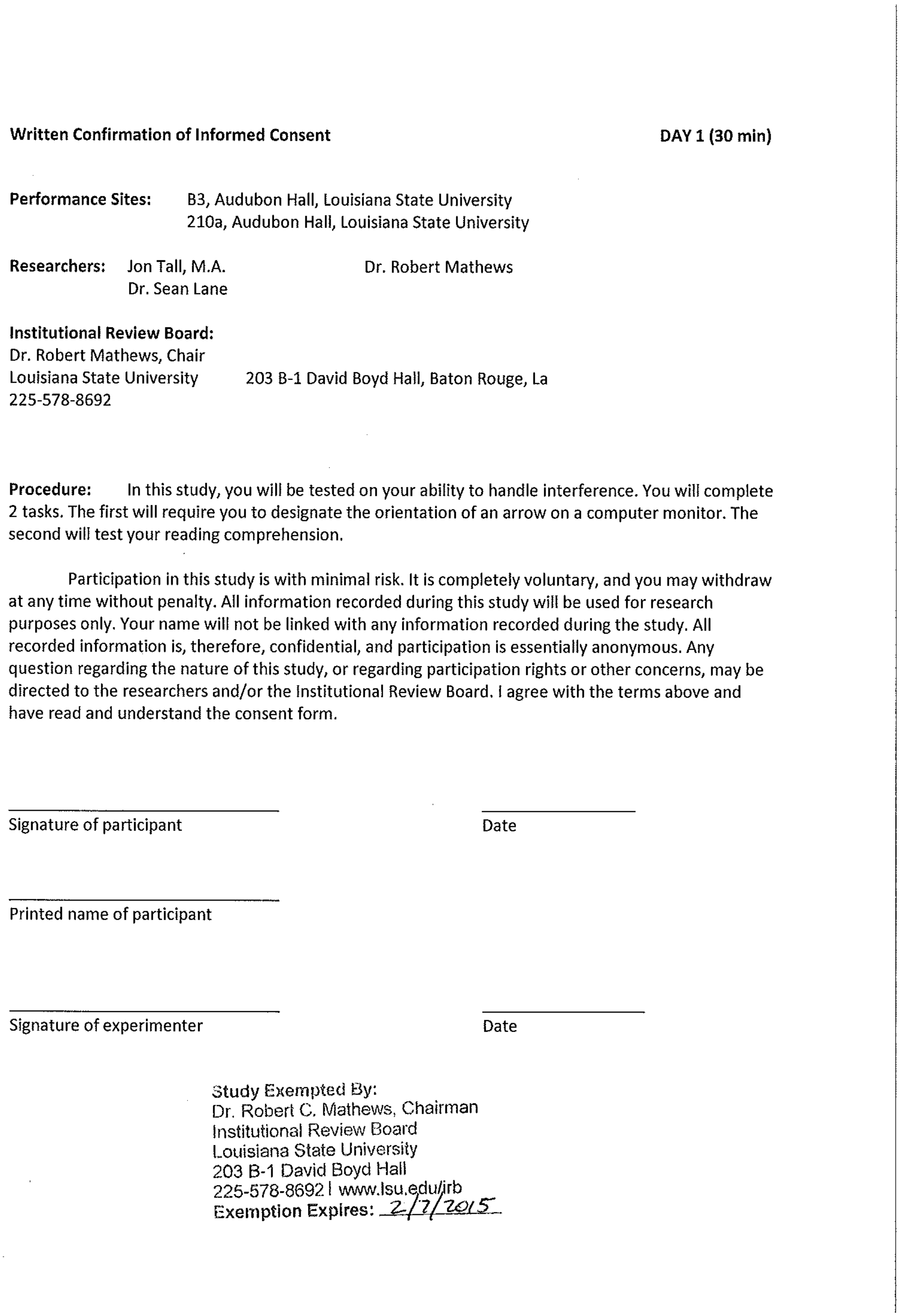
Participation in this study is with minimal risk. It is completely voluntary, and you may withdraw at any time without penalty. All information recorded during this study will be used for research purposes only. Your name will not be linked with any information recorded during the study. All recorded information is, therefore, confidential, and participation is essentially anonymous. Any question regarding the nature of this study, or regarding participation rights or other concerns, may be directed to the researchers and/or the Institutional Review Board. I agree with the terms above and have read and understand the consent form.

____________________________ ________________
Signature of participant Date

____
Printed name of participant

____________________________ ________________
Signature of experimenter Date

Consent Forms- Experiment 2



Written Confirmation of Informed Consent **DAY 1 (30 min)**

Performance Sites: B3, Audubon Hall, Louisiana State University
210a, Audubon Hall, Louisiana State University

Researchers: Jon Tall, M.A. Dr. Robert Mathews
Dr. Sean Lane

Institutional Review Board:
Dr. Robert Mathews, Chair
Louisiana State University 203 B-1 David Boyd Hall, Baton Rouge, La
225-578-8692

Procedure: In this study, you will be tested on your ability to handle interference. You will complete 2 tasks. The first will require you to designate the orientation of an arrow on a computer monitor. The second will test your reading comprehension.

Participation in this study is with minimal risk. It is completely voluntary, and you may withdraw at any time without penalty. All information recorded during this study will be used for research purposes only. Your name will not be linked with any information recorded during the study. All recorded information is, therefore, confidential, and participation is essentially anonymous. Any question regarding the nature of this study, or regarding participation rights or other concerns, may be directed to the researchers and/or the Institutional Review Board. I agree with the terms above and have read and understand the consent form.

______________________________ ________________
Signature of participant Date

____
Printed name of participant

______________________________ ________________
Signature of experimenter Date

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Exemption Expires: 2/7/2015

Written Confirmation of Informed Consent **DAY 2 (60 min)**

Performance Sites: B3, Audubon Hall, Louisiana State University
210a, Audubon Hall, Louisiana State University

Researchers: Jon Tall, M.A. Dr. Robert Mathews
Dr. Sean Lane

Institutional Review Board:
Dr. Robert Mathews, Chair
Louisiana State University 203 B-1 David Boyd Hall, Baton Rouge, La
225-578-8692

Procedure: In this study, you will be tested on your ability to handle interference. You will complete 3 tasks. The first will require you to designate the orientation of an arrow on a computer monitor. The second will test your ability to remember letters after solving simple mathematical problems. The third will assess your spatial reasoning ability.

Participation in this study is with minimal risk. It is completely voluntary, and you may withdraw at any time without penalty. All information recorded during this study will be used for research purposes only. Your name will not be linked with any information recorded during the study. All recorded information is, therefore, confidential, and participation is essentially anonymous. Any question regarding the nature of this study, or regarding participation rights or other concerns, may be directed to the researchers and/or the Institutional Review Board. I agree with the terms above and have read and understand the consent form.

__________________________ _______________
Signature of participant Date

____
Printed name of participant

__________________________ _______________
Signature of experimenter Date

Study Exempted By:
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Exemption Expires: 2/7/2015

The Vita

Jon Tall received his Bachelor of Science in psychology from Northwestern State University in 2003. He went on to receive a Master of Arts in philosophy of science from Louisiana State University in 2006. His interest in philosophical issues over expertise and decision making eventually led him to work for the Office of Applied Cognition. He re-enrolled in graduate studies at Louisiana State University getting a Master of Arts in cognitive psychology in 2009. He will receive his Doctorate degree in cognitive psychology in May 2014.