DISSERTATION

MECHANISMS OF EXECUTIVE CONTROL:

BEHAVIORAL INVESTIGATIONS OF THE CONFLICT ADAPTATION EFFECT

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY JULIE M. BUGG ENTITLED MECHANISMS OF EXECUTIVE CONTROL: BEHAVIORAL INVESTIGATIONS OF THE CONFLICT ADAPTATION EFFECT BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

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BEHAVIORAL INVESTIGATIONS OF THE CONFLICT ADAPTATION EFFECT

The conflict adaptation effect refers to a reduction in reaction time on an incompatible trial of the Eriksen Flanker task that is preceded by another incompatible trial as compared to being preceded by a compatible trial. The repetition priming account contends that the effect is a memory phenomenon limited to complete repetition trials. The conflict monitoring account contends that preceding trial conflict triggers a tightening of control, making participants less susceptible to conflict on the subsequent incompatible trial. The effect is expected, therefore, on complete repetition and non-repetition trials. Experiments 1, 2, and 3 were designed to contrast the two accounts by manipulating the degree of conflict present on incompatible trials. In Experiment 1, conflict was manipulated by varying the frequency of incompatible trials. The conflict adaptation effect was found on repetition but not non-repetition trials, with a trend toward greater conflict adaptation in response to greater conflict in the mostly compatible condition. In Experiment 2, conflict was manipulated by varying the identity of the flanker stimuli, with left or right flankers expected to produce a greater degree of response conflict than up or down flankers. The conflict adaptation effect was observed for both repetition and non-repetition trials though a greater degree of conflict did not result in greater adaptation. In Experiment 3, conflict was manipulated by altering the

size of the incompatible flankers to be either larger or smaller than the central stimulus. Again, the conflict adaptation effect was limited to repetition trials and the degree of conflict did not alter the magnitude of the effect. A negative priming explanation of the lack of conflict adaptation on non-repetition trials was not supported in Experiment 4, though a follow-up experiment revealed a 16 ms negative priming effect. Taken together, the results suggest that the conflict adaptation effect reflects repetition priming and under some conditions, conflict monitoring. Further clarifying the nature of these conditions such as the size of the response set, size of the stimulus set, and the length of the response to stimulus interval is an important next step in this line of research.

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CHAPTER ONE- GENERAL INTRODUCTION

Over the past decade, a significant amount of cognitive and neuroscience research has been dedicated to understanding the processes underlying executive control. In comparison, relatively few studies have addressed an equally important issue, how the brain controls control. That is, how does the brain determine that there is a need for an increase in cognitive control? What role does the monitoring of one's environment play in situations where control must be engaged more strongly and how is this information communicated to regions like the dorsolateral prefrontal cortex, which appear to play an active role in the implementation of control? A more thorough understanding of the conflict adaptation effect may allow us to address this question.

Although there is no single agreed upon definition of executive or cognitive control in the literature, there is some agreement about the situations in which the need for control exists. For example, executive control is believed to be important for situations where an incorrect response is likely to occur, for example when error correction or troubleshooting is required, when links between input and response representations are novel or not well learned, and when the appropriate response is competing with a habitual response. Executive control is also believed to be critical in situations where a routine procedure for making the appropriate response does not exist, like when planning of a new sequence of behaviors is needed to obtain a goal, when novel situations arise, and when a situation is difficult or dangerous (Gazzaniga, Ivry, & Mangun, 1998; Norman & Shallice, 1996).

Although numerous paradigms have been used to investigate executive control function, two specific paradigms, the Eriksen Flanker Task (EFT) (Eriksen & Eriksen, 1974) and the Stroop task (Stroop, 1935) are of interest to the current study. Both tasks require participants to select an appropriate response in the face of a competing response. In the EFT, participants are asked to respond to a target stimulus that is surrounded by flanker stimuli on each side. A variant of the EFT, involves a central target stimulus, a right (>) or left (<) pointing arrow, which indicates which response button should be pressed, the right or left, respectively. In the incompatible condition (e.g. <<><<), the flanker stimuli point in a direction opposite to the target stimulus; thus, the participant must resolve the competition between the two potential responses. In the compatible condition (e.g. <<<<<), the flanker stimuli and target stimulus point in the same direction; thus, only one response is elicited. Reaction times and error rates tend to be higher in the incompatible condition relative to the compatible condition or a neutral condition (e.g.^ ^ > ^ ^) in which the flanker arrows depict a direction that is not one of the available responses.

Eriksen and Schultz (1979) portray competition during the EFT as a continuous flow model, wherein activation or priming of responses accumulates as visual information about the stimuli accumulates. Responses are believed to be withheld by an inhibitory process as the visual information is binded together. The flankers produce competition when they are incompatible with the target stimulus and corresponding response. Eriksen and Schultz theorize that the amount of competition between the two incompatible responses is dependent on the extent to which each response is primed. As the response linked to the flanker is primed, the target response is inhibited with this

inhibition expected to be greater when a larger number of incompatible responses are primed.

In the Stroop paradigm, participants are asked to name the color of ink that words, which are themselves colors, are written in. In the incongruent condition (e.g., the word BLUE written in red ink), color naming is slowed relative to a congruent condition in which the name of the word matches the color of ink (e.g., the word BLUE written in blue ink) or a neutral condition in which random letter strings are written in various ink colors (e.g., XXXX written in blue ink) (MacLeod, 1991). Existing models of the Stroop effect propose that efficient performance in the incongruent condition depends on one's ability to resolve the competition between the two responses evoked by each of the stimulus dimensions (Dyer, 1973). Some researchers portray this competition as a race between a habitual reading response that a participant must suppress and a controlled naming response that must be activated (Posner & Snyder, 1975).

Physiological Investigations of Executive Function

Investigations of the neurophysiological locus of EFT and Stroop task performance have revealed that executive control in these paradigms is accomplished via interactions among a distributed network of brain regions (Carter et al., 2000; Pardo, Pardo, Janer, & Raichle; 1990). For instance, areas within the prefrontal cortex, such as the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC), have been found to be active in parallel with posterior parietal and subcortical areas such as the basal ganglia during a variant of the EFT (Casey et al., 2000). Of primary concern to the current set of studies is the role of and interaction of prefrontal regions involved in the monitoring of conflict and the implementation of executive control. A description of the

functional role believed to be played by the dorsolateral prefrontal cortex and anterior cingulate cortex is presented below.

Dorsolateral Prefrontal Cortex.

The role of the DLPFC in executive control is perhaps best characterized as a goal-oriented coordinator of information. More specifically it serves to maintain contextual or relevant information. An important component of many executive control tasks involves maintaining information on-line. For example, in the Stroop task, participants may be asked to keep in mind the instructions for a given condition (e.g., "Name the color the word is written in."). The role of the DLPFC in working memory maintenance functions is supported by single cell recordings in the monkey that show persistent activity during the delay in the delayed matching to sample task, activity which is also present in the face of distraction (Gazzaniga et al., 1998). Activation in the DLPFC has been found to be dependent on the degree to which maintenance is required. For instance, Bunge, Ochsner, Desmond, Glover, and Gabrieli (2001) found that the right DLPFC was active when a working memory load increased from 4 to 6 items, but not during a small load increase from 1 to 4. Similarly, during a simple task requiring maintenance of just 3 spatial locations, activation in the DLPFC region was not found (Rowe, Toni, Josephs, Fackowiak, & Passingham, 2000).

The DLPFC not only maintains information relevant to a present context, but can also integrate current on-line information and goals with stored knowledge, consistencies, and rules from past experiences that are no longer in the present view, providing a top-down influence on behavior. For example, MacDonald, Cohen, Stenger, and Carter (2000) found that activity was observed in the DLPFC during instructions that informed

participants to name the color of the word in a Stroop task, but not during word-reading instructions. This finding suggests that the DLPFC is especially critical in representing the top-down demands of the task when the need for attentional control is present, as in the color naming condition. Similarly, Banich et al. (2000) found increased DLPFC activation during incongruent Stroop trials as compared to neutral trials, and cited this as evidence for a role of the DLPFC in imposing an attentional set, which aids in the selection of a stimulus attribute particularly when a need is present to override an automatic attentional bias. Interestingly, MacDonald et al. also found that participants who showed the greatest left DLPFC activation during the color-naming instructions, showed the smallest Stroop interference effect. This result implicates a direct influence of the DLPFC on control functions.

Inhibitory processes are another crucial aspect of executive control tasks. In regards to the DLPFC's role in inhibitory functions, some researchers such as Kimberg and Farah (2001) have suggested that inhibitory and working memory functions are carried out by the same neural circuitry, the prefrontal cortex. There is some evidence to suggest that the DLPFC may play a role in inhibitory control. For instance, patients with lesions to the DLPFC have difficulty on the anti-saccade task, which requires an individual to inhibit a reflexive eye movement toward a stimulus, in order to move their eyes in the opposite direction. Likewise, positron emission topography (PET) studies have shown DLPFC activation during the anti-saccade task (Corbetta., 1998). Additional evidence comes from Liddle, Kiehl, and Smith (2001) who found that the DLPFC was more active during inhibition demanding no-go trials than during go trials of a go/no-go task in an event-related fMRI study and interpreted this finding as a role of the DLPFC in

response inhibition. Using a proactive interference task, Bunge et al. (2001) found evidence suggesting the right DLPFC was involved in interference resolution. Similar to the results of MacDonald et al., a negative correlation was found between susceptibility to interference and activation in this area suggesting that the DLPFC may contribute to the ability to resolve conflict in a proactive interference task.

One influential model of executive control is that of Miller and Cohen (2001). They have proposed a model of PFC function that suggests a mechanism through which the PFC exerts its top-down influence. In their model, the PFC biases the flow of neuronal activity through its excitatory top-down influence. The PFC is believed to guide activity along task-relevant pathways in the brain. Activity of some neurons is increased by the PFC, biasing the competition that may arise in different pathways when multiple sources of information are competing for expression, as in the Stroop Task or EFT. Without this biasing influence, the most frequently used pathways would dominate and "dysexecutive behavior" would prevail. Consistent with such a view, patients with damage to the PFC exhibit utilization behaviors, display perseverative errors on the WCST, and are more susceptible to interference in the Stroop task. In Miller and Cohen's view, inhibition occurs because of competition, and is the consequence that biasing has on the irrelevant information. It is plausible that the DLPFC activation observed in the MacDonald study described above, reflects this attentional biasing. An interesting aspect to the model is that with repeated biasing of the same pathway, the process can become independent of the PFC, as the behavior in a sense is becoming more automatic. This has the potential to explain the beneficial effect of practice on many neuropsychological tasks of frontal function that are often considered indices of executive control. For instance,

practice on tasks such as the Stroop can largely reduce the interference that is found on the first few trials of the task. Although Miller and Cohen's model addresses PFC function more generally, and not specifically the role of the DLPFC, it seems that many of the functions ascribed to the system are consistent with the role that other studies have assigned to the DLPFC.

Anterior Cingulate Cortex.

There are several existing views concerning the exact role of the ACC in higher cognitive functions. For instance, some theorists believe that its role is strategic in nature, involving "selection for action" (Allport, 1994) functions. In this view, ACC activity is a reflection of processes that directly "limit the potential conflicting actions taken toward stimuli" (Posner, Peterson, Fox, & Raichle; 1988). Other theorists argue that the primary function of the ACC is the detection of and compensation for errors. Support for this view largely stems from electrophysiological investigations of the error related negativity (ERN), a scalp potential that occurs shortly after a participant makes an error or partially makes an error, but corrects oneself. The ERN is believed to be generated by the ACC. According to this view, the role of the ACC is evaluative rather than strategic.

The findings of Carter, Botvinick, and Cohen (1999) provide evidence to support an evaluative role for the ACC, but it is an evaluative role that is different in nature from the previous view. Using a continuous performance task, they found that the ACC showed activation not only during trials in which errors occurred, but also during correct trials in which a high degree of response competition was present. Importantly, greater activation was not found in the ACC for correct trials relative to incorrect trials, as would be expected if the ACC played a strategic role. The findings lead them to suggest that the

ACC, and in particular, the dorsal ACC evaluates the degree of conflict that is present in the response system (for further elaboration of this view, see Botvinick, Braver, Barch, Carter, & Cohen, 2001). Converging evidence for this view comes from MacDonald, Cohen, Stenger, and Carter (2000) who found that ACC activity was greater during the response period for incongruent trials of the Stroop task than during congruent trials. Incongruent trials present two competing sources of information, and a high potential for response conflict whereby the congruent trials elicit only one response from the two sources of information. In a verb generation study, Barch, Braver, Sabb, and Noll (2000) found greater ACC activity to nouns that were considered low constraint and were likely to elicit numerous competing responses, compared to nouns that typically elicited a single verb, further supporting the idea that the ACC evaluates the degree of response conflict.

Interaction Between Dorsolateral Prefrontal Cortex and Anterior Cingulate Cortex.

From the evidence reviewed above, it appears that in situations where executive control is warranted, the ACC and DLPFC interact in order to accomplish a given task goal. The ACC seems to be responsible for monitoring the perceptual and cognitive environment for response competition and conflict, and communicating this information to control areas such as the DLPFC through some signaling process. In their computational model of cognitive control, Botvinick et al. (2001) represented this signaling process as a feedback loop by which the ACC could communicate with the DLPFC and other control areas to trigger them to increase their influence on processing. In the Bunge et al. study described earlier, the ACC was more active when participants were aware of the conflict and the increased demands of the task than when they were not aware. The combination then of an evaluation of conflict or a situation demanding more

control coupled with awareness may trigger a signal to occur, and subsequently a tightening of control. The DLPFC, as suggested above, seems to have a direct top-down influence on situations requiring additional control (for instance, when response competition exists; or in Norman and Shallice's (1986) terms when contention scheduling can not passively resolve the competition) and appears to play a direct role in resolving the competition. Activation of the DLPFC in situations of response conflict may reflect the biasing operations that the DLPFC is performing. In this way, the ACC and DLPFC seem to be operating together as a Supervisory Attentional System, which controls control, perhaps explaining why the ACC and DLPFC have been found to show concurrent activation in many existing studies (see e.g., Casey et al., 2000).

Behavioral Investigations of Executive Function

Behavioral investigations of the ACC and the conflict-monitoring signal have relied exclusively on the conflict-adaptation effect, an effect that has primarily been investigated through use of the EFT and Stroop Task. As reviewed earlier, cognitive control in the EFT task is believed to enhance selection of the central, target stimulus, while reducing the influence of the flankers and is measured by examining performance on incompatible trials relative to compatible or neutral trials. The conflict-adaptation effect refers to a reduction in reaction time on trial *n* by virtue of a conflict monitoring signal from the ACC on trial *n – 1.* Specifically, Gratton, Coles, and Donchin (1992) and Botvinick, Nystrom, Fissell, Carter, and Cohen (1999) showed that reaction times on incompatible trials that immediately followed another incompatible trial (II) were faster than incompatible trials that followed a compatible trial (CI). Furthermore, performance on compatible trials that followed another compatible trial (CC) was faster than those that

followed an incompatible trial (IC). More recent work has suggested that such effects can also be found for error rates. Specifically, Ullsperger, Bylsma, and Botvinick (2005) showed that post incompatible trial adjustments included decreased error rates on a subsequent incompatible trial.

One account of the conflict-adaptation effect is based on the conflict-monitoring model (Botvinick, Braver, Barch, Carter, & Cohen, 2001) which posits that the ACC elicits a conflict-monitoring signal on trial $n - 1$, particularly for cases in which conflict is present, as in an incompatible trial. This signal is purported to trigger the prefrontal cortex (and perhaps other control regions) to increase cognitive control, and thereby reduces one's susceptibility to conflict. Thus performance on the immediately following incompatible trial *(n)* benefits from this increase in cognitive control, as evidenced by a reduction in reaction time relative to when a compatible trial preceded trial *n.* Similarly, performance on a C trial following an I trial is often slowed relative to CC trials by the recruited control, which leads participants to ignore the compatible flankers. Gratton et al. have proposed a similar account of the behavioral consequences of preceding conflict, suggesting that the preceding incompatible trial may elicit a more focused strategy of responding. Direct support for the conflict monitoring account has been found by Kerns, Cohen, MacDonald, Cho, Stenger, and Carter (2004) using a Stroop task. Specifically, performance on II trials was not only faster than CI trials, but significantly less activity was found in the ACC on II trials relative to CI trials, and the amount of ACC activity correlated negatively with response time on II trials. In addition, they found that the greater degree of post-conflict adjustment, the greater activation of the DLPFC,

supporting the idea that ACC signals modulate control regions' influence on performance.

A recent study, however, presents a challenge to the conflict-monitoring account of the conflict-adaptation effect. Mayr, Awh, and Laurey (2003) found that the magnitude of the conflict-adaptation effect depended largely upon the match between the stimuli and responses on trial *n – 1* and trial *n*. More specifically, the pattern of findings representative of the conflict-adaptation effect (II trials faster than CI trials) was found only for II trials in which the stimuli and responses on trial *n – 1* (e.g., <<><<) matched those on trial *n* (e.g., <<><<) but not on II trials in which both the stimuli and responses on trial *n* (e.g., <<><<) changed from those presented on trial *n – 1* (e.g., >><>>). This finding led them to conclude that the effect was completely driven by stimulus-specific repetition priming, an episodic memory phenomenon, rather than by some measure of preceding conflict that influences the degree of control that is present on trial *n*.

In a second experiment, Mayr et al. found additional support for their view by eliminating complete repetitions of stimuli and responses from the EFT task. They accomplished this by alternating trial by trial between a left/right EFT task and an up/down EFT task. According to Mayr et al., the conflict-monitoring account continues to predict a conflict-adaptation effect on trial *n*, as long as conflict is present on trial *n – 1*. On the other hand, the repetition priming account predicts that the conflict-adaptation effect should be eliminated on trial *n* since complete stimulus/response repetitions no longer exist. Findings supported the repetition priming account.

Within the same experiment, Mayr et al. considered repetitions of stimuli and responses on trials *n* - 2 and trial *n*. The conflict adaptation effect was again found for

these repetitions. Mayr et al. cited this as further support for the repetition priming account, suggesting that this account easily handles effects occurring across non-consecutive trials while the conflict monitoring account does not, given that the consecutive trial conflict adaptation effect was not found.

Current Experiments

Mayr et al. (2003) undermine the conflict monitoring account by virtue of a differentiation of II non-repetition and II repetition trials. They claim that the pattern of means (reaction times are faster on II trials compared to CI trials) that Botvinick et al. (2001) have cited as evidence of a conflict adaptation effect reflects merely repetition priming and not an increase in top-down control that occurs in response to some preceding measure of conflict on trial n - 1. The claim is driven by their finding that the effect is found on II repetition trials but not on II non-repetition trials.

Further exploration of the conflict adaptation effect and the interaction of monitoring functions with top-down control functions are warranted on several grounds. First, numerous brain-imaging and computational modeling studies, using a variety of paradigms, have provided convincing data relating ACC function to executive processes of monitoring and conflict detection. In addition to the work of Kerns et al., Carter et al. (1999) found a strong correlation (r = .66) between ACC activation and the degree of conflict present in a given trial, measured as the difference between CI and II trials in terms of fMRI signal activation and reaction time, respectively. ACC activation and reaction times were higher on I trials that followed a C trial, than on I trials that followed another I trial, suggesting more conflict was present in the former situation. Second, replication of the findings of Mayr et al. has yet to be established. In fact, on the contrary,

in an earlier application of the repetition-elimination logic and methodology used by Mayr et al., a small conflict adaptation effect was still found (Gratton et al., 1992). In addition, in the study of Kerns et al., the conflict adaptation effect and corresponding changes in ACC activation and subsequent DLPFC influence occurred on a Stroop task in which complete repetition trials were eliminated. More recently, Ullsperger, Bylsma, and Botvinick (2005) reported two experiments in which a conflict adaptation effect was found during non-repetition trials of flanker tasks. It should be noted though, that different methodologies have been used by Gratton et al., Ullsperger et al., and Kerns et al. as compared to Mayr et al. For instance, Gratton et al. and Ullsperger et al. used speeded versions of the flanker task while Mayr et al. used an unspeeded version. In addition Ullsperger et al. and Kerns et al. used lengthier inter-trial intervals, up to 6000 ms and 1500 ms, respectively, than Mayr et al. who used 1000 ms. Furthermore, Ullsperger used short stimulus presentation times (100 ms or less) and Kerns et al. presented the stimuli for 1500 ms, while Mayr permitted the stimulus to remain on-screen until the response was made. These differences may be responsible for the mixed findings regarding the presence of conflict adaptation effects on non-repetition trials. Thus it is necessary to further evaluate the effect using a similar methodology to Mayr et al. before it is accepted that the effect occurs, as Mayr et al. suggest, in the absence of executive control or as Botvinick et al., suggest, in the presence of control.

One additional concern with the repetition priming account of the conflict adaptation effect is that it eliminates the role of conflict-triggered regulation, in light of evidence from Mayr et al.'s study that suggests conflict may be at least partly responsible for the advantage obtained on II trials. Specifically, although the conflict-adaptation

effect is concerned with the difference in performance on CI trials and II trials, the difference in performance on II non-repetition and II repetition trials, as well as CC non-repetition and CC repetition trials becomes relevant when one considers the validity of the repetition priming account. If, according to this account, the improvement on II trials can be attributed solely to "stimulus driven repetitions of just-executed responses", a bottom up process (Mayr et al., p. 452), then the difference in performance between II non-repetition and II repetition trials should be similar to the difference in performance between CC non-repetition and CC repetition trials. In both comparisons, the stimuli and responses remain exactly the same in one type of trial (i.e., repetition), but change in the other type of trial (i.e., non-repetition). Given that the other difference between these two comparisons is that one involves response conflict and the other does not, the repetition priming account predicts a comparable difference (since this account suggests response conflict has no role in the effect). However, there is clearly a benefit (~ 45 ms) on II repetition trials relative to II non-repetition trials that is greater in magnitude than the benefit (~ 30 ms) observed on CC repetition trials relative to CC non-repetition trials. Thus, it appears that the repetition priming account's disregard for a role of conflict-triggered regulation in the II repetition advantage may be premature.

One way to contrast the repetition priming and conflict monitoring accounts is by parametrically manipulating the conflict that is present during trial *n* - 1 of an II trial. This approach is advantageous in comparison to an all or none contrast of the type that is usually conducted to examine the conflict adaptation effect (i.e., reaction time differences on CI vs. II trials), because it permits investigation of II trials that are structurally alike (e.g., complete repetitions), but involve varying degrees of conflict. The first three

experiments were aimed at examining the conflict adaptation effect by virtue of a comparison between CI trials and II repetition trials that vary in the degree of conflict or length of time that conflict is present in the response system on trial *n* -1.

CHAPTER TWO- EXPERIMENT ONE

Introduction

Prior research using the EFT task has shown that ACC activation is significantly higher (i.e., conflict is greater) when presented with an incompatible trial in a context in which 70% of trials are compatible and 30% are incompatible, as compared to when 70% of trials are incompatible and 30% are compatible (Casey et al., 2000). In the study, behavioral performance was also found to be worse for incompatible trials in the context that included a larger proportion of compatible trials. It is believed that expectancy of an incompatible trial (as in the mostly incompatible condition) enhances control, or in the terms of Gratton, Coles, and Donchin (1992) increases the participant's reliance on a focused strategy of responding, thereby reducing conflict, relative to when an incompatible trial is unexpected, as in the 30% incompatible condition. In a similar study, using a Stroop task, Carter et al. (2000) found robust increases in ACC activity during incongruent trials that occurred in a mostly (80%) congruent block. Furthermore, the size of the Stroop effect was 154 ms in the mostly congruent block compared to 44 ms in the mostly incongruent block.

If the repetition account is valid, and conflict plays no role in the conflict adaptation effect, then reaction times should not differ between II repetition trials in which conflict is high on trial *n* - 1 (i.e., an II trial in the 70% compatible and 30% incompatible condition) compared to when conflict is low on trial *n* - 1 (i.e., an II trial in

the 30% compatible and 70% incompatible condition). On the other hand, if, as the conflict monitoring account proposes, the degree of conflict influences the degree of ACC activation (and the recruitment of control) on trial *n* - 1, then one would expect faster reaction times on II trials in which conflict is high on trial *n* - 1 compared to when conflict is low on trial *n* - 1. Importantly, a comparison of II repetition trials with varying degrees of conflict circumvents the problem of solely comparing performance on II repetition and non-repetition trials, a potentially flawed comparison given the possibility of negative priming in the latter type of II trial.

Because Experiment 1 employs a between subjects manipulation of context, concerns about the validity of the comparison of II repetition trials from the high-conflict context to II repetition trials from the low-conflict context may be apparent. Thus, performance on II repetition trials for each of the two contexts will be assessed relative to baseline performance on CI trials (as in the standard conflict adaptation effect) within each context. The repetition priming account would predict no difference in the magnitude of the effect when comparing CI trials to II repetition trials that are high in conflict versus those that are low conflict trials. On the other hand, the conflict monitoring account would predict an interaction, such that the magnitude of the conflict adaptation effect would be greater in the high conflict (mostly compatible) condition compared to the low conflict (mostly incompatible) condition.

Although a direct comparison of repetition and non-repetition trials may be flawed as described above, contrasting performance on CC, CI, II, and IC non-repetition trials is nonetheless critical. Especially strong support for the conflict monitoring account (and strong evidence against the repetition priming account) would be garnered in the

case that the standard conflict adaptation effect is observed for non-repetition trials in either the high or low frequency context. Non-repetition trials are trials in which neither the stimulus nor response repeats from trial *n* - 1 to trial *n*. That is, the conflict monitoring account predicts that reaction time will be faster on I trials that follow a non-repeating I trial (e.g. <<<><<<; >>><>>>) than on I trials that follow a compatible trial requiring a different response from the previous I trial. The repetition priming account would predict a conflict adaptation effect for II repetition trials but not for II non-repetition trials, as compared to baseline CI trials.

One potential limitation in using a parametric manipulation of conflict of the sort presented here is that the manipulation may not be sufficiently sensitive. Thus, if the degree of conflict on trial *n* – 1 does not appear to have a significant impact on trial *n* performance, an additional analysis will be conducted prior to forming any conclusions about the validity of either account. In the Casey et al. study, ACC activity was correlated with reaction time on the EFT task. Specifically, ACC activity increased as reaction time increased. This finding suggests that an alternative way to analyze the data would be to separate performance on the *n* - 1 trials into fast and slow reaction times, using a median or mean split for example, and then analyze each reaction time bin separately for the II high conflict and II low conflict conditions. Based on the findings of Casey et al., it may be expected that a reaction time advantage would be found in high conflict II trials as compared to low conflict II trials, but only for those *n* -1 trials with the longest reaction times (greater ACC activation). Also relevant here is work by Coles et al. (1985) and Gratton et al. (1988). They found that accuracy on incompatible trials with the shortest and longest RTs was similar to accuracy on the compatible trials of an EFT task, while

incompatible trials associated with middle latency RTs (between 200 – 300 ms) had the worst accuracy. This led them to suggest that the flankers may actually be more likely to determine a response during the 200 -300 ms time period than is the target stimulus. Though this reaction time range may be specific to the particular methodologies (i.e. participants, frequency of trial types, stimulus presentation times) used by Coles et al. and Gratton et al., it does lend support to the prediction that a reaction time advantage for high conflict II trials as compared to low conflict II trials may be present, but only for those *n* -1 trials with the greatest degree of response conflict.

Method

Participants.

85 Colorado State University undergraduates participated in the study in partial fulfillment of course credit. Informed consent was obtained from each participant. Participants were screened, by means of a brief questionnaire, for handedness, neurological and/or psychiatric illnesses (such as ADHD), and past history of significant head trauma. Data from 21 participants who were left handed, or reported the presence of either illness or head trauma were excluded from further analysis.

Design.

The study employed a 2 x 2 x 2 mixed design using the EFT task. Previous Trial Type (Compatible (C) or Incompatible (I)) and Current Trial Type (Compatible (C) or Incompatible (I)) represented the first two factors. Compatible trials were composed of a central display with seven right or left arrows in a row facing the same direction (e.g. <<<<<<<), while incompatible trials were composed of seven arrows in a row with the central arrow facing an opposite direction to the flanker arrows (e.g. <<<>><<<). The

stimulus display was 15 degrees wide, and individual arrows were 1 degree high and wide. The combination of the first two factors produced four possible trial types (CC, CI, II, and IC). The between subjects factor was Type of Context with two levels. For the mostly compatible context, 70% of trials were compatible and 30% were incompatible. For the mostly incompatible context, 70% of the trials were incompatible and 30% were compatible. For the mostly compatible condition, there were 50 CC, 20 CI, 10 II, and 20 IC trials in each block. For the mostly incompatible condition, there were 10 CC, 20 CI, 50 II, and 20 IC trials in each block.

Procedure.

Participants were randomly assigned to one of the two context levels (*Ns* = 32). Participants in both conditions performed the task individually and the experimenter was present for the duration of the experiment. Prior to performing the task, participants read self-paced instructions in which they were introduced to the experimental stimuli and asked to press the left or right response key depending on the direction that the central arrow in the stimulus display was pointing. Participants were informed that they should respond as quickly and accurately as possible. The left response key was marked by a gold star placed over the "h" key and the right response key was marked by a gold star placed over the "j" key on a standard keyboard. Participants were instructed to use the index finger from their left hand to press the left response key, and the index finger from their right hand to press the right key. Once participants acknowledged that the directions were understood, 24 practice trials were presented to familiarize participants with the task.

Following the practice trials, the test component of the task began. The test consisted of five blocks of 100 trials. Each block was separated by a screen indicating the block was completed, and informing participants to press the "s" key to start the next block. During the task, the stimulus remained on-screen until a response was made and the response to stimulus interval (RSI) was set at 1000 ms, replicating Mayr et al. Also following Mayr et al., a fixation cross was presented beneath the central arrow on stimulus screens and remained on-screen during the otherwise blank RSI. The dependent measures of interest were reaction time and accuracy. The task was completed in approximately 20 minutes. Participants were debriefed and thanked for their participation.

Results

Three-way mixed analyses of variance (ANOVAs) were conducted for reaction time (RT) and error rates, with within subjects factors of previous trial type (compatible vs. incompatible) and current trial type (compatible vs. incompatible), and a between subjects factor, context (mostly compatible vs. mostly incompatible). Trials following errors and error trials were excluded from the reaction time analyses. For the analyses of accuracy, trials following errors were excluded. The alpha level was set at .05 for all analyses.

The main effect of current trial type was significant indicating that the standard flanker effect was evident, $F(1, 62) = 88.83$, $p < .01$, partial $eta^2 = .63$. Reaction time was slower for incompatible trials ($M = 689$ ms) than for compatible trials ($M = 520$ ms). Likewise, accuracy was significantly higher for compatible trials ($M = .98$) than incompatible trials ($M = .96$), $F(1, 62) = 62.88$, $p < .01$, partial $eta^2 = .50$. In addition, a

main effect of previous trial type was significant for accuracy ($F(1, 62) = 20.47, p < .01$, partial eta^2 = .25) but not reaction time, $p > .10$. Accuracy was higher following incompatible trials ($M = .98$) as opposed to compatible trials ($M = .96$). For reaction time but not accuracy, the main effect of current trial type was qualified by a significant interaction between current trial type and context, $F(1, 62) = 4.95, p < .05$, partial eta^2 = .07. A larger flanker effect (Incompatible RT – Compatible RT) was apparent for the mostly compatible context ($M = 206$ ms) as compared to the mostly incompatible context ($M = 132$ ms). An independent t-test comparing the mean reaction time for I trials in the mostly incompatible ($M = 668$ ms) and mostly compatible contexts ($M = 711$ ms) was not significant, $t(62) = -.87, p > .10$. Similarly, an independent t-test comparing the mean reaction time for C trials in the mostly incompatible ($M = 536$ ms) and mostly compatible contexts ($M = 505$ ms) was not significant, $t(62) = 1.36, p > .10$.

For reaction time ($F(1, 62) = 53.51, p < .01$, partial eta^2 = .46) and accuracy ($F(1, 62) = 26.81, p < .01$, partial eta^2 = .30), a significant interaction was found between previous trial type and current trial type that resulted in a pattern of means consistent with the conflict adaptation effect. Specifically, II trials ($M = 656$ ms) were significantly faster than CI trials ($M = 722$ ms), $t(63) = -5.37, p < .01$, and IC trials ($M = 546$ ms) were significantly slower than CC trials (495 ms), $t(63) = 8.78, p < .01$. Furthermore, II trials ($M = .97$) were significantly more accurate than CI trials ($M = .94$), $t(63) = 5.99, p < .01$, and IC trials ($M = .98$) were significantly less accurate than CC trials (.99), $t(63) = -1.72$, $p < .05$. The three way interaction of context, current trial type, and previous trial type, was not significant for either dependent measure, $ps > .10$. A closer look at the effect of context on the conflict adaptation effect was achieved by examining whether the

difference in performance between two specific trial types, CI and II, varied depending on context by means of a two-way mixed ANOVA. Again, the interaction was not significant, indicating that the reaction time advantage for II trials over CI trials was equivalent for the mostly incompatible (M = 61ms) and mostly compatible contexts (M = 70 ms), $F(1, 62) = .22, p > .05$.

In an effort to more precisely contrast the repetition priming and conflict monitoring accounts of the conflict adaptation effect, separate three-way ANOVAs were conducted for each of two transition types. Transition type refers to the relationship (i.e. match) between the stimulus on the previous trial and the stimulus on the current trial. The first transition type of interest, repetition represented a transition in which the stimulus repeated and the response repeated (CC and II trials) or simply the response repeated (baseline IC and CI trials). For the second transition type, non-repetition, neither the stimulus nor response repeated.

For repetition trials, the three-way ANOVA revealed a significant two-way interaction of previous and current trial type (for RT, $F(1, 62) = 95.79, p < .01$, partial $eta^2 = .61$; for Accuracy, $F(1, 62) = 45.63, p < .01$, partial $eta^2 = .42$) (see Figure 2.1 a and 2.1 b). Specifically, dependent t-tests revealed that II trials (M = 612 ms) were significantly faster than CI trials (M = 782 ms), $t(63) = -8.17, p < .01$, and CC trials (M = 478 ms) were significantly faster than IC trials (M = 569 ms), $t(63) = -10.04, p < .01$. Likewise, II trials (M = .97) were significantly more accurate than CI trials (M = .91), $t(63) = 7.23, p < .01$, and CC trials (M = .99) were significantly more accurate than IC trials (M = .96), $t(63) = 3.39, p < .01$. Though the three-way interaction of previous trial type, current trial type, and context was not significant ($p > .10$), there was a tendency for

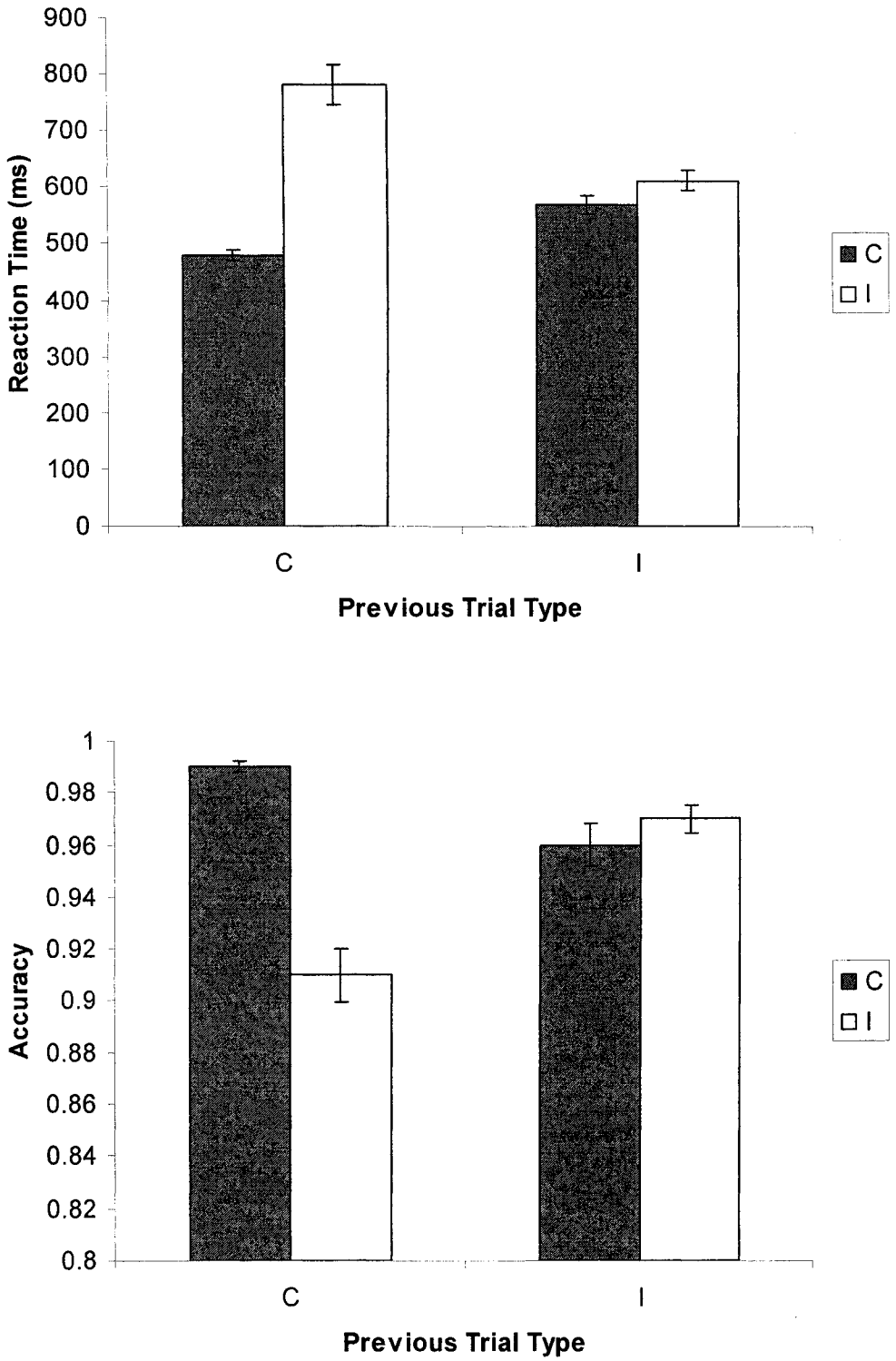

Figure 2.1 a. (upper) and b. (lower). Mean reaction time and accuracy for repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

the reaction time ($t(62) = -1.44, p = .08$) and accuracy advantage ($t(62) = -1.55, p = .06$) for II trials over CI trials to be greater in the mostly compatible condition (Ms = 201 ms and .08, respectively) as compared to the mostly incompatible condition (Ms = 141 ms and .05, respectively). The reaction time advantage for CC trials over IC trials was significantly greater in the mostly incompatible condition (M = 109 ms) as compared to the mostly compatible condition (M = 74 ms), $t(62) = 61.91, p < .05$. This advantage did not exist for accuracy, $p > .10$.

For non-repetition trials, the critical two-way interaction of previous and current trial type was not significant for reaction time ($F(1, 62) = .18, p > .10$) or accuracy ($F(1, 62) = .70, p > .10$) indicating that the conflict adaptation effect was not present for this transition type (see Figures 2.2 a and 2.2 b). The three-way interaction of previous trial

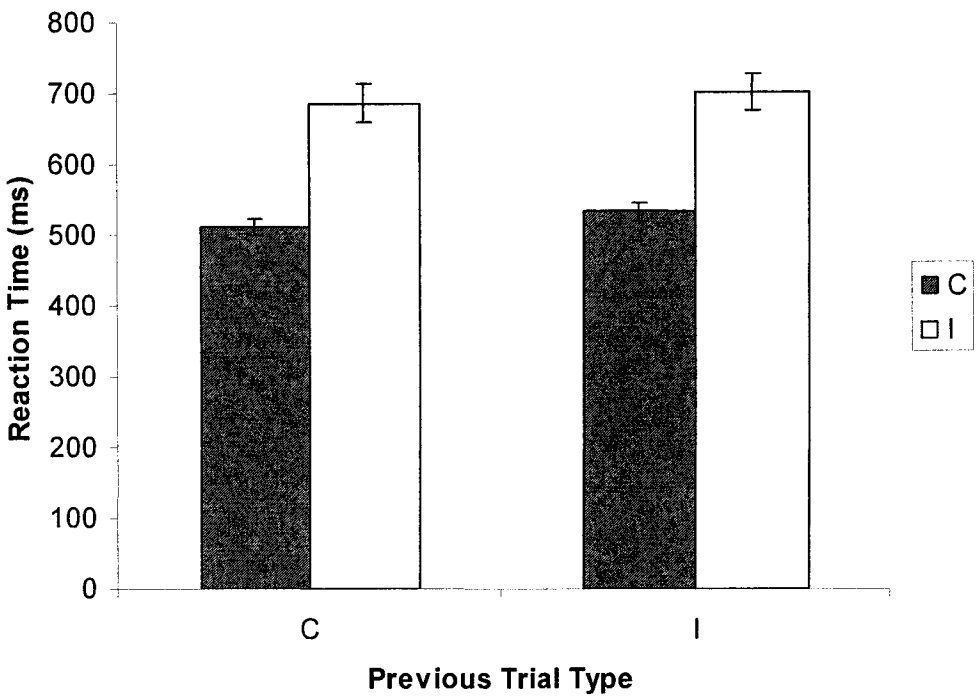

Figure 2.2 a. Mean reaction time for non-repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

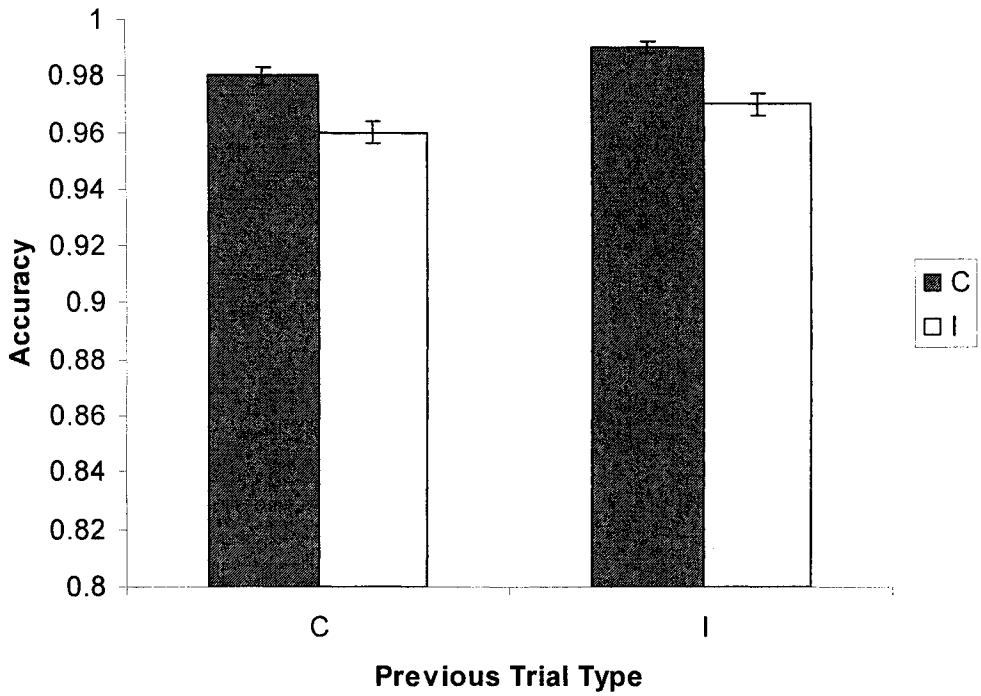

Figure 2.2 b. Mean accuracy for non-repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

type, current trial type, and context was not significant (for RT, $F(1, 62) = 2.5$, $p > .10$; for Accuracy, $F(1, 62) = .05$, $p > .10$) nor were the follow-up interactions focusing on the difference between CI and II trials, separately for each context, $ps > .05$ for RT and Accuracy. Furthermore, when II trials were separated into high conflict or low conflict trials based on preceding I trial reaction time (above average = high conflict, below average = low conflict), II low conflict trials ($M = 653$) were significantly faster than CI trials ($M = 691$), which were significantly faster than II high conflict trials ($M = 821$), $ps < .05$, contrary to the conflict monitoring account.

Discussion

The purpose of E1 was to examine the repetition priming and conflict monitoring accounts of the conflict adaptation effect by means of a contextual manipulation that varied the frequency of incompatible and compatible trials presented to participants. In the mostly compatible condition (70% compatible, 30% incompatible), conflict was expected to be higher on incompatible trials relative to compatible trials, as compared to the mostly incompatible condition (70% incompatible, 30% compatible). This was indeed the case, as the flanker effect was larger in the mostly compatible context. Such a result has been observed in past research (Carter et al., 2000; Casey et al., 2000) using both the flanker task and a Stroop task. These studies have also shown corresponding changes in ACC activation believed to reflect the degree of response conflict that correlated with behavioral performance on incompatible trials. Some researchers explain these effects on the basis of strategy changes induced by the expectancy of an incompatible trial (as in the mostly incompatible condition). For instance, Gratton et al. (1992) have suggested that such expectancy enhances control in the form of more focused responding. The contextual manipulation, and perhaps the corresponding strategy differences in the current study appear to have slowed the performance on the infrequent trial type within each context, leading to a significant interaction between current trial type and context but non-significant simple effects for C and I trials. In other words, not only does it appear that a non-focused strategy of responding slows performance on I trials in a mostly compatible context, but a focused strategy of responding is detrimental to C trials in a mostly incompatible context. This is not surprising when one considers that the flankers can be beneficial to performance on C trials. A strategy focused on the central

target, as in the mostly incompatible condition, may "miss out" on the potential benefit associated with attending to the information conveyed by the flankers.

When all trial types, (repetitions and non-repetitions) were collapsed across context and analyzed, the standard conflict adaptation effect was found. Specifically, participants were faster and more accurate on II trials than on CI trials. Such a result suggests that shifts in control following I trials did not simply correspond to a speed/accuracy tradeoff. Participants were also faster and more accurate on CC trials than on IC trials.

Of greatest interest in E1 though, was examining the repetition priming and conflict monitoring accounts' predictions regarding the conflict adaptation effect. This was accomplished by testing two main hypotheses. The first examined the difference in the magnitude of the II repetition advantage over baseline CI response repetition trials for each type of context, mostly compatible and mostly incompatible. Repetition priming predicted no difference in the magnitude of the advantage between the two contexts, while conflict monitoring expected a greater advantage in the mostly compatible condition as adjustments following I trials in this condition were expected to be greater in response to the increased conflict that was expected to be present on I trials. Though the reaction time advantage was 201 ms in the mostly compatible condition as compared to 141 ms in the mostly incompatible condition, this difference only approached significance (p = .08). Similarly, the accuracy advantage of 8% in the mostly compatible condition as compared to 5% in the mostly incompatible condition also approached significance (p = .06). Recall that the reaction time on incompatible trials in the mostly compatible condition was 43 ms longer than in the mostly incompatible condition, but

this difference was not significant. An even stronger manipulation, for example 80% compatible and 20% compatible, or a within subjects manipulation of context might have been necessary to differentiate the degree of response conflict experienced on incompatible trials in each of the two contexts, and alter the subsequent adjustments in control. Recent work by Jones, Cho, Nystrom, Cohen, and Braver (2002) also suggests that the trial to trial changes in response conflict may be most dependent on the conflict that is present on trials that precede the incompatible trial closely in time. For instance highest conflict, in their study, was experienced on non-repetition I trials following several repetition trials, and was related to heightened ACC activity. Thus, future studies may seek to vary conflict by manipulating recently experienced context. Nonetheless, the trend is in the direction expected by the conflict monitoring account as is the finding that the reaction time and accuracy advantage observed for CC trials over IC trials was significantly greater in the mostly incompatible context.

The second hypothesis that was tested to contrast the two accounts related to the differentiation between repetition and non-repetition trials. Inconsistent with the predictions of the conflict monitoring account, the pattern of means corresponding to the conflict adaptation effect were observed on repetition trials but not on non-repetition trials for both dependent measures. This is unexpected by the conflict monitoring account, because even II non-repetition trials would be expected to benefit from the conflict that is present on the preceding trial and thus be faster than CI non-repetition trials. In addition, there was no effect of the contextual manipulation on the interaction of current and previous trial type for non-repetition trials.

Taken together, the results of E1 lend strong support to the repetition priming account given that the conflict adaptation effect was observed for repetition trials but not non-repetition trials. Some support for the conflict monitoring account was also found through the comparison of II repetition trials from each context to the corresponding baseline CI trials, with reaction time and accuracy advantages approaching significance in the mostly compatible context that was expected to produce the greatest degree of conflict on II trials. As well, the finding of faster and more accurate CC trials than IC trials in the mostly incompatible context fits nicely with the idea of sequential dependency effects not solely attributable to repetition priming.

Though previous work has found strong support for the idea that conflict on a given trial type (and corresponding ACC activation) is influenced by the overall frequency of various trial types (i.e. context) in a given block of trials (Carter et al., Casey et al.), such was not convincingly the case in E1. This type of conflict manipulation may be less effective in increasing or decreasing the relative amount of conflict on trial n - 1 than would be a conflict manipulation that occurs directly on trial n - 1, and thus requires no overall record of context. Relevant to this issue is recent modeling work by DePisapia and Braver (submitted) which proposes a multi-mechanism control system involving two conflict control loops, a modification of the original Botvinick et al. (2001) conflict monitoring model. The first loop is characterized by a proactive control mechanism. Such a mechanism is purported to involve the sustained, and active maintenance of information regarding task-set. This particular mechanism is influenced by conflict over the course of long periods of time (seconds or minutes), as more control is exerted following periods of high response conflict. The modeling work

has supported the idea of engaged proactive control during the performance of mostly incompatible conditions, such as the condition in E1, and the involvement of right PFC in this function. DePisapia and Braver propose that proactive control serves to suppress task irrelevant information (such as the flanker driven response) "just prior to when it could interfere with responding" (p. 2). Hence, interference effects (such as the flanker effect) are reduced in the mostly incompatible condition. On the other hand, a second mechanism, reactive control, is proposed to bias processing towards task-relevant information (such as the target driven response). This mechanism is similar to the control mechanism in the original model, and is proposed to prime the relevant pathways "prior to stimulus-onset, in a preparatory fashion" (p. 2). Activation of this control mechanism is influenced by transient activity in left PFC and the ACC that fluctuates on the basis of short-time scale conflict, such as when responding to the incompatible trials in the mostly compatible condition. In the computational model, increases in proactive control (as in the mostly incompatible condition) led to a decreased need for reactive control. If the conflict adaptation effect is driven largely by reactive control influences, then the contextual manipulation of E1, which most directly alters proactive control, may have been unsurprisingly ineffective. The goal of E2 and E3 was to manipulate the transient need for reactive control, by varying the degree of conflict experienced on trial $n - 1$, in an effort to further contrast the repetition priming and conflict monitoring accounts of the conflict adaptation effect.

CHAPTER THREE- EXPERIMENT TWO

Introduction

As described earlier, the standard incompatible conditions in the EFT task include the condition in which a right target arrow is flanked by left target arrows (i.e., <<<><<<) and the condition in which a left target arrow is flanked by right target arrows (i.e., >>><>>>). Conflict, as measured by an increase in RT, in these conditions is believed to occur because the direction of the flanker arrows corresponds to one response while the direction of the target arrow corresponds to the opposite, or competing response. One other source of conflict in this task stems from the pre-existing relationship between the hand that is used to respond to the left and right arrows. In the task, the left hand is used to make the left key press response to the left pointing arrow and the right hand is used to make the right key press response to the right pointing arrow. Thus, when one is presented with the stimulus ">><>>", reaction times may be slowed and errors may be higher relative to a compatible condition, not only because of the conflict between the two potential responses, but also because the incorrect response may be primed rather rapidly due to the direct mapping between the right facing arrow and the right response key, resulting in competition with the correct response rather early in the response system. On the other hand, if the left facing arrow was surrounded by downward facing arrows (arrows which have also been assigned the right response key), it could be argued that although response conflict exists in this situation, it is to a lesser degree than the case

in which right arrows flank the left target arrow, since only the latter case involves a strong preexisting association between target direction and key press response. Thus, it would be expected that competition would arise later in processing, possibly at a point at which the correct response is far enough along that it can override the incorrect response tendency. Conflict in the response system would be expected for a shorter period of time in this condition.

Research in the realm of stimulus-response compatibility effects lends support to this logic. Donders (1868) was perhaps the first to study the effects of spatial compatibility on choice reaction times. He found that choice reaction time using left and right hands took 66 ms when an impulse was presented to either the left or right foot. On the other hand, when the stimulus was a red or white light, reaction time increased to 122 ms. He attributed the faster reaction times in the left/right foot condition to the natural correspondence between stimuli and responses. The advantage of compatible mapping over incompatible mapping (i.e. press the left key when the right foot is stimulated) has now become a standard finding (Proctor & Lu, 2002) and has been attributed in some cases, to well-established habits (or long term associations) (Fitts, 1964). Specifically, when the stimulus automatically activates the correct response, reaction times are facilitated. Teichner and Krebs (1974) also found that reaction times were faster when the spatial code of the test (target) stimulus matched the spatial code of the response. Interestingly, when only left-right codes or up-down codes have been used in isolation, participants exhibit compatibility effects of equal magnitude for the horizontal and vertical dimensions (Nicoletti & Umilta, 1984). However, when the two codes were used simultaneously, the compatibility effect for the up-down code was significantly

weakened (Nicoletti & Umilta) or eliminated (Nicoletti, Umilta, Tressoldi, & Marzi, 1988), while the left-right compatibility effect increased.

Hommel (1996) suggested that the right-left prevalence effect may be attributable to the time at which horizontal and vertical response codes become available in the system. Horizontal codes tend to become available prior to vertical codes, thus responses to the left-right stimulus dimensions are faster. The results of Proctor, Vu, and Nicoletti (2003) support this conclusion in that a larger Simon effect was found for the horizontal dimension in the fastest two-thirds of the reaction time distribution, with this difference reversed in the slowest third of the distribution, where a larger Simon effect was found for the vertical dimension.

If, indeed, as the research reviewed above suggests, reaction times are faster when the stimulus location matches the response location, the compatibility effect is stronger for the left-right than up-down dimensions, and the horizontal dimension becomes available earlier than the vertical dimension in the response system, then varying the stimulus-response compatibility of the flankers in an EFT task, between the left-right and up-down dimensions, should allow one to manipulate the degree to which the flankers cause response competition and the length of time that conflict is present in the response system. Trials in which the flankers depict a horizontal code would be expected to elicit more response competition (and competition that occurs early on) and greater increases in reactive control, while trials in which the flankers depict a vertical code would be expected to elicit less response competition (and competition that occurs later in processing) and a decreased need for reactive control.

Like Experiment 1, this manipulation was used with the intent of comparing baseline CI trials to II trials of the repetition type that vary in their need for reactive control, again avoiding the potentially confounded comparison of II repetition and II non-repetition trials. The conflict monitoring account predicts a conflict adaptation effect of greater magnitude on incompatible high-conflict trials that are preceded by another incompatible high conflict trial than on incompatible low-conflict trials that are preceded by another incompatible low-conflict trial. On the other hand, the repetition priming account predicts an equivalent advantage on II repetition trials of the high-conflict and low-conflict type over baseline CI trials.

The conflict monitoring and repetition priming accounts also predict differing results for non-repetition trials. Specifically, the conflict monitoring account expects the conflict adaptation effect to be present on non-repetition trials, where as the repetition priming account expects that the pattern of means consistent with the conflict adaptation effect will be present on repetition trials but not non-repetition trials.

Method

Participants.

47 Colorado State University undergraduates participated in the study in partial fulfillment of course credit. Informed consent was obtained from each participant. Participants were screened, by means of a brief questionnaire, for handedness, neurological and/or psychiatric illnesses (such as ADHD), and past history of significant head trauma. Data from 10 participants who were left handed, or reported the presence of either illness or head trauma were excluded from further analysis.

Design.

The study employed a 3 x 3 within subjects design during an EFT task. Previous trial type (compatible (C) vs. incompatible high conflict (Ihc) vs. incompatible low conflict (Ilc)) and Current trial type (compatible (C) vs. incompatible high conflict (Ihc) vs. incompatible low conflict (Ilc)) represented the factors. Compatible trials were composed of a central display with seven arrows in a row. Each arrow pointed in the same direction and thus corresponded to the same response. Incompatible trials were composed of seven arrows in a row, with the central arrow corresponding to the response that was opposite of the response associated with the flanker arrows. The stimulus display was 15 degrees wide, and individual arrows were 1 degree high and wide. On high conflict trials, the flankers were associated with a horizontal code (right or left) while on low conflict trials, the flankers were associated with a vertical code (up or down). There were four different displays used on incompatible high conflict trials, including a left central arrow surrounded by right arrows, a right central arrow surrounded by left arrows, an up facing central arrow surrounded by right arrows, and a down facing central arrow surrounded by left arrows. There were seven displays of each type within a block. Likewise, there were four different displays used on incompatible low conflict trials, including a left central arrow surrounded by down facing arrows, a right central arrow surrounded by up facing arrows, an up facing central arrow surrounded by down facing arrows, and a down central facing arrow surrounded by up facing arrows. There were seven displays of each type within a block. There were four different displays used on compatible trials, a right central arrow surrounded by right arrows, a left central arrow surrounded by left arrows, an up facing arrow surrounded by up facing arrows, and a

down facing arrow surrounded by down facing arrows Each display was used 14 times within a block. Of interest was the interaction of the two independent variables, previous and current trial type. Within each experimental block, there were 28 CC, 28 CI (14 CIhc, 14 CIlc), 28 II (7 IhcIhc, 7 IhcIlc, 7 IlcIlc, 7 IhcIlc), and 28 IC (14 IhcC, 14 IlcC) trials.

Procedure.

Participants performed the task individually and the experimenter was present for the duration of the experiment. During the initial training phase, participants responded to individual arrows presented one at a time in the center of the screen. Twelve right, left, up, and down facing arrows were randomly presented for a total of 48 trials. This phase was included so that participants had the opportunity to familiarize themselves with the response key assignments, particularly in the case of the up and down keys. Participants were instructed to press the left key if the arrow pointed left or up and to press the right key if the arrow pointed right or down. The left response key was marked by a gold star placed over the "h" key and the right response key was marked by a gold star placed over the "j" key on a standard keyboard. Participants were instructed to use the index finger from their left hand to press the left response key, and the index finger from their right hand to press the right response key. Participants were informed that they should respond as quickly and accurately as possible.

Following the training phase, a practice phase began. Participants read self-paced instructions in which they were introduced to the experimental stimuli and asked to press the left or right response key depending on the direction that the central arrow in the stimulus display was pointing. Participants were instructed to press the left key if the central arrow pointed left or up, and to press the right response key if the central arrow

pointed right or down. Participants were again instructed to use the index finger from their left hand to press the left response key, and the index finger from their right hand to press the right key. Participants were informed that they should respond as quickly and accurately as possible. Once participants acknowledged that the directions were understood, 24 practice trials were presented during which each of the trial types (C, Ihc, Ilc) were randomly presented.

Following the practice trials, the test component of the task began. The test consisted of five blocks of 112 trials. Each block was separated by a screen that commended the participants on completing the block, and reminded them to press the left key if the central arrow pointed left or up, and the right key if the central arrow pointed right or down. Participants were required to press the "s" key to begin each new block. During the task, the stimulus remained on-screen until a response was made and the response to stimulus interval (RSI) was set at 1000 ms, replicating Mayr et al. Also following Mayr et al., a fixation cross was presented beneath the central arrow on stimulus screens and remained on-screen during the otherwise blank RSI. The dependent measures of interest were reaction time and accuracy. The task was completed in approximately 25 minutes. Participants were debriefed and thanked for their participation.

Results

Two-way within subjects analyses of variance (ANOVAs) were conducted for reaction time (RT) and accuracy, with factors of previous trial type (compatible (C) vs. incompatible high conflict (Ihc) vs. incompatible low conflict (Ilc)) and current trial type (compatible (C) vs. incompatible high conflict (Ihc) vs. incompatible low conflict (Ilc)).

Trials following errors and error trials were excluded from the reaction time (RT) analyses. For the analyses of accuracy, trials following errors were excluded. The alpha level was set at .05 for all analyses.

The main effect of current trial type was significant for reaction time, $F(2, 72) = 26.15$, $p < .01$, partial eta$^2 = .42$, and accuracy, $F(2, 72) = 15.75$, $p < .01$, partial eta$^2 = .30$. Dependent t-tests indicated that reaction time was significantly slower for Ihc trials ($M = 756$ ms) than for Ilc trials ($M = 640$ ms) and compatible trials ($M = 627$ ms), $ps < .01$. The reaction times for Ilc trials and compatible trials did not differ, $p > .05$. For accuracy, Ihc trials ($M = .93$) were significantly less accurate than Ilc trials ($M = .97$) and C trials ($M = .95$), $ps < .05$. Ilc trials were significantly more accurate than C trials, $p < .05$. The main effect of previous trial type compatibility was significant for reaction time ($F(2, 72) = 17.90$, $p < .01$, partial eta$^2 = .33$) but was not significant for accuracy ($F(2, 72) = 1.39$, $p > .05$, partial eta$^2 = .04$). Reaction time was significantly faster following Ihc trials ($M = 654$ ms) and Ilc trials ($M = 665$ ms) than following compatible trials ($M = 704$ ms), $ps < .05$. Reaction time was similar on trials following Ihc or Ilc trials, $p > .05$.

The main effects were qualified by a significant interaction between previous trial type and current trial type (For RT, $F(4, 144) = 29.44$, $p < .01$, partial eta$^2 = .45$; for Accuracy, $F(4, 144) = 14.96$, $p < .01$, partial eta$^2 = .29$). Follow-up dependent t-tests revealed that IhcIhc trials ($M = 665$ ms) were significantly faster than CIhc trials ($M = 805$ ms) and IlcIhc trials ($M = 797$ ms) $ps < .01$, while reaction time on CIhc and IlcIhc trials did not differ, $p > .05$. Furthermore, IlcIlc trials ($M = 564$ ms) were significantly faster than IhcIlc trials ($M = 641$ ms) which were significantly faster than CIlc trials ($M = 715$ ms), $ps < .01$. CC trials ($M = 593$ ms) were significantly faster than IlcC trials ($M =$

635 ms), which were significantly faster than IhcC (M = 654 ms) trials. For accuracy, performance was similar on CIhc (M = .95) and IhcIhc (M = .94) trials, $p > .05$. Accuracy was significantly worse on IlcIhc trials (M = .91) as compared to CIhc and IhcIhc trials, $ps < .05$. For Ilc trials, accuracy was significantly higher on IlcIlc (M = .99) trials than on CIlc (M = .95) or IhcIlc (M = .95) trials ($ps < .05$), which were similar in accuracy, $p > .05$. Accuracy was significantly higher on IhcC trials (M = .96) than on either CC trials (M = .94) or IlcC trials (M = .95), $ps < .05$, which were similar in accuracy, $p > .05$.

In an effort to more precisely contrast the repetition priming and conflict monitoring accounts of the conflict adaptation effect, separate two-way within subject ANOVAs were conducted for each of two transition types. The factors were previous trial type and current trial type. Transition type refers to the relationship (i.e. match) between the stimulus on the previous trial and the stimulus on the current trial. The first transition type of interest, repetition represented a transition in which the stimulus repeated and the response repeated (CC and II trials) or simply the response repeated (IC and CI trials). For the second transition type, non-repetition, neither the stimulus nor response repeated. Of primary interest were two comparisons. The first focused upon repetition trials only, and analyzed the difference in performance between II repetition trials that were high in conflict as compared to those low in conflict, relative to baseline repetition trials. The second comparison assessed whether the conflict adaptation effect would be present for one or both transition types. Therefore, another set of analyses focused on the interaction between previous and current trial type, rather than the main effects.

For repetition trials, IhcIhc trials were performed on average 145 ms faster than CIhc trials, while IlcIlc trials were performed on average 200 ms faster than CIlc trials. A dependent t-test on the mean differences revealed a significantly greater advantage for IlcIlc than IhcIhc over baseline CI trials, $t(36) = -1.84$, $p < .05$. Furthermore, a subsequent two-way ANOVA revealed a significant interaction between previous trial type and current trial type for reaction time, $F(4, 144) = 22.59$, $p < .01$, partial eta^2 = .39 (see Figure 3.1 a). IhcIhc trials (M = 589 ms) were significantly faster than CIhc trials (M = 735 ms), $p < .01$. CIhc trials were significantly faster than IlcIhc trials (M = 853 ms), p = .01. There was also an advantage for IlcIlc trials (M = 536 ms) over CIlc trials (M = 737 ms) and IhcIlc trials (M = 614 ms), $ps < .01$. In addition IlcIlc trials were significantly faster than IhcIlc trials, $p < .01$. CC trials (M = 505 ms) were significantly faster than IlcC trials (M = 534 ms), $p < .05$, which were significantly faster than IhcC trials (M = 579 ms), $p < .01$.

For repetition trials, IhcIhc trials were on average 2% more accurate than CIhc trials, while IlcIlc trials were on average 7% more accurate than CIlc trials. A t-test on the mean differences revealed a significantly greater accuracy advantage for IlcIlc than IhcIhc over baseline CI trials, $t(36) = 3.25$, $p < .01$. The two-way within subjects ANOVA for the repetition trials also revealed that the interaction of previous and current trial type was significant for accuracy, $F(4, 144) = 11.34$, $p < .01$, partial eta^2 = .24 (see Figure 3.1 b). Specifically, IhcIhc trials (M = .98) were significantly more accurate than CIhc trials (M = .96) which were significantly more accurate than IlcIhc trials (M = .92), $ps \leq .05$. IlcIlc trials (M = .99) were significantly more accurate than IhcIlc trials (M = .96) and CIlc trials (M = .92), $ps \leq .01$. The difference in accuracy between IhcIlc and

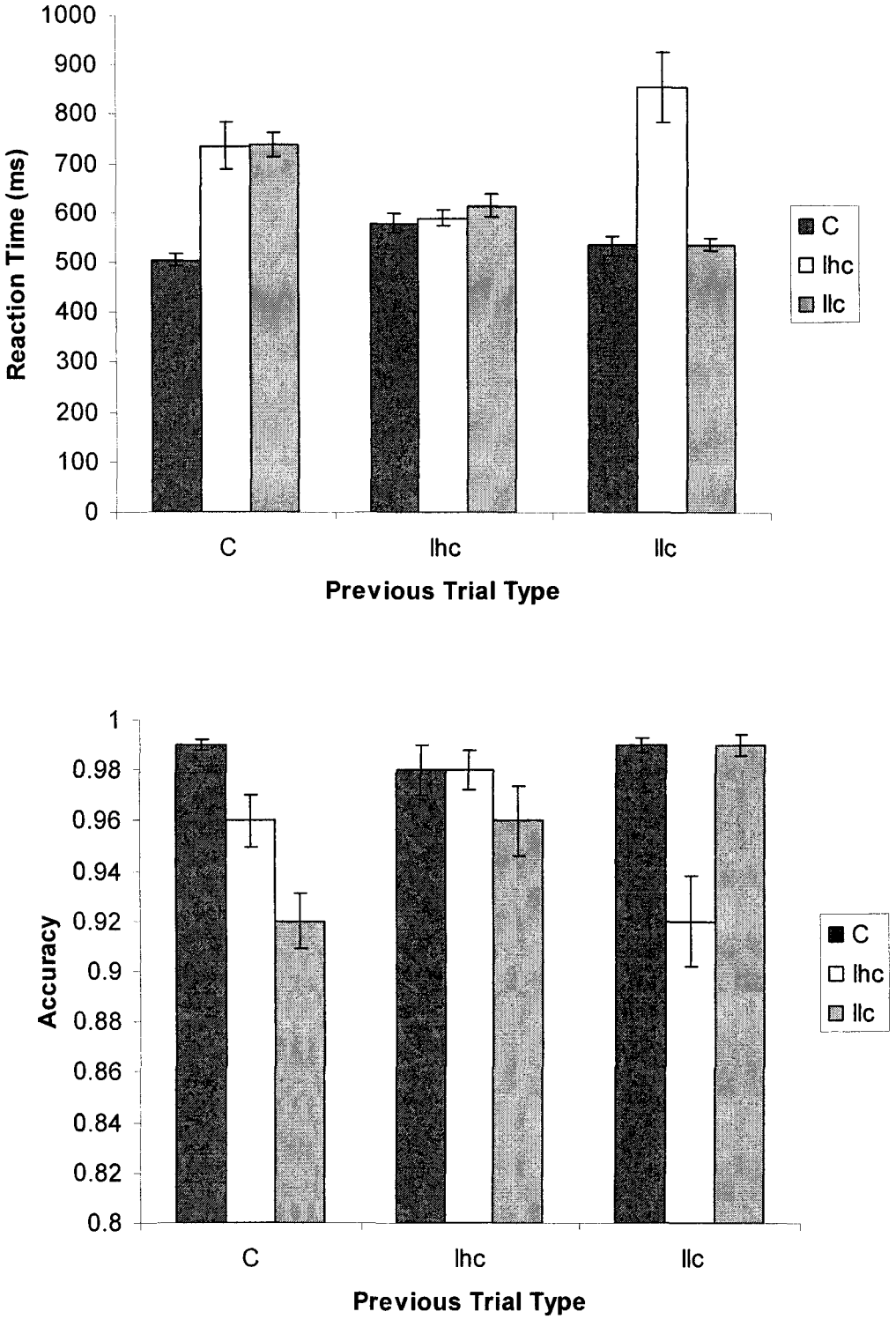

Figure 3.1 a. (upper) and b. (lower). Mean reaction time and accuracy for repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

CIlc trials approached significance, p =. 07. All C trial types (CC (M = .995), IhcC (M = .98), IlcC (M = .997)) were similar in accuracy, ps > .05.

For non-repetition trials, the two way ANOVA revealed that the critical two-way interaction of previous and current trial type was significant for reaction time (F(4, 144) = 10.76, p < .01, partial eta^2 = .23) (see Figure 3.2 a). Though IhcIhc trials (M = 782 ms) were faster than CIhc trials (M = 832 ms) by 50 ms, this difference approached significance, p = .12. Importantly though, IlcIhc trials (M = 767 ms) were significantly faster than CIhc trials, p < .05 and reaction time did not differ between IlcIhc and IhcIhc trials, p > .05. There was also an advantage for IlcIlc trials (M = 586 ms) over IhcIlc trials (M = 663 ms) and CIlc trials (M = 688 ms), ps < .01. Furthermore, IhcIlc trials were

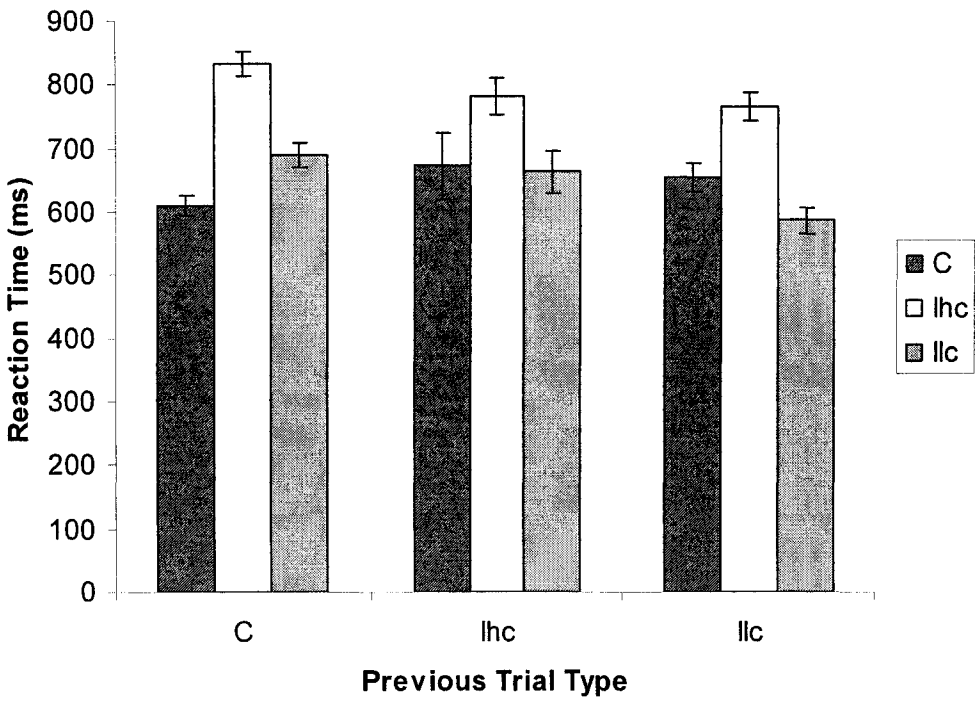

Figure 3.2 a. Mean reaction time for non-repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

significantly faster than CIlc trials, $p < .05$. In addition IlcIlc trials were significantly faster than IhcIlc trials, $p < .01$. CC trials ($M = 609$ ms) were significantly faster than IhcC trials ($M = 672$ ms) and IlcC trials ($M = 654$ ms), $ps < .01$. The difference in reaction time between IhcC trials and IlcC trials approached significance, $p = .06$. Looked at in a different way, the flanker effect (RT for collapsed incompatible trials minus RT for compatible trials) was 151 ms following compatible trials, 113 ms following incompatible high conflict trials, and 29 ms following incompatible low conflict trials.

For non-repetition trials, the two way ANOVA revealed that the critical two-way interaction of previous and current trial type was significant for accuracy ($F(4, 144) = 13.14, p < .01$, partial eta$^2 = .27$) (see Figure 3.2 b). CIhc trials ($M = .95$) were

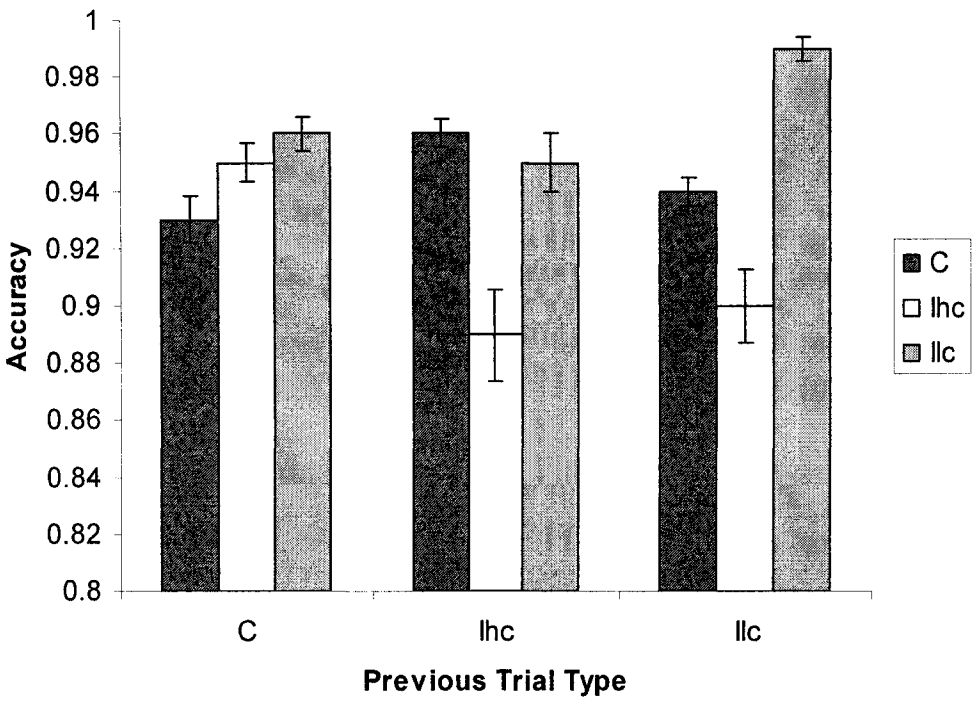

Figure 3.2 b. Mean accuracy for non-repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

significantly more accurate than IhcIhc trials (M = .89) and IlcIhc trials (M = .90), ps < .01. Accuracy was similar for IhcIhc trials and IlcIhc trials, p > .05. IlcIlc trials (M = .99) were significantly more accurate than CIlc trials (M = .96) and IhcIlc trials (M = .95), ps < .01. The latter two trial types did not differ in accuracy, p > .05. There was also an advantage in accuracy for IhcC trials (M = .96) over IlcC trials (M = .95) and CC trials (M = .93), ps ≤ .01. The difference in accuracy between IlcC trials and CC trials approached significance, p = .06.

Discussion

The purpose of E2 was to examine reactive control adjustments following incompatible trials with varying degrees of response conflict, high or low, and compatible trials with no response conflict. High conflict trials involved incompatible flankers that pointed either right or left, while low conflict trials involved incompatible flankers that pointed either up or down. The manipulation appeared to be effective in varying the degree of conflict experienced on each type of incompatible trial as reaction times were slower and performance was less accurate on incompatible high conflict trials as compared to incompatible low conflict trials or compatible trials. Interestingly, the reaction times for Ilc and compatible trials were similar, and compatible trials were less accurate than Ilc trials. Of particular interest was contrasting the repetition priming and conflict monitoring accounts of the conflict adaptation effect by examining two hypotheses related to the conflict manipulation.

The first hypothesis focused on a comparison between IhcIhc repetition trials, IlcIlc repetition trials, and corresponding baseline CIhc and CIlc response repetition trials. The conflict monitoring account predicts a greater adjustment following high

conflict as compared to low conflict trials, and thus expects corresponding reaction time differences between the two conditions. The results did not confirm this prediction, as greater adjustments in cognitive control, as evidenced by faster performance on trial *n*, were observed for IlcIlc repetition trials relative to baseline CIlc trials than were observed for IhcIhc trials relative to baseline CIhc trials. This result is not readily handled by the repetition priming account either, as this account predicted an equivalent advantage for IlcIlc and IhcIhc trials.

The second hypothesis related to the effects of the conflict manipulation on the magnitude of the conflict adaptation effect, on repetition and non-repetition trials. Consistent with the repetition priming account, performance on IhcIhc repetition trials was significantly faster and more accurate than performance on CIhc or IlcIhc response repetition trials. Similarly, IlcIlc repetition trials were significantly faster and significantly more accurate than CIlc and IhcIlc response repetition trials. However, inconsistent with the repetition priming account, and in support of the conflict monitoring account, reaction time was 50 ms faster for IhcIhc non-repetition trials than CIhc non-repetition trials and 65 ms faster for IlcIhc non-repetition trials than CIhc non-repetition trials, with the latter effect being significant. On the other hand accuracy was significantly greater in the CIhc condition relative to the IhcIhc and IlcIhc conditions. Reaction time was also significantly faster for IlcIlc non-repetition trials than CIlc non-repetition trials and IhcIlc non-repetition trials, and a significant reaction time advantage was found for IhcIlc trials over CIlc non-repetition trials. For this trial type, accuracy was also significantly higher for IlcIlc trials as compared to CIlc trials. The latter set of results showing conflict-adaptation like effects deviates strongly from the predictions of the

repetition priming account, with the exception of the accuracy advantage obtained on CIhc trials relative to the IhcIhc and IlcIhc trial types. Though these results strongly support the conflict monitoring account, given that they were found on non-repetition trials, consistent support was not found for this account's prediction of increased reactive control in response to greater response conflict given that reaction time and accuracy were similar on IhcIhc and IlcIhc trials, and IlcIlc trials were faster and more accurate than IhcIlc trials.

Nonetheless, the finding of conflict adaptation on non-repetition trials is important for several reasons. Most importantly, along with a recent study conducted by Ullsperger, Bylsma, and Botvinick (2005), it questions the generalizability of Mayr et al.'s (2003) repetition priming account. In the first experiment of Ullsperger et al., a conflict adaptation effect was observed on non-repetition trials during a standard flanker task with directions emphasizing speed over accuracy. In their second experiment, a conflict adaptation effect was observed on non-repetition trials during a digit based flanker task involving a large set of nine responses. The results of the current experiment are especially noteworthy, given that the differences between the paradigm used by Mayr et al. and the paradigm used here were minimal. For instance, directions were similar in emphasizing speed and accuracy, in both studies the stimulus remained on screen until a response was made, the response to stimulus interval was 1000 ms, and a fixation cross remained on-screen throughout the task. Such was not the case in the Ullsperger et al. study, which used brief stimulus presentation times (100 ms and shorter) and lengthy inter-trial intervals up to 6000 ms in length to minimize the influence of negative priming on II non-repetition trials. The difference of note between the current study and the first

experiment reported by Mayr et al. concerns the size of the response set. Four targets were utilized in the current study compared to two used by Mayr et al. Barch et al. (2000) showed that the ACC was more responsive under conditions in which multiple responses might be activated. Thus, one might suppose that the current paradigm induced greater ACC activation, and greater adjustments in control in response to the larger response set. Though possible, this explanation is unlikely to account for the difference between the current work and Mayr et al. given that Mayr et al. used a four response set in their second experiment, and still the conflict adaptation effect was not present on non-repetition trials. Alternatively, the difference might stem from the mapping of the responses to response keys or the order of presentation of the up/down and left/right targets. More specifically, Mayr had participants utilize up and down keys that were separate from the right and left keys. In the current study, two responses (one vertical and one horizontal) were assigned to each of two response keys. Hence, conflict may have been concomitantly higher in the latter case. In addition, Mayr used a predictable alternating version of the flanker task, in which trials alternated between stimuli requiring an up/down response and stimuli requiring a left/right response. Such predictability may have reduced the conflict produced by the vertical dimension when a horizontal response was required, and vice versa. Such reductions in conflict would be expected to directly impact the transient adjustments in reactive control that may be necessary for the sequential modulations in performance that characterize the conflict adaptation effect. E3 aimed to further examine such modulations by means of another manipulation designed to alter response conflict on a trial by trial basis.

CHAPTER FOUR- EXPERIMENT THREE

Introduction

The focus of the previous experiment was to manipulate conflict directly on trial *n* – 1 by altering the type of flankers that are utilized on these trials. Although E3 also aims to vary conflict on trial *n* – 1 by virtue of a manipulation which requires no overall record of context, unlike E2 which utilized a manipulation that was aimed at the speed of response selection processes directly, E3 utilizes a manipulation that occurs at a perceptual level, thus, impacting the speed of stimulus selection processes more directly, and response selection processes only indirectly. E2 will rely on the work of Eriksen and Schulz (1979). They reported a large compatibility effect, incompatible trials were significantly slower (by about 40 ms) than compatible trials, in Experiment 2 when flankers were twice as large as the central target stimulus. In Experiment 1, the flanker letters had little effect on processing of the target stimulus when the target stimulus was larger than the flanker letters. Reaction time on compatible trials was approximately 20 ms less than reaction time on incompatible trials. Eriksen and Schulz proposed a continuous flow model to account for the findings of their second experiment, suggesting that the increase in the size of the letters enhanced their competitive effect because more time was required for the visual system to identify the target stimulus than was required to identify the flanker stimuli. Thus, "the level of priming for the competing response was concomitantly higher" (Eriksen & Schulz, 1979, p. 256).

Relating these effects to the conflict adaptation effect, the two conditions (a) target larger than flankers and (b) flankers larger than targets present a nice comparison of low competition (conflict) and high competition (conflict) situations, respectively. Using this manipulation on trial $n - 1$ allows one to contrast the repetition priming and conflict-monitoring accounts. Similar to the predictions of E1 and E2, the conflict monitoring account would predict a larger conflict adaptation effect for incompatible trials that follow an incompatible trial that is high in conflict compared to one which is lower in conflict. On the other hand, the repetition priming account predicts an equivalent advantage on II repetition trials of the high-conflict and low-conflict type over baseline CI trials.

The conflict monitoring and repetition priming accounts also predict differing results for non-repetition trials. Specifically, the conflict monitoring account expects the conflict adaptation effect to be present on non-repetition trials, where as the repetition priming account expects that the pattern of means consistent with the conflict adaptation effect to be present only on repetition trials.

Method

Participants.

51 Colorado State University undergraduates participated in the study in partial fulfillment of course credit. Informed consent was obtained from each participant. Participants were screened, by means of a brief questionnaire, for handedness, neurological and/or psychiatric illnesses (such as ADHD), and past history of significant head trauma. Data from 8 participants who were left handed, or reported the presence of either illness or head trauma were excluded from further analysis.

Design.

The study employed a 4 x 4 within subjects design during an EFT task. Previous trial type (Compatible High Conflict (Chc) vs. Compatible Low Conflict (Clc) vs. Incompatible High Conflict (Ihc) vs. Incompatible Low Conflict (Ilc)) and current trial type (Compatible High Conflict (Chc) vs. Compatible Low Conflict (Clc) vs. Incompatible High Conflict (Ihc) vs. Incompatible Low Conflict (Ilc)) represented the factors. Compatible trials were composed of a central display with seven right or left arrows in a row facing the same direction, while incompatible trials were composed of seven arrows in a row, with the central arrow facing an opposite direction to the flanker arrows. Following Eriksen and Schultz, on high conflict trials, the flankers were approximately twice as large as the 1 degree high and wide central arrow. On low conflict trials, the flankers were approximately half the size of the 1 degree high and wide central arrow. Within each experimental block, there were 28 CC trials, 28 CI trials (14 CIhc, 14 CIlc), 28 II trials (7 IhcIhc, 7 IhcIlc, 7 IlcIlc, 7IlcIhc) and 28 IC (14 IhcC, 14 IlcC) trials. For each trial type (e.g. CI), approximately equivalent numbers of each possible combination were utilized (e.g. ClcIhc, ChcIhc, ClcIlc, and ChcIlc).

Procedure.

Participants performed the task individually and the experimenter was present for the duration of the experiment. Prior to performing the task, participants read self-paced instructions in which they were introduced to the experimental stimuli and asked to press the left or right response key depending on the direction that the central arrow in the stimulus display was pointing. Participants were informed that they should respond as quickly and accurately as possible. The left response key was marked by a gold star

placed over the "h" key and the right response key was marked by a gold star placed over the "j" key on a standard keyboard. Participants were instructed to use the index finger from their left hand to press the left response key, and the index finger from their right hand to press the right key. Once participants acknowledged that the directions were understood, 24 practice trials were presented.

Following the practice trials, the test component of the task began. The test consisted of five blocks of 112 trials. Each block was separated by a screen that commended the participants on completing the block, and reminded them to press the left key if the central arrow pointed left and the right key if the central arrow pointed right. During the task, the stimulus remained on-screen until a response was made and the response to stimulus interval (RSI) was set at 1000 ms, replicating Mayr et al. Also following Mayr et al., a fixation cross was presented beneath the central arrow on stimulus screens and remained on-screen during the otherwise blank RSI. The dependent measures of interest were reaction time and accuracy. The task was completed in approximately 20 minutes. Participants were debriefed and thanked for their participation.

Results

Two-way within subjects analyses of variance (ANOVAs) were conducted for reaction time (RT) and accuracy, with factors of previous trial type (Compatible High Conflict (Chc) vs. Compatible Low Conflict (Clc) vs. Incompatible High Conflict (Ihc) vs. Incompatible Low Conflict (Ilc)) and current trial type (Compatible High Conflict (Chc) vs. Compatible Low Conflict (Clc) vs. Incompatible High Conflict (Ihc) vs. Incompatible Low Conflict (Ilc)). Trials following errors and error trials were excluded

from the reaction time analyses. For the analyses of accuracy, trials following errors were excluded. The alpha level was set at .05 for all analyses.

The main effect of current trial type was significant for reaction time, $F(3,126) = 214.95$, $p < .01$, partial eta$^2 = .84$, and accuracy, $F(3,126) = 39.19$, $p < .01$, partial eta$^2 = .48$. Follow-up dependent t-tests indicated that all conditions differed in reaction time except Chc trials ($M = 490$ ms) and Ilc trials ($M = 492$ ms), $p > .05$. Importantly, participants took significantly longer to respond to Ihc trials ($M = 582$ ms) than Ilc trials, and took longer to respond to Chc trials than Clc trials ($M = 466$), $ps < .05$. For accuracy, the dependent t-tests indicated that all conditions differed except Chc trials ($M = .99$) and Clc trials ($M = .99$), $p > .05$. Ihc trials ($M = .92$) were significantly less accurate than Ilc trials ($M = .98$), $p < .05$. A subsequent analysis that collapsed across C trials and I trials showed that performance on these trials was consistent with the standard flanker effect, with slower and less accurate performance for incompatible trials ($Ms = 537$ ms and .95, respectively) than for compatible trials ($M = 478$ ms and .99, respectively) ($F(1, 42) = 294.15$, $p < .01$, partial eta$^2 = .88$ and accuracy, $F(1, 42) = 46.37$, $p < .01$).

The main effect of previous trial type was also significant for reaction time ($F(3, 126) = 3.46$, $p < .05$, partial eta$^2 = .08$) and accuracy ($F(3, 126) = 13.42$, $p < .01$, partial eta$^2 = .24$). Reaction time was similar following Chc trials ($M = 503$ ms) and Ilc trials ($M = 503$ ms), and similar following Clc trials ($M = 512$ ms) and Ihc trials ($M = 512$ ms), $ps > .05$. Reaction time was similar on trials following Ihc or Ilc trials, $p > .05$. The reaction time advantage for trials following Chc trials over trials following Clc trials was significant ($p < .01$), while the advantage over Ihc trials approached significance, $p = .06$. The reaction time advantage for trials following Ilc trials over trials following Clc trials

was significant (p =<.05), while the advantage over Ihc trials approached significance (p = .08). For accuracy, the dependent t-tests revealed that trials following Ihc trials (M = .98) were significantly more accurate than trials following any of the other three trial types, ps < .05. Accuracy was similar for trials following Chc trials (M = .97) and trials following Ilc trials (M = .97), p > .05. Accuracy was significantly higher for trials following Chc trials, than for trials following Clc trials, p < .05.

The main effects were qualified by a significant interaction between previous trial type and current trial type (For RT, $F(9, 378) = 13.83$, $p < .01$, partial eta^2 = .25; for Accuracy, $F(9, 378) = 9.34$, $p < .01$, partial eta^2 = .18). Follow-up dependent t-tests revealed that IhcIhc trials (M = 561 ms) were significantly faster than ClcIhc trials (M = 616 ms) but not significantly faster than ChcIhc trials (M = 572 ms). The reaction time advantage for IhcIhc trials over IlcIhc trials (M = 581 ms) approached significance, p = .07. For Ilc trials, IlcIlc trials (M = 472 ms) were significantly faster than IhcIlc trials (M = 513 ms), ChcIlc trials (M = 493), and ClcIlc trials (M = 488), ps < .05. IhcIlc trials were significantly slower than ChcIlc trials and ClcIlc trials, ps < .05. Reaction time for ChcIlc and ClcIlc trials was equivalent, p > .05. Reaction time on ChcChc trials (M = 473 ms) was significantly faster than ClcChc trials (M = 497 ms), IhcChc trials (M = 497 ms), and IlcChc trials (M = 494 ms), ps < .05. Reaction time was similar on the latter three trial types. Similarly, reaction time on ClcClc trials (M = 447 ms) was significantly faster than ChcClc trials (M = 473 ms), IhcClc trials (M = 479 ms), and IlcClc trials (M = 466 ms), ps < .05. Furthermore, reaction time was significantly faster on IlcClc trials than on IhcClc trials, p < .05. All other comparisons were non-significant for Clc trials.

For accuracy, performance was significantly more accurate on IhcIhc trials (M = .96) than IlcIhc trials (M = .92), ChcIhc trials (M = .91), or ClcIhc trials (M = .90), ps < .01. Performance was similar on IlcIhc, ChcIhc, and ClcIhc trials, p > .05. Accuracy was higher on IhcIlc trials (M = .99) than on IlcIlc trials (M = .98) or ClcIlc trials (M = .96), ps < .05. Though accuracy was higher on IlcIlc trials than on ClcIlc trials (ps < .05) , it was not higher than ChcIlc trials (M = .98), ps > .05. Performance was equivalent on ChcChc trials (M = .99), ClcChc trials (M = .99), IhcChc trials (M = .98), and IlcChc trials (M = .99). The only difference that approached significance, p = .09 was between IhcChc and IlcChc trials. For Clc trials, accuracy was significantly lower on IlcClc trials (M = .98) than on ClcClc (M = .99) or ChcClc (M = .99) trials. The difference in accuracy between IlcClc trials and IhcClc (M = .99) trials approached significance, p = .06.

In an effort to more precisely contrast the repetition priming and conflict monitoring accounts of the conflict adaptation effect, separate two-way within subject ANOVAs were conducted for each of two transition types. Consistent with the previous set of analyses, the factors were previous trial type and current trial type. Transition type refers to the relationship (i.e. match) between the stimulus on the previous trial and the stimulus on the current trial. The first transition type of interest, repetition represented a transition in which the stimulus repeated and the response repeated (CC and II trials) or simply the response repeated (IC and CI trials). For the second transition type, non-repetition, neither the stimulus nor response repeated. Of primary interest was whether the conflict adaptation effect would be present for one or both transition types. Therefore, this set of analyses focused on the interaction between previous and current trial type, rather than main effects.

For repetition trials, the two-way ANOVA revealed a significant interaction between previous trial type and current trial type for reaction time, $F(9, 378) = 28.20$, $p < .01$, partial eta$^2 = .40$ (see Figure 4.1 a). For reaction time, IhcIhc trials ($M = 549$ ms) were significantly faster than ClcIhc trials ($M = 624$ ms) and IlcIhc trials ($M = 613$ ms), $ps < .01$. Though IhcIhc trials were 25 ms faster than ChcIhc trials ($M = 574$ ms), this

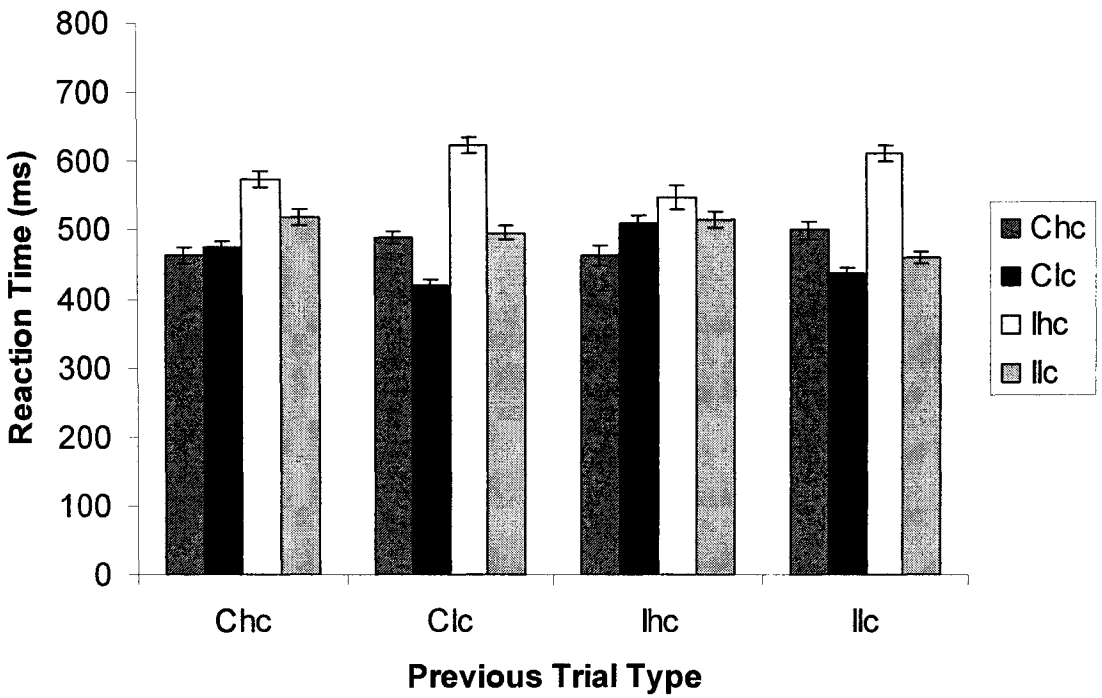

Figure 4.1 a. Mean reaction time for repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

difference was not statistically significant $p > .05$. In addition, performance was significantly faster on ChcIhc trials than on ClcIhc or IlcIhc trials, $ps < .01$. There was an advantage for IlcIlc trials ($M = 460$ ms) over IhcIlc trials ($M = 516$ ms), ChcIlc trials ($M = 519$ ms), and ClcIlc trials ($M = 496$ ms), $ps < .01$. In addition, ClcIlc trials were significantly faster than IhcIlc trials and ChcIlc trials, $ps \leq .01$. The mean reaction time

advantage for IhcIhc trials compared to ChcIhc trials was compared to the mean reaction time advantage for IlcIlc trials compared to ClcIlc trials, and there was no difference, $p >$ .05. For Chc trials, performance was equivalent and fastest on ChcChc trials (M = 462 ms) and IhcChc trials (M = 462ms), compared to ClcChc trials (M = 489 ms) and IlcChc trials (M = 500 ms). All dependent t-tests comparing the various Clc trial types were significant. Reaction time was fastest on ClcClc trials (M = 419 ms), second fastest on IlcClc trials (M = 436 ms), third fastest on ChcClc trials (M = 474 ms), and slowest on IhcClc trials (M = 510 ms).

For repetition trials, the interaction of previous and current trial type was also significant for accuracy, $F(9, 378) = 14.07$, $p < .01$, partial $eta^2 = .25$ (see Figure 4.1 b). Specifically, IhcIhc trials (M = .97) were significantly more accurate than IlcIhc trials (M = .84), ChcIhc trials (M = .93), or ClcIhc trials (M = .87), $ps < .05$. Furthermore, ChcIhc trials were significantly more accurate than IlcIhc trials or ClcIhc trials, $p < .05$, while reaction time was similar on IlcIhc trials and ClcIhc trials, $p > .05$. Accuracy was equivalent for IlcIlc trials (M = .98), IhcIlc trials (M = .99), and ChcIlc trials (M = .98), $ps > .05$. Accuracy for each of these trial types was significantly higher than ClcIlc trial accuracy (M = .95), $ps < .05$. Accuracy was significantly higher on IhcChc trials (M = .999) than any other Chc trial type including ChcChc trials (M = .99). The accuracy advantage for ChcChc trials over ClcChc trials (M = .98) approached significance, p = .06, while the advantage for ChcChc trials over IlcChc trials (M = .98) was not significant. Accuracy on ClcClc trials (M = .99) was similar to accuracy on ChcClc trials (M = .99) and IlcClc trials (M = .995), $ps > .05$, but significantly higher than accuracy on IhcClc trials (M = .97), $p < .05$.

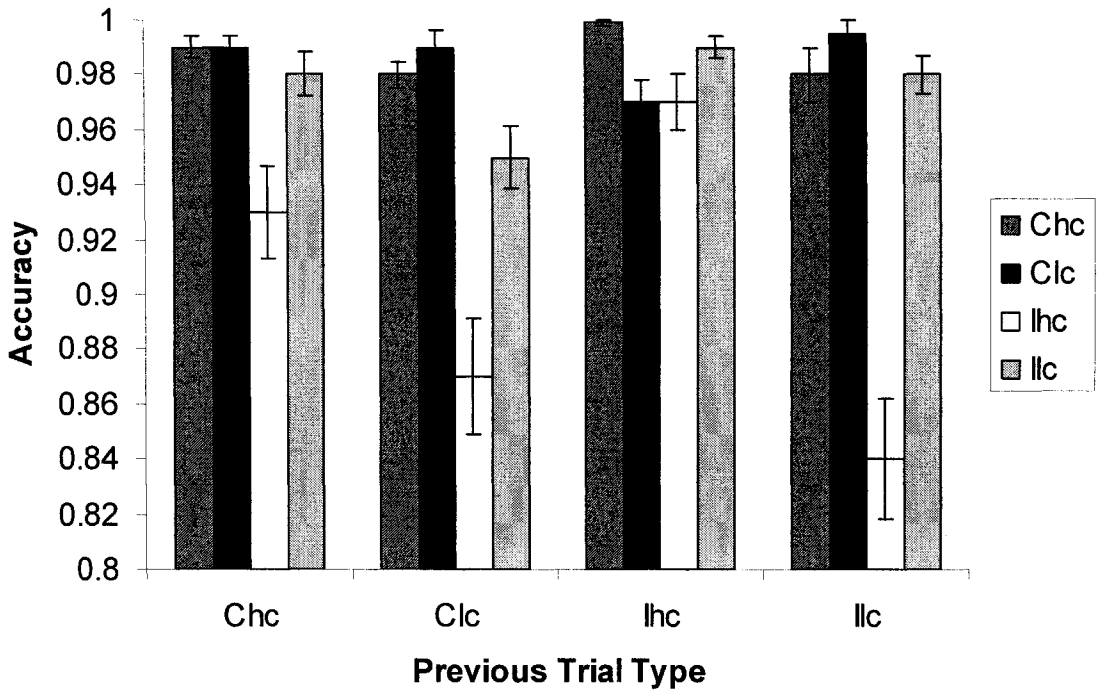

Figure 4.1 b. Mean accuracy for repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

For non-repetition trials, the two way ANOVA revealed that the critical two-way interaction of previous and current trial type was significant for reaction time, $F(9, 378) = 7.57, p < .01$, partial $eta^2 = .15$) (see Figure 4.2 a). Follow-up dependent t-tests showed that Ihc trials were faster when preceded by an Ilc trial ($M = 561$) than when preceded by another Ihc trial ($M = 593$). IlcIhc trials were also significantly faster than ClcIhc trials, $p < .01$. Furthermore the difference in reaction time between IhcIhc trials and ChcIhc trials ($M = 570$) approached significance, $p = .09$. In addition, ClcIhc trials ($M = 612$) were performed at a speed that was equivalent to IhcIhc trials $p > .05$, but significantly slower than ChcIhc trials, $p < .05$. Reaction time for IlcIlc trials ($M = 501$) was similar to IhcIlc trials ($M = 511$), and both were significantly longer than reaction time on ClcIlc ($M =$

471) and ChcIlc trials ($M = 483$), $ps < .05$. ChcChc trials ($M = 481$) were significantly faster than ClcChc trials ($M = 507$) or IhcClc trials ($M = 532$), $ps < .05$. However, performance was similar on IlcChc ($M = 492$) and ChcChc trials, $p > .05$. Reaction time was also significantly faster on IlcChc trials than IhcChc trials, $p < .05$. Reaction time was similar on Clc trials preceded by another Clc trial ($M = 468$), a Chc trial ($M = 473$), an Ihc trial ($M = 464$), or an Ilc trial ($M = 470$), $ps > .05$.

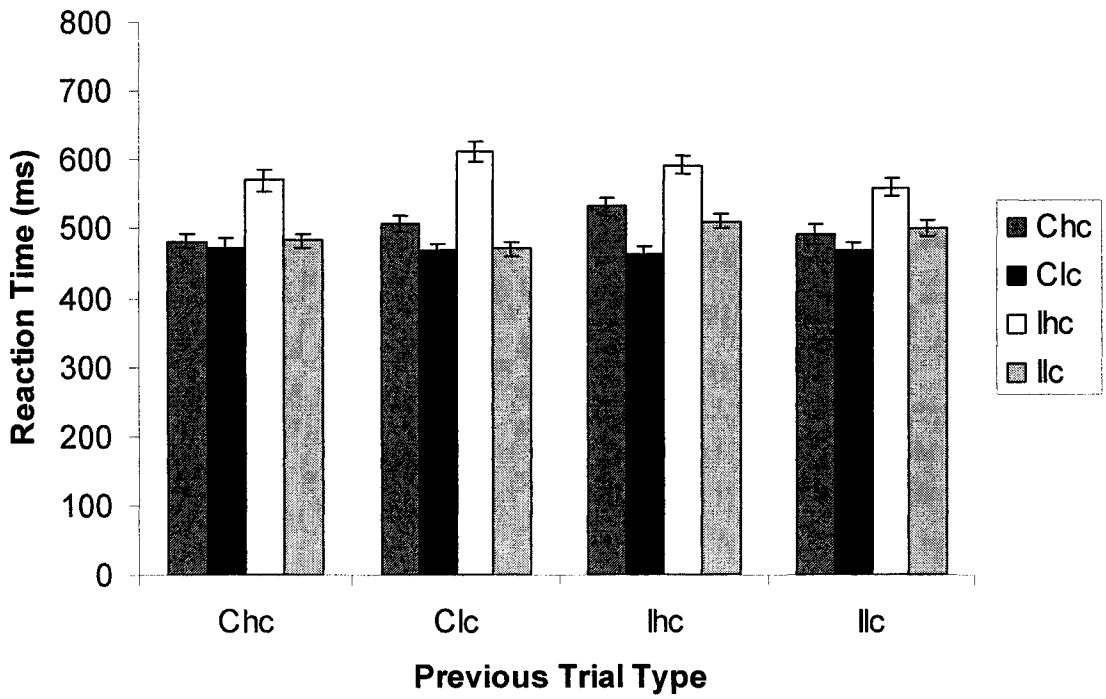

Figure 4.2 a. Mean reaction time for non-repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

For non-repetition trials, the two way ANOVA revealed that the critical two-way interaction of previous and current trial type was significant for accuracy ($F(9, 378) = 8.32, p < .01$, partial $eta^2 = .17$) (see Figure 4.2 b). Accuracy was similar for IhcIhc trials

(M = .95) and IlcIhc trials (M = .97). Both trial types were significantly more accurate than ChcIhc trials (M = .91), though only IlcIhc trials were significantly more accurate than ClcIhc trials (M = .93), ps < .01 were significantly more accurate than IhcIhc trials (M = .89) and IlcIhc trials (M = .90), ps < .01. Accuracy was similar for IlcIlc trials (M = .97), IhcIlc trials (M = .99), ChcIlc trials (M = .98), and ClcIlc trials (M = .99), ps > .05, though the difference in accuracy between ChcIlc and IhcIlc trials did approach

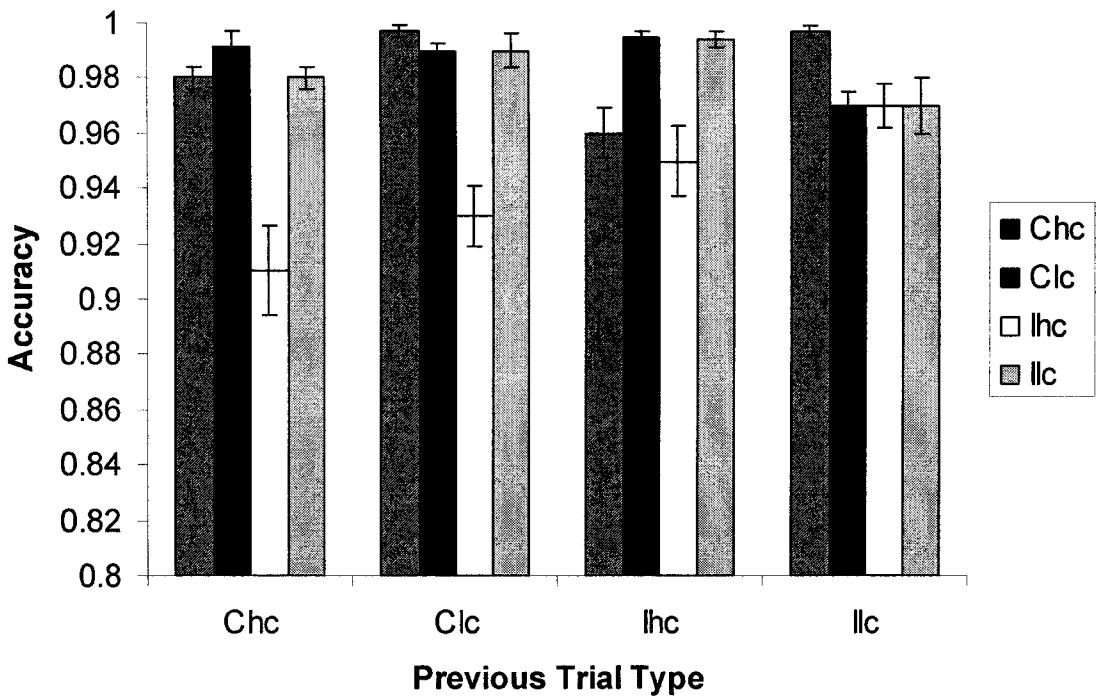

Figure 4.2 b. Mean accuracy for non-repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

significance as did the difference between IhcIlc and IlcIlc trials (ps = .06). Accuracy was greatest on Chc trials (M = .99) preceded by a Clc trial (M = .997) or Ilc trial (M = .997) (which did not differ) as compared to being preceded by another Chc trial (M = .98) or an Ihc trial (M = .96), ps < .01. Accuracy was significantly lower on IlcClc trials (M = .97)

than on ClcClc trials (M = .99), ChcClc trials (M = .99), or IhcClc trials (M = .995), ps < .05. Performance on ClcClc trials was similar to ChcClc trials (p > .05), but was significantly less accurate than IhcClc trials.

Discussion

The perceptually based manipulation of the size of target and flanker stimuli was effective in that Ihc trials were significantly slower and less accurate than Ilc trials. Reaction time was also significantly slower on Chc trials than Clc trials, though the two trial types were similar in accuracy. Interestingly, Ilc trials were performed as quickly but not as accurately as Chc trials. It appears then, that the perceptual conflict on the Chc trials led to a similar performance decrement as the response conflict on the Ilc trials.

The main purpose of E3 was to further contrast the repetition priming and conflict monitoring accounts of the conflict adaptation effect by examining the influence of a perceptual manipulation on response conflict, and potential adjustments in reactive control. The results support the repetition priming account. Specifically, a pattern of means fairly consistent with the conflict adaptation effect was found for repetition trials. That is, IhcIhc trials were significantly faster than Ihc trials preceded by any other trial type, with the exception that the 25 ms advantage over ChcIhc trials was not significant. Similarly, IlcIlc trials were significantly faster than any other Ilc trial type. Also supporting the repetition priming account, was the finding that the advantage for IhcIhc repetition trials over baseline CIhc trials was similar to the advantage for IlcIlc repetition trials over baseline CIlc trials. Furthermore, performance on compatible trials was not consistent with what the conflict monitoring account would predict either. If control is heightened followed incompatible trials, performance on compatible trials is expected to

be worse due to the increased focus on the central target and/or inhibition of flankers relative to when a compatible trial is preceded by another compatible trial. Here, IhcChc trials were as fast as ChcChc trials, and both were faster than the ClcChc and IlcChc trials. Similarly, reaction time was faster on ClcClc trials and IlcClc trials as compared to ChcClc and IhcClc trials. This latter set of results suggests that participants may have been adopting a different strategy in response to a high or low conflict $n - 1$ trial, and such a strategy was most beneficial to subsequent trial performance when the subsequent trial matched the conflict level of the previous trial. Even on incompatible trials, such strategy adjustments are evident as the two types of Ihc trials that were closest (and fastest) in reaction time are IhcChc and IhcIhc, and the two types of Ilc trials that were closest (and fastest) in reaction time are IlcClc and IlcIlc.

In regards to non-repetition trials, the previous trial type by current trial type interaction was significant for reaction time, but the pattern of means was not as consistent with the conflict adaptation effect. Though IlcIhc trials were performed significantly faster than ClcIhc trials, which is troublesome for the repetition priming account, IlcIhc trials were also faster than IhcIhc trials, which were not faster than either of the CIhc trial types. This latter finding is troublesome for the conflict monitoring account as is the finding that reaction time was slower on IlcIlc and IhcIlc trials than both CIlc trial types. Thus, it does not appear the strategy adjustments that were evident on the repetition trials were present on the non-repetition trials.

Accuracy on repetition trials was significantly higher on IhcIhc trials relative to all other Ihc trial types, but was similar for IlcIlc trials and all other Ilc trial types. For non-repetition trials, IhcIhc accuracy and IlcIhc accuracy was significantly higher than

ChcIhc accuracy, while only IlcIhc accuracy was significantly higher than ClcIhc accuracy. No differences in accuracy were obtained for Ilc trial types, as in the analysis of repetition trials. Taken together, the reaction time and accuracy findings are somewhat consistent with the findings of the computational modeling work of Jones et al. (2002). They found that control adjustments following high conflict incompatible trials were in the form of slower reaction times and higher accuracy, while adjustments following low conflict incompatible trials tended to be in the form of faster reaction times and decreased accuracy. In other words, variations in conflict appear to alter speed – accuracy tradeoff functions. A similar speed accuracy tradeoff may be evident in this experiment. The main effects of previous trial type showed that trials that were preceded by Ihc trials were more accurate than trials that were preceded by any other trial type. Furthermore, the reaction time advantage for trials that were preceded by Ilc trials over trials preceded by Ihc trials approached significance, $p = .08$. However, when one considers the mean reaction times and accuracy rates in Figures 3.2 a. and b., evidence in support of such tradeoffs is not as consistent. Thus, this particular strategy adjustment remains an issue to be explored in future studies.

Although the results of Experiment 3 are consistent with Mayr et al. (2003) in supporting the repetition priming account, a major methodological confound may be present in the examination of the conflict-adaptation effect on non-repetition trials. One could argue that a comparison of the effect on II repetition and II non-repetition trials is inherently flawed, given that performance on trial *n* in the former condition is likely to benefit from positive priming (and thus, be associated with faster reaction times relative to CI trials (i.e., a conflict adaptation effect)) while performance on trial n in the latter

condition is likely to suffer from negative priming (and thus, be associated with slower reaction times relative to CI trials). For instance in the non-repetition condition, the stimulus "<<<><<<" might be presented on trial *n* -1. If processing of the stimulus in the central location is accompanied by inhibition of the flankers and the response associated with them (left key press), then the left key press response to ">>><>>>" on trial n may be slowed because the participant has to overcome the inhibition from the preceding trial in order to produce the correct response. In the current study, there is some support for a negative priming explanation evident in the non-repetition trials. Specifically, Ihc trials were faster when preceded by an Ilc trial (M = 561) than when preceded by another Ihc trial (M = 593). IhcIhc trials were also slower than ChcIhc trials by 23 ms, a difference that approached significance. In addition, though statistically similar IhcIlc trials were slower than IlcIlc trials by 11 ms. Such results are not surprising given one would expect stronger inhibition on a high conflict incompatible trial than a low conflict incompatible trial. In the study of Mayr et al., reaction times in the II non-repetition condition were not only slower than reaction times in the repetition condition, but were also slower than reaction times in the CI condition, the baseline condition Mayr et al. used to examine the conflict adaptation effect. Again, using the logic described above, this is not surprising given that for CI trials, *n* -1 is a congruent trial and therefore inhibition of a competing response is not required. Supplemental support for this analysis of CI trials stems from the finding of no difference in reaction time on I trials where the central stimulus required the opposite response than that which was driven by the stimulus on the previous C trial, as compared to I trials where the same response was required as on the previous C trial.

There are several approaches to studying the conflict adaptation effect that can circumvent this potential confound. For instance, brief stimulus presentation times and lengthier inter-trial (or response to stimulus) intervals appear to reduce the influence of negative priming (Ullsperger et al., 2005). First, though it is necessary to directly examine negative priming in the Eriksen Flanker Task. Such is accomplished by including neutral trials in the task. The use of neutral trials, where in the flankers are perceptually incompatible with the target, but not incompatible at a response level, allows one to assess the impact of negative priming on the performance of II change trials. It also allows one to assess whether conflict at the stimulus identification level can elicit a conflict adaptation effect and to further contrast the repetition priming and conflict monitoring accounts.

CHAPTER FIVE- EXPERIMENT FOUR

Introduction

The final experiment addresses the question concerning the type of conflict on trial *n* - 1 (stimulus based vs. response based) that is responsible for eliciting a tightening of control on trial *n* and will further contrast the repetition priming and conflict monitoring accounts of the conflict adaptation effect. The main difference between Experiment 4 and that of Mayr et al. (2003) is the inclusion of neutral (N) trials in the Eriksen Flanker Task. On neutral trials, the target stimulus will be surrounded by upward or downward facing arrows. Although the presence of these arrows may cause conflict at the level of stimulus processing and identification as compared to compatible stimuli, conflict at the response level would not be expected since an up (top) or down (bottom) key press is not one of the available responses in the task. In an event-related fMRI study, Van Veen, Cohen, Botvinick, Stenger, and Carter (2001) found that ACC activation was specific to conflict at the response level. Activation of the ACC was significantly greater in response to trials wherein conflict occurred at the response level than to stimulus-based conflict trials or compatible trials, even though conflict at the stimulus identification level also led to behavioral interference.

If the ACC is responsive specifically to conflict at the response level, as suggested by the work of van Veen et al. and Milham et al. (2001), the ACC would not be expected to send a conflict monitoring signal to the PFC in response to the stimuli presented on

neutral trials, thus a conflict adaptation effect would not be expected on I trials that followed immediately after neutral trials. On the other hand, if the ACC is responsive to conflict at a stimulus level, then one would expect performance on NI or NN trials to show an advantage over CI or CN trials since no conflict exists on trial $n - 1$ for these latter two trial types. The conflict-monitoring model (Botvinick et al., 2001) allows room for both of these predictions. In their computational model, Botvinick et al. simulated the role of the ACC in monitoring conflict and recruiting control. Importantly, they defined conflict as "the simultaneous activation of incompatible representations" and focused "exclusively on the role of response conflict" in successfully accounting for ACC activation during EFT and Stroop tasks. However, Botvinick et al. also suggested that the ACC might be responsive to conflict that occurs at levels other than response selection, such as stimulus evaluations, although their model did not directly account for this type of conflict. Thus, if the conflict adaptation effect is found for NI, NN, IN and II trials (relative to baseline CI or CN trials), a revision of their model may be justified.

According to the repetition priming account of Mayr et al., the effect is driven by "stimulus-specific repetition priming", and is limited to "complete target and flanker repetitions" in the EFT (p. 451). Thus, in the current experiment, when comparing CI or CN trials to II trials or NN trials respectively, the repetition priming account would predict a conflict adaptation effect only for Complete Stimulus Repetition/ Response Repetition II and NN trials. If the effect is found for NI non-repetition, II non-repetition, NN non-repetition, and/or IN non-repetition trials relative to baseline CI or CN trials, a revision of the repetition priming account is also required.

If response conflict is critical to the obtainment of a conflict adaptation effect (contrary to what Mayr et al. would suggest), then an advantage on II repetition trials would be expected over NN repetition trials (relative to baseline CI and CN, respectively) since II repetition trials would benefit from both repetition priming and conflict in the response system on trial n - 1 while NN repetition trials would benefit only from repetition priming, since no benefit would be expected from the conflict that is present at the stimulus identification level on trial $n - 1$. It may be the case that a combination of two factors is critical in explaining the effect, both the presence of a conflict-monitoring signal and response specific priming.

Importantly, the use of neutral trials also allows one to examine the extent to which performance on II non-repetition trials in the Mayr et al. study reflects negative priming. If indeed an inhibitory process is acting on the target response on II non-repetition trials, then reaction times on II non-repetition trials should be slower than reaction times on the NI trials, contrary to the conflict monitoring account. The magnitude of the slowing would be expected to be greater in the comparison of II non-repetition trials to NI trials on which the response remains the same relative to NI trials in which the response changes. Using subtraction logic, both switching target responses and negative priming would be expected to slow performance on II non-repetition trials compared to NI response consistent trials, while only negative priming would be expected to slow performance on II non-repetition trials compared to NI response change trials.

Method

Participants.

51 Colorado State University undergraduates participated in the study in partial fulfillment of course credit. Informed consent was obtained from each participant. Participants were screened, by means of a brief questionnaire, for handedness, neurological and/or psychiatric illnesses (such as ADHD), and past history of significant head trauma. Data from 9 participants who were left handed, or reported the presence of either illness or head trauma were excluded from further analysis.

Design.

The study employed a 3 x 3 within subjects design during an EFT task. Previous trial type (Compatible vs. Neutral vs. Incompatible) and Current trial type (Compatible vs. Neutral vs. Incompatible) represented the factors. 24 of each previous and current trial types were included in each experimental block. Compatible trials were composed of a central display with seven right facing or seven left facing arrows in a row. Incompatible trials were composed of a central display of seven arrows, wherein the central arrow facing right or left corresponded to the opposite response to the flanker arrows (left or right, respectively). Neutral trials were composed of a central display of seven arrows, wherein the central arrow faced right or left, and the flanker arrows faced up or down. Given that a response key was not assigned to the up or down facing arrows, this condition was designed to elicit perceptual conflict but not response conflict. For each trial type, the stimulus display was 15 degrees wide, and individual arrows were 1 degree high and wide. Of interest were the nine trial types produced by the interaction of the first

two factors, *n* trial type and *n* – 1 trial type. Within each experimental block, there were eight CC, CN, CI, NC, NN, NI, IC, IN, and II trials.

Procedure.

Participants performed the task individually and the experimenter was present for the duration of the experiment. During the practice phase, participants read self-paced instructions in which they were introduced to the experimental stimuli and asked to press the left or right response key depending on the direction that the central arrow in the stimulus display was pointing. Participants were instructed to press the left key if the central arrow pointed left and to press the right response key if the central arrow pointed right. Participants were instructed to use the index finger from their left hand to press the left response key, and the index finger from their right hand to press the right key. Participants were informed that they should respond as quickly and accurately as possible. Once participants acknowledged that the directions were understood, 24 practice trials were presented during which each of the trial types (C, I, N) was shown.

Following the practice trials, the test component of the task began. The test consisted of eight blocks of 72 trials. Each block was separated by a screen that commended the participants on completing the block, and reminded them to press the left key if the central arrow pointed left, and the right key if the central arrow pointed right. During the task, the stimulus remained on-screen until a response was made and the response to stimulus interval (RSI) was set at 1000 ms, replicating Mayr et al. Also following Mayr et al., a fixation cross was presented beneath the central arrow on stimulus screens and remained on-screen during the otherwise blank RSI. The dependent measures of interest were reaction time and accuracy. The task was completed in

approximately 25 minutes. Participants were debriefed and thanked for their participation.

Results

Two-way within subjects analyses of variance (ANOVAs) were conducted for reaction time (RT) and accuracy, with within subjects factors of previous trial type (compatible vs. neutral vs. incompatible) and current trial type (compatible vs. neutral vs. incompatible). Trials following errors and error trials were excluded from the reaction time analyses. For the analyses of accuracy, trials following errors were excluded. The alpha level was set at .05 for all analyses.

The main effect of current trial type was significant indicating that the standard flanker effect was evident, $F(2, 82) = 99.16$, $p < .01$, partial $eta^2 = .71$. Follow-up dependent t-tests revealed that reaction time was significantly slower for incompatible trials ($M = 587$ ms) than for neutral trials ($M = 484$ ms), $p < .01$, which were significantly slower than compatible trials ($M = 473$ ms), $p < .01$. Likewise, there was a main effect of current trial type for accuracy, $F(2, 82) = 53.79$, $p < .01$, partial $eta^2 = .57$. Dependent t-tests revealed that accuracy was significantly higher for compatible trials ($M = .99$) than for neutral trials ($M = .98$), $p < .01$, which were significantly more accurate than incompatible trials ($M = .93$), $p < .01$. In addition, a main effect of previous trial type was significant for reaction time, $F(2, 82) = 3.25$, $p < .05$, partial $eta^2 = .07$. Dependent t-tests revealed that performance was faster following a neutral trial as compared to following an incompatible trial, $p < .05$. All other comparisons were non-significant. A main effect of previous trial type was also significant for accuracy, $F(2, 82) = 4.93$, $p = .01$, partial

eta^2 = .11. Accuracy was significantly higher following incompatible trials (M = .97) as opposed to neutral (M = .96) or compatible trials (M = .96), ps < .05.

For both dependent measures, the main effects were qualified by a significant interaction between previous trial type and current trial type (for RT, $F(4, 164) = 13.24$, p < .01, partial eta^2 = .24; for Accuracy, $F(4, 164) = 2.78$, $p < .05$, partial eta^2 = .06). For reaction time, the pattern of means was consistent with the conflict adaptation effect. Dependent t-tests showed that II trials (M = 572 ms) were significantly faster than CI trials (M = 596 ms) and NI trials ((M = 594 ms), ps < .01. Furthermore, CC trials (M = 463 ms) and NC trials (M = 468 ms) did not differ in speed, while IC trials (M = 488) were significantly slower than both, $p < .01$. NN trials (M = 471) were significantly faster than CN trials (M = 484) which were significantly faster than IN trials (M = 497), ps < .05. For accuracy, II trials (M = .94) were significantly more accurate than NI trials (M = .92), $p < .05$, but statistically similar to CI trials (M = .92), $p > .05$. NC trials (M = .99) and IC trials (M = .99) were significantly more accurate than CC trials (.98), ps < .05. Accuracy was similar on CN trials (M = .98), NN trials (M = .98), and IN trials (M = .98), ps > .05.

In an effort to more precisely contrast the repetition priming and conflict monitoring accounts of the conflict adaptation effect, separate two-way ANOVAs were conducted for reaction time and accuracy for each of two transition types. Transition type refers to the relationship (i.e. match) between the stimulus on the previous trial and the stimulus on the current trial. The first transition type of interest, repetition represented a transition in which the stimulus repeated and the response repeated (CC, NN, or II trials) or simply the response repeated (baseline CI , CN, NC, NI, IC, or IN trials). For the

second transition type, non-repetition, neither the stimulus nor response repeated. This transition type included the case of two back to back incongruent trials wherein the influence of negative priming may be present (NP). Of primary interest was whether the conflict adaptation effect would be present for one or both transition types. Therefore, this set of analyses focused on the interaction between previous and current trial type, rather than the main effects.

For repetition trials, the two-way ANOVA revealed a significant two-way interaction of previous and current trial type for reaction time, $F(4, 164) = 24.32$, $p < .01$, partial $eta^2 = .38$ (see Figure 5.1 a). Specifically, II trials ($M = 545$ ms) were significantly faster than CI trials ($M = 591$ ms) and NI trials ($M = 591$ ms), $ps < .01$. CC trials ($M = 439$ ms) were significantly faster than NC trials ($M = 454$ ms), which were significantly faster than IC trials ($M = 484$ ms), $ps < .01$. NN trials ($M = 445$ ms) were significantly faster than either CN ($M = 470$ ms) or IN trials ($M = 480$ ms), $ps < .01$, which did not differ statistically ($p > .05$). As mentioned in the introduction to this experiment, an additional way to assess the effects of conflict on performance on II rep trials is to compare them to the CI baseline, and assess whether the reaction time advantage is similar or different to that observed for NN rep trials over baseline CN trials. A dependent t-test on the corresponding difference scores (CI – II; CN – NN) was significant, $t(41) = -2.13$, $p < .05$, indicating an average difference of 46 ms in the former case and 25 ms in the latter case.

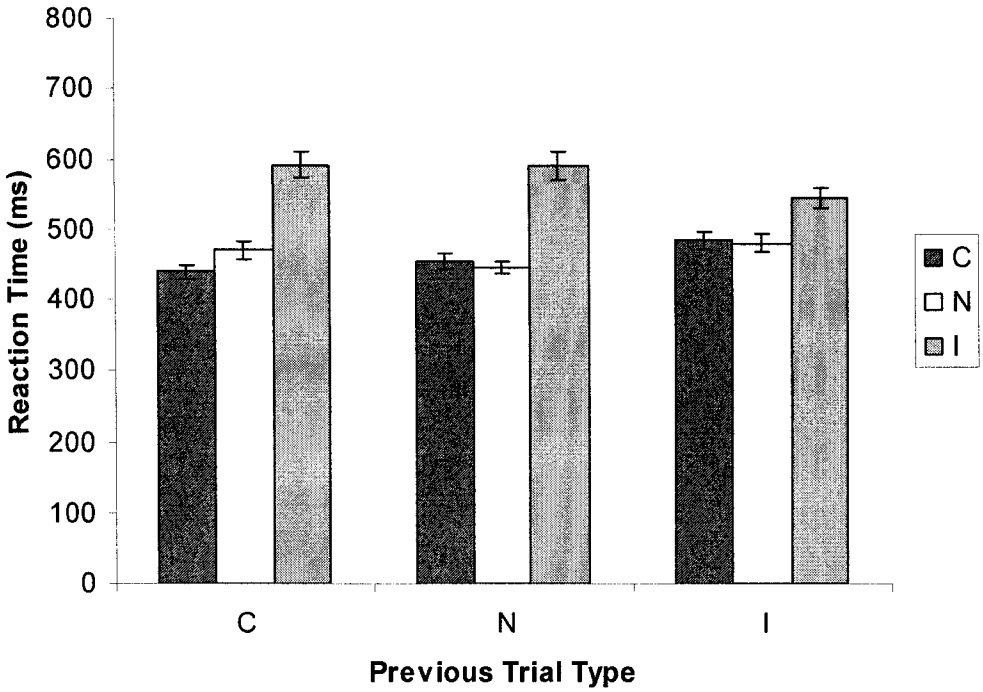

Figure 5.1 a. Mean reaction time for repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

The two-way ANOVA also revealed a significant two-way interaction of previous and current trial type for accuracy on the repetition trials, $F(4, 164) = 7.27$, $p < .01$, partial $eta^2 = .15$ (see Figure 5.1 b). II trials ($M = .93$) and CI trials ($M = .93$), which did not differ from each other, $p > .05$, were significantly more accurate than NI trials ($M = .89$), $ps \leq .01$. CC trials ($M = .99$) and IC trials ($M = .99$) were significantly less accurate than NC trials ($M = .998$), $p < .05$. Accuracy was similar for CN trials ($M = .98$), NN trials ($M = .99$), and IN trials ($M = .99$), $ps > .05$.

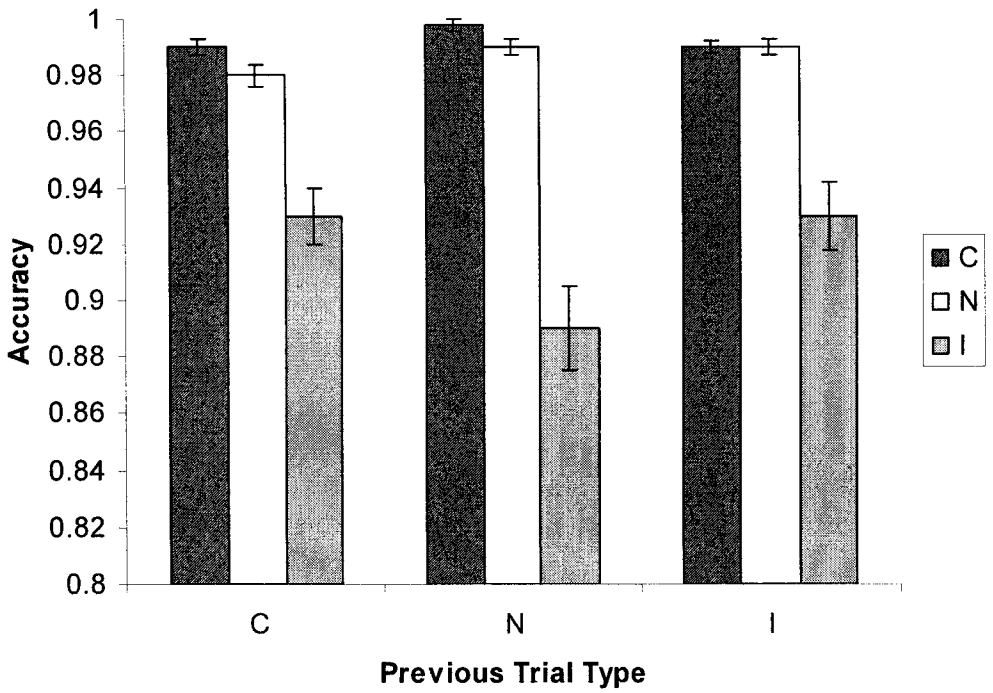

Figure 5.1 b. Mean accuracy for repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

For non-repetition trials, the critical two-way interaction of previous and current trial type was not significant for reaction time ($F(4, 164) = .87, p > .10$) or accuracy ($F(4, 164) = 1.38, p > .10$) (see Figures 5.2 a. and 5.2 b., respectively). Furthermore, the test for negative priming, a dependent t-test comparing the difference in reaction time between II ($M = 598$) and NI trials ($M = 597$) was not significant, $p > .10$.

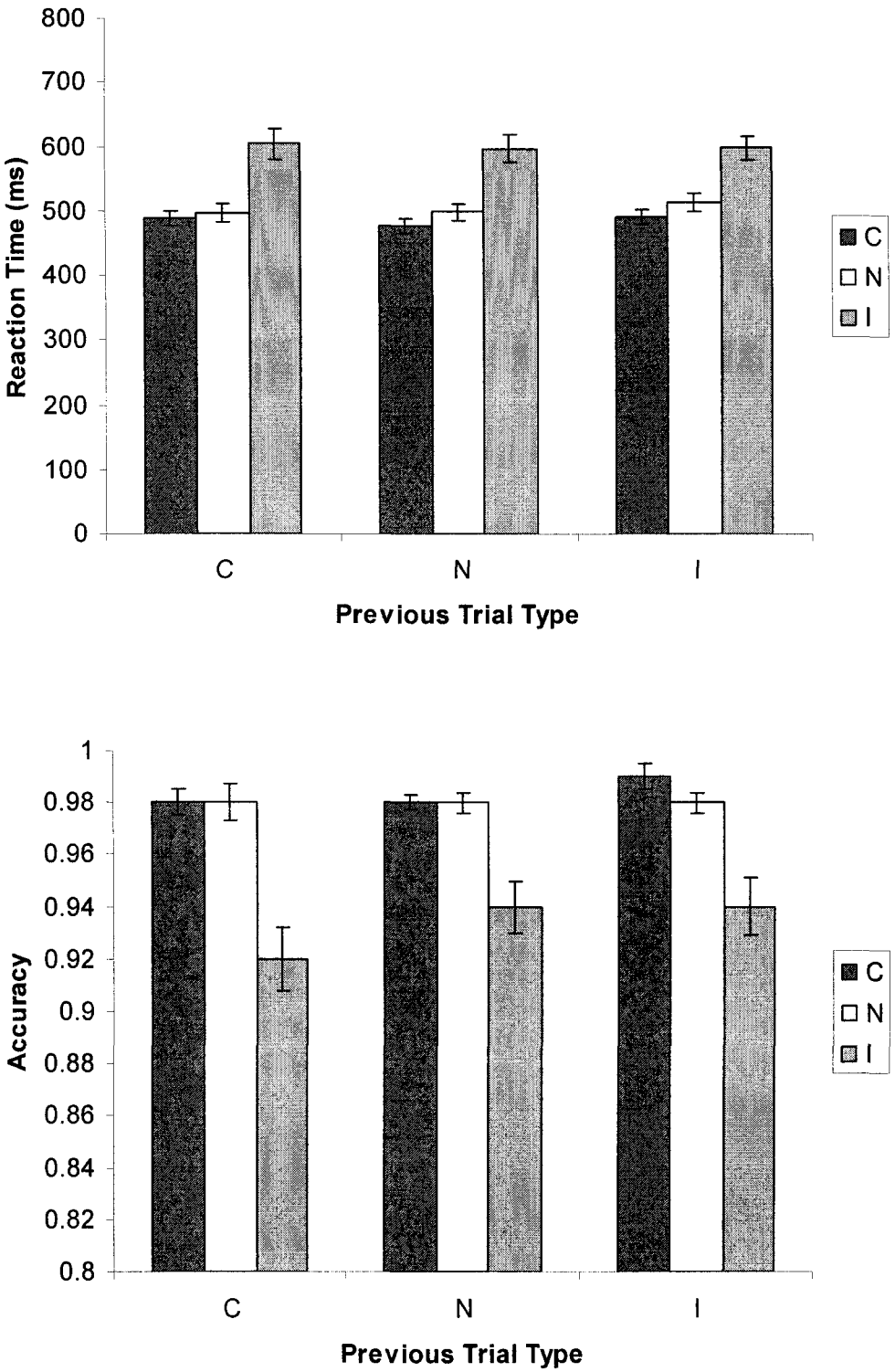

Figure 5.2 a. (upper) and b. (lower). Mean reaction time and accuracy for non- repetition trials as a function of previous and current trial type. Error bars represent standard error of the mean.

Discussion

The purpose of E4 was three-fold. The first goal was to further contrast the repetition priming and conflict monitoring accounts of the conflict-adaptation effect by examining performance on repetition and non-repetition trials. Consistent with repetition priming, for II repetition trials were faster than CI or NI while CI and NI did not differ and NN repetition trials were significantly faster than CN or IN, which did not differ. Furthermore, when these same comparisons were performed on non-repetition trials, the pattern of means consistent with the conflict adaptation effect was not found. This lends even stronger support to repetition priming, and is contrary to the predictions of the conflict monitoring account.

A related goal was to better understand the particular type of conflict that is necessary to bring about a conflict adaptation effect. Past research by van Veen et al. (2001) and Milham et al. (2001) indicated that response conflict was key to the effect, and though conflict at stimulus levels brings about behavioral interference, it does not induce a conflict adaptation effect. In the current experiment, the results concur with past research in showing that stimulus induced conflict of the sort introduced on neutral trials in the current experiment, led to behavioral interference. Neutral trials were slower than incompatible trials, but faster than compatible. As well, neutral trials were more accurate than incompatible, but less accurate than compatible. In regards to the conflict adaptation effect, there was no evidence to suggest that stimulus induced conflict was capable of enhancing performance on subsequent neutral or incompatible trials. That is, NI non-repetition trials were not faster than CI non-repetition trials, and NN non-repetition trials were not faster than CN non-repetition trials. Then again, there was only weak evidence

to suggest that response conflict, rather than repetition priming alone, was responsible for the conflict adaptation effect. Specifically, there was a significantly greater reaction time advantage for II repetition trials over baseline CI trials (46 ms) relative to the advantage observed on NN repetition trials over baseline CN trials (25 ms). Given that both comparisons involve a difference between a complete stimulus/response repetition trial and a response repetition trial, one would expect a comparable difference in performance. The II advantage may suggest that response conflict does play at least some role in the conflict adaptation effect that is observed on repetition trials.

If there is a role of response conflict in the conflict adaptation effect, one then naturally questions why the effect was not observed on non-repetition trials. It may be the case that negative priming is negatively impacting performance on the critical II non-repetition trials. On the $n - 1$ incompatible trial, participants may be inhibiting the response related to the flankers, in order to select and activate the target response related to the central arrow. On the subsequent incompatible trial, participants would have to overcome the inhibition linked to the flanker response on the previous trial in order to select the target response on trial *n*. In other words, what was previously ignored must now be attended and selected. Overcoming the inhibition would be expected to slow performance on II trials relative to NI trials, given that the latter would not be expected to involve inhibition of the competing response on trial $n - 1$. Research by Stadler and Hogan (1996) suggests that reaction time is especially slowed on incompatible trials when the location and corresponding response of target and flanker items on trial *n* is completely reversed from the location and corresponding response of target and flanker

items on trial $n - 1$ (e.g. <<<><<<; >>><>>>). This is precisely the case in E4 wherein there were only two possible trial types for incompatible trials.

The third goal of E4 was therefore to test for negative priming, addressing the extent to which performance on II non-repetition trials, and perhaps performance on these trials in other studies (e.g. Experiment 1 and 3 of Current Study; Experiment 1 Mayr et al; 2003) involving two incompatible trial types, is slowed by virtue of such a mechanism. Taken at face value, the findings of E4 do not support a negative priming explanation of performance on II non-repetition trials. These trials were performed just as quickly as NI non-repetition trials. However, there are a few concerns with the particular type of neutral trial used here, up or down arrows surrounding a central target arrow facing left or right. Though the up and down arrows were not linked to a response in this particular study, there is research that shows that above (i.e. up) and below (i.e. down) vertical dimensions can be coded as left or right horizontal dimensions (Hommel & Lippa, 1995). That is, on neutral trials, participants may have been associating the up/down arrows with either the left or right direction bringing about some degree of response conflict with the central left or right facing arrow, hence slowing reaction times. This type of conflict may have occurred relatively late in processing at a time during which the target response was already far enough along, given the translation that would be necessary from the vertical code to a horizontal code. Nonetheless, using up or down arrows as flankers for a neutral stimulus may not have been a good choice for a test of negative priming.

A subsequent experiment was undertaken to address this concern. The experiment was identical to E4 with the exception of utilizing a different set of Colorado State

University undergraduates (Mean age = 18; $N = 53$) who were screened according to the procedures listed in E4 and a different neutral stimulus. Specifically, this new neutral stimulus was a right or left facing central arrow surrounded by similarly sized asterisks, three on each side. Unlike E4, the findings provided preliminary support for a negative priming explanation of performance on II non-repetition trials. Specifically, II non-repetition trials ($M = 599$ ms, $SD = 190$) were slower than NI non-repetition trials ($M = 583$ ms, $SD = 175$), a difference that approached significance, $p = .09$, and is greater in magnitude than average negative priming effects which are typically on the order of 8 – 9 ms (May, Kane, & Hasher, 1995).

CHAPTER SIX- GENERAL DISCUSSION

This dissertation was concerned with examining the conflict adaptation effect, or more specifically the increased speed with which participants respond to incompatible trials during an Eriksen Flanker Task when they are preceded by another incompatible trial. This effect is of current interest because of the potential implications the effect has on our understanding of how the brain monitors the response environment for situations in which cognitive control is needed, as well as how the brain implements strategic adjustments in control.

Four experiments were designed to examine two existing theoretical accounts of the conflict adaptation effect. The conflict monitoring account (Botvinick et al., 2001) explains the effect on the basis of a conflict monitoring signal triggered by the ACC in response to conflict on the preceding incompatible trial. This signal is purported to communicate a need for enhanced control to the prefrontal cortex. Evidence in favor of this theory would strengthen the idea that the effect occurs in the presence of cognitive control mechanisms. On the other hand, the repetition priming account (Mayr et al., 2003) conveys the effect as being the result of stimulus specific repetition priming. Evidence in support of this theory would strengthen the argument that the effects occurs, as Mayr posits "in the absence of control", and rather represents an episodic memory phenomenon. Examining the two accounts is critical, as the conflict adaptation effect is

one of the primary pieces of behavioral evidence supporting many tenets of cognitive control theories.

Across the four experiments in the current work, evidence was found in support of both the conflict monitoring account and the repetition priming account. The most convincing support for the conflict monitoring account came from Experiment 2 wherein the conflict adaptation effect was observed even when repetition trials were eliminated from the analysis. Specifically, high conflict incompatible trials (e.g. a left facing arrow surrounded by right arrows) that followed low conflict incompatible trials (e.g. a right facing arrow surrounded by up facing arrows) were faster than those that followed no conflict compatible trials (e.g. a left facing arrow surrounded by left arrows). In addition low conflict incompatible trials that followed either a non-repeating low conflict incompatible trial or a high conflict incompatible trial were faster than low conflict incompatible trials that followed no conflict compatible trials. The fact that such conflict adaptation effects were found on non-repetition trials in Experiment 2, and in the work of Kerns et al., Gratton et al., and recently Ullsperger et al., is problematic for the memory based repetition priming account.

The current findings are especially important, in that unlike the studies of Kerns et al., Gratton et al., and Ullsperger et al., the major methodological features of the Mayr et al. study were held consistent in Experiment 2 (and the rest of the studies reported herein). For instance, stimuli were of the same size, the stimulus remained on-screen until a response was made, the response to stimulus interval was set at 1000 ms, and participants were asked to respond as quickly and accurately as possible. Thus, the presence of conflict adaptation in the absence of repetition priming in Experiment 2 can

not be attributed solely to differences in methodology that enhance the likelihood of conflict adaptation.

Though this result is theoretically very important, it is equally important to point out that Experiments 1, 3, and 4 largely support repetition priming. In each experiment, a conflict adaptation effect was found for repetition trials but not non-repetition trials. The conflict monitoring account has trouble explaining such findings, given that a conflict monitoring signal would be expected to benefit performance on any II trial regardless of whether or not it is of the repetition or non-repetition type. One major difference between Experiment 2, wherein evidence of conflict adaptation was strong, and Experiments 1, 3, and 4 was the size of the response set. Barch et al. (2001) and Botvinick et al. (2001) showed that the anterior cingulate is responsive to decision uncertainty or underdetermined responding as when a single stimulus activates multiple responses somewhat equivalently. In Experiment 2, there were four available responses and in Experiment 2 of Ullsperger et al., there were nine available responses. In both cases, a conflict adaptation effect was found on non-repetition trials leading one to question the degree of response conflict or underdetermined responding that was evoked in each of these two studies compared to the current Experiments 1, 3, and 4. The extent to which the context manipulation (i.e. percentage of incompatible vs. compatible trials) was effective in altering the response conflict observed on incompatible trials was already considered in the discussion of the first experiment. Similarly, one might question whether the perceptual manipulation used in Experiment 3 was effective in altering levels of response conflict, rather than simply heightening behavioral interference. As acknowledged in the introduction to Experiment 3, varying the size of the target/flankers

was expected to "indirectly" impact response priming/conflict (Eriksen & Schultz, 1979). Given such is the case, response conflict may have occurred but relatively late in processing, such that any preparatory adjustments that were to be made to ready oneself for the next trial may not have had enough time to be established. Furthermore, Experiment 4 provided evidence against the notion that stimulus induced conflict could bring about a conflict adaptation effect, confirming the earlier work of vanVeen et al. (2001).

Another major difference between Experiment 2, wherein evidence of conflict adaptation was strong, and Experiments 1, 3, and 4 as well as Experiment 2 of Ullsperger et al., was the size of the stimulus set used on incompatible trials. In Experiment 4, there were 4 possible stimuli utilized on incompatible high conflict and incompatible low conflict trials. For every incompatible stimulus (digits 1 through 9) in Experiment 2 of Ullsperger et al., there were 8 possible stimulus arrangements. In the current experiments, there were 2 possible incompatible stimuli (i.e. <<<><<<; >>><>>>) used in Experiment 1 and 4, and 4 possible incompatible stimuli used in Experiment 3, though again only left or right targets and left or right flankers were used, with corresponding size manipulations. An increased stimulus set reduces the likelihood that the unattended flankers on trial $n - 1$ will become the target, and vice versa on trial n. This is highly important given the work of Stadler and Hogan (1996) who showed that negative priming is at its peak when the location and corresponding response of target and flanker items on incompatible trial n is completely reversed from the location and corresponding response of target and flanker items on incompatible trial $n - 1$ (e.g. <<<><<<; >>><>>>). Along with the results of the additional experiment reported in the discussion of Experiment 4,

showing that reaction time is almost 16 ms slower on II non-repetition trials relative to NI non-repetition trials, one continues to question the extent to which a comparison of II non-repetition trials and CI non-repetition trials is confounded. Interestingly, when one examines only repetition trials and the effects of varying degrees of conflict on II repetition trials, the results are fairly supportive of the conflict monitoring account. For example, in Experiment 1, there was a trend for the II repetition trial reaction time and accuracy advantage over CI repetition trials to be larger in the mostly compatible (high conflict) condition, relative to the mostly incompatible (low conflict) condition. In addition, the CC repetition reaction time advantage over IC repetition trials was larger in the mostly incompatible (low conflict) condition. Furthermore, in Experiment 4, the reaction time advantage for II repetition trials over CI trials was significantly larger than the reaction time advantage for NN repetition trials over CN trials, lending support to the idea that conflict plays at least some role even in the II repetition advantage.

An alternative means by which one can reduce the influence of negative priming on II non-repetition trials and on the conclusions that are inferred on the basis of such trials is to lengthen the response to stimulus interval or inter trial interval . Ullsperger et al. did just the latter in their experiments, lengthening the inter trial interval up to 6000 ms. They cite this change as one of the key reasons they may have found evidence of conflict adaptation on non-repetition trials. Two reasons can be suggested as to why a lengthier interval decreases the influence of negative priming or enhances the likelihood of conflict adaptation. One relates to the decay of the inhibition that has been applied to the competing response on trial $n - 1$, and the second relates to the amount of time that is necessary for a conflict monitoring signal to bring about subsequent adjustments in

performance on trial *n*. Another study was undertaken to examine the effects of lengthening the response to stimulus interval on non-repetition trial performance. Specifically, Experiment 3 was re-conducted with a new set of Colorado State University undergraduates ($N = 43$) screened according to the same procedures used in Experiment 3. The only change to the procedure was the use of a response to stimulus interval of 1750 ms rather than 1000 ms. Of specific note is performance on Ihc non-repetition trials depending on whether they were preceded by a C, Ihc, or Ilc trial. The figure below presents the original results for Experiment 3 on the left graph and the results of the new experiment on the right graph (See Figure 6.1). For IhcIhc trials, performance is faster than CIhc trials and similar to IlcIhc trials in the new experiment, suggesting that perhaps the strong negative priming that would be expected in the case of a high conflict trial has had the chance to decay over the longer interval, thus performance is enhanced

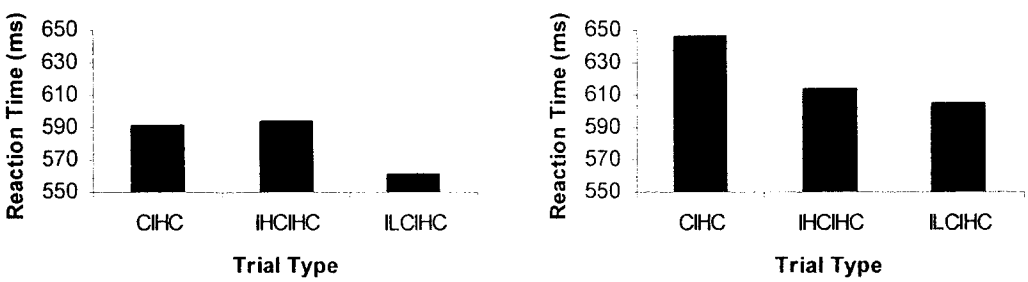

Figure 6.1. Mean reaction time for incompatible high conflict non- repetition trial types during Experiment 3, RSI = 1000 ms (left) and a follow-up Experiment, RSI = 1750 ms (right).

(i.e. conflict adaptation) relative to CIhc trials. The ideal length of the response to stimulus interval is an appropriate subject for future research, as is ascertaining the particular effects of lengthening the interval, as it may be that such changes reduce the

influence of negative priming or they assist in providing ample time for individuals to effectively heighten cognitive control, or a combination of the two.

On the basis of the results of all six experiments presented in this dissertation, it would not be appropriate to completely reject (or accept) either the repetition priming or conflict monitoring account. The fairest conclusion, given the evidence, is to assume that the II advantage over CI trials during the Eriksen Flanker task reflects the influence of both repetition priming and under some conditions, conflict monitoring. In other words, it appears that the effect occurs by virtue of remembering the recently experienced past and adjusting cognitive control on the basis of this memory. Future research is necessary to clarify the nature of the conditions under which the effect can largely be attributed to conflict monitoring. Such conditions may include, but are not limited to the size of the response set, the size of the stimulus set, and the length of the response to stimulus interval.

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