Characterizing Cognitive Control

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.
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Abstract

A series of experiments examined both the phenomenological nature and centrality of Cognitive Control in common cognitive paradigms. This was done primarily by employing manipulations of Congruency Proportion (CP), which are thought to modulate key aspects of Cognitive Control. Experiment 1 leads this investigation by examining the degree to which participants are consciously aware of the influence of CP in the Simon task. Here, it was observed that participants' subjective reports of the proportion of congruent trials did not predict their actual CP effects, suggesting a non-conscious locus of CP effects. Experiments 2 and 3 followed up these preliminary findings by assessing the degree to which CP effects differentially modulate the application of Cognitive Control in two variants of the size congruity paradigm (Numerical Judgement and Physical Judgement). Here, I found that manipulations of CP significantly impacted the Numerical Judgement task, but not the Physical Judgement task, and thus seriously challenge the notion of a central and unitary Cognitive Control module. In Experiment 4, I assessed the systematic variation (via correlations) of effects from the size congruity paradigm and the Stroop task across blocks of trials at different levels of CP. In addition, I examined the degree to which the effects of CP were related to common self report measures of Cognitive Control (the Need for Cognition scale and Cognitive Failures Questionnaire). The pattern of within-task and between-task reliabilities was examined to elucidate the degree to which there is a common central control component that governs behaviour in all tasks. There was surprisingly little to no relation among the CP effects observed in these three tasks. In addition, neither participants' engagement with the task (as indexed by the

Need for Cognition Scale), nor their propensity to have attentional slips (as indexed by the Cognitive Failures Questionnaire) predicted their performance in any way. Taken together, this set of experiments has seriously undermined the received view that CP effects arise from a central and unitary form of conscious control. These results are discussed in terms of contemporary theories of Cognitive Control.

Acknowledgements

Not all wild adventures have an exotic locale. This one had its share of danger, fear, triumph and growth despite the quiet halls it occurred in. Like the most epic of adventures it would not have been possible without a lot of Grace, and many helping hands along the way.

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To my very best thing.

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Chapter 1: Introduction

"A final factor that may serve to our belief in direct introspective awareness is motivation. It is naturally preferable, from the standpoint of prediction and subjective feelings of control, to believe that we have such access. It is frightening to believe that one has no more certain knowledge of the working of one's own mind than would an outsider with intimate knowledge of the workings of one's history and of the stimuli present at the time the cognitive process occurred." Nisbett and Wilson (1977)

The idea of being the sovereign ruler over our own motivations and goals is ubiquitous throughout psychological research. This is perhaps especially true in the more narrow definitions within Cognitive Psychology, in which we use the terms "cognitive control", "response selection", and "selective attention", and thus make personal goals seem more manageable and testable. The idea of control has been around since the very earliest days of psychological research. Then as now, the idea of control has been tied to attentional processes and consciousness (Baldwin, 1901; Angell, 1907). In the current widely accepted view, and contrary to some earlier conceptions going back to Wilhelm Wundt, Cognitive Control is not a higher order mechanism that is unavailable to strict laboratory tests. Rather, Cognitive Control is viewed as an integral part of many cognitive phenomena. Because of the widespread use of the idea of control throughout a number of differing lines of research, it is quite difficult to find a clear history of the evolution of the current concept of Cognitive Control. Two of the earliest and most popular areas of research, in which control was a central component, were individual differences and memory. While these two different major areas of research did not cross reference each other for the most part, it is interesting to see the commonalities between them in their use of language. As such, it is perhaps useful to briefly describe the development of the construct of Cognitive Control through these different lines of research.

Control as an Individual Difference

Some of the earliest conceptions of Cognitive Control were considered only as an individual differences variable, more similar to a static personality trait than a dynamic resource. While intuitively backwards from how the cognitive literature currently uses the term, Klein (1956), and Gardner and colleagues (e.g., Gardner, 1959; Gardner & Long, 1960) defined certain individual consistencies in cognitive behaviour which have many similarities to modern conceptions of control. These ideas were used to create individual cognitive “styles” that ranged on a number of different dimensions. For example, one dimension of Cognitive Control was “Field Articulation", which could be defined as the ability to selectively attend to parts of a visual display while ignoring other less pertinent parts in a visual estimation task. Thus, even though control was conceptualized as a trait level phenomenon, it was a way in which individuals exerted top-down influences on task performance.

Many of the constructs of Cognitive Control were of interest to those studying clinical phenomenon, such as Schizophrenia (e.g., McKinnon & Singer, 1969; Schooler & Silverman, 1969), as well as social phenomenon, such as Cognitive Dissonance (Wolitzky, 1967). Around the same time (late 1960’s), researchers began to examine the influence of Cognitive Control on more basic cognitive processes, such as Stroop performance (Grand, 1968), and attention (Wachtel, 1967). The earliest examples of Cognitive Control being conceptualized as a process, or dynamic variable, however, are not seen until the early 1970s. Hammond and Summers (1972) were some of the first to articulate these concepts in line with our current understanding of Cognitive Control as being a measurable variable that can change as a function of task. This is a clear departure from earlier conceptions, where Cognitive Control was viewed more as a static individual difference. Specifically, Hammond and Summers suggest that Cognitive Control is a necessary component of behaviour and one that will influence performance in a wide range of tasks. Most importantly, they argue that Cognitive Control is not only measurable, but can be experimentally manipulated. Similarly, Furedy (1973) argued that Cognitive Control must be measured more systematically, so as to better understand the relation of Cognitive Control to “autonomic” responses, or in today's parlance, “automatic” responses. This shift in emphasis from an individual trait to a process open to manipulation and systematic measurement is an important one. It is hard to judge the impact of this line of research on current work as it is not independent of other investigations from around the same time that deal with the workings of control. In the end, however, this later sentiment would have a profound impact on current research and theoretical developments.

Control and Memory

In the first two-store memory model of Atkinson and Shiffrin (1968), control appears as a transient component of memory rather than a permanent structure. Given this, Cognitive Control would then be best conceptualized as a conscious effortful phenomenon under the control of the individual. In a sense, it was not explicitly part of their model at all. Here we see an early example of what will become a common modeling trend. Control in essence, in many models, is a free parameter to help explain the complexity of human behavior. In some cases control could even be considered a crutch, something to be leaned on whenever behavioral patterns become too complicated to model explicitly.

In a related trend, Cognitive Control began to be slightly more defined, while still maintaining its amorphous nature. For example, shortly after Atkinson and Shiffrin's Modal Model, Baddeley and Hitch (1974), developed what has become perhaps one of the most influential models of short-term memory, the Working Memory Model. In their model, Cognitive Control featured prominently in the "Central Executive" module, which was, in essence, a limited capacity attentional controller. This model set the tone for many future iterations of Cognitive Control as a means of directing attention. Implications of this model can be seen throughout many different areas of cognitive research.

One further profound impact of the idea of control on memory research, is the development of the concept of inhibition. Inhibition has a great deal of intuitive appeal when thinking about control. In essence, inhibition is a specific type of control, wherein a mental process (or a component of a mental process) is stopped or attenuated. This idea has had a huge impact through a number of current research paradigms, including negative priming (see Tipper, 2001, for a review), and directed forgetting (see MacLeod, 1998, for a review). Inhibition also has had a continuing impact, whether explicitly stated or implicitly apparent in the model, in current Cognitive Control research.

Control and Automaticity

Parallel to the development of notions of Cognitive Control in research and theory in memory, researchers began to appreciate its potential role in a wide variety of cognitive tasks. Specifically, the concept of Cognitive Control became important to the study of word reading (Neely, 1977; Posner & Snyder, 1975), inhibition in go-nogo paradigms (Logan & Cowan, 1984), and studies of slips of attention (Reason, 1979; Norman, 1981). Central to much of these varied fields of research is the dichotomy between *controlled* versus *automatic* processes. The idea of two types of processes was first expressed more than a century ago (James, 1890) but only became heavily influential after the seminal work of Shiffrin and Schneider (1977) and Schneider and Shiffrin (1977). Influenced by work on memory and attention (see Atkinson & Shiffrin, 1968; Deutsch & Deutsch, 1963), Shiffrin and Schneider laid out the fundamental properties of these two types of processes: controlled processes are very resource dependent, slow, and flexible, whereas automatic processes are resource independent, fast, and inflexible. Of note, Schneider and Shiffrin (1977) suggested that when an automatic process is initialized, it will enter the short-term store (working/short-term memory) but need not be brought to conscious attention. By contrast, controlled processes are activated only with the attention of the individual, and require attention to be maintained. It is widely accepted that most complex behaviours arise from an interplay between these two types of processes, but how these two processes interact is still debated. Schneider and Shiffrin (1977) suggested that both processes (automatic and controlled) could run in parallel and then a further controlled process would be needed to utilize the outputs of these two processes.

Whereas attention is postulated to be required for a controlled process, not all controlled processes are posited to be made available to consciousness. Thus, attention and consciousness are not synonymous. Additionally, like many others before and since, Schneider and Shiffrin also found it difficult to keep clear the concepts of controlled processes and Cognitive Control, despite listing one of their seven principles as being that Cognitive Control could exert a larger influence over controlled processes than automatic ones (the evidence of this being obtained from examples including the Stroop task).

The Stroop Task and Cognitive Control

Stroop (1935) was the first to describe a phenomenon which would later become a central means of exploring the interplay between controlled and automatic processes. When a colour word (e.g., "red") is presented in a print colour (e.g., red or blue), subjects are faster and more accurate to identify the colour when the word is congruent with the print colour ("red" presented in red print) than when the word is incongruent with the print colour ("red" presented in blue print). This is commonly referred to as the Stroop effect and is one of the most robust phenomenon in the cognitive literature (see MacLeod, 1991, for review).

The Stroop effect is widely believed to reflect the automatic processing of the colour word:

> “the automatization of word recognition allows much quicker reading... but also leaves us vulnerable to the Stroop effect... knowing about this effect is no protection -- the processes are not open to control.” Reisberg (1997), p. 603.

Thus, in the view of Shiffrin and Schneider (Shiffrin & Schneider, 1977; Schneider & Shiffrin, 1977) the controlled process of colour naming would be more open to Cognitive Control than the automatic process of word reading. Put in terms of inhibition, in order to correctly name the colour the word is printed in, the individual must inhibit the word reading process. The first test of this came soon after, albeit with a different task.

Using a "Stroop-like" task, Logan and Zbrodoff (1979) tested the extent to which automatic and controlled processes were influenced by strategic (or cognitive) control. Instead of colour words displayed in congruent or incongruent colours, they used the words ABOVE and BELOW printed above or below a central fixation. Interestingly, although word reading is taken to be automatic with the standard Stroop task being cited as evidence (Reisberg, 1997), indicating the physical location is the faster and more fluent process, whereas identifying the word is thought to be the slower, less fluent process. Logan and Zbrodoff manipulated the expectation of conflicting trials by varying the proportion of trials in different conditions. They did this by including conditions with a low proportion of congruent trials (10%, 20%, and 40%) and conditions with a high proportion of congruent trials (60%, 80%, and 90%). A double dissociation was found; as the number of congruent trials increased, the size of the "Stroop" effect increased, and as the number of congruent trials decreased, the "Stroop" effect reversed in direction. This manipulation revealed two major findings. First, the more fluent process of identifying the location of the word and the less fluent process of identifying the word were both subject to "strategic" influences. Second, the extent to which "strategic" influences impacted the component processes was modulated not only by the extremity of the proportion of the congruent trials, but also, and more importantly, by the relative fluency of the component process. Thus (in Logan and Zbrodoff's terms) the automatic process of localization was less open to selective attentional processes (or Cognitive Control) than the attentional process of word reading.

Subsequently, the influence of Cognitive Control in the traditional colour word Stroop task was tested with similar results (Logan, Zbrodoff & Williamson, 1984). This replication and extension showed the same pattern as Logan and Zbrodoff (1979) when two colour words were used (Experiments 1 and 2) but did not hold in the case of four colour words (Experiment 3). The conclusion drawn from this research was that four colour words perhaps created too many contingencies to "keep in mind". This is an interesting conclusion to make, given that the manipulation of the proportion of congruent trials still modulated the size of the Stroop effect, even though there was no reversal of the effect.

It is worth pointing out here the language that is used to describe the nature of Cognitive Control. In line with the Nisbett and Wilson (1977) quote above, there has always been an implicit assumption that Cognitive Control is a conscious willful component of our being. Certainly, there is a clear implicit assumption that the manipulation of expectations is something that subjects are aware of, as the terms "keep in mind", and "strategic" are replete throughout the literature. This is a trend that has continued into later models and theories, and is of central concern to the current work. As conceptions of Cognitive Control have grown and developed, is the construct still aptly named? An additional problem is keeping distinct Cognitive Control from controlled processes. If controlled processes require attention and continuing conscious effort, how are they different from Cognitive Control?

Current Views on Cognitive Control

One of the earliest and most influential examples of an explicit model of the Stroop paradigm brings to light a key issue: that tied up with the notion of Cognitive Control being a conscious component of our psyche, it is also thought to be a central and unitary one. Cohen, Dunbar, and McClelland (1990) proposed an explicit model in which "Attentional Selection" nodes were used as a means to modulate the input of the component processes in the Stroop task:

> "We assume that this information is available as the output from some other module and results from encoding and interpreting the task instructions. Clearly, this is a highly flexible process and can adapt to the wide variety of information processing tasks that humans can perform". Cohen, Dunbar, and McClelland (1990), p. 338.

Clearly, the assumption made here is one of control being a unitary process that is shared by many different tasks, and organized in such a way as to adapt itself to those different tasks. Presumably then, the same selective attention mechanism could be used to perform a Stroop task as to perform a different task, for example, a cueing task (e.g., Risko & Stolz, 2010).

The current received view of Cognitive Control is based upon the work of

Botvinick, Braver, Barch, Carter, and Cohen (2001) who modified Cohen et al. (1990) to include a conflict monitoring node in order to account for Congruency Proportion (CP) effects, like those of Logan, Zbrodoff and Williamson described above (see Figure 1). The complete set of mechanisms suggested by Botvinick and colleagues to account for implemented Cognitive Control is remarkably simple. As the proportion of congruent trials decreases, there is more conflict at the response level. As the conflict increases (see Eq. 1 in Figure 1), an error detector (the conflict monitoring node) signals the need for more top-down control. Subsequently the task demand units are reinforced (see Eq. 2 in Figure 1). Conversely, as the proportion of congruent trials increases, there is less conflict, and less need for top-down control. To put it in more simple terms, the implication of a change in the proportion of congruent trials has two consequences: the task becomes more difficult or easier. If the task becomes more difficult, subjects try harder to fulfill the task instructions, but if the task becomes easier, then the subjects try less. Thus, in the Stroop task, when there are more congruent trials than incongruent trials, the putatively automatic process of word reading is relied upon more than the more controlled process of colour naming, as most of the time reading the word will generate the correct response.

This leads to a pattern of data in which reaction times and error rates to incongruent trials increase as CP increases. Interestingly, this is an example of a positive form of control rather than an inhibitory one. Note that it would be equally easy to generate a model in which inhibitory control is utilized. The above, however, is an existence proof of control with no need for inhibition.

The mechanism suggested for error detection has been proposed to be localized in

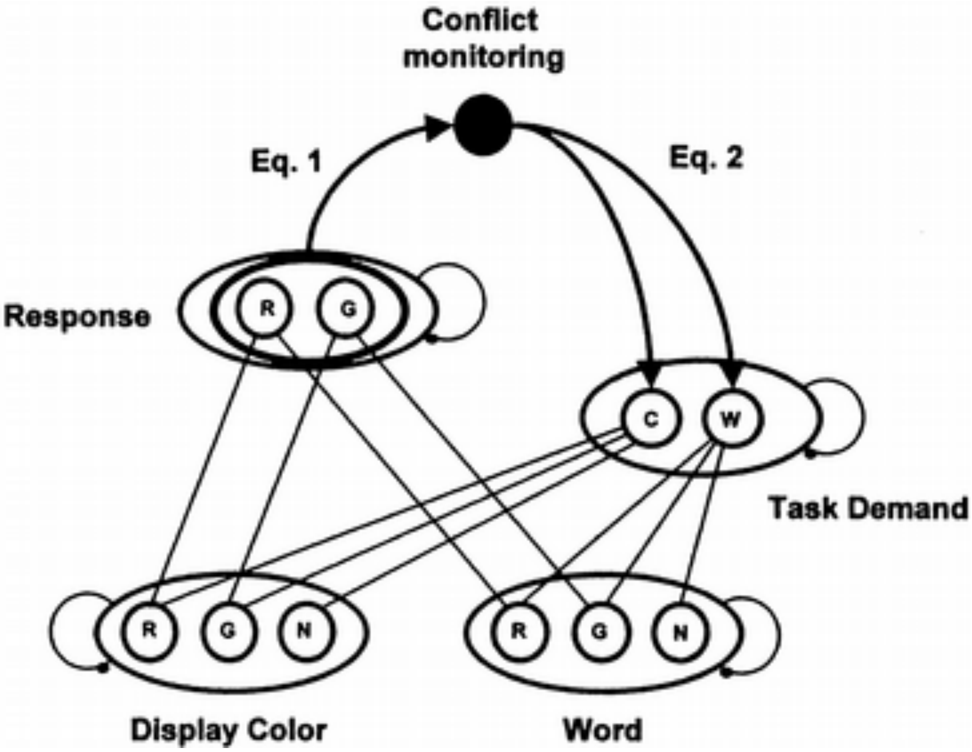

Figure 1. This graphical depiction of the model is from Botvinick, Braver, Barch, Carter, and Cohen (2001). Display Colour and Word units activate Response units. The amount of conflict at the Response level is fed forward to the Conflict monitoring node (which is analogous to the Anterior Cingulate Cortex) which modulates control. Control is represented in the Task Demand units which in turn modulates the Display Colour and Word units.

the Anterior Cingulate Cortex (ACC) of the brain. A wide range of neuroimaging studies have found that when conflict is present, there is activation in the ACC (e.g., Ansari, Fugelsang, Dhital, & Venkatraman, 2006, in the size congruity paradigm; Swick & Jovanovic, 2002, in the Stroop Paradigm). Botvinick et al. have therefore proposed a model in which a unitary control unit modulates activation in task units. Explicitly in their model, control is a single and simple mechanism shared by all the task relevant nodes. Interestingly, the location of the activation "in" the ACC is widely variable (Botvinick, Cohen, & Carter, 2004). In a number of meta analyses, the "error detector" is activated in a wide region outside the anatomical ACC (Bush, Luu, & Posner, 2000). The diffusion of activation which is dependent on task does not undermine the conflict monitoring hypothesis. It does however call into question the localization of the subsequent control purported to be recruited by the detection of conflict. If the error detector is a diffuse and non-unitary mechanism, what is the nature of the subsequent "control" mechanism? At a higher level of conception, how well does such a simple mechanism capture the nature of Cognitive Control?

Despite the general acceptance of the view of Botvinick and colleagues, there are a number of works that call into question such a simple view of control. The first was the finding that individual words and colours in the Stroop task could form distinct Congruency Proportions within the list wide set of Congruency Proportion. For example, Jacoby, Lindsay and Hessels (2003) reported that within a list wide set of a CP of .50, some of the items could have a higher CP, and some a lower CP. The resulting pattern of data showed a clear separation, such that the Stroop effect was larger for those items with a high CP, and smaller for those items with a low CP. In order to account for such a finding, clearly an additional mechanism, or a modification of the single mechanism already utilized, must be made to Botvinick et al.'s (2001) model. Such a model was developed by Blais, Robidoux, Risko, and Besner (2007). Blais et al. were able to account for the Item Specific Proportion Congruent Effect (or ISPC effect) by modifying the way the feedback from the conflict monitoring node influenced the pathways to the component processes. Rather than having a singular mechanism provide input to a complete component process, the Blais et al. model has the same singular mechanism provide feedback to each level of each component process (see Figure 2). This simple theoretical adjustment allows the Blais et al. model to account for both the traditional (list-wide) CP effect, and the ISPC effect.

Although the above "problem", and the solution to that problem, of the account of Botvinick and colleagues is relatively straight forward, the trouble does not end there. While endorsing the Blais et al. model, Jacoby and colleagues (Bugg, Jacoby, & Toth, 2008) have added another empirical finding that requires accommodation. Extending their previous findings, they showed evidence for another level of CP effects within the Stroop task. Specifically, by varying the font of some items, Bugg et al. (2008) demonstrated a *font specific* CP effect. Bugg et al. argued that this suggests there are multiple levels of control within each task. Such an argument, however, could make modeling a nightmare, as multiple levels of item specific CP may not be so easily accommodated.

Perhaps (in part at least) in response to these findings, Braver, Gray, and Burgess

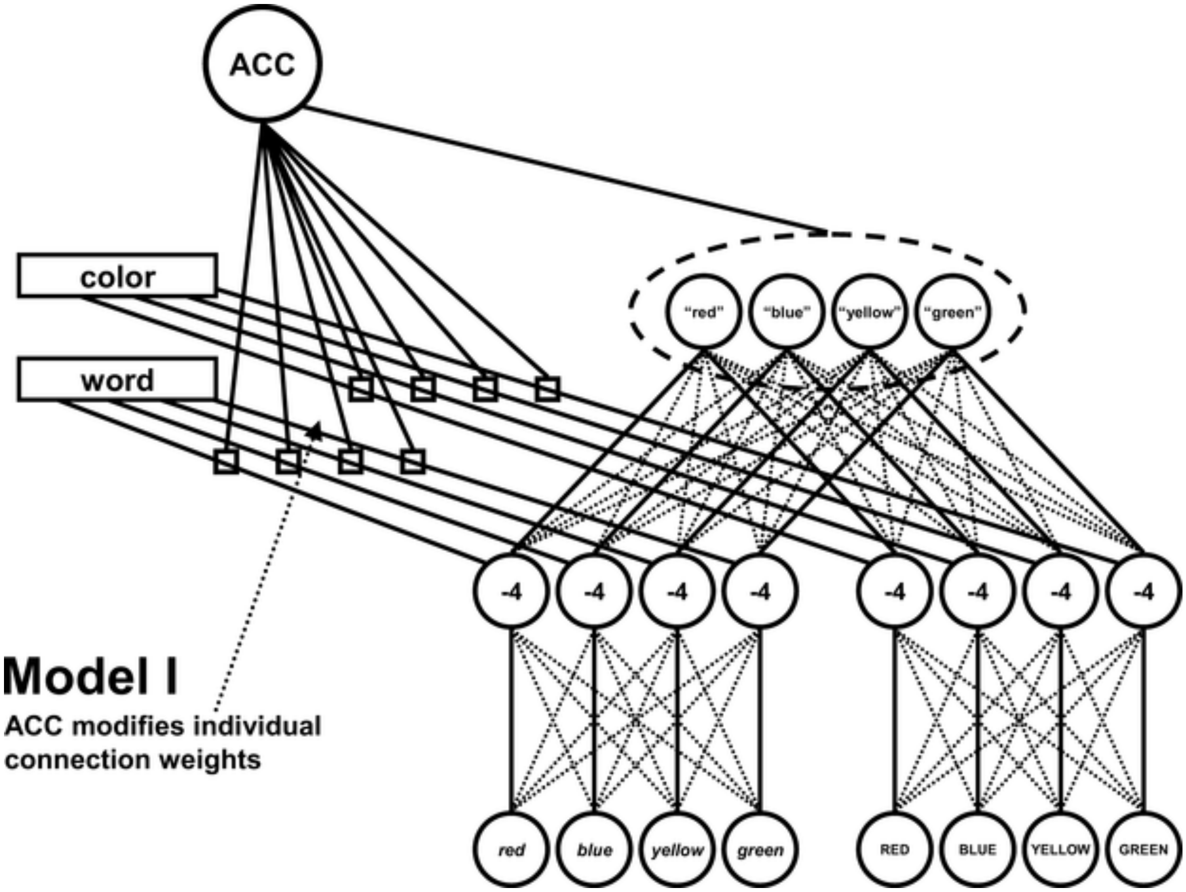

Figure 2. This graphical depiction of the model is from Blais, Robidoux, Risko, and Besner (2007), which is a more clearly specified version of the model from Botvinick et al. (2001). Note that it shares all the same components, but ACC connections are to the individual pathways and Task Demand units. This implemented model has a much more integrated role for the ACC.

(2007) have suggested that Cognitive Control may in fact reflect two separate control mechanisms: Proactive Control, and Reactive Control. Proactive Control is suggested to be a top-down, task demand and contextual driven form of control. As such, Proactive Control is more conceptually similar to earlier uses of the term Cognitive Control in which the subject may well be conscious of the control and its consequences. By contrast, Reactive Control is thought to be stimulus driven and occurs “after the occurrence of an imperative event” (Braver et al., 2007, p. 79). It is Reactive Control then, according to Braver et al., that accounts for item specific phenomena, and is most likely related to the ACC activation and feedback mechanism posited by Botvinick et al. (2001). Reactive Control, as the mechanism by which item level effects arise, is therefore what is largely responsible for “strategic” control in many tasks, including the Stroop effect.

Perhaps the most striking expression of item specificity has been demonstrated by Schmidt and Besner (2008) who elegantly showed how contingencies between the dimensions of the different stimuli interact in the Stroop paradigm. Of serious import, they demonstrated that the contingency between each combination of print colour and colour word in the Stroop task has its own impact on performance. That is, the word green appearing in the print colour blue can have a distinct contingency from the word green appearing in the print colour yellow. Thus, the simple case of a general central mechanism that modulates attention to task level, or even item level components is called into question. This raises the question of what common control mechanisms exist between tasks. If the error detection/attentional control mechanism proposed by Botvinick and colleagues holds given Schmidt and Besner's (2008) results, albeit with a level of specificity modification, then it seems probable that the mechanism is not a unitary one shared by many distinct processes, but rather is more of an epiphenomenon and represents a fundamental way in which conflicts amongst stimuli are resolved. In line with Braver et al.'s (2007) conception of Reactive Control, if each separate component of a stimulus has a unique relation with the other components, then the application of an error detection/control framework as above requires separate control nodes for each combination of the multiple components of a stimulus.

An Alternative Account of Congruency Proportion effects

An alternative way to account for the intricate and complex behaviour seen in many cognitive paradigms is to limit the role of top-down control (or strategic processing) to response selection. As such, subjects would use Cognitive Control to implement task instructions, but CP effects would arise from an entirely separate mechanism. One example of such an account is a formal model proposed by Melara and Algom (2003).

Melara and Algom (2003) depart from much of the literature in a number of interesting ways. For example, their model includes a role for trial-to-trial (short-term) memory as well as long-term memory, and starts from the implicit assumption that subjects need not be aware of (or in control of) all of their behaviour. To oversimplify their account, it is the inclusion of a memory of recent past trials that produces CP effects (see Figure 3). More specifically, their model is structurally similar to Botvinick et al.'s model, with the difference being in small part the labels given to the specific components (i.e., perceptual space in Melara and Algom's model is analogous to the input nodes in Botvinick et al.'s model), and in large part the component that gives rise to CP effects.

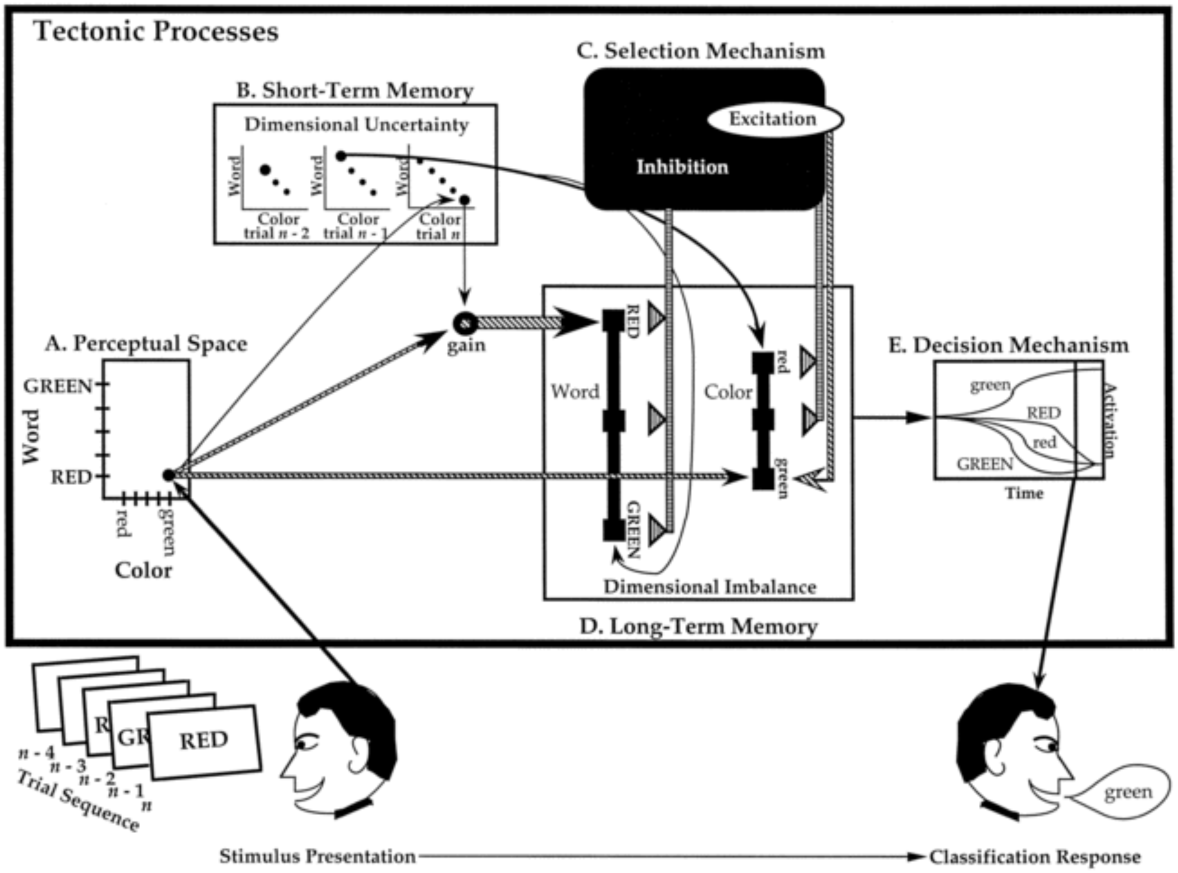

Figure 3. This graphical depiction of the model is from Melara and Algom (2003), which highlights the role of short-term memory in CP effects. This model is conceptually similar but differs in implementation and in a few vital ways from Botvinick et al.'s (2001) model. For the purposes of this thesis, the most important difference is the short-term memory component (B). Stimuli activate both a short-term representation (a sum of recent events) and a long-term representation (D) (which functions more like representations in the Botvinick et al. (2001) model). The main significance of this is that the short-term memory unit drives this models ability to produce CP effects. Thus there is no role for the ACC in this implemented account of CP effects.

Here, whereas Botvinick et al. use an error detector that modulates the influence of other components, Melara and Algom use a short-term memory component that interacts with long-term memory (or “pre-set” values). It is important to highlight then, that whereas Botvinick et al. suggest that increases in conflict monitoring (or recent events) *reinforce* task demands, Melara and Algom posit that short-term memory (or recent events) *interact* with task demands. More importantly, however, it is the way in which recent events are captured that distinguished these two prominent models. Specifically, whereas the Botvinick et al. (2001) model simply measures the amount of conflict on a given trial, the Melara and Algom (2003) model measures (at least theoretically) the entirety of the previous events. Here, short-term memory is thought to record not only the proportion of congruent to incongruent trials (by summing across recent events), but also other stimulus dimensions (e.g., such as font) on a trial-by-trial basis. In essence, this model captures some of the better qualities of traditional memory models (see the MINERVA II memory model for example, Hintzman, 1984, 1986), and integrates them into a processing model framework.

While some of the examples of research above (e.g., Bugg et al., 2008; Schmidt & Besner, 2008) suggest problems for a single top-down Cognitive Control mechanism to explain CP effects (that Melara and Algom's model does not share), there is also a particular study that seems well suited to highlight the difference in the two modeling approaches outlined here. Whereas most studies confound proportion training with the conflict task under investigation (the proportion of congruent trials is learned while doing the task), Tagliabue, Zorzi, Umilta, and Bassignani (2000) were able to delineate these two factors by employing a congruency stimulus/response mapping task prior to a conflict task. Specifically, they studied the impact of a stimulus/response mapping pre-task on children's performance on the Simon task, which will briefly be described below.

When a to-be-identified stimulus is presented to the left or right of a central fixation, subjects are faster and more accurate when the stimulus location, despite being irrelevant to the task, is on the same side as the correct response key. This is commonly referred to as the Simon effect (see Simon, 1990, for a review) and is a robust and easily replicable phenomenon (Lu & Proctor, 1995). Convention is to refer to Compatible and Incompatible trials/conditions in the Simon literature, but for the sake of consistency, I will maintain the use of the terms Congruent, Incongruent, and Congruency Proportion (CP) when referring to specific conditions in this task. On the first day of Tagliabue et al.'s (2000) study, children performed a localization task in one of two conditions. In the "congruent" condition, they identified a stimulus via key press that was always mapped ipsilaterally (i.e., if the stimulus appeared on the left side of the screen, the correct response key was on the left side of the keyboard), and in the "incongruent" condition, they identified a stimulus that was always mapped contralaterally (i.e., if the stimulus appeared on the left side of the screen, the correct response key was on the *right* side of the keyboard). On the second day, all the children did the Simon task, with the usual results. Specifically, the children were faster and more accurate when the stimulus location, despite being irrelevant to the task, was on the same side as the correct response key. However, the children who had previously been in the congruent condition in the previous task, performed the Simon task as though they were in a high CP version of the Simon task.

The children who had previously been in the incongruent condition on the previous task, on the other hand, performed the Simon task as though they were in a low CP version of the Simon task.

Tagliabue et al.'s (2000) data effectively demonstrated that recent memories from a different task can produce an effect that looks (and may in fact prove to be) a CP effect. Viewed from the perspective of the Melara and Algom (2003) model, this effect could be interpreted as arising from the “automatic” spatially corresponding response, the controlled response (response selection in accordance with task instructions), and the influence of recent memories that, while not for the Simon task, had enough similarity to be cued from memory and influence the children's behaviour. Melara and Algom are very explicit in defining the short-term memory component of their model as implicit and unconscious, and thus provide an existence proof for a way of conceptualizing Cognitive Control solely as a mechanistic interaction of the kind we have some insight into (i.e., short-term, long-term memory and response selection interactions).

Interim Conclusion

There has been a vast body of research conducted on the influences of subtle changes in the field of information available to us in a task, and how these subtle changes influence our behaviour. What is worthwhile noting here, however, is that very little of this research directly tackles the question of whether these changes in behaviour are due to conscious effortful control or are the result of some other mechanism. This omission is not really surprising. In some cases, it is most probable that there is an implicit assumption that our behaviour is of course under our control, and therefore must be conscious.

Although appealing, this assumption is premature. This omission is also probably due in part to the complex nature of the question, as “consciousness” and “control” are difficult concepts to tackle and explicitly define.

Nonetheless, it seems vital that as we delve into more and more complicated patterns of behaviour, we need to be clear about what we mean by consciousness, and when we think consciousness is in play. In the case of manipulations of CP, there are a few clear conclusions. The first concerns the general pattern of behaviour identified across a very wide range of studies showing the impact of CP manipulations on behaviour. Generally, as the proportion of congruent trials increases, the subjects performance on the task gets faster (and less error prone). Secondly, there is certainly a component of consciousness in these tasks (as there must be in all tasks). The subject is very likely aware on some level of his/her performance as he/she is in the midst of performing the task. In some cases they may get immediate feedback on a trial-by-trial basis from the task itself (depending on the methodology). Probably in all cases, subjects do have at least a limited sense of how well they are doing on the task as they notice the number of errors they make while making them. The real issue at play then is the following question: does this conscious involvement account for the CP effect?

There is a growing body of evidence that suggests that CP effects do not arise from the conscious involvement in the task. The largest and most compelling part of this evidence is that CP effects can be extremely complex. At face value, it is difficult to believe that subjects are able to hold on to the very complex set of contingencies involved with a large number of associations in a given task. This is especially compelling when contrasted against our ability to remember the name of a person we just met in a social circumstance, or a new phone number. How are we able to remember such a large number of complex associations and have them consistently affect our performance when the merest task of remembering a name or phone number can be so difficult? This research, and the questions it raises, does not invalidate the work that has gone before it empirically or theoretically. It does however suggest that perhaps the largest component of CP effects does not come from conscious effort, but from some other source.

It may be that we need to strictly redefine what we mean by “control”. The terms “control” and “Cognitive Control” have become confused with descriptions of complex behaviour. Perhaps we need to redefine control as Braver et al. (2007) have, with two separate components: one being a conscious form of control, which represents the type of control we use in deciding how to interact with our environment; the other being an unconscious form of control, in which memory and attention interact to make use of the information around us. Even this delineation of control does not go far enough. Once we separate consciousness from "control", then we are left asking, what is the nature of unconscious control? Is it a unitary mechanism in which we can plug in whatever task we are currently occupied with? Or, is it the other extreme? Specifically, could it be an epiphenomenon; not a form of control at all but just a pattern of how information from different sources interacts? It is very likely that individual views on this question are largely informed by opinions on the nature of memory and attention.

Although these are difficult questions, they need not be answered in a vacuum. There are particular examples of research already conducted that address this problem to some degree. As such, this thesis will be primarily concerned with tying these disparate studies together, along with new research presented here, in order to more fully understand how Cognitive Control should be viewed in the future. Thus, the overarching goals of this thesis are to (1) examine the phenomenological nature of Cognitive Control (i.e., whether the processes underlying Cognitive Control are available to consciousness), and (2) examine the extent to which CP effects in conflict tasks (such as the Stroop and Size Congruity task) arise from a central and unitary (Cognitive Control) mechanism or from a non-unitary set of mechanisms.

Methods and Approach

The first experimental goal then, is to see to what extent consciousness plays a role in Cognitive Control. It may seem remarkable that this question has remained unanswered, especially in light of over 100 years of implicit language suggesting that consciousness is very central to control. Experimental 1 will tackle this question head on by examining the degree to which people are consciously aware of experimental manipulations that modulate control in a task. Additionally, in Experiment 4, I examine the degree to which one's susceptibility to variables that modulate control are related to measures of individual differences in Cognitive Control.

The second, and arguably more important, experimental goal will be to determine the extent to which Cognitive Control is a unitary or multidimensional phenomenon. This second goal will be addressed by examining the degree to which control operates similarly or differently in different conflict tasks (Experiments 2 to 4). To do this, Experiments 2 and 3 will utilize the Size Congruity paradigm in two between-subject experiments. This paradigm offers some unique benefits over other paradigms when exploring Cognitive Control. Specifically, there are two main versions of the task (Numerical Judgement and Physical Judgement) which differ only in terms of instructions. In addition, in the Numerical Judgement variant of the task, there is a clear and well understood delineation of the semantic space, which will be discussed later.

Experiment 4 will extend this line of research by directly comparing the effects of CP in the Size Congruity paradigm and the Stroop paradigm in a single within-subjects experiment. The Stroop task is useful to include here as it offers a well known “baseline” and “gold standard” by which the other two tasks can be compared. If the same mechanism is applied consistently to different tasks under a CP manipulation, we would expect to see a high degree of correlation between the relative size of the effects that the CP manipulation elicits. To be clear, if Cognitive Control is a unitary mechanism, it means that the different tasks will be modulated by precisely the *same* mechanism. Whereas there may be differences in the magnitude of the sizes of the effects across task, those differences should correlate across tasks.

Additionally, there is an opportunity here to examine other measures of Cognitive Control, and address the first experimental goal. Specifically, two measures that capture some of the conscious aspects of control are the Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982), which measures slips in attention, and the Need for Cognition Scale (Cacioppo, Petty, & Morris, 1983), which is viewed as a measure of the extent to which an individual engages (attends effortfully) in a task.

These two experimental goals should provide evidence for or against the centrality of a Cognitive Control mechanism, at least insofar as it relates to CP effects. If the CP manipulation elicits a response from a unitary attentional control mechanism (i.e., Cognitive Control as defined by Botvinick et al., 2001), we would expect to see a pattern of behaviour that would indicate a common influence. If, however, the CP manipulation elicits a response from a more complex set of control mechanisms, we may see little consistency in CP effects across tasks.

There are two main experimental methodologies that will be used to achieve these two experimental goals in this thesis: manipulations of CP, and assessments of Reliability and Cross Task Consistency. These will be discussed in turn below.

Congruency Proportion Manipulations

The manipulation of the proportion of congruent trials, or CP manipulation, is a straight forward experimental factor. In all the experiments in this thesis, the proportion of congruent trials will be at one of three levels. All four experiments utilize two congruency proportions; .25 in which most of the trials (75%) are incongruent, and .75 in which most of the trials (75%) are congruent. In addition, Experiment 2 includes a .50 CP condition in which half of the trials are congruent and half incongruent.

Assessing Reliability and Cross Task Consistency

In Experiment 4, I assess reliability by correlating the Stroop effect and Size Congruity effect across two different points in time. To do this, difference scores from the different tasks (representing the magnitude of the Congruency and CP effects in each task) will be directly compared. This method has been used successfully in the past (see Borgmann et al., 2007 and Stolz et al., 2005 for examples of this approach applied to the

Simon Task and Semantic Priming respectively) and will be discussed in more detail in the introduction to Experiment 4.

Chapter 2: Experiment 1

Investigations of the type that are of interest here are, at least in part, of a broad nature and rarely directly investigated. The role of consciousness in CP manipulation paradigms has been largely overlooked, perhaps due to the vagueness in the language used, and the difficulties associated with specifying definitions and operationalizing the construct. As such, a methodologically solipsistic view would suggest an early starting point for this investigation. In other words, step one should be to simply ask subjects if they are consciously aware of the effect that they are producing.

The most straightforward approach in this case is to use a simple task and then ask subjects about their subjective experiences. This approach will answer the most basic question of whether or not subjects are aware of the size of the congruency effects that are manifested in their responses. It also affords the opportunity to ask subjects to estimate the size of their congruency effect, and measure the degree to which their subjective estimations are correlated to their actual effect. If subjects are able to predict their congruency effect, then it suggests that subjects are doing so consciously, or at the very least, that they are consciously aware of the output of whatever processes are generating the CP effect.

An appropriate task widely believed to reflect some combination of automatic and controlled processes is the Simon task (Kornblum, Hasbrouq, & Osman, 1990; Lu & Proctor, 1995; Simon, 1990). As noted in the introduction, when a to-be-identified stimulus (e.g., a colour patch) is presented to the left or right of a central fixation, subjects are faster and more accurate when the stimulus location, *despite being irrelevant to the* *task*, is on the same side as the correct response key. This is commonly referred to as the Simon effect, and is one of the hallmark effects used to index aspects of Cognitive Control (see Simon, 1990, for a review).

The Simon effect is argued to arise because two separate internal responses are generated: an automatic spatially corresponding response and a controlled response based on task instructions (e.g., Kornblum, Hasbrouq, & Osman, 1990; Lu & Proctor, 1995; Simon, 1990). When the automatic and controlled processes produce the same response (i.e., the correct response key corresponds spatially to the stimulus location; a congruent trial) subjects are faster than when the automatic and controlled processes produce different responses (i.e., the correct response key does not correspond spatially to the stimulus location; an incongruent trial). CP modulates both the *magnitude* and *direction* of the Simon effect. Previous work has established that when CP is high, the Simon effect is large, and when CP is low, the Simon effect actually reverses direction (e.g., Borgmann et al., 2007; Toth et al., 1995).

The Simon task is particularly appropriate here, not only because it is a hallmark Cognitive Control task, but also because it elicits ample variance in responses, which in turn has the potential to produce differences in subjective experience. This difference in relative variance is important from a measurement standpoint (both in terms of reaction times and errors), and also affords the greatest opportunity to elicit the largest possible variance in subjective experience from the participants.

An additional way that the variable subjective experiences of participating in the experiment can be maximized, is to use extreme CP manipulations. Using a CP of .25 and

.75 will increase the magnitude of congruency effects, and thus allow a maximal opportunity for subjects to be consciously aware of said effects. The different Congruency Proportions will be implimented as a between-subjects manipulation so as to limit the amount of spillover effects (subjects will not be influenced by a prior CP while working on their current task) and eliminate the potential for anchoring effects of previous estimations influencing subsequent ones.

This design leads to a number of potential outcomes. The first is that subject's estimates of the CP might predict performance at the .75 level of CP. The second is that subject's estimates of the CP might predict performance at the .25 level of CP. Finally, the third possibility is that subject’s estimates of CP might predict their congruency effects across both levels of CP. These three possibilities allow for a graduated insight into the role of consciousness in CP effects. If subject’s estimations of the actual CP predicts their performance within one of the two above conditions, then there is support for the idea that conscious control is what is behind the generation of CP effects, or at the very least, that subjects are intimately (and rapidly) aware of the processes that give rise to said effects. It seems intuitively valid that *if* subjects are consciously producing the CP effect, then they *must* be aware of what the approximate proportion of trials is. If subject’s estimations of the actual CP predicts their performance *across* the two above conditions, but *not within* each condition, then there is also support for the idea that subjects are consciously aware of their relative performance. In this case, however, the awareness most likely arises more slowly and after the fact. Subjects may be able to develop a general feel for the CP as they do the task and still not have this awareness influence their performance. Of course, if subjects are not at all aware of the processes that give rise to CP effects, then their estimates will not correlate with the actual effects. Additionally, it seems statistically necessary that if subject’s estimates of their performance within a CP are predictive, then their estimates correlated across both CPs will also be predictive.

Experiment 1

In this investigation it seems particularly important to articulate to the participants a little bit more clearly what they will be experiencing. It also remains important to maintain the typical reserve such that there are no experimenter demands on the subject. Therefore, particular care was made in informing the subjects about the nature of the task. The task was clearly explained, including an emphasis on the fact that there would be congruent trials and incongruent trials (with examples given for both) and that they would see both types of trials, but no hints were given as to the possibility that there may not be an equal proportion of these trials.

Method

Participants

Seventy one undergraduates from the University of Waterloo were each paid $2 for their participation. All participants reported normal or corrected-to-normal vision.

Design

The experiment consisted of a 2 (Congruency: Congruent vs. Incongruent) within x 2 (Block: Block 1 vs. Block 2) within x 2 (CP: .25 vs. .75 congruent) between mixed design. Trials were considered *congruent* when the target appeared on the same side as the required response and *incongruent* when the target appeared on the opposite side to the required response. Thirty-seven subjects were assigned to the .25 CP condition, and 34 subjects to the .75 CP condition.

Procedure

The stimuli were presented on a 17" colour monitor driven by a Pentium computer running E-Prime v1.1 software (Schneider, Eschman, & Zuccolotto, 2001). The target consisted of an “X” or an “O,” 8 mm vertically by 8 mm horizontally, displayed 38 mm to the left or right of a central fixation point (+). Each target appeared an equal number of times within the experiment. Responses were collected using a standard QWERTY keyboard. Subjects used the “A” and “L” keys to make their responses. Mapping of stimuli to responses was counterbalanced across subjects. The midpoint between the two response keys was aligned with the central fixation.

Subjects were tested individually in a sound attenuated room. Instructions for the task were displayed visually and relayed verbally by the experimenter. Subjects were told to identify the stimulus by pressing the appropriate key, to ignore the location of the stimulus, to maintain their focus on the central fixation, and to respond as quickly and accurately as possible.

Each trial began with the presentation of a fixation cross for 500 ms, followed by a target. The target remained on the screen until a response was made. This was followed by an inter-trial interval of 500 ms. Eighty practice trials were followed by two blocks of 120 experimental trials. Trial order was determined randomly for each subject.

After participants completed the Simon task, they were asked to answer three questions:

(1) “If you had to guess what the proportion of congruent trials was; that is, if you had to guess the percentage of times that the correct response key was on the *same* side as the X or O appeared, what would you guess?”

(2) “How confident are you of that guess?”

(3) “Do you believe that you were able to use your knowledge of the proportion to do the task?”

Results

Response time (RT) analysis was conducted for trials in which the response was correct. RTs were submitted to a recursive data trimming procedure (Van Selst & Jolicoeur, 1994) using a 2.5 standard deviation cut-off in each cell resulting in 2.53% of the RT data being removed in the .25 condition, and 2.18% of the RT data being removed in the .75 condition. Mean RT and percentage error data are presented in Figure 4. A 2 (Block: Block 1 vs. Block 2) x 2 (Congruency : Congruent vs. Incongruent) x 2 (CP: .25 congruent vs. .75 congruent) mixed ANOVA was conducted on mean RT and on percentage errors (subject mean RTs and % Error data are presented in Appendix A).

Reaction Times

There was no main effect of Block ($F < 1$) and no interaction between the effect of Block and either the effects of Congruency or CP (Fs < 1). The main effect of Congruency was significant, $F(1, 69) = 12.6$, $MSE = 480.6$, $p < .001$, as was the Congruency x CP interaction, $F(1, 69) = 241.0$, $MSE = 480.6$, $p < .001$. This interaction was the product of a reversal of the Congruency effect for the two CP conditions. Specifically, in the .25 CP condition, congruent trials were 31 ms *slower* than incongruent trials, whereas, in the .75 CP condition, congruent trials were 50 ms *faster* than incongruent trials. The Block x Congruency x CP interaction was not significant $F(1, 69) = 2.5$, $MSE = 208$, $p = .12$.

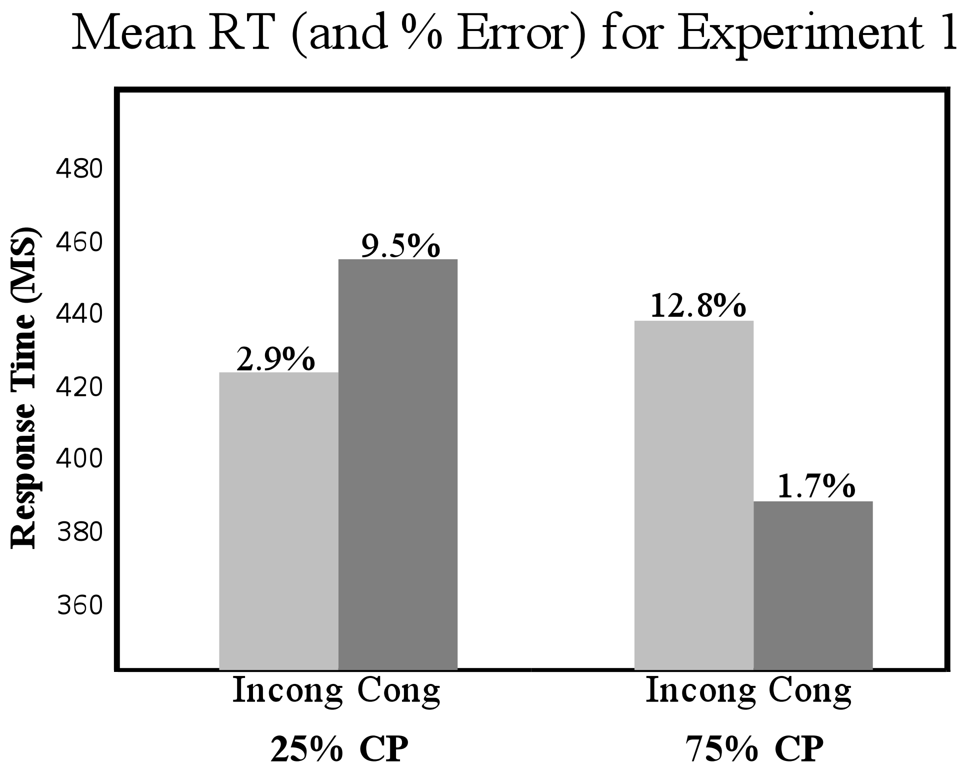

Figure 4. Mean RTs and percentage error data as a function of Congruency and CP for Experiment 1.

Errors

There was a main effect of Block, F (1,97) = 6.1, MSE = 14.39, $p < .05$, but Block did not interact with either Congruency or CP (Fs < 1). The main effect of Congruency was significant, F(1, 97) = 9.4, MSE = 22.74, $p < .005$, as was the Congruency x CP interaction, F(1, 97) = 74.7, MSE = 22.74, $p < .001$. Here, in the .25 CP condition, subjects made 6.6% *more* errors on congruent trials than on incongruent trials. In the .75 CP condition, however, subjects made 11.1% fewer errors on congruent trials than on incongruent trials. As such, there was no speed/accuracy trade-off. The Block x Congruency x CP interaction was not significant (F < 1).

Summary

The expected pattern of behaviour was observed in which responses to Congruent trials were faster than responses to Incongruent trials in the .75 CP condition but slower in the .25 CP condition. This led to a Simon effect in the .75 CP condition and a reversal of the Simon effect in the .25 CP condition. This pattern was also observed in the error data, which replicated previous investigations of the Simon effect, and thus permits the novel correlation analyses between *actual* and *subjective* responses.

Correlational Investigation

Task instructions prior to commencement of the Simon task highlighted that some trials in the task would be congruent and some incongruent. As noted in the procedure, participants were asked to answer three questions regarding their subjective experience. These subjective responses were subsequently correlated with participants' behaviour (see Figure 5). I am only going to focus on the question regarding their subjective estimate

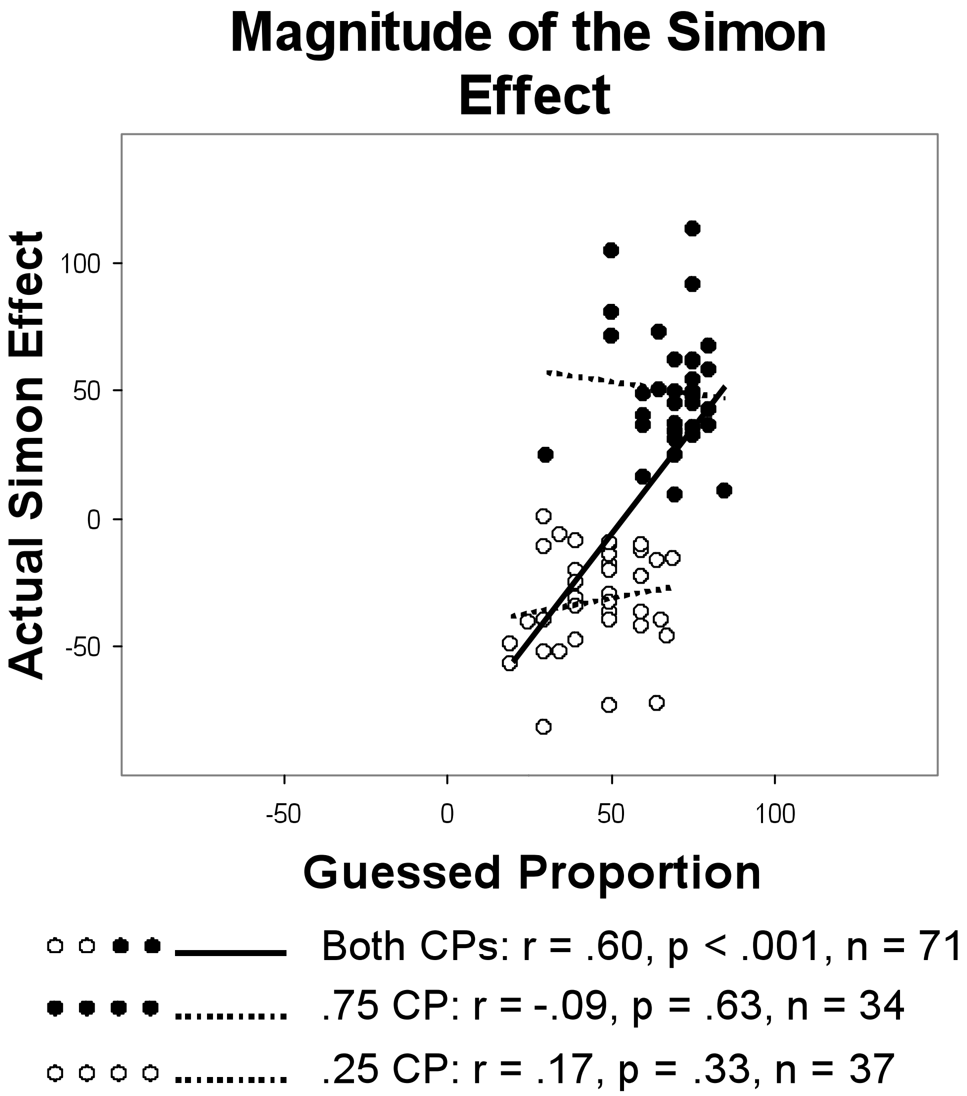

Figure 5. Relation between the *actual* Simon effect and the *estimated* proportion of congruent trials for Experiment 1.

of the proportion of congruent trials (question 1). In both the .25 CP condition (open circles) and the .75 CP condition (filled in circles) subjects estimates of the proportion of congruent trials did <u>not</u> predict their actual performance, *r(31)* = .17, *p* = .33, and *r(32)* = -.09, *p* = .63, respectively. However, these same estimates do predict performance across the CPs, *r(69)* = .60 , *p* < .001).

Discussion

As can be seen in Figure 4, the standard Simon effect (as modulated by a manipulation of CP) was observed. As can be seen in Figure 5, an interesting pattern of correlations between subjective experience and behaviour emerges. The substantial and statistically significant correlation across CP conditions, which represents participants' estimations of the proportion of congruent trials against their actual performance on the Simon task, indicates that subjects are at some level aware of the output of the processes that give rise to the congruency effect. The question then becomes how aware are they? The complete lack of correlations within each level of the CP conditions indicates a boundary to the role of conscious awareness of performance in this task. The pattern of data observed suggests that subjects become aware of the performance after the completion of the processes that give rise to the CP effect. Certainly there is conscious control involved in the performance of any task. The subject is conscious of the task demands, and willfully engages in the task. To say that subjects are not in conscious control of the mechanisms that give rise to the CP effect, or the congruency effect, is not to say that subjects are not in conscious control of response selection. Rather, it suggests that the processes that "control" the magnitude of said effects is completed somewhere between the conscious desire to do the task, and conscious response selection.

It seems then, at a minimum, that we must update our (or constrain any newly generated) definition of Cognitive Control. Whereas certainly the CP manipulation modulates behaviour, it does so without a conscious locus. This does not mean however that there *is not* a control mechanism that gives rise to these effects. Moreover, it does not mean that there *is* a control mechanism either. It should be noted that more contemporary models of Cognitive Control do not include a homunculus per se. Whether or not a model has a box optimistically labeled "Cognitive Control" or has a well-defined control mechanism, that box, component, or mechanism does not require or entail the use of consciousness.

The above data do not speak to the nature of Cognitive Control in the sense that they do not describe how it works except to exclude consciousness as a central component. What then remains to be determined, is the extent to which Cognitive Control is a unitary or multidimensional phenomenon. The experiments presented in Chapter 3 address this issue, and seek to better describe the inner workings of the control mechanism(s) that gives rise to CP effects.

Chapter 3: Experiments 2 and 3

Hand-in-hand with the assumption of the role of consciousness in Cognitive Control is the assumption of centrality. That is to say that if control is a conscious phenomenon, it is by its very nature probably a single central mechanism. However, excluding consciousness from our conception of Cognitive Control does not mean that Cognitive Control is *not* a single central mechanism. The problem, of course, is that any comparison between different tasks opens the door to the possibility that differences in performance and observed behaviour between tasks may be due to the very fact that the tasks themselves use different components, rather than to differences in how Cognitive Control is manifested. Without knowing how component task processes influence (or are influenced by) potential control processes, there is no way to separate the aspects of performance that arose out of those differing component processes, versus aspects of performance that arose out of Cognitive Control processes.

This problem is exacerbated by the findings of numerous fMRI studies that have found a wide degree of variability in brain activation patterns associated with differing tasks requiring Cognitive Control (e.g., Bush et al., 2000). The ACC, as outlined in the introduction, is thought to be the anatomical location of the "error detector" that is a central part of the Cognitive Control mechanism proposed by Botvinick et al. (2001). Even if multiple tasks produced fMRI data with overlapping activation in the ACC, however, it could still be argued that separate mechanisms in the same location were being utilized. This severely limits the utility of fMRI as a method for the investigation at hand.

What is needed here are two tasks that share virtually everything, except for the allocation of control in the tasks. If a set of tasks can be found that vary only in their task instructions (the instructions that speak to Cognitive Control), then differences in performance between the tasks can be greatly reduced. Therefore, the only cause of differences in task performance will be due to the differences in the interplay of component processes that arise out of the differing task instructions. Fortunately, the Size Congruity paradigm offers just such a set of tasks.

Experiment 2

The Size Congruity Paradigm

The Size Congruity effect refers to the impact that congruency between the physical (e.g., font size of Arabic numerals) and symbolic (numerical magnitude) dimensions of a numerical stimulus has on the time it takes to make a judgement about that stimulus. In numerous experiments with both adults and children it has been shown that the physical size of an Arabic numeral or number word affects the processing of relative magnitude (e.g., Ansari, Fugelsang, Dhital, & Venkatraman, 2006; Besner & Coltheart, 1979; Girelli, Lucangeli, & Butterworth, 2000; Henik & Tzelgov, 1982; Rubinsten, Henik, Berger, & Shahar-Shalev, 2002; Schwarz & Ischebeck, 2003). Typically, subjects are asked to identify which of two numbers is *numerically* larger, and to ignore the physical size in which the numbers are presented. The standard finding is that subjects are faster when the numerically larger numeral also appears in a larger font size (congruent trial) than when the numeral printed in the larger font size is numerically smaller (incongruent trial). Thus, there is significant interference on the judgement of *relative* numerical magnitude from the *irrelevant* physical size. Conversely, it has also been found that when subjects are asked to judge which of two stimuli is *physically* larger, there is interference from the *irrelevant* numerical magnitude (e.g., Schwarz & Ischebeck, 2003; Tzelgov, Meyer, & Henik, 1992). This impact of irrelevant numerical information on physical judgements is typically smaller than the impact of physical information on numerical judgements (e.g., Henik & Tzelgov, 1982; Schwarz & Ischebeck, 2003). Although previous work has indicated that both irrelevant numerical magnitude interferes with relative physical size judgements and, conversely, irrelevant physical size interferes with subjects' abilities to judge which of two numbers is numerically larger, the relative equivalence of these two types of interference effects has not been systematically assessed with a CP manipulation.

Because the proportion of congruent trials modulates the size of the interference effect in many cognitive domains, it can be used as a measure of the strength of particular effects of irrelevant (but conflicting) stimulus dimensions. In addition, given that CP is thought to index strategic control, according to Botvinick and colleagues (Botvinick et al., 2001), this manipulation offers a powerful method by which to test the relative strength of the interference effects in both directions, and the degree to which such control influences responding to that dimension (i.e., physical versus numerical dimension) of the stimuli. Against the background of the evidence for a stronger influence of physical size on numerical magnitude relative to numerical magnitude on physical size judgements, it is expected that the CP manipulation will have a larger influence in the Numerical Judgement task than the Physical Judgement task. Specifically, the Congruency x CP interaction will likely be larger in the Numerical Judgement task than in the Physical Judgement task. This is not to say that there will be no effect of CP on the Physical Judgement task. Due to the significant impact of the numerical dimension on physical judgements, a significant CP effect in the Physical Judgement task (although one that is relatively smaller than the CP effect for the Numerical Judgement task) should also be found.

Although some aspects of these tasks are difficult to compare (e.g., the equivalence of a unit of Symbolic Distance to a unit of Physical Distance), using an identical design with the only difference being the task instructions will provide useful insight into how these stimuli are processed. This should allow for the symbolic component (i.e., accessing semantics) of the Numerical Judgement task to be pitted against the more purely visual components of the Physical Judgement task.

An additional benefit of this methodology is that in the Numerical Judgement task, there exists a well understood delineation of the semantic space. As the Symbolic Distance increases between two numbers to be compared, the time it takes to make such a comparison decreases (Moyer & Landauer, 1967). For example, subjects are faster to say that 9 is larger than 1 than to say that 5 is larger than 1. If this Symbolic Distance effect is also influenced by a CP manipulation, then it would seem likely that there is overlap in the time course of the semantic activation of numerical information, and the control mechanism that gives rise to the CP manipulation. If, however, there is *no* interaction, then the opposite conclusion can be made, that there is no overlap in processes (Sternberg, 1969). There is little discussion of the interplay of semantic access and the role of Cognitive Control in most of the literature. As such, the logical prediction should be that a CP manipulation will have no impact on the Symbolic Distance effect.

Method

Participants

One hundred and eight undergraduates from the University of Waterloo participated in the experiment for course credit. Fifty-five students participated in the Numerical Judgement task, and 53 participated in the Physical Judgement task. All participants reported normal or corrected-to-normal vision.

Design

Each task (Numerical and Physical Judgements) contained stimuli that varied in terms of Congruency (Congruent vs. Incongruent), Symbolic Distance (2, 3, 4, 5, and 6 units) and CP (.25 congruent, .50 congruent, and .75 congruent). Stimuli consisted of the numerical digits 1, 2, 3, 5, 6, and 7 and were presented in Arial font sizes 58 (1.96° of visual angle) and 30 (1.06° of visual angle), with each of 1, 2, and 3 being presented in every possible combination with 5, 6 and 7 in both font sizes. Congruency and Symbolic Distance were within-subject variables and CP was a between-subjects variable. For the Numerical Judgement task, 19 subjects participated in the .25 CP condition, 18 subjects in the .50 CP condition, and 18 subjects in the .75 CP condition. For the Physical Judgement task, 17 subjects participated in the .25 CP condition, 17 subjects in the .50 CP condition, and 19 subjects in the .75 CP condition. Trials were considered *congruent* when the stimulus was both numerically larger and physically larger (e.g., 7 and 2), and *incongruent* when the target stimulus was numerically larger but physically smaller (e.g., 7 and 2).

Procedure

The stimuli were presented on a 17” colour monitor driven by a Pentium computer running E-Prime v1.1 software (Schneider et al., 2001). The targets consisted of two numerals presented to the left and right of a central fixation point (+). The physically large numeral was presented in font size 58 and the physically small numeral was presented in font size 30. Responses were collected using a standard QWERTY keyboard. Subjects used the “Q” and “P” keys to make their responses. Mapping of stimuli to responses was counterbalanced across subjects. The midpoint between the two response keys was aligned with the central fixation. Subjects were tested individually in a sound attenuated room. Instructions for the task were displayed visually and relayed verbally by the experimenter. Subjects were also requested to respond as quickly and accurately as possible.

Each trial began with the presentation of a fixation cross which was presented for a random duration of 600, 900, or 1200 ms. Subsequently, the numerals were presented and remained on the screen until a response was made. Twelve practice trials (with a CP of .50) were followed by 108 experimental trials. Trial order was determined randomly for each subject.

Results

Reaction Times

RT analysis was conducted for all trials in which the response was correct. RTs were submitted to a recursive data trimming procedure (Van Selst & Jolicoeur, 1994) using a 2.5 standard deviation cut-off in each cell resulting in 2.32% of the RT data being removed (subject mean RTs and % Error data are presented in Appendix B).

The alpha level for all statistical tests was set at .05 (two-tailed) unless otherwise stated. A 2 (Congruency: Congruent vs. Incongruent) x 5 (Symbolic Distance: 2, 3, 4, 5, and 6 units) x 3 (CP: .25, .50, and .75 congruent) x 2 (Task: Numerical Judgement vs. Physical Judgement) mixed ANOVA conducted on mean RTs (see Figure 6) revealed a main effect of Congruency, $F(1, 102) = 203.6$, $MSE = 1273$, $p < .001$, a main effect of Symbolic Distance, $F(4, 408) = 8.7$, $MSE = 672.4$, $p < .001$, and a main effect of Task, $F(1, 102) = 69.2$, $MSE = 47681$, $p < .001$. There was no main effect of CP ($F < 1$).

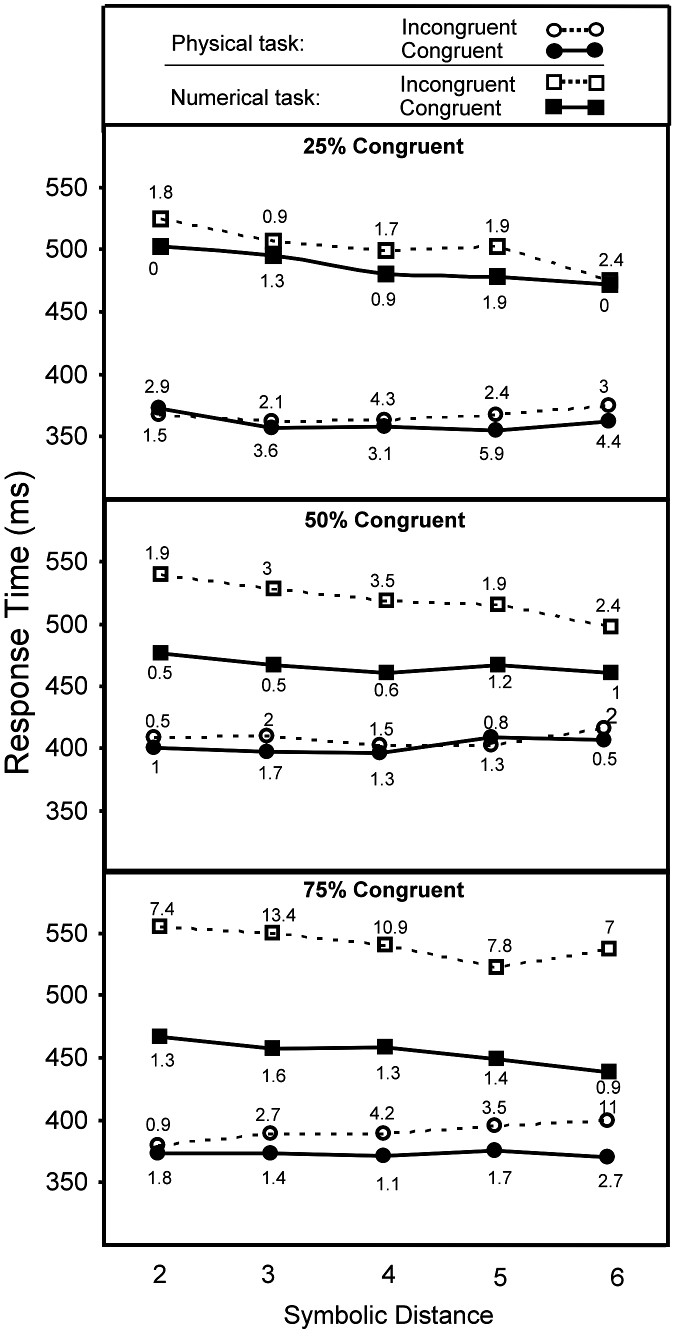

Figure 6. Mean RTs (ms) and percentage errors as a function of Judgement Task, Congruency Proportion, Congruency, and Symbolic Distance for Experiment 2 .

The analyses are now decomposed by focusing on two key aspects of the data: (1) interactions between Congruency, CP and Task, and (2) interactions with Symbolic Distance.

Congruency, congruency proportion and task. Most importantly, and in line with the predictions, there was a three-way interaction between Congruency, CP and Task, *F*(2, 102) = 15.7, *MSE* = 1273, $p < .001$. As is evident in Figure 6, the CP manipulation interacted unequally on the Congruency effect for the Numerical Judgement task, *F*(2, 52) = 29.4, *MSE* = 1977, $p < .001$, and the Physical Judgement Task *F*(2, 50) = 4.0, *MSE* = 540, $p < .05$. Specifically, the size congruency effect (incongruent – congruent) for the Numerical Judgement task increased from 16 ms in the .25 CP condition, to 53 ms in the .50 CP condition, to 87 ms in the .75 CP condition. For the Physical Judgement task, however, the congruency effect was 6 ms in both the .25 CP and .50 CP conditions, and increased to 18 ms in the .75 CP condition.

Consistent with prior research, Congruency and Task also interacted, *F*(1, 102) = 94.9, *MSE* = 1273, $p < .001$, in that the difference between congruent and incongruent trials was larger for the Numerical Judgement task (mean difference = 52 ms) than the Physical Judgement task (mean difference = 10 ms). In addition, the predicted two-way interaction between Congruency and CP was also significant, *F*(1, 102) = 30.8, *MSE* = 1273, $p < .001$, such that as the proportion of congruent trials increased, so too did the difference between RTs for congruent and incongruent trials.

Interactions with symbolic distance. With respect to interactions with Symbolic Distance, there was an interaction between the effect of Symbolic Distance and Task, *F*(4,

408) = 14.5, *MSE* = 841, $p < .001$, such that the Symbolic Distance effect in the Numerical Judgement task was larger than in the Physical Judgement task. A post hoc analysis examining the effect of Symbolic Distance for each Judgement task revealed a main effect of Symbolic Distance in the Numerical Judgement task *F*(4, 208) = 15.6, *MSE* = 969.3 $p < .001$, and a main effect of Symbolic Distance in the Physical Judgement task *F*(4, 200) = 2.8, *MSE* = 363.7 $p < .05$, but in the opposite direction, such that in the Physical Judgement task, as Symbolic Distance increased, so too did RT. No other main effects or interactions were significant (largest *F* = 1.5).

Errors

An analogous 2 (Congruency: Congruent vs. Incongruent) x 5 (Symbolic Distance: 2, 3, 4, 5, and 6 units) x 3 (CP: .25, .50, and .75 congruent) x 2 (Task: Numerical Judgement vs. Physical Judgement) mixed ANOVA was conducted on errors and revealed a significant four-way interaction, *F*(8, 408) = 2.3, *MSE* = 19.8, $p < .05$. Additionally, a main effect of Congruency, *F*(1, 102) = 30.7, *MSE* = 41.2, $p < .001$, a main effect of Symbolic Distance, *F*(4, 408) = 2.6, *MSE* = 21.5, $p < .05$, and a main effect of CP, *F*(1, 102) = 5.2, *MSE* = 133.2, $p < .01$ were observed. There was no main effect of Task ($F < 1$). The error analyses are further decomposed in a parallel fashion to the RT analyses.

Congruency, congruency proportion and task. As with the RT analyses, and central to the predictions, there was a three-way interaction between Congruency, CP and Task, *F*(2, 102) = 14.84, *MSE* = .003, $p < .001$. This interaction was of identical form to the RTs. Specifically, the CP manipulation interacted unequally on the Congruency effect for the Numerical Judgement task , *F*(2, 52) = 11.5, *MSE* = 58.8, $p < .001$, and the Physical

Judgement Task $F(2, 50) = 5.8$, $MSE = 23.0$, $p < .01$. Here, the size congruency effect (incongruent – congruent) for the Numerical Judgement task increased from 1% errors in the .25 CP condition, to 1.8% errors in the .50 CP condition, to 7.9% errors in the .75 CP condition whereas for the Physical Judgement task the congruency effect increased from -0.8% errors in the .25 CP condition, to 0.4% errors in the .50 CP condition, to 2.7% errors in the .75 CP condition.

Congruency and Task also interacted, $F(1, 102) = 12.9$, $MSE = 41$, $p < .01$, in that the difference between congruent and incongruent trials was larger for the Numerical Judgement task (mean difference = 3.5% errors) than the Physical Judgement task (mean difference = 0.8% errors). In addition, the predicted two-way interaction between Congruency and CP was also significant, $F(1, 102) = 17.0$, $MSE = 41$, $p < .001$, such that as the proportion of congruent trials increased, so too did the difference between errors for congruent and incongruent trials.

Interactions with symbolic distance. With respect to interactions with Symbolic Distance, there was a two-way interaction between Symbolic Distance and Task, $F(4, 408) = 2.9$, $MSE = 21.5$, $p < .05$, and a marginal interaction between Symbolic Distance and Congruency, $F(4, 408) = 2.0$, $MSE = 19.8$, $p = .09$. No other main effects or interactions were significant (largest $F = 1.70$).

Discussion

In summary, the most important of the above results is the clear asymmetry in the size of the congruency effect (and how the congruency effect is modulated by the CP manipulation) between the Numerical Judgement task and the Physical Judgement task.

Specifically, the effect of Congruency, and the Congruency by CP interaction was larger for the Numerical Judgement task, than the Physical Judgement task.

On the surface, these results challenge a unitary notion of control, as such a model should assume that control would be manifested (as a function of the manipulation of CP) to a similar degree for both variants of the task. It is possible, however, that the differential impact of CP could be a product of the ease with which each dimension of the tasks is processed, and not due to the differential impact of control per se. Indeed, there is a fair amount of evidence for this latter argument in the literature. For example, typically in size congruity experiments, the physical size judgement is faster than the numerical size judgement. As such, the effect of the irrelevant numerical magnitude on physical size judgements is correspondingly smaller than the effect of the irrelevant physical size on numerical magnitude judgements (e.g., Henik & Tzelgov, 1982; Schwarz & Ischebeck, 2003). Furthermore, developmental studies suggest that young children do not show an interference effect of numerical magnitude on physical size judgements, suggesting that the automatic activation of numerical magnitude during judgements of the physical size of numerical digits emerges gradually over developmental time (Rubinstein, Henik, Berger, & Shahar-Shalev, 2002; Girelli, Lucangeli, & Butterworth, 2000). As such, it could be the case that this very asymmetry in mean response time also leads to the asymmetry in the influence of the CP manipulation (i.e., we might find this asymmetry due to a scaling effect).

An additional factor that may have influenced the outcome of this experiment is the inclusion of five Symbolic Distances and only one Physical Distance. This could result in making the physical distance dimension more salient to participants, and thus easier. Although it is difficult to find a basis on which to equate Physical and Symbolic Distances, an effort was made to replicate the key findings of Experiment 2 with a more parametric design that included more Physical distances and fewer Symbolic distances (see Pansky & Algom (1999) for a discussion on the difficulties associated with equating these two dimensions). Therefore, Experiment 3 was conducted with these factors in mind. Specifically, the Physical Judgement task was made more difficult via the inclusion of three physical sizes, each closer in size than the original physical difference. Additionally, the number of Symbolic Distances was reduced from five distances to three distances. Experiment 3 should then provide a stricter test of the Congruency x CP x Task three-way interaction as both the mean speed of the tasks, and the number of levels of Physical and Symbolic Distance will be roughly equated.

Experiment 3

Method

Participants

Sixty-nine undergraduate students with normal or corrected-to-normal vision from the University of Waterloo participated for course credit.

Design

Each task (Numerical and Physical Judgement) contained stimuli that varied in terms of Congruency (Congruent vs. Incongruent), Symbolic Distance (1, 3, and 5 units) and CP (.25 vs. .75 congruent). Stimuli consisted of the numerical digits 1 through 9 inclusive, presented in Arial font sizes 44 (1.47° of visual angle), 54 (1.88° of visual angle), and 64 (2.21° of visual angle) with each numeral being presented in every possible combination of congruency and font size. CP was manipulated by presenting proportionately more (.25 or .75) congruent trials from the stimulus set while maintaining an equal number of trials at each of the three distances for both tasks. Therefore, trial composition was identical for the Numerical and Physical Judgement task and was invariant across CP.

Congruency and Symbolic Distance were within-subject variables, and CP and Judgement task were between-subjects variables. For the Numerical Judgement task, 17 subjects participated in the .25 CP condition and 17 subjects in the .75 CP condition. For the Physical Judgement task, 16 subjects participated in the .25 CP condition, and 19 subjects participated in the .75 CP condition. Trials were considered *congruent* when the stimulus was both numerically and physically larger (e.g., 7 and 2), and *incongruent* when the target stimulus was numerically larger but physically smaller (e.g., 7 and 2).

Procedure

The stimuli were presented on a 17” colour monitor driven by a Pentium computer running E-Prime v1.1 software (Schneider et al., 2001). The targets consisted of two numerals presented to the right and left of a central fixation point (+). The physically large numeral was presented in font size 64 or 54 and the physically small numeral was presented in font size 54 or 44. Responses were collected using a standard QWERTY keyboard. Subjects used the “Q” and “P” keys to make their responses. Mapping of stimuli to responses was counterbalanced across subjects. The midpoint between the two response keys was aligned with the central fixation. Subjects were tested individually in a sound attenuated room. Instructions for the task were displayed visually and relayed verbally by the experimenter. Subjects were also requested to respond as quickly and accurately as possible.

Each trial began with the presentation of a fixation point that was presented for 900 ms. Subsequently, the target numerals were presented and remained on the screen until a response was made. Twelve practice trials with a CP of .50 were followed by 576 experimental trials. Trial order was determined randomly for each subject.

Results

Reaction Times

RT analysis was conducted for all trials in which the response was correct. RTs were submitted to a recursive data trimming procedure (Van Selst & Jolicoeur, 1994) using a 2.5 standard deviation cut-off in each cell resulting in 3.8% of the RT data being removed. The alpha level for all statistical tests was set at .05 (two-tailed) unless otherwise stated (subject mean RTs and % Error data are presented in Appendix C).

A 2 (Congruency: Congruent vs. Incongruent) x 3 (Symbolic Distance: 1, 3, and 5) x 2 (CP: .25 vs. .75 congruent) x 2 (Task: Numerical vs. Physical Judgement) mixed ANOVA was conducted on mean RTs (see Figure 7), revealing a significant four-way interaction, $F(2, 130) = 6.32$, $MSE = 436$, $p < .01$. In parallel fashion to Experiment 2, the analyses will be decomposed by focusing on two key aspects of the data: (1) interactions between Congruency, CP and Task, and (2) interactions with Symbolic Distance.

Congruency, congruency proportion and task. Most important given our predictions, there was a three-way interaction between Congruency, CP and Task, $F(1, 65) = 4.85$, $MSE = 2628$, $p < .005$. As is evident in Figure 7, the CP manipulation had a significant impact on the Congruency effect for the Numerical Judgement task, $F(1, 32) = 28.88$, $MSE = 463$, $p < .001$, <u>but not</u> the Physical Judgement Task *($F < 1$).* Specifically, the size congruency effect (incongruent – congruent) for the Numerical Judgement task increased from 35 ms in the .25 CP condition, to 91 ms in the .75 CP condition, whereas for the Physical Judgement task the congruency effect remained statistically equivalent (37 ms in the .25 CP condition, and 49 ms in the .75 CP condition).

Consistent with prior research, Congruency and Task also interacted, $F(1, 65) = 4.0$, $MSE = 2628$, $p < .05$, in that the difference between congruent and incongruent trials was larger for the Numerical Judgement task (mean difference = 63 ms) than the Physical Judgement task (mean difference = 43 ms). In addition, the predicted two-way interaction between Congruency and CP was also significant, $F(1, 65) = 11.23$, $MSE = 2628$, $p <$

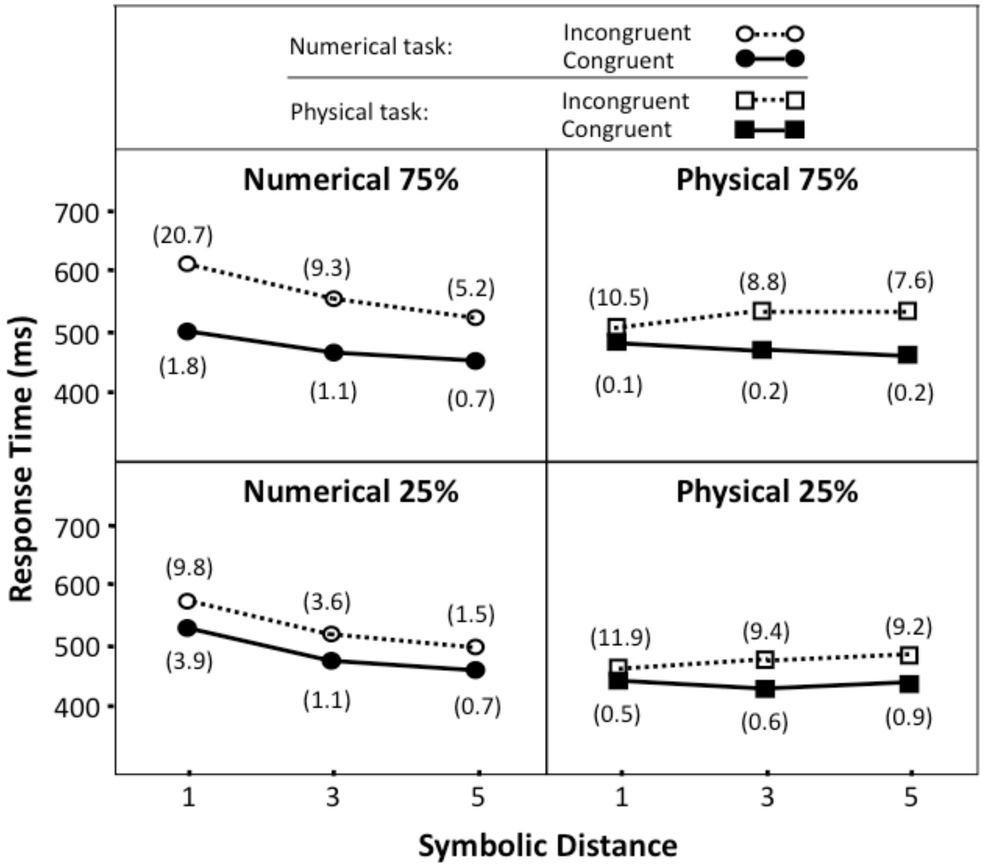

Figure 7. Mean RTs (ms) and percentage errors as a function of Judgement Task, Congruency Proportion, Congruency, and Symbolic Distance for Experiment 3.

.01, such that as the proportion of congruent trials increased, so too did the difference between RTs for congruent and incongruent trials.

Interactions with symbolic distance. With respect to interactions with Symbolic Distance, there was a three-way interaction between Symbolic Distance, Congruency and Task, *F*(2, 130) = 20.0, *MSE* = 436, *p* < .001. This three-way interaction was the product of two Symbolic Distance by Congruency interactions that take opposite forms in each Task. Specifically, for the Numerical Judgement task, as Symbolic Distance *increased*, the size of the congruency effect got *smaller*, *F*(2, 64) = 6.50, *MSE* = 400, *p* < .01, whereas for the Physical Judgement task, as the Symbolic Distance *increased*, the size of the congruency effect got *larger*, *F*(2, 66) = 14.22, *MSE* = 471, *p* < .001.

There was also a two-way interaction between Symbolic Distance and Task, *F*(2, 130) = 89.40, *MSE* = 654, *p* < .001, as well as main effects of Congruency, *F*(1, 65) = 109.37, *MSE* = 2628, *p* < .001, Symbolic Distance, *F*(2, 130) = 70.10, *MSE* = 654.10, *p* < .001, and Task, *F*(1, 65) = 6.54, *MSE* = 36825, *p* < .05[1]. No other main effects or interactions were significant (largest *F* = 1.28).

Errors

An analogous 2 (Congruency: Congruent vs. Incongruent) x 3 (Symbolic Distance: 1, 3, and 5) x 2 (CP: .25 vs. .75 congruent) x 2 (Task: Numerical vs. Physical Judgement) mixed ANOVA on errors revealed a significant four-way interaction, *F*(2, 130) = 6.67,

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[1] It should be noted that the baseline Physical and Numerical judgements were virtually identical despite the main effect of Task. That is, due to the differential interactions of Task with Congruency, Congruency Proportion and Distance, a main effect of Task is to be expected as the differences in slopes increase the marginal Task means. If we directly compare the congruent conditions at the medium distance (arguably the best approximation of a baseline for this experiment), performance on the two Tasks are not significantly different (mean difference = 14ms), *t*(67) = .929, *p* =.356.

MSE = .001, *p* < .01. The analysis is now decomposed in a parallel fashion to the RT analyses.

Congruency, congruency proportion and task. As with the RT analyses, and central to the predictions, there was a three-way interaction between Congruency, CP and Task, *F*(1, 65) = 14.84, *MSE* = .003, *p* < .001. This interaction was of identical form to the RTs. Specifically, the CP manipulation had a significant impact on the Congruency effect for the Numerical Judgement task, *F*(1, 32) = 16.10, *MSE* = .004, *p* < .001, but not the Physical Judgement task *(F < 1).*

Congruency and Task also interacted, *F*(1, 65) = 5.11, *MSE* = .003, *p* < .05. Here, however, the difference between congruent and incongruent trials was slightly larger for the Physical Judgement task (mean difference = 9.2%) than the Numerical Judgement task (mean difference = 7.0%). In addition, the predicted two-way interaction between Congruency and CP was also significant, *F*(1, 65) = 10.434, *MSE* = .003, *p* < .01, such that as the proportion of congruent trials increased, so too did the difference between errors for congruent and incongruent trials.

Interactions with symbolic distance. With respect to interactions with Symbolic Distance, there was a three-way interaction between Symbolic Distance, Congruency and Task, *F* (2, 130) = 12.40, *MSE* = .001, *p* < .001. This three-way interaction was the product of two Symbolic Distance by Congruency interactions that were of different magnitudes in each Task. Specifically, consistent with the RT analyses for the Numerical Judgement task, as Symbolic Distance *increased*, the size of the congruency effect got *smaller*. Unlike the RT analyses, however, for the Physical Judgement task, as Symbolic

Distance *increased*, the size of the congruency effect also got *smaller*, just to a significantly lesser degree, $F(2, 66) = 5.20$, $MSE = .001$, $p < .01$. There was also a three-way interaction between Symbolic Distance, Congruency and Congruency Proportion, $F(2, 130) = 5.75$, $MSE = .001$, $p < .005$. Here, the modulation of the congruency effect by Symbolic Distance was moderately smaller for the .25 CP condition than the .75 CP condition.

There were also two-way interactions between Symbolic Distance and Task, $F(2, 130) = 30.52$, $MSE = .001$, $p < .001$, Symbolic Distance and Congruency, $F(2, 130) = 44.43$, $MSE = .001$, $p < .001$, as well as main effects of Congruency, $F(1, 65) = 227.57$, $MSE = .003$, $p < .001$, and Symbolic Distance, $F(2, 130) = 62.98$, $MSE = .001$, $p < .001$. No other main effects or interactions were significant (largest $F = 1.70$).

Discussion

The most important of the above results is that, as in Experiment 2, there is a clear asymmetry in the size of the congruency effect (and how the congruency effect is modulated by the CP manipulation) between the Numerical Judgement task and the Physical Judgement task. Despite relatively equal baseline responses for the two judgement tasks (refer to footnote 1), the effect of Congruency, and the Congruency by CP interaction was larger for the Numerical Judgement task, than the Physical Judgement task.

This finding of an asymmetry in CP effects could be indicative of the relative fluency of the two dimensions at play in these tasks. Schwarz and Ischebeck's (2003) relative speed account of the size congruity effect, while not making any predictions about CP manipulations, provides a framework for understanding these results. The Physical

Judgement task is based upon purely physical characteristics of the stimuli. By contrast, judging the numerical symbols requires the activation of a semantic representation in order for the Numerical Judgement to be made. As the Physical Judgement can be performed faster than the Numerical Judgement, the expected result is that the physical size of the stimuli interferes more with the judging the numerical size than vice versa. Thus, the physical characteristics of the stimulus have a larger impact on numerical judgements than the semantic characteristics of the stimulus have on physical judgements. This interpretation is also consistent with developmental studies of young children in which the activation of numerical magnitude during judgements of the physical size of numerical symbols emerges gradually (Rubinstein et al., 2002; Girelli et al., 2000). The data from Experiment 3, however, do not fit as neatly with Schwarz and Ischebeck's (2003) relative speed account: despite the mean response time for the Numerical and Physical Judgement tasks being similar, we still find a significant difference in the influence of the CP manipulation between tasks.

Can these findings be reconciled with contemporary models of Cognitive Control? Given Botvinick et al.'s (2001) explanation of CP effects, to explain these results, it is first necessary to posit that the physical dimension of the stimulus is processed faster and more "automatically" (earlier, more fluently) compared to the symbolic (i.e., numerical) dimension. It would then be this difference in processing fluency that subsequently impacts task performance: the physical dimension is amplified *more* by a CP manipulation than the impact made by the numerical dimension. Thus, we could expect a larger impact on the Size Congruity effect from the irrelevant physical size dimension in the Numerical

Judgement task than from the irrelevant numerical size dimension in the Physical Judgement task. This asymmetry in CP effects then could also be seen as an indication of the relative automaticity or fluency of the relevant dimensions of the stimuli used (even when the tasks are equated on relative difficulty). Here, it is important to note that to accept this view, one must also accept the idea that processing different dimensions of a stimulus (e.g., processing the Physical or Symbolic dimensions) can be achieved with different efficiency and speed despite being equated on a behavioural response (e.g., responding to the Physical or Symbolic dimension).

Alternatively, and perhaps more parsimoniously, it could be argued simply that differences between the Numerical and Physical Judgement task arise solely due to task instructions. In terms of control, as conceptualized by Braver et al (2007): the task demands would require a different emphasis of Proactive Control. As such, instructions prompting an emphasis on different stimuli dimensions would mean a unique interplay between those task demands and the strictly stimulus based Reactive Control to the conflict found in the stimuli list. By this way of thinking then, every task should produce a unique strategic control effect or CP effect. This idea will be flushed out in more detail in the General Discussion.

Another interesting finding of note from Experiments 2 and 3, is that in the Numerical Judgement task, Symbolic Distance is additive with the CP effect. This is a novel and interesting finding. It suggests that the component process(es) associated with Symbolic Distance are completed in entirety prior to, or begin after the completion of, the impact of Cognitive Control. According to additive factors logic (as outlined by Sternberg,

1969) if the effects of two processes are additive with each other, it means that one of those processes must be completed before the other one begins. Alternatively, if the effects of two processes interact, it means that one of those processes can begin before the other one is completed. Given the additive pattern observed here, although we cannot say which process occurs first, we can clearly conclude that whichever process does occur first, it is completed in its entirety before the other one begins.

There is a great deal of appeal to the idea that semantic processing occurs first and then subsequently the processes that give rise to the CP effect are engaged. This explanation would certainly fit with the current trends in popular theory. If, however, the CP effect has a much earlier locus than the popular accounts state, the additivity found here is perfectly consistent with the idea of the CP effect running to completion before semantic access. What would be quite useful, then, is to disentangle these two possibilities with further experimentation on the nature of the CP effect.

Chapter 4: Experiment 4

The purpose of Experiment 4 is three fold. The primary goal is to evaluate the extent to which there is consistency (in the form of correlations in the size of the effects measured) in the application of Cognitive Control across multiple conflict tasks. For this reason, three tasks are included: the Numerical Judgement variant of the Size Congruity task, the Physical Judgement variant of the Size Congruity task, and the Stroop task. If there is consistency found between tasks, presumably due to those tasks sharing resources/processes, it could be due to the role of a unitary Cognitive Control module, or due to other shared processes. That is, any correlation found may be due to the similar component processes engaged in the task prior to Cognitive Control: the same visual stimuli are used in the Numerical and Physical Judgement tasks. Alternatively, it may be the case that the extent to which Cognitive Control is engaged will lead to a cross-task correlation: the Numerical Judgement task, and the Stroop task both require the subject to make a judgement about the less fluent dimension of the stimuli (physical size/word), while ignoring the more fluent dimension (semantic meaning of stimuli). These three tasks then allow me to more easily interoperate a pattern of cross task correlations in which the Numerical Judgement task correlates with either the Physical Judgement task *or* the Stroop task.

Related to the primary purpose is the second goal, which is to evaluate the extent to which the effects measured in these three computer tasks are related to existing scales of cognitive engagement. Two scales, the Cognitive Failures Questionnaire (CFQ), which is a measure of attentional slips (Broadbent, Cooper, FitzGerald & Parkes, 1982), and the

Need for Cognition Scale (NFC), which is a measure of the extent to which subjects willingly engage in effortful mental activities (Cacioppo, Petty, Feinstein, & Jarvis, 1996) will be used. Both of theses scales (although perhaps in different ways) can be thought of as capturing individual differences in a construct of Cognitive Control more similar to earlier conceptions, or to how Braver et al. (2007) have conceptualized Proactive Control. The question is: does the size of Congruity effects from any of the three computer tasks, or the difference of difference scores (the Congruity effect at a CP of .75 – the Congruity effect at a CP of .25) correlate with either of these measures? If so, then earlier conceptions of Cognitive Control, or to how Braver et al. (2007) have conceptualized Proactive Control, is what is being captured in these conflict tasks. If, however, these two measures do not correlate with any of the tasks, or the higher-order difference scores, then it is more likely that these tasks are reflecting the more recent conceptualization of "strategic control" or Reactive Control.

The third purpose of Experiment 4 is to replicate and extend the findings of Experiment 2 and Experiment 3 using a completely within-subjects design. Specifically, this experiment provides a very powerful method to explore the complicated pattern of interactions between the Judgement tasks, Congruency Proportion, and Symbolic Distance observed in Experiments 2 and 3 within the same participants.

Assessing Reliability using Difference Scores

In Experiment 4, I assess reliability by correlating the Stroop effect and Size Congruity effect across two different points in time (e.g., Borgmann et al., 2007; Stolz et al., 2005). Difference scores from the different tasks (representing the magnitude of the

Congruency and CP effects in each task) will be directly compared. It should be noted here, that some researchers (e.g., Williams & Zimmerman, 1996) have pointed out that correlating difference scores can be problematic. This is due to the fact that difference scores are made up of other scores which themselves may be unreliable. Here, the argument is that any results from a difference score analysis may be artifactual and due to the inherent unreliability of the underlying component scores. Specifically, when correlating difference scores, the absence of reliability may indeed indicate low reliability. However, it may also indicate an inability to detect reliability that is actually present (Williams & Zimmerman, 1996).

I address these concerns in the present investigation in two ways. Firstly, I do so by assessing the reliability of the Stroop and Size Congruity effects as a function of another variable (i.e., Congruency Proportion). Here, I can focus on changes in reliability as a point of interest rather than the presence or absence of reliability per se. For example, if the Stroop effect is reliable when CP is high but not when CP is low, it is difficult to argue that the lack of reliability in the latter case was due to an inability to detect a correlation when correlating difference scores. Secondly, I measure the reliability of the component scores used in generating the difference scores, thus eliminating concerns of unreliable component scores.

The method of comparing reliabilities and correlations is unusual in Cognitive Psychology. It is, however, a clear, and as outlined above, valid way to investigate consistency in processing. As stated above: if the CP manipulation elicits a response from a unitary attentional adjustment mechanism we would expect to see a pattern of behaviour that would indicate a common influence. If the CP manipulation elicits a response from a more complex set of mechanisms, there may be little consistency in CP effects across tasks. This should be borne out in the consistency of the size of the task effects as measured by reliabilities and inter-correlations (both within and across tasks).

Size Congruity, Stroop, and Reliability

In order to accomplish these goals, the Size Congruity paradigm as used in Experiments 2 and 3 will be used. Although the results of Experiments 2 and 3 are quite clear, the Size Congruity paradigm is not one of the most well understood paradigms in Cognitive Psychology, especially pertaining to the role of Cognitive Control in the task. If the goal is to contrast the results and size of effects across a number of different tasks, it seems necessary to include a task, which is both popularly understood, and can serve as a "baseline", or at the very least an understood reference point. To this end, a simple four choice manual Stroop task will be used.

As outlined earlier, the Stroop effect is robust, and some believe it to be a hallmark index of automaticity (Reisberg, 1997). Contrary to Reisberg's view, word recognition in the context of the Stroop task appears open to some form of "control". This is typically demonstrated by varying the utility of the irrelevant colour word via changing the proportion of congruent trials. When the proportion of congruent trials increases, the magnitude of the Stroop effect increases (Logan & Zbrodoff, 1979; Logan, Zbrodoff & Williamson, 1984; Lowe & Mitterer, 1982). This is hypothesized to result from the strategic or controlled use of the colour word as a function of its utility in predicting the colour (but see Risko, Blais, Stolz & Besner, 2008, Schmidt et. al. 2007, Schmidt &

Besner, 2008). Thus, the Stroop effect can be viewed parsimoniously as emerging from interplay of automatic and controlled processes.

It is key to note here that the Stroop effect is considered very widely to be *the gold standard* for investigating "strategic", "cognitive", or any other of a wide variety of controlled processing. It is the task upon which the Botvinick, Cohen and colleagues models are built, and is one of the most (if not the most) studied phenomenon in cognitive research. It has been used as a foundation in a huge variety of research programs with well in excess of 10,000 publications making use of some variant of the task.

By investigating the reliability of the Stroop effect as a function of CP, I can assess the relative contribution of "automatic" and "controlled" processes to reliability. Although there have been no explicit claims about the relative reliability of "automatic" and "controlled" processes, our working hypothesis is that "automatic" processes should yield reliability whereas "controlled" processes should be less likely to do so. In the context of the Stroop task, Botvinick et al. (2001) have suggested that as the proportion of congruent trials is increased, the amount of control is reduced. If "automatic" processes are reliable, we would therefore expect to find that reliability increases as the proportion of congruent trials increases.

This prediction is in line with results of Borgmann et al. (2007), who reported that the magnitude of the Simon effect increased with increases in the proportion of congruent trials. Interestingly, when the proportion of congruent trials was .25 and a reverse Simon effect was observed (i.e., incongruent trials responded to faster than congruent trials) this effect was unreliable. This lack of reliability was contrasted with highly reliable Simon effects in both a .50 and .75 congruent condition.

In addition, previous work using the list method in Stroop has found substantial reliability in a low CP condition, whereas Borgmann et al. (2007) found no reliability in a low CP version of the Simon effect. Given these results it seems prudent to re-assess the reliability of the Stroop effect in its now dominant form (i.e., with a discrete trial procedure) as a function of CP. As the prior assessed list method utilizes a blocked design, it is possible that previous findings of reliability have arisen due to reliability in processing the same trial type repeatedly in sequence. Put another way, perhaps previous findings of reliability of the Stoop effect at low CPs is due to the consistency of processes utilized going from one trial to the next. By contrast, the discrete trial procedure is likely a better index of the underlying processes, as the trial sequence is random and trial sequence effects can be limited. Indeed, the repetition of trial types has been shown to have an impact on the size of an effect, and removing complete repetitions can be thought of as a more pure measure of interference free from trial sequence effects (e.g., Risko, Blais, Stolz, & Besner, 2008).

The oversight of assessing reliability in common cognitive tasks is not just limited to the Stroop task. Reliability is standardly viewed as a fundamental psychometric property that needs to be determined in the measurement of any theoretically important psychological construct (e.g., semantic activation). In Cognitive Psychology, however, empirically assessing the reliability of phenomena used to index these constructs is the exception rather than the rule. This oversight is interesting in light of the fact that in some of the studies that have assessed reliability, the results have been less than encouraging.

Reliability is not found consistently in what many consider to be robust phenomena (e.g., Simon effect: Borgmann et al., 2007; Semantic Priming: Stolz et al., 2005; Symbolic Distance Effect: Maloney, Risko, Preston, Ansari, & Fugelsang, 2010).

This suggests that a concerted effort should be made to determine which phenomena are (or are not) reliable and which factors might affect this reliability. In the present investigation we assess the reliability of the Stroop and the Size Congruity effects as a function of the proportion of congruent trials. Previous work on the reliability of the Stroop effect has found it to be highly reliable (Santos & Montgomery, 1962; Jensen, 1965; Sjoberg, 1969; Uechi, 1972; Smith & Nyman, 1974; and Schubo & Hentschel, 1978). As noted above; however, these findings are limited to the list method presentation, a methodology that is now largely extinct. There are a few studies using the modern discrete trial method in which the reliability of the Stroop effect has been assessed, and perhaps surprisingly to many, the reliability was modest (Siegrist, 1995; Strauss, Allen, Jorgensen, & Cramer, 2005). In the present experiment, I assessed the Stroop effect using the contemporary discrete trials version. Where this work is unique is that it assesses this reliability across multiple levels of CP.

In the case of the Size Congruity paradigm, reliability has yet to be determined. It would perhaps come as a surprise for many researchers and may compromise their work if it were found that the Numerical Judgement and/or the Physical Judgement version of this paradigm did not yield reliable data. Here, as in the Stroop task, I will assess reliability across two levels of CP for both versions of the Size Congruity paradigm.

Size Congruity, Stroop, and Cross Task Correlations

Whatever the reliabilities are found to be in the tasks, another level of analysis becomes pertinent to the question of Cognitive Control. Rarely are cognitive paradigms directly compared to each other. Because of the differing components involved in different cognitive paradigms, it could be argued that many of these tasks have little in common with each other, utilizing different underlying processes. This would mean there is little reason to study the overlap between cognitive tasks with a reliability measure, as after the commonalities have been subtracted out, there would be no shared processes. One clear exception to this of course, is the process of Cognitive Control, which is widely believed to be active in many if not all of the popular cognitive paradigms. If Cognitive Control is common to, and operates similarly across, different cognitive paradigms, then it should be expected that cross task reliability should be found to at least some extent.

Additionally, assessing the relative differences between-subjects in the amount of control they exhibit in cognitive tasks can be informative (Kane & Engle, 2003). For example, a subject with little Cognitive Control should have trouble modulating the influence of the irrelevant Arabic numeral in the Numerical Judgement variant of the Size Congruity task to the same extent that they have trouble modulating the influence of the irrelevant word dimension in the Stroop task. Between task consistencies should become apparent to the extent that Cognitive Control is a shared resource between these tasks.

In summary then, there should be a clear pattern of results from Experiment 4; the within-subjects design and large number of subjects should provide an ideal setting to investigate the nature of Cognitive Control. If Cognitive Control is a central phenomenon common to the resolution of conflict in a wide variety of tasks, there should be a high degree of inter-correlation between the 3 tasks. In addition, and critical to the present thesis, there should also be significant inter-correlations between the the CP change scores (the .75 CP condition - the .25 CP condition) for each task, and the 2 measures of cognitive engagement (i.e., the CFQ and NFC). Finally, there should be a high degree of inter-correlation between different levels of CP in the same task (e.g., Stroop at .25 and Stroop at .75 should correlate at least somewhat) as those two measures share many task relevant processes (e.g., name prink colours).

The received view would suggest there should be reliability found at each level of CP, though as seen in previous work, reliability should increase with CP. Whereas the above pattern of results may be what is expected by the received view of Cognitive Control, it has been until now an empirical question. If a different pattern of results is observed, an updated theory of Cognitive Control as it relates to CP will be needed.

Experiment 4

Method

Participants

Ninety-eight undergraduate students with normal or corrected-to-normal vision from the University of Waterloo participated for course credit.

General Design

Three computer tasks were administered to each subject that participated: The Stroop task, the Numerical Judgement variant of the Size Congruity paradigm, and the Physical Judgement variant of the Size Congruity paradigm. Two paper and pencil tasks were also administered: The Cognitive Failures Questionnaire (CFQ) and the Need for Cognition Scale (NFC). Order always consisted of the two paper and pencil tests being administered first, themselves counterbalanced in order, followed by the computer tasks. The order of the three computer tasks was counterbalanced, with each task containing 4 blocks of trials that were presented in random order: Two of the blocks of trials had a CP of .25 and two blocks of trials had a CP of .75.

The Size Congruity Paradigm

Design. Each task (Numerical and Physical Judgement tasks) contained stimuli that varied in terms of Congruency (Congruent vs. Incongruent), Symbolic Distance (2, 4, 5, and 6 units) and CP (.25 congruent vs. .75 congruent). Stimuli consisted of the numerical digits 1, 2, 3, 5, 6, and 7, and were presented in Arial font sizes 58 (1.96° of visual angle) and 30 (1.06° of visual angle), with each of 1, 2, and 3 being presented in every possible combination with 5, 6 and 7 in both font sizes. Congruency, Symbolic Distance and CP were all within-subject variables. Trials were considered *congruent* when the stimulus was both numerically larger and physically larger (e.g., 7 and 2), and *incongruent* when the target stimulus was numerically larger but physically smaller (e.g., 7 and 2).

Procedure. The stimuli were presented on a 17" colour monitor driven by a Pentium computer running E-Prime v1.1 software (Schneider et al., 2001). The targets consisted of two numerals presented to the right and left of a central fixation point (+). The physically large numeral was presented in font size 58 and the physically small numeral was presented in font size 30. Responses were collected using a standard QWERTY keyboard. Subjects used the "Q" and "P" keys to make their responses. Mapping of stimuli to responses was counterbalanced across subjects. The midpoint between the two response keys was aligned with the central fixation. Subjects were tested individually in a sound attenuated room. Instructions for the task were displayed visually and relayed verbally by the experimenter. Subjects were also requested to respond as quickly and accurately as possible.

Each trial began with the presentation of a fixation cross which was presented for a duration of 900 ms. Subsequently, the numerals were presented and remained on the screen until a response was made. Twenty-eight practice trials (with a CP of .50) were followed by four blocks of 56 experimental trials. Trial order was determined randomly for each subject.

The Stroop Task

Design. The task consisted of trials in which the stimuli varied in terms of Congruency (Congruent vs. Incongruent) and CP (.25 vs. .75 congruent). The stimuli consisted of four words, red, blue, yellow, and green, presented in one of four colours: red, blue, yellow, and green. Congruency and CP were within-subject variables. Trials were considered "congruent" if the colour was the same as the word and "incongruent" if the colour was different from the word.

Procedure. The stimuli were presented on a 17" colour monitor driven by a Pentium computer running E-Prime v1.1 software (Schneider et al., 2001). Responses were collected using a standard QWERTY keyboard. Subjects used the “A”, “S”, “K” and “L” keys to respond to the colours red, blue, yellow, and green respectively.

Subjects were tested individually in a sound attenuated room. Instructions for the task were displayed visually, and relayed verbally by the experimenter. Subjects were told to identify the colour of the word as quickly and accurately as possible by pressing one of the keys on the keyboard.

Each trial began with the presentation of a fixation cross for 500 ms, followed by a coloured word. The target remained on the screen until a response was made. This was followed by an inter-trial interval of 1000 ms. Sixteen practice trials (with a CP of .50) were followed by four blocks of 48 experimental trials. Trial order was determined randomly for each subject.

Results

Reaction Times

RT analysis was conducted for all trials in which the response was correct. RTs were submitted to a recursive data trimming procedure (Van Selst & Jolicoeur, 1994) using a 2.5 standard deviation cut-off in each cell resulting in 3.2% of the RT data being removed. The alpha level for all statistical tests was set at .05 (two-tailed) unless otherwise stated (subject mean RTs and % Error data are presented in Appendix D).

Due to the complexity of the design and the many factors included, the analyses for this experiment are sub-divided into three separate sections: (1) the main Task effects and interactions examining the effect of CP and Congruency in the three Tasks (see Figures 8, 9, and 10), (2) an in-depth analysis of the Size Congruity paradigm on its own, and (3) the reliabilities and correlations within and between the 3 Tasks (see Tables 1 and 2).

Main Effects, RTs and Errors

A 3 (Task) x 2 (CP) x 2 (Congruency) ANOVA on the RT data revealed a main effect of Task, $F(2, 194) = 503$, $MSE = 29287$, $p < .001$, a main effect of CP, $F(1, 97) = 5.39$, $MSE = 3461$, $p < .05$, and a main effect of Congruency, $F(1, 97) = 333$, $MSE = 5732$, $p < .001$. In all three tasks, there was a Congruency effect such that Incongruent trials were slower than Congruent trials. Furthermore, in all 3 Tasks, the Congruency effect was smaller in the .25 CP condition than the .75 CP condition, as evidenced by the overall CP x Congruency interaction, $F(1, 97) = 130.7$, $MSE = 2374$, $p < .001$. Additionally, the Task x Congruency, $F(2, 194) = 86.5$, $MSE = 44197$, $p < .001$, and the Task x CP x Congruency interactions, $F(2, 194) = 14.4$, $MSE = 2157$, $p < .001$, were all significant. Here, the size of the Congruency effect was largest in the Stroop task, next largest in the Numerical Judgement task, and smallest in the Physical Judgement task. Furthermore, the magnitude of the CP by Congruency interaction was largest in the Stroop task, next largest in the Numerical Judgement task, and smallest in the Physical Judgement task. The Task x CP interaction, $F(2, 194) = 1.76$, $MSE = 3300$, $p = .18$, was the only interaction that was *not*

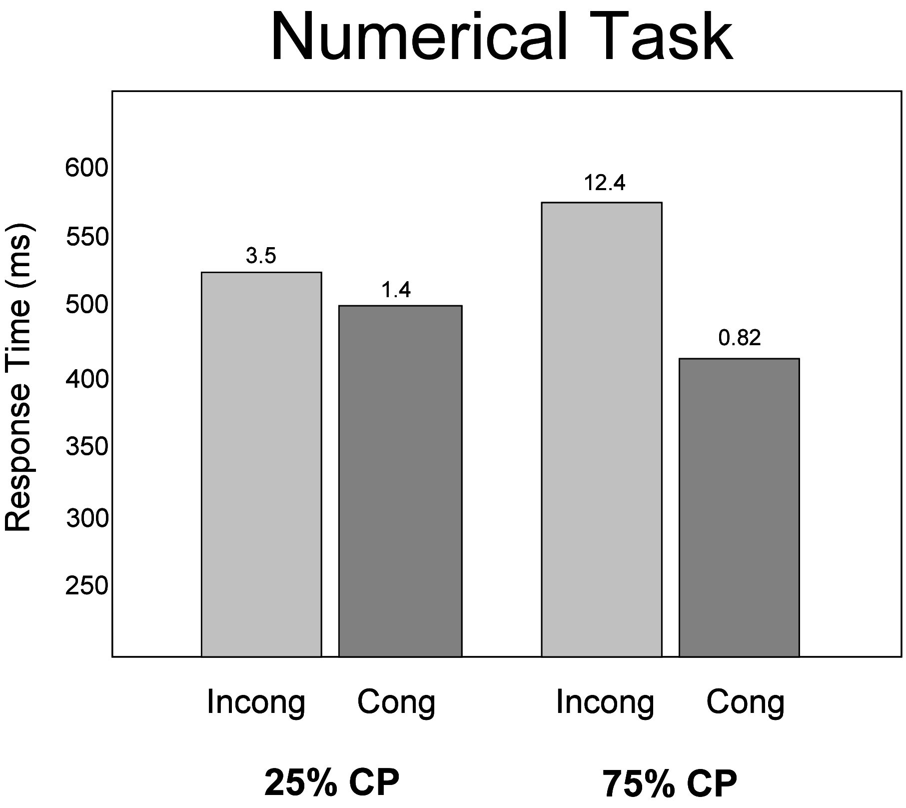

Figure 8. Mean RTs and percentage error data as a function of Congruency and CP for the Numerical Judgement Task for Experiment 4.

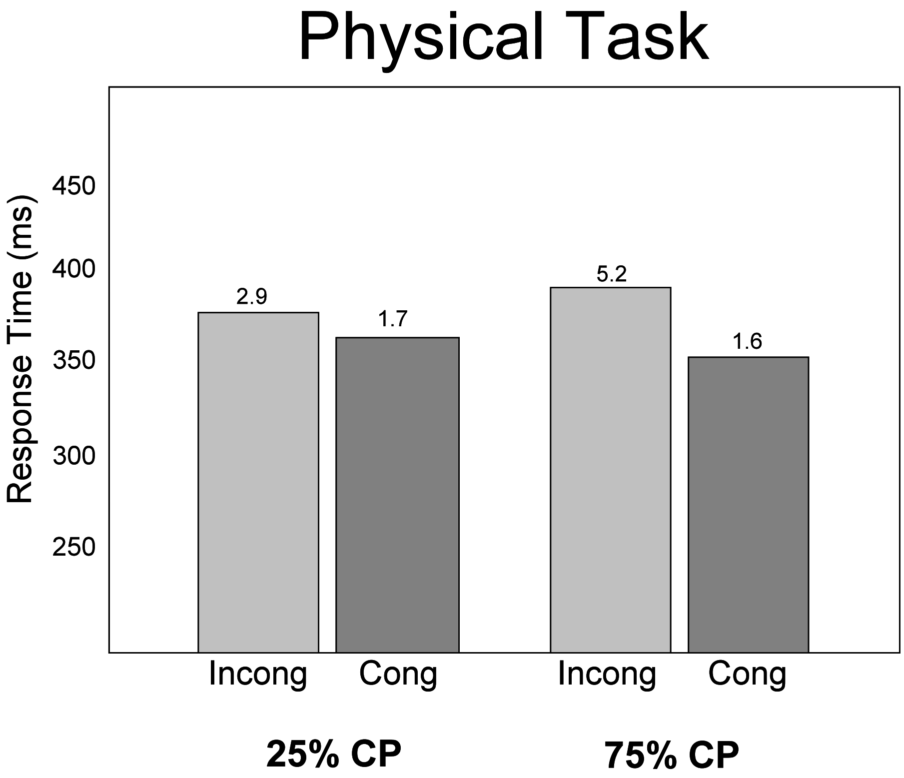

Figure 9. Mean RTs and percentage error data as a function of Congruency and CP for the Physical Judgement Task for Experiment 4.

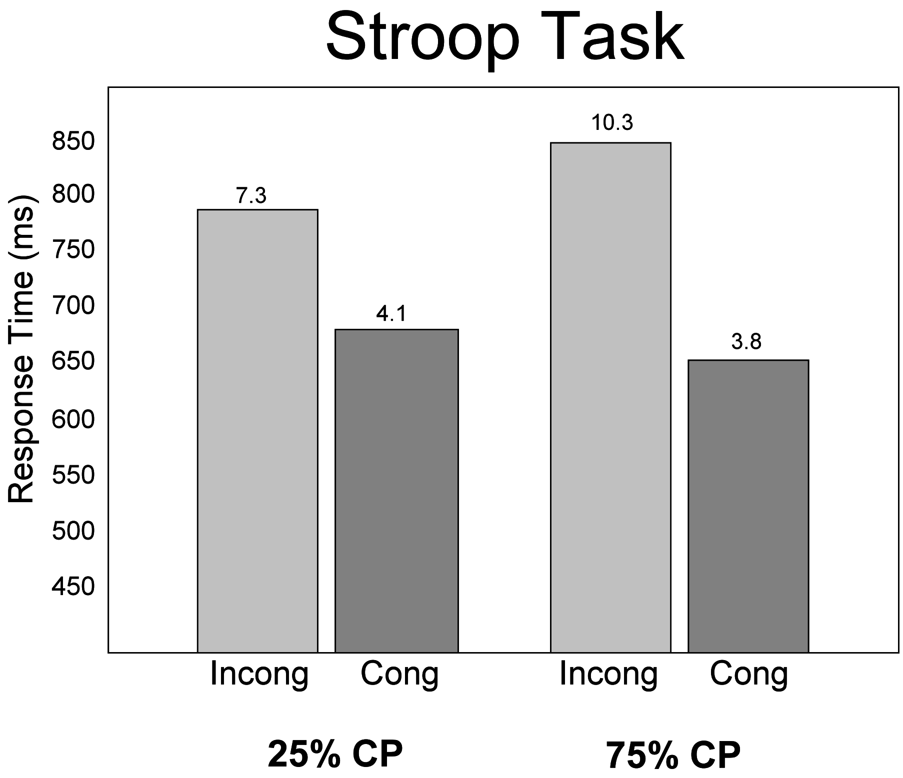

Figure 10. Mean RTs and percentage error data as a function of Congruency and CP for the Stroop Task for Experiment 4.

significant.

A 3 (Task) x 2 (CP) x 2 (Congruency) ANOVA on the Error data revealed a similar pattern to the RTs (with the exception of the null Task x CP interaction observed in RTs). Specifically there was a main effect of Task, *F*(2, 194) = 36.8, *MSE* = 33.1, *p* < .001, a main effect of CP, *F*(1, 97) = 96.0, *MSE* = 14.5, *p* < .001, and a main effect of Congruency, *F*(1, 97) = 219.8, *MSE* = 29.7, *p* < .001. Additionally, the Task x CP, *F*(2, 194) = 24.1, *MSE* = 12.0, *p* < .001, Task x Congruency, *F*(2, 194) = 24.0, *MSE* = 20.6, *p* < .001, CP x Congruency, *F*(1, 97) = 107.4, *MSE* = 17.9, *p* < .001, and the Task x CP x Congruency interactions, *F*(2, 194) = 22.6, *MSE* = 15.8, *p* < .001, were all significant.

Replication and Extension of the Size Congruity Paradigm

A 2 (Congruency: Congruent vs. Incongruent) x 4 (Symbolic Distance: 2, 4, 5, and 6 units) x 2 (CP: .25 vs. .75 congruent) x 2 (Task: Numerical vs. Physical Judgement) ANOVA was conducted on mean RTs, revealing a significant four-way interaction, *F* (3, 285) = 4.05, *MSE* = 2339, *p* < .01. In the same manner of Experiments 2 and 3, the analysis is now decomposed by focusing on two key aspects of the data: (1) interactions between Congruency, CP and Task, and (2) interactions with Symbolic Distance.

Congruency, congruency proportion and task. Replicating Experiments 2 and 3, there was a three-way interaction between Congruency, CP and Task, *F* (1, 95) = 54.2, *MSE* = 3083, *p* < .001. Here, although CP interacted with Congruency in both the Numerical and Physical Judgement tasks (*F*(1, 95) = 171.8, *MSE* = 3887, p < .001, and *F*(1, 97) = 33.2, *MSE* = 1719, p < .001, respectively), the interaction was greater for the Numerical than the Physical Judgement task. Specifically, the size congruency effect (incongruent – congruent) for the Numerical Judgement task increased from 24 ms in the .25 CP condition, to 107 ms in the .75 CP condition, whereas for the Physical Judgement task the congruency effect increased from 15 ms in the .25 CP condition, to 39 ms in the .75 CP condition.

Consistent with prior research, Congruency and Task also interacted, $F(1, 95) = 58$, $MSE = 4788$, $p < .001$, in that the difference between congruent and incongruent trials was larger for the Numerical Judgement task (mean difference = 65 ms) than the Physical Judgement task (mean difference = 27 ms). In addition, the predicted two-way interaction between Congruency and CP was also significant, $F(1, 95) = 219$, $MSE = 2542$, $p < .001$, such that as the proportion of congruent trials increased, so too did the difference between RTs for congruent and incongruent trials.

Interactions with symbolic distance. With respect to interactions with Symbolic Distance, there was a three-way interaction between Symbolic Distance, Congruency and Task, $F(3, 285) = 7.9$, $MSE = 1862$, $p < .01$. This three-way interaction was the product of two Symbolic Distance by Congruency interactions that take opposite forms. Specifically, for the Numerical Judgement task, as Symbolic Distance *increased*, the size of the congruency effect got *smaller*, $F\ (3, 285) = 3.0$, $MSE = 2707$, $p < .05$, whereas for the Physical Judgement task, as the Symbolic Distance *increased*, the size of the congruency effect got *larger*, $F\ (3, 291) = 4.5$, $MSE = 1335$, $p < .05$.

There was also a two-way interaction between Symbolic Distance and Task, $F(3, 285) = 44.4$, $MSE = 2546$, $p < .001$, as well as main effects of Congruency, $F(1, 95) = 296$, $MSE = 5577$, $p < .001$, Symbolic Distance, $F(3, 285) = 13.4$, $MSE = 2347$, $p < .001$, and

Task, *F*(1, 95) = 281.7, *MSE* = 21623, *p* < .001. No other main effects or interactions were significant (largest *F* = 1.95).

Errors

An analogous 2 (Congruency: Congruent vs. Incongruent) x 4 (Symbolic Distance: 2, 4, 5, and 6 units) x 2 (CP: .25 vs. .75 congruent) x 2 (Task: Numerical vs. Physical Judgement) ANOVA was conducted on mean errors, revealing a significant four-way interaction, *F* (3, 291) = 8.0, *MSE* = 48.1, *p* < .001. As with the RT analyses, these data are now decomposed by focusing on two key aspects of the data: (1) interactions between Congruency, CP and Task, and (2) interactions with Symbolic Distance.

Congruency, congruency proportion and task. Consistent with the RT analyses, and most important given our predictions, there was a three-way interaction between Congruency, CP and Task, *F*(1, 97) = 39.3, *MSE* = 66, *p* < .001. This three way interaction was the product of two 2-way interactions that took opposite forms. That is, although CP interacted with Congruency in both the Numerical and Physical Judgement tasks (*F*(1, 97) = 90, *MSE* = 101.2, p < .001, and *F*(1, 97) = 13.6, *MSE* = 40.99, p < .001, respectively), the interaction was overadditive for the Numerical Judgement task and underadditive for the Physical Judgement task. Specifically, the size congruency effect (incongruent – congruent) for the Numerical Judgement task *increased* from 2.1% errors in the .25 CP condition, to 11.6% errors in the .75 CP condition, whereas for the Physical Judgement task the congruency effect actually *decreased* from 3.6% errors in the .25 CP condition, to 1.2% errors in the .75 CP condition.

Consistent with the RT analysis, Congruency and Task also interacted, *F*(1, 97) =

46.8, *MSE* = 80.1, $p < .001$, in that the difference between congruent and incongruent trials was larger for the Numerical Judgement task (mean difference = 6.8 % errors) than the Physical Judgement task (mean difference = 2.5 % errors). In addition, the predicted two-way interaction between Congruency and CP was also significant, $F(1, 97) = 93.4$, *MSE* = 76.1, $p < .001$, such that as the proportion of congruent trials increased, so too did the difference between errors for congruent and incongruent trials.

Interactions with symbolic distance. With respect to interactions with Symbolic Distance, there was a three-way interaction between Symbolic Distance, Congruency and Task, F (3, 291) = 8.1, *MSE* = 54.2, $p < .01$. Like the RT analysis, this three-way interaction was the product of two Symbolic Distance by Congruency interactions that take opposite forms. Specifically, for the Numerical Judgement task, as Symbolic Distance *increased*, the size of the congruency effect got *smaller*, F (3, 285) = 4.7, *MSE* = 61.3, $p < .01$, whereas for the Physical Judgement task, as the Symbolic Distance *increased*, the size of the congruency effect got *larger*, F (3, 291) = 3.8, *MSE* = 31.0, $p < .05$.

There was also a two-way interaction between Symbolic Distance and Task, $F(3, 291) = 18.6$, *MSE* = 49.7, $p < .001$, as well as main effects of Congruency, $F(1, 97) = 158$, *MSE* = 108.7, $p < .001$, and Task, $F(1, 97) = 19.9$, *MSE* = 2159, $p < .001$. No other main effects or interactions were significant (largest $F = 2.1$).

Interim Summary (RTs and Errors)

The expected effects and patterns of data regarding the relation between CP and Congruency were found in all tasks. Specifically, in each Task, as the proportion of congruent trials increased, so too did the size of the congruency effect. In addition, regarding the Size Congruity paradigm, I replicated the asymmetry found in Experiments 2 and 3, whereby the CP manipulation differentially modulated the Congruency effect in the Numerical and Physical Judgement tasks. Specifically, in both RTs and errors, the Congruency by CP interaction was larger in the Numerical Judgement task than the Physical Judgement task. These findings are key, as they now allow us to examine the reliabilities, and cross correlations, between Tasks.

Additionally, as found in Experiments 2 and 3, the Symbolic Distance effect for the Numerical Judgement task was additive with the CP effect. This null is particularly interesting as it is a further replication under conditions in which even a marginal interaction should be apparent. I will reserve discussion of these findings to the General Discussion

Reliabilities and Correlations

As a preliminary first step when interpreting the reliabilities and correlations of difference scores, it is necessary to first look at the component scores' reliabilities to ensure that there are no limitations to looking at the reliabilities derived from the difference of these components (Williams & Zimmerman, 1996). The entire set of task correlations are presented in Appendix F, and the scatterplots depicting task reliabilities are presented in Appendix G. None of the component scores were unreliable, and only one was uncorrelated with any of the other component scores (i.e., Stroop .25 / Congruent Block 1 with Numerical 25 / Incongruent Block 1 was uncorrelated). Indeed, the lowest component score reliability was .67. The difference score reliabilities (i.e., reliabilities of congruency effects) and inter-correlations within and between tasks are presented in Table

1. The difference of difference scores, or the CP score (e.g., the .75 CP difference score - .25 CP congruent difference score) inter-correlations are presented in Table 2.

All correlations presented were subjected to an outlier procedure in which studentized residuals were calculated and any value exceeding 3.5 was not included in the analysis (but is included in the scatterplot as a circled point). It should be noted that in all cases, probably due to the large number of subjects, the inclusion or exclusion of outliers made no significant difference in the strengths of the correlations or the significance of the correlations. The scatterplots are displayed in appendices G - K inclusive and are divided into the following categories (in which order they will also be further discussed): Reliability (test-retest correlations), within task cross CP, cross task within CP, cross task cross CP, and finally CP change inter-correlations and correlations with Need for Cognition and Cognitive Failures Questionnaires.

Reliability

All three tasks were reliable at both levels of CP (see Table 1, and Appendix G for the scatterplots). As has been found in the past (e.g., Borgmann et al., 2007), the general trend for higher reliability with higher CPs was found with all three tasks having reliabilities in the low .50 range for the .75 CP conditions, and between .33 and .45 for the .25 CP conditions. It has been pointed out before that reliabilities for common cognitive phenomenon are often lower than many might expect (see Borgmann et al., 2007; Stolz et al., 2005). This is indeed surprising given that the cognitive tasks they are taken from are so robust. The current data do show significant reliability, but may surprise many

Table 1: Reliabilities and Correlations for Experiment 4

	Num 25	Num 75	Phy 25	Phy 75	Stroop 25	Stroop 75
Num 25	.35*	.25*	-.12	.04	-.23*	.05
Num 75		.52**	.00	.02	.15	.33**
Phy 25			.33**	.50**	.29**	-.05
Phy 75				.53**	.21*	.02
Stroop 25					.45**	.51**
Stroop 75						.51**

&p =.05
*p <.05
**p <.01

Table 2: CP Difference Scores and Scales for Experiment 4

	CFQ	Numerical	Physical	Stroop
NFC	-.08	.09	-.08	-.01
CFQ		-.01	.14	.01
Numerical			-.08	-.07
Physical				.03

$^{\&}p = .05$

$^{*}p < .05$

$^{**}p < .01$

researchers that they are not higher, even with a substantial number of subjects. This is suggestive that we take for granted the robustness and replicability of many cognitive phenomenon. It is important that we do not overlook the fact that there is still considerable variance in the measurement of these phenomenon.

Within Task, Cross Congruency Proportion

The correlations for Cross CP within the *same* task, is in essence, a test of the degree to which, at different CPs, performance on a task is consistent. Not too surprisingly, all three tasks showed at least some consistency across CPs (see Table 1, and Appendix H for the scatterplots). The Physical Judgement task and Stroop tasks were both fairly consistent across CPs, with correlations of .50 and .51 respectively (both significant at $p < .01$). The Numerical Judgement task was less consistent across CPs with a correlation of .25 ($p < .05$).

Cross Task, Within Congruency Proportion

Perhaps the strongest test of a central top-down Cognitive Control account of CP effects is the test of consistency of the CP manipulations *across* tasks. As these data were collected via a within-subjects methodology, the level of consistency between performance here is suggestive of the level of shared processing across tasks. If there is a single mechanism giving rise to CP effects, we would expect to see a large degree of consistency for all 6 comparisons (i.e., Numerical Judgement task at .25 with Physical Judgement task at .25, Numerical Judgement task at .25 with Stroop task at .25, Physical Judgement task at .25 with Stroop task at .25, Numerical Judgement task at .75 with Physical Judgement task at .75, Numerical Judgement task at .75 with Stroop task at .75, and Physical Judgement task at .75 with Stroop task at .75).

What is striking here is that there is no consistent pattern of correlations (these data are depicted in Table 1 and Appendix I). There are three correlations that are significant: Numerical Judgement task at .25 and Stroop task at .25 ($r(96) = -.23$, $p < .05$), Physical Judgement task at .25 and Stroop task at .25 ($r(96) = .29$, $p < .01$), Numerical Judgement task at .75 and Stroop task at .75 ($r(96) = .33$, $p < .05$). The other three correlations are all very small and non-significant. Additionally, the first significant correlation (Numerical Judgement task at .25 and Stroop task at .25) is in the negative direction!

Cross Task, Cross Congruency Proportion

The final set of six correlations form the remainder of Table 1 (see Appendix J for the scatterplots). Of these correlations, only one is significant: the Physical Judgement task at .75 and the Stroop task at .25 ($r(96) = .21$, $p < .05$).

Congruency Proportion Change Scores and Cognitive Control Scales

The final set of correlations examined is the CP change scores (the .75 CP condition – the .25 CP condition) and the Cognitive Control scales (NFC and CFQ). These correlations would also seem to be central to the question of the role of Cognitive Control in producing CP effects, as the change scores should be consistent with each other (correlated) if they are produced by a single unitary control mechanism. In addition, the NFC and CFQ scales should correlate with these scores as they are thought to index central aspects of Cognitive Control. Interestingly, none of these scores correlate (see Table 2 and Appendix K for the scatterplots).

This null effect really encompasses two separate findings. The first is that the NFC and CFQ do not correlate with the CP change scores. The second is that there is no inter-correlation between the tasks in the CP change scores. One explanation for these nulls is that the underlying component scores (here the inter-correlations presented in Table 1) are not sufficiently high to detect these higher order correlations. This interpretation loses lustre though when considering that the NFC and CFQ did not correlate with any of the three tasks which did show significant reliability. The upper limits of any detectable correlation may have been moderate, but was theoretically well within the limits of the component scores statistical utility. The more theoretically interesting explanation is that these measures did not correlate because they measure different things.

Summary

The reliabilities of the component scores and difference scores follow the expected pattern; that is, all of the component scores were reliable and as the proportion of congruent trials increased, so to did the reliability of the difference scores. The pattern of inter-correlations, however, is more difficult to interpret. Specifically, whereas there were at least modest inter-correlations between different CPs of the *same* task, there was only one between tasks. In the cases in which CP was the same *across* tasks, only half of the correlations were significant, and one of those three significant correlations was negative. To unpack this pattern more completely, there are a total of 12 correlations between the three tasks, generated from the different combinations of the 3 tasks at both levels of CP. Six of the twelve correlations are cross task, same CP (e.g., Stroop at .25 and Physical Judgement task at .25) and six are cross task, different CP (e.g., Stroop at .25 and Physical Judgement task at .75). Of the former group, half of the correlations are non-existent/not-significant, one was negative (Numerical Judgement task at .25 and Stroop at .25) and two were significant but low (Numerical Judgement task at .75 and Stroop at .75, and Physical Judgement task at .25 and Stroop at .25). Of the latter six, only the Physical Judgement task at .75 and Stroop at .25 correlated. The other five correlations were all remarkably close to zero. In sum, three of a possible twelve correlations were positive and significant. This pattern of data is hard to reconcile with an account of CP that is thought to derive from a central and unitary Cognitive Control mechanism.

Exploratory Factor Analyses of Control Components

As a post-hoc exploratory analysis, a number of Factor Analysis models were tested (see Appendix L for the models). Of the five models tested, none of them were a "good" fit (a Comparative Fit Index (CFI) of .9 is generally considered acceptable). However, rank ordering them from best fit to worst offers an interesting insight that fits with the above correlational analyses. The best fit model tested was a stimulus driven model in which the type of stimulus loaded onto the 6 conditions (three tasks at two CPs each). The next best fit model was similar, but had a "Cognitive Control" factor (which was simply a single predictor at a higher level than the stimulus level predictors) associated with the three task/stimulus types. The CFI was .74 for the first model and .68 for the second model. The next three models tested the factors high and low congruency, and "Cognitive Control" alone and in combination. All three models had a CFI of .33 or worse. As such, the single best predictor of this set of within-subject data then was the stimuli/task used. More importantly, a central (or unitary) high level process actually worsened the model's ability to predict this data set. Not only is there no evidence *for* a role for a unitary Cognitive Control module in these tasks, there is evidence *against* a role for a unitary Cognitive Control module.

The correlational analysis and Factor Analysis models seem to point in a common direction; the best method of explaining the variance of CP effects is to look at the task specific qualities (or stimuli used). These data, then, seem to fit better with an account of CP effects that has a larger role for memory and attention than a role for a singular account of Cognitive Control. In short, an explanation for CP effects based on earlier attentional factors fits much better to these data.

The first and perhaps most obvious finding in the correlational analysis, then, is that there is little shared variance between tasks. The largest correlations were found within task, with the .25 CP correlating with the .75 CP for each task. This finding may not be surprising at all, but is nonetheless a vital clue given the lack of correlations elsewhere. These three correlations dovetail nicely with the Factor Analysis in which the "best" fitting model was one in which task specific factors drive the pattern of data seen. Succinctly then, those factors which are shared within task (stimuli, task instructions, task context) are of central importance in understanding the CP effects seen here.

The correlations that would be most important to the idea of a central top-down Cognitive Control mechanism shared across tasks are the Cross Task / Within CP correlations (Appendix I). Of these six correlations, three were insignificant, one was negative, and only two were significant and positive. As to a specific explanation for this pattern of correlations, the imagination is left wanting for a parsimonious account. Just as it is easy to imagine that the similarities in the processes shared by the same task lead to the correlations between the .75 CP and .25 CP versions of each task, so too could it be that similarities in processes between tasks give rise to inter task correlations. If the similarities in tasks are not ubiquitous (and therefore seemingly related to a central component of all the tasks), then finding the particular similarity between specific tasks may be more difficult. It could be, for example, that the shared direction of conflict in the .75 CP Numerical Judgement and Stroop tasks is what leads to a correlation there. By this explanation, the fact that the more fluent process (physical size assessment / word reading) is interfering with a less fluent process (number meaning / colour identification) would be important. This, however, would not explain why the Numerical and Stroop tasks then *negatively* correlate at the .25 CP. Nor would it explain the correlation between the .25 CP conditions of the Physical Judgement task and the Stroop task.

An additional observation that bears on Cognitive Control is the higher order difference scores, or the difference between levels of CP across task. If the tasks share the same mechanism of control that gives rise to the CP effect, then it would be expected that these scores would correlate. The CP effects were uncorrelated across tasks, however, as noted above, this higher order comparison should be viewed critically, as unlike the correlation of component scores or the correlation of difference scores, the reliabilities of the .25 CP condition (which themselves are *based* on reliable scores) for all three tasks were moderate at best. This places a theoretical boundary on the size of any subsequent correlations between difference scores. So, although the difference scores may be of interest, the difference of difference scores should be viewed with caution. This caution seems pertinent as in other cases, the lack of a correlation in one condition is offset by the finding of a correlation in another, and thus, the lack of a correlation cannot be due to an inability to find a correlation that really exists. This is not the case in the difference of difference scores, as no correlations at this level of analysis were significant.

Finally, the two scales that purportedly index key aspects of Cognitive Control (i.e., the CFQ and NFC scale) were poorly correlated with any of the measures of CP. These two scales offer important insights into the nature of the relation between Cognitive Control and CP effects as they each represent an independent measure of Cognitive Control. Specifically, the CFQ is thought to be a measure of the degree to which an individual experiences slips of attention (or loss of control), whereas the NFC is thought to be a measure of the extent to which an individual willfully engages (tries to apply Cognitive Control) when engaged in a task. The lack of a correlation here with CP effects suggest that any form of Cognitive Control (or “strategic” influences) engaged in these tasks that give rise to the CP effect are separate and distinct from these measures of Cognitive Control. Further, if there is a mechanism engaged in the production of CP effects, it would seem to be task specific, and does not reflect a construct related to earlier conceptions of Cognitive Control or to what Braver et al. (2007) refer to as Proactive Control.

Chapter 5: General Discussion

The findings reported in this thesis significantly extend prior research that has employed CP manipulations to uncover key aspects of Cognitive Control in conflict tasks. Previous studies using CP manipulations in different paradigms have produced results similar to those of the current study. In Stroop (Logan & Zbrodoff, 1979; Logan, Zbrodoff & Williamson, 1984; Lowe & Mitterer, 1982), Simon (Hommel, 1994; Sturmer, Leuthold, Soetens, Schröter & Sommer, 2002), and Flanker studies (Gratton, Coles & Donchin, 1992), the common finding is that as the proportion of congruent/compatible trials increases, so too does the magnitude of the effect being studied. Importantly, this thesis extends this prior work in two important ways. First, I demonstrated that participants' conscious awareness of their performance in these types of experiments is quite limited. Subject's self report of their experience doing the task (Experiment 1), their engagement with the task (NFC, Experiment 4), and their propensity to have attentional slips (CFQ, Experiment 4) did not predict their performance in any way. Secondly, in three experiments, I was able to demonstrate that a CP manipulation in one task is completely distinct from a CP manipulation in a different task. I was able to show this in both a between-subjects design when all the stimuli and the context of the experiment were identical. I was also able to demonstrate this in a within-subjects design. This set of experiments has undermined the received view that CP effects arise from a central and unitary form of conscious control.

Botvinick et al. (2001) have explained CP manipulation effects in terms of a reduction in the amount of attentional control required as the proportion of congruent trials increases. That is, when there is a high proportion of trials that are congruent, the odds are that on any given trial the irrelevant dimension will provide the same response as the relevant dimension. By contrast, when the proportion of congruent trials is low, more often than not the subject will be presented with conflicting information from the relevant and irrelevant dimensions. Thus, the proportion of congruent trials moderates the amount of conflict in the task and thus the attentional demands on the subject. The reduction of attentional control in the high CP condition allows the contribution of more "automatic" or highly fluent processes to have an increased influence over performance. This increase in reliance on more putatively automatic processes then, leads to faster processing of congruent trials and much slower processing of incongruent trials. In the current tasks, Botvinick et al.'s (2001) account can be applied to explain the CP effects seen for each task, but has no recourse to explain the differences between tasks, or the lack of correlation between tasks.

By contrast, Melara and Algom (2003) produce a CP effect in their model via a short-term memory mechanism. More specifically, as noted in the introduction, Melara and Algom posit that short-term memory (or recent events), in which proportion information is encoded along with contextual information, interacts with task demands. Recent data seem to fit better with the Melara and Algom (2003) model than the Botvinick et al. (2001) model. For example, Jacoby and colleagues (Jacoby et al, 2003; Bugg et al, 2008) have demonstrated that there are a number of item specific effects that can be shown to produce separate CP effects, while maintaining a global or list level of proportion. They suggest that, although it may be possible to explain all the list level effects as a function of the individual component item specific effects, within each of these individual component item specific effects there are multiple levels of control. The problem with this account is with how far it could be taken. If, for example, you design a Stroop experiment and assign half the items one proportion and half another, and then further have two fonts for each of these proportions, each font with its own CP, could you not then distinguish within each level of font some third method for splitting the proportion of trials? How many separate levels of control are possible? As it seems that each of the contingencies between the dimensions of the different stimuli interact uniquely (see Schmidt & Besner, 2008), there may be no limit to the number of unique ways in which a potentially unlimited number of dimensions of stimuli could co-vary in different proportions to each other. The conception of levels of control loses its value rather rapidly.

The current data make clear that these numerous CP effects are distinct from each other. One of the novel findings of Experiment 2, Experiment 3, and Experiment 4 is that even with identical stimuli, task instructions can lead to asymmetrical CP effects. This is further evidence that CP effects are highly dependent on specific and minimal factors. Although this finding is not sufficient in itself to suggest that the theory presented by Botvinick et al (2001) is wrong, it does suggest that their account, as it is currently specified, is insufficient. The correlational data from Experiment 4 is more difficult to reconcile with the Botvinick et al. (2001) account. Here, the quantitative differences in CP effects from contextual manipulations, different item contingencies, and (as in Experiments 2, 3, and 4) task instruction, are suggestive of a far more intricate factor at play in producing these effects. This is not to say that there is no role for an error detector as posited by Botvinick and colleagues, but rather to say that such a detector cannot explain all CP effects. An error detector may be a completely viable mechanism to explain how Cognitive Control is modulated in tasks following the commission of an error. It might well be the case that an error detector is engaged when a subject makes an error, and then Cognitive Control is increased to reduce the likelihood of an error on a subsequent trial. This example is a completely different event from a correct response being made on a trial in which the accuracy and response time to that trial is determined by previous experience with the task.

Whereas the current data combined with the recent research mentioned above is not consistent with the notion of a single Cognitive Control mechanism, it is at least somewhat consistent with a memory account such as proposed in Melara and Algom's (2003) model. The strength of this model is that all of the CP effects from contextual manipulations, different item contingencies, or task instruction can be accounted for by the same parsimonious mechanism. There is, however, one further key piece of the picture that needs to be considered: the novel finding reported here in three experiments that a manipulation of the proportion of congruent trials has no effect on the Symbolic Distance effect. How does this additive pattern of data fit if CP effects are indeed due to a memory mechanism? At issue is the fact that the Symbolic Distance effect has its locus in long-term memory. Whereas the basic structure of Melara and Algom's (2003) model is straight forward, the way in which memory interacts with task demands is relatively complex. Short-term memory in Melara and Algom's (2003) model is a separate and distinct implemented mechanism; it is this mechanism that gives rise to the CP effects.

What may not be immediately apparent, however, is that they are agnostic on the relative role of short-term memory in representations of stored information in long-term memory. Specifically, they make no argument as to whether short-term memory is a separate component of memory or a subset of long-term memory. Their model theoretically is consistent with both possibilities. What is clear in their model is that the contents of short-term memory have a direct influence on the ease with which long-term memory is accessed. In their account, it is the "relative dimensional uncertainty" between stimulus dimensions (i.e., the CP) that dictates the ease of access to the long-term memory component of the model. As the dimensional uncertainty rises (CP decreases) the difficulty in accessing representations in long-term memory that correspond with the current stimuli increases.

What might the additive relation between CP and Symbolic Distance observed in Experiments 2, 3, and 4 entail for models of CP effects? By applying additive factors logic (Sternberg, 1969) it would seem clear that the mechanism(s) that give(s) rise to the CP effects do not occur during, or in conjunction with, the mechanism(s) that give(s) rise to the Symbolic Distance effect. Rather, the factors that give rise to the Symbolic Distance effect must occur separately from the factors that give rise to the CP effect. With the Symbolic Distance effect taken as a measure of semantic access (to long-term memory) in the Numerical Judgement task, it then follows that the CP effect has its locus prior to, or following, semantic access. This result then could be at odds with the Melara and Algom (2003) model. Specifically, if the CP effect arises from short-term memory, and if short-term memory is a subset of long-term memory, and the Symbolic Distance effect is presumably a function of access to long-term memory, it would seem likely that CP manipulations would have an impact on the Symbolic Distance effect. Certainly Symbolic Distance interacted with the effect of *Congruency* in the Numerical and Physical Judgement task.

There are two ready explanations as to why it may be that CP and Symbolic Distance do not interact. The most obvious is that there is some degree of separation between short-term memory and long-term memory, and possibly that they are completely independent from each other as memory stores (Atkinson & Shiffrin, 1968). This explanation would fit with the Melara and Algom (2003) model as it stands, as presumably the Symbolic Distance effect arising from long-term memory and, the CP effect arising from short-term memory do not interact. Alternatively though, some researchers have argued that memory is comprised of a single store. For example, Kwantes (2005) uses an implemented model of semantic effects derived from a lexicon that illustrates that more than one memory "effect" (both Lexical memory and Semantic memory) can be generated from a single memory store. By this second view, short-term memory, long-term memory, and semantic memory are part of a single store. This second view would seem inconsistent with Melara and Algom's implemented model.

One further piece of evidence worth considering is that the CFQ and NFC scales do not correlate with the CP effect. As noted previously, these scales are claimed to capture different aspects of conscious engagement. Specifically, the CFQ is thought to capture the involuntary slips in control, and the NFC is thought to capture the willful desire to engage control. If the scales correlated with the CP effect, it could have been argued that the influence of control has a late locus, after semantic access. Additionally, it could be argued that the CP effect was generated from a central conscious locus. That these measures do not speak to the CP effect undermines the idea of conscious volitional control playing a role in the production of the CP effect. It seems more likely that the locus of the CP effect occurs early, or alternatively, that the CP effect has very little to do with Cognitive Control as classically defined.

Dovetailing nicely with the results of the CFQ and NFC scales, Experiment 1 lends credibility to the idea that conscious control is not engaged in producing the CP effect. Although subjects' estimates of the proportion of congruent trials correlated with the actual CP, they only did so when analyzing *across* the two CPs. Subject's estimates of the proportion of congruent trials had no predictive value on their actual performance *within* a given CP. This suggests that certainly there is some seepage, as in retrospect, subjects can gain a vague sense of the actual CP, albeit a widely inaccurate one. However, it absolutely does not fit with a notion of a conscious online effort to maximize performance with a strategy. Indeed, the word strategy seems entirely out of place. Given this, where then does the CP effect arise from?

A single memory store account would seem to require that CP effects arise early (i.e., via short-term memory). Both the Botvinick et al (2001) model, and the Melara and Algom (2003) model exert Cognitive Control late for the purpose of response selection. Botvinick et al (2001) also generate the CP effect from the adjustment of this control. Melara and Algom (2003) generate the CP via an earlier influence in the form of a short-term memory module. The data here seem to suggest that whereas Cognitive Control may indeed be active for setting up task demands/responses, it plays no role in producing CP effects. The data also suggest, however, that CP effects do not arise from short-term memory influencing long-term memory. What is left is an account in which short-term memory (as a separate store, or as a subset of the active components of long-term memory) influences the attention to the target stimuli. Short-term memory records the sum of recent trials and the responses given to those trials. On each given trial, short-term memory influences the attentional weight to the separate components of the stimuli. CP effects do not have their locus *in* short-term memory, but rather arise because the contents of short-term memory influence attention. In a high CP condition, the irrelevant dimension is highly correlated with the relevant dimension, and when they both provide the correct response, performance is speeded. On incongruent trials, the irrelevant dimension provides evidence for one response that has in the past been correct, while the relevant dimension still provides the correct response. The result is a more difficult response selection as two opposing responses are highly salient, and response time is longer. In a low CP condition, the irrelevant dimension is poorly correlated with the relevant dimension (or negatively correlated in the case of a set of two stimuli), and when they both provide the correct response, performance is speeded. However, on incongruent trials the irrelevant dimension has less of an impact as recent trials have not raised the saliency of any of the distractors. In the special case of a low CP condition with a stimuli set of two (for example, a Stroop task with Red and Blue), the irrelevant dimension actually gains saliency such that the "incorrect" meaning of the irrelevant dimension predicts the correct response. Thus, simply identifying the separate components of the stimuli that have utility in producing the correct response (they are predictive) is sufficient to produce CP effects.

Conclusion

Interestingly, the empirical evidence may suggest that the title of Cognitive Control be restricted to earlier conceptions in which control is considered to likely be conscious, driven by task demands/context, and individual approaches to a task. Certainly, the current literature and current data point to a potentially infinite level of complexity in our ability to discriminate between different aspects of a stimulus. The current data could be explained via recourse to positing the existence of separate control mechanisms, or separate implementations of the same control mechanism for each task. As each subject would then need at minimum three different sets of control for the three tasks used here, it is not difficult then to argue that explaining the current data in terms of separate control mechanisms has the same shortcomings as an account with multiple levels of control.

Cognitive Control then really may be limited to that which we have "*direct introspective awareness*" of, and "*subjective feelings of control"* (Nisbett & Wilson, 1977). The complex pattern of data that arises from CP manipulations across tasks can be reduced to as simple and elegant an explanation as our incredible ability for implicit learning. Certainly there is a role for the concept of Cognitive Control in many facets of human cognition and behaviour, just not as an explanation of CP effects.

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Appendix A

Subject Mean RTs, Errors, and Estimates for Experiment 1

Experiment 1 Mean RT for congruent and incongruent trials in Block 1 and Block 2

CP	Incong Blck 1	Cong Blck 1	Incong Blck 2	Cong Blck 2
25	365	385	389	398
25	475	511	408	515
25	440	445	443	459
25	444	478	423	472
25	579	631	574	594
25	340	389	334	363
25	401	427	395	404
25	399	468	397	471
25	488	510	509	549
25	338	362	328	394
25	441	453	416	476
25	406	428	399	455
25	597	652	507	476
25	384	443	388	432
25	544	539	452	502
25	454	459	435	471
25	440	528	448	522
25	465	524	421	455
25	367	373	384	397
25	412	441	420	468
25	457	522	414	462
25	425	428	387	396
25	425	471	453	446
25	440	453	445	464
25	429	434	423	435
25	386	383	400	401
25	403	410	446	466
25	397	424	403	424
25	388	441	409	415
25	381	388	377	389
25	393	452	380	422
25	420	434	496	549
25	429	423	464	488
25	399	404	367	406
25	368	411	384	438
25	353	381	343	378
25	451	478	448	500
75	422	411	429	422
75	354	348	388	363
75	380	363	420	368
75	478	443	560	472

75	443	389	405	386
75	422	391	466	400
75	363	330	391	348
75	372	331	384	336
75	427	419	442	400
75	389	342	411	360
75	477	421	475	408
75	486	399	522	449
75	390	342	426	378
75	303	296	314	300
75	407	350	386	373
75	334	314	358	292
75	442	398	422	404
75	450	342	415	340
75	512	452	537	461
75	465	435	500	458
75	472	441	477	419
75	424	405	447	402
75	411	355	405	361
75	395	348	405	330
75	432	358	384	342
75	580	470	569	454
75	464	405	461	374
75	540	432	481	380
75	439	404	448	435
75	430	363	421	346
75	458	439	510	450
75	350	307	374	309
75	460	387	419	394
75	513	467	498	447

Experiment 1 Mean % Error for congruent and incongruent trials in Block 1 and Block 2

CP	Incong Blck 1	Cong Blck 1	Incong Blck 2	Cong Blck 2
25	1	17	1	7
25	2	7	2	3
25	6	7	7	13
25	0	7	3	0
25	1	3	0	4
25	0	37	4	27
25	6	13	9	11
25	0	3	2	13
25	3	11	4	17
25	2	13	4	17
25	1	7	4	20
25	0	10	0	13
25	3	12	5	11
25	3	10	2	7
25	5	17	3	11
25	3	0	2	10
25	0	3	0	13
25	2	13	4	14
25	10	13	4	23
25	0	7	0	7
25	2	7	3	17
25	1	7	2	7
25	1	10	6	0
25	0	3	2	0
25	5	3	3	3
25	0	13	4	7
25	2	3	4	14
25	1	7	1	3
25	4	0	2	14
25	2	3	6	13
25	3	10	3	7
25	4	3	1	11
25	12	17	18	17
25	3	3	4	10
25	6	10	0	17
25	0	7	0	3
25	2	0	2	3
75	17	1	17	4
75	13	1	7	4
75	17	4	7	7
75	21	2	14	5

75	7	0	0	0
75	10	1	7	2
75	10	3	3	0
75	20	4	3	1
75	7	0	7	0
75	10	2	7	2
75	7	1	17	2
75	3	1	7	1
75	13	2	17	0
75	47	8	37	4
75	10	0	10	0
75	13	3	27	7
75	3	2	7	2
75	20	2	37	2
75	13	1	7	1
75	3	0	0	0
75	20	0	10	2
75	30	3	31	3
75	3	1	10	0
75	20	1	13	1
75	0	0	7	0
75	4	1	10	0
75	3	1	10	1
75	15	1	27	3
75	7	2	14	1
75	3	0	7	0
75	10	0	17	1
75	13	0	17	3
75	17	1	17	1
75	14	2	20	2

Experiment 1 Subject estimations of CP

CP	Guess	Confidence	Uesful
25	70	60	No
25	50	80	No
25	30	50	No
25	60	80	Yes
25	60	70	No
25	66	75	Yes
25	50	30	Yes
25	65	65	Yes
25	40	60	No
25	68	70	No
25	50	80	Yes
25	50	60	No
25	60	70	Yes
25	30	20	Yes
25	60	40	Yes
25	50	40	No
25	30	60	No
25	40	80	Yes
25	50	20	No
25	30	5	No
25	20	70	No
25	35	50	No
25	40	20	No
25	65	10	No
25	40	30	Yes
25	30	20	Yes
25	50	86	No
25	40	10	No
25	50	70	Yes
25	60	70	No
25	35	70	No
25	40	40	Yes
25	50	60	Yes
25	60	50	No
25	20	80	Yes
25	50	10	No
25	25	40	Yes
75	70	60	Yes
75	60	60	Yes
75	70	60	Yes
75	70	60	Yes

75	60	60	No
75	60	60	Yes
75	70	50	Yes
75	70	60	Yes
75	30	60	No
75	75	90	No
75	75	60	Yes
75	50	50	Yes
75	75	60	Yes
75	85	90	No
75	75	80	No
75	80	70	Yes
75	70	50	Yes
75	75	50	Yes
75	80	80	Yes
75	80	70	Yes
75	75	80	Yes
75	75	70	Yes
75	65	70	Yes
75	75	70	No
75	80	80	Yes
75	75	95	Yes
75	65	70	Yes
75	50	40	No
75	70	90	Yes
75	50	60	Yes
75	60	60	Yes
75	75	70	Yes
75	70	60	Yes
75	75	75	Yes

Appendix B

Subject Mean RTs and Errors for Experiment 2

Experiment 2: Numerical Task Subject Mean Rts

CP	Distance of 2		Distance of 3		Distance of 4		Distance of 5		Distance of 6	
	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong
25	559	521	582	537	556	524	550	495	528	485
25	644	614	549	521	549	539	566	541	559	560
25	371	357	368	372	378	359	358	357	386	366
25	438	407	477	412	444	418	475	425	436	403
25	658	626	592	581	579	567	555	524	540	642
25	602	649	542	645	546	654	562	585	544	494
25	412	444	416	423	415	408	411	419	393	377
25	494	427	487	432	494	440	483	438	452	420
25	501	576	488	542	473	504	477	454	430	441
25	498	467	462	448	456	448	453	452	456	449
25	524	539	487	539	508	482	522	493	476	493
25	490	457	502	479	489	485	495	441	473	456
25	420	338	404	386	400	368	419	401	380	402
25	758	713	711	704	684	647	694	694	613	592
25	592	456	548	593	559	519	577	648	492	509
25	538	519	488	462	491	465	480	464	444	465
25	422	405	438	375	426	356	426	362	393	392
25	461	442	483	412	458	403	461	390	470	399
25	600	581	607	541	572	543	581	496	557	627
50	667	567	656	589	626	505	608	560	615	528
50	575	409	541	450	494	430	515	466	543	414
50	437	384	418	377	426	367	385	344	404	367
50	418	408	424	379	426	388	414	391	422	387
50	563	576	538	520	527	475	536	530	525	461
50	470	421	489	441	490	452	488	435	476	445
50	484	423	463	441	462	432	487	428	444	478
50	540	498	556	501	551	536	520	535	510	489
50	559	505	580	511	558	506	589	515	582	501
50	559	486	534	472	567	449	500	490	523	453
50	834	777	825	719	821	754	803	709	708	734
50	665	577	608	535	592	515	590	526	544	563
50	516	392	508	408	435	393	441	417	455	360
50	468	416	441	402	443	382	479	391	463	356
50	514	425	458	410	458	398	436	414	420	436
50	524	425	498	429	536	485	529	442	468	470
50	556	535	571	492	540	493	575	478	492	495
50	378	341	387	337	383	338	378	340	375	366
75	662	604	750	583	649	559	629	551	712	531
75	614	428	542	435	521	447	533	445	525	406
75	601	453	515	453	530	469	500	490	511	435
75	525	523	560	518	548	519	562	496	717	489
75	720	467	713	487	584	463	610	456	579	431
75	486	423	473	391	486	401	476	391	465	397
75	355	355	307	366	451	364	418	368	451	323
75	470	440	484	429	498	398	475	385	533	392
75	602	423	492	434	498	416	524	418	420	404
75	509	441	498	470	536	460	500	446	542	468
75	595	440	566	500	572	518	514	476	503	443
75	497	435	577	463	533	430	528	419	512	443
75	522	493	519	440	499	461	474	436	459	410
75	862	658	739	621	740	656	664	652	657	670
75	539	549	593	515	583	556	564	525	668	547
75	583	532	602	428	619	420	597	422	535	393
75	409	354	493	337	410	344	390	342	463	343
75	439	390	468	351	456	356	442	372	419	357

Experiment 2: Physicall Task Subject Mean Rts

CP	Distance of 2		Distance of 3		Distance of 4		Distance of 5		Distance of 6	
	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong
25	361	353	378	348	385	395	382	352	382	365
25	492	458	484	416	472	452	498	458	457	501
25	358	337	361	336	356	323	354	336	352	372
25	297	299	295	291	296	295	288	302	321	277
25	344	440	354	361	360	364	365	387	372	348
25	360	370	385	372	375	357	373	366	368	382
25	489	443	458	445	465	443	474	442	480	475
25	355	404	357	366	370	352	362	362	375	370
25	348	353	328	339	322	334	352	350	369	359
25	378	408	369	370	369	386	377	397	387	348
25	380	354	359	411	372	360	395	337	373	399
25	354	354	351	359	348	354	358	314	370	339
25	391	348	343	360	352	347	348	374	341	350
25	337	370	341	305	331	312	329	318	323	310
25	375	402	384	363	384	352	361	352	400	402
25	350	328	322	329	319	346	332	312	391	290
25	306	340	313	332	321	350	323	298	331	309
50	401	379	389	377	375	391	383	373	346	379
50	377	376	370	352	356	362	353	372	351	385
50	357	352	345	335	355	354	366	358	377	353
50	464	429	449	495	530	442	450	459	436	437
50	503	460	493	477	465	476	452	483	463	491
50	368	345	376	364	368	370	377	368	400	376
50	405	391	369	383	377	381	366	383	397	385
50	376	364	371	368	334	330	351	360	349	346
50	379	381	381	362	373	373	391	358	394	361
50	393	348	365	357	344	368	366	364	372	346
50	391	385	408	409	378	396	431	411	419	393
50	398	406	405	393	418	387	385	409	449	450
50	420	418	436	418	442	439	451	467	436	476
50	358	325	373	352	387	356	357	351	363	363
50	464	484	497	436	461	447	470	535	519	510
50	448	493	474	427	428	418	442	445	457	429
50	456	476	482	453	454	453	452	461	553	435
75	363	309	313	324	328	318	328	318	328	311
75	292	332	339	329	335	318	307	315	341	328
75	430	386	401	406	383	370	402	409	386	394
75	381	411	415	383	382	380	380	396	408	365
75	307	310	312	324	314	310	341	303	310	314
75	327	308	344	334	310	321	318	315	361	314
75	467	460	489	469	503	479	473	490	508	476
75	439	526	454	471	460	463	538	456	520	468
75	385	355	353	351	373	371	388	365	384	365
75	290	315	328	326	307	323	320	318	250	306
75	379	378	415	363	440	369	402	374	566	358
75	362	379	420	373	467	361	466	362	374	386
75	351	334	462	357	380	365	363	353	390	344
75	358	378	369	366	385	378	441	379	369	371
75	395	314	357	337	350	343	358	342	379	337
75	477	451	417	448	475	447	452	456	481	430
75	381	368	372	344	334	357	375	371	401	363
75	391	359	385	375	394	373	392	384	391	376
75	424	409	426	411	459	402	470	416	438	414

Experiment 2: Numerical Task Subject Mean Errors

CP	Distance of 2		Distance of 3		Distance of 4		Distance of 5		Distance of 6	
	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong
25	6	0	0	8	9	0	0	0	6	0
25	6	0	3	0	0	6	3	0	0	0
25	0	0	3	8	4	6	9	18	18	0
25	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
25	12	0	0	8	2	0	0	0	0	0
25	0	0	0	0	7	6	0	0	0	0
25	0	0	3	0	2	0	3	9	0	0
25	6	0	0	0	2	0	0	0	0	0
25	0	0	3	0	0	0	0	0	0	0
25	0	0	6	0	0	0	3	0	6	0
25	0	0	0	0	0	0	6	8	6	0
25	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	4	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	3	0	6	0
25	6	0	0	0	2	0	8	0	6	0
25	0	0	0	0	0	0	3	0	0	0
50	0	0	0	0	0	0	4	0	0	0
50	0	0	8	0	3	0	9	0	8	9
50	8	0	4	0	6	0	0	0	0	0
50	0	0	8	0	3	0	0	0	0	8
50	0	0	4	0	6	0	4	0	0	0
50	0	0	0	0	0	0	0	0	0	0
50	0	0	4	0	0	0	0	4	0	0
50	0	8	4	0	3	3	0	0	0	0
50	0	0	0	0	8	0	4	8	9	0
50	0	0	0	4	6	0	4	0	0	0
50	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
50	8	0	4	0	11	0	0	4	0	0
50	17	0	4	0	9	0	0	4	8	0
50	0	0	0	0	0	6	0	0	0	0
50	0	0	0	0	3	0	0	0	0	0
50	0	0	0	4	0	3	0	0	0	0
50	0	0	12	0	6	0	8	0	17	0
75	0	0	0	0	6	0	0	0	0	0
75	0	0	0	6	18	0	17	0	0	0
75	0	0	0	0	17	0	8	0	17	0
75	0	0	0	0	17	2	8	3	0	0
75	0	0	25	0	18	0	0	0	17	0
75	0	0	17	0	11	0	0	0	0	0
75	17	11	73	23	28	17	33	19	50	11
75	17	0	18	0	11	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0
75	33	0	31	0	32	0	23	2	25	0
75	0	0	0	0	0	0	8	0	0	0
75	17	0	8	0	6	2	0	0	0	0
75	17	0	0	0	0	0	0	0	0	0
75	0	6	9	0	0	0	8	0	0	0
75	0	0	0	0	0	2	0	0	0	6
75	0	0	18	0	11	0	8	0	0	0
75	17	6	33	0	6	0	8	0	17	0
75	17	0	8	0	17	0	17	0	0	0

Experiment 2: Physical Task Subject Mean Errors

CP	Distance of 2		Distance of 3		Distance of 4		Distance of 5		Distance of 6	
	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong
25	0	0	0	0	0	0	3	0	0	0
25	0	0	0	0	4	0	0	8	0	0
25	0	0	0	0	2	0	3	0	6	0
25	9	8	10	0	7	6	1	4	6	8
25	6	0	3	0	4	0	0	8	6	0
25	0	0	3	8	2	0	0	0	0	0
25	6	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	8	6	0
25	0	0	3	0	2	0	0	0	0	0
25	0	0	0	0	2	6	0	0	0	17
25	0	0	0	0	0	0	0	0	6	0
25	6	0	0	9	0	0	0	9	0	0
25	6	0	0	0	2	0	3	20	0	0
25	6	0	3	8	18	6	0	0	12	0
25	6	0	3	17	8	6	6	8	0	0
25	6	17	11	18	19	23	20	8	11	50
25	0	0	0	0	4	6	6	25	0	0
50	0	0	4	8	0	0	4	0	0	8
50	0	0	0	0	0	0	0	0	0	0
50	0	8	4	0	0	0	0	0	0	0
50	8	0	0	0	6	6	13	4	9	0
50	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
50	0	0	4	0	0	3	0	0	0	0
50	0	0	17	8	6	3	4	0	0	0
50	0	8	0	4	0	6	0	4	0	0
50	0	0	0	4	0	0	0	4	25	0
50	0	0	0	0	3	0	0	0	0	0
50	0	0	4	0	6	3	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
50	0	0	0	4	3	3	0	0	0	0
50	0	0	0	0	3	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
75	0	6	0	0	11	2	8	0	0	0
75	17	6	0	6	0	4	8	18	33	11
75	0	0	0	0	0	2	0	3	0	6
75	0	0	0	0	0	2	8	0	0	0
75	0	6	0	0	11	0	0	0	0	0
75	0	0	0	0	6	0	0	3	0	0
75	0	0	0	0	0	0	0	0	17	0
75	0	0	0	0	0	0	0	0	0	0
75	0	0	9	0	6	2	8	0	0	0
75	0	11	8	3	6	6	8	3	67	6
75	0	0	0	0	0	0	8	0	17	0
75	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	3	0	0
75	0	0	0	3	11	2	8	0	17	6
75	0	0	0	9	11	0	0	3	17	18
75	0	6	0	0	0	2	0	0	0	0
75	0	0	17	3	12	0	8	0	0	6
75	0	0	17	3	0	0	0	0	17	0
75	0	0	0	0	6	0	0	0	17	0

Appendix C

Subject Mean RTs and Errors for Experiment 3

Experiment 3: Numerical Task Subject Mean Rts

CP	Distance of 1		Distance of 3		Distance of 5	
	Incong	Cong	Incong	Cong	Incong	Cong
25	633	565	600	536	582	487
25	536	552	490	471	478	434
25	577	515	541	483	527	479
25	522	486	446	415	430	408
25	610	578	635	507	535	491
25	549	602	532	565	505	485
25	663	708	619	575	505	534
25	494	469	450	442	430	415
25	745	708	620	554	581	496
25	528	435	437	371	409	402
25	505	486	455	437	440	432
25	606	549	555	536	547	541
25	721	744	682	673	645	625
25	602	529	541	451	492	431
25	581	521	563	486	521	499
25	675	651	615	541	584	558
25	535	519	472	411	452	409
75	672	536	607	518	568	490
75	599	453	530	408	523	388
75	633	572	713	460	588	467
75	571	525	561	499	532	478
75	653	632	638	556	666	537
75	555	401	456	405	400	375
75	526	423	496	397	464	386
75	595	493	557	464	526	447
75	738	626	679	558	628	544
75	511	449	480	430	447	408
75	539	468	505	420	471	409
75	762	562	637	534	591	504
75	577	517	556	487	513	477
75	710	456	549	419	522	409
75	665	544	592	478	528	472
75	749	660	683	597	659	572
75	547	462	518	438	478	429

Experiment 3: Physical Task Subject Mean Rts

CP	Distance of 1		Distance of 3		Distance of 5	
	Incong	Cong	Incong	Cong	Incong	Cong
25	399	405	402	388	411	401
25	479	483	504	417	547	409
25	537	588	516	452	737	528
25	543	564	529	530	543	504
25	404	434	416	396	421	408
25	549	538	502	483	544	479
25	446	427	450	423	438	432
25	497	492	505	445	519	495
25	372	379	402	356	382	382
25	418	383	414	387	425	406
25	470	450	468	453	468	470
25	1151	938	1049	898	1159	940
25	492	437	457	439	487	421
25	431	445	439	424	450	384
25	512	503	485	523	506	489
25	605	601	601	581	602	602
75	594	664	664	573	683	586
75	509	425	458	402	457	393
75	706	615	550	656	689	605
75	467	452	591	468	641	465
75	479	474	618	445	526	437
75	432	426	503	431	443	427
75	508	457	539	461	542	445
75	620	556	619	548	587	569
75	550	464	549	443	579	435
75	561	543	585	561	578	543
75	639	583	743	568	708	594
75	531	442	504	447	524	411
75	404	399	413	409	424	407
75	443	422	466	436	475	426
75	435	407	450	407	458	398
75	538	453	499	436	519	442
75	432	400	455	396	438	373
75	403	381	439	395	407	377
75	401	393	410	404	421	390

Experiment 3: Numerical Task Subject Mean Errors

CP	Distance of 1		Distance of 3		Distance of 5	
	Incong	Cong	Incong	Cong	Incong	Cong
25	8	0	4	0	4	0
25	8	8	1	0	1	0
25	6	0	5	2	2	0
25	9	10	5	2	1	0
25	12	0	3	0	1	0
25	6	10	1	2	2	0
25	19	15	7	8	3	13
25	10	6	4	0	1	0
25	4	0	1	0	0	0
25	17	2	3	2	5	0
25	1	2	0	0	0	0
25	18	10	6	0	1	0
25	8	2	2	2	1	0
25	13	0	5	0	0	0
25	3	0	7	0	0	0
25	8	0	1	0	1	0
25	17	0	6	0	3	0
75	4	0	0	0	0	0
75	48	5	23	1	13	0
75	27	4	4	1	6	2
75	10	4	8	3	4	1
75	15	2	10	3	4	1
75	40	3	25	3	13	3
75	23	1	4	1	2	0
75	23	1	10	1	8	1
75	13	0	6	0	4	1
75	10	1	0	1	2	0
75	8	0	8	1	4	0
75	27	1	17	0	8	0
75	13	0	4	0	2	0
75	40	1	17	1	13	0
75	17	3	2	1	2	1
75	15	2	8	1	0	0
75	21	2	10	1	2	1

Experiment 3: Physical Task Subject Mean Errors

CP	Distance of 1		Distance of 3		Distance of 5	
	Incong	Cong	Incong	Cong	Incong	Cong
25	15	0	8	2	4	0
25	6	0	10	0	8	2
25	16	0	10	0	11	0
25	9	0	8	0	7	0
25	12	0	10	0	8	0
25	10	0	10	0	8	0
25	17	0	9	0	11	0
25	19	0	12	0	8	0
25	14	2	13	0	14	4
25	6	2	6	0	13	4
25	13	0	9	0	10	0
25	4	4	4	6	6	4
25	9	0	15	0	9	0
25	17	0	8	2	10	0
25	13	0	10	0	11	0
25	11	0	10	0	10	0
75	8	0	10	0	6	0
75	6	0	2	0	0	0
75	8	0	4	0	8	1
75	17	0	8	0	21	0
75	6	0	15	0	8	0
75	8	0	8	0	10	0
75	17	0	13	0	8	0
75	25	0	8	0	6	0
75	6	0	6	0	13	0
75	8	0	13	0	2	0
75	17	0	13	0	6	0
75	13	0	8	0	6	1
75	10	0	4	1	8	0
75	10	0	13	0	4	0
75	2	0	19	1	8	0
75	13	0	4	1	13	0
75	8	0	4	0	6	1
75	4	1	13	1	6	0
75	15	0	8	0	8	0

Appendix D

Subject Mean RTs and Errors for Experiment 4

Experiment 4 Mean RT for Numerical, Physical, and Stroop tasks at 25% and 75% congruent

Task	Numerical				Physical				Stroop			
CP	25		75		25		75		25		75	
	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong
	398	408	426	381	363	338	385	310	640	496	678	545
	485	498	495	457	426	437	437	417	750	652	795	711
	532	553	633	461	414	464	399	378	848	764	954	657
	517	402	408	336	327	316	341	313	443	451	453	421
	501	436	554	448	488	403	390	399	943	772	1361	948
	504	473	686	423	393	384	456	352	1018	1024	1589	750
	445	457	481	370	370	370	391	354	765	704	573	591
	504	455	582	413	385	391	394	384	1429	1370	1582	1069
	425	408	612	349	346	339	321	322	684	637	703	529
	405	365	429	382	365	344	374	373	699	623	713	568
	513	525	496	453	432	435	471	417	821	667	859	762
	460	441	504	393	371	357	373	344	643	600	687	605
	395	379	483	366	281	284	313	308	726	900	718	573
	633	624	655	519	369	375	373	375	1161	776	1246	775
	503	461	509	411	460	441	456	411	1131	1005	965	871
	401	400	430	343	321	317	327	328	786	581	773	615
	439	508	465	394	346	318	365	341	931	620	879	649
	503	522	588	433	402	372	364	346	1165	857	1264	892
	379	339	375	320	305	346	271	284	624	622	581	550
	432	356	537	359	310	301	360	309	1009	661	1261	738
	457	481	523	420	359	341	435	364	758	658	924	700
	518	480	559	462	357	345	344	332	630	618	657	646
	556	529	560	486	484	506	506	450	817	781	976	683
	381	316	376	320	316	326	303	312	591	561	588	501
	510	424	570	385	359	352	334	345	876	718	1074	688
	451	404	522	404	386	369	371	345	744	586	829	614
	662	621	752	625	460	468	412	420	947	786	882	764
	450	419	484	391	405	407	439	387	905	759	1002	703
	471	411	496	403	359	354	369	352	658	597	858	628
	507	530	567	460	421	384	376	354	845	589	861	559
	399	335	403	322	309	294	309	290	466	444	406	428
	361	348	394	290	314	330	324	293	683	505	737	563
	513	472	598	416	326	322	320	309	684	706	799	627
	396	381	409	383	328	341	376	322	668	672	874	614
	491	474	483	462	337	315	315	313	703	583	781	640
	401	368	450	357	340	328	375	329	725	627	784	541
	362	334	422	325	287	284	273	272	563	477	606	463
	430	423	451	348	346	334	334	331	1046	969	1245	837
	464	382	501	387	369	366	375	362	750	732	954	585
	480	426	430	417	440	421	563	437	785	595	652	560
	386	372	411	359	319	322	311	309	474	439	466	470
	468	506	543	423	444	396	501	390	1179	802	1245	755
	413	384	443	382	330	324	307	300	564	535	671	515
	512	479	567	419	402	399	399	392	1132	1090	1064	836
	572	513	633	479	371	366	367	358	872	712	951	636
	392	370	392	350	339	337	357	328	615	503	749	528
	473	455	617	468	352	349	358	339	561	573	590	610

440	417	492	377	443	381	408	361	813	801	648	692
396	350	473	331	316	302	345	311	609	509	614	452
451	445	485	400	410	392	401	373	916	721	959	639
381	352	443	338	296	286	315	302	543	600	498	502
422	418	473	412	368	331	432	385	818	710	746	704
589	556	561	457	400	429	411	397	850	889	999	738
419	366	480	322	348	325	409	319	568	488	608	488
478	445	541	398	399	348	403	353	973	772	830	659
657	559	718	573	513	486	540	390	813	686	873	594
517	543	462	413	352	346	362	344	964	878	887	882
497	503	503	421	441	407	538	424	863	759	1016	916
467	403	492	377	367	358	392	352	1080	620	1111	629
482	430	552	387	351	340	408	353	878	603	1015	624
660	565	804	506	445	417	529	442	924	708	1145	1190
571	475	647	428	350	353	350	338	615	563	809	531
621	672	772	610	489	448	447	432	1236	922	982	739
465	419	593	414	373	373	406	372	840	835	858	764
408	400	490	404	404	378	480	377	906	782	1081	777
392	363	471	371	359	332	350	329	560	488	558	476
554	503	580	465	398	435	443	388	808	641	987	659
514	469	567	461	339	321	326	325	575	498	674	528
543	530	527	467	400	366	412	360	577	654	706	577
486	467	494	421	348	349	413	354	710	520	768	586
579	529	581	520	484	430	500	430	857	672	919	683
492	452	474	395	390	376	477	406	716	677	764	576
596	637	683	555	595	492	572	419	878	672	916	913
441	414	492	364	343	339	338	326	633	497	572	502
463	436	561	407	524	373	515	381	818	547	815	605
503	483	579	478	398	385	372	363	766	776	1002	832
415	454	442	388	326	329	328	295	574	525	711	499
432	415	454	390	543	481	533	397	866	757	1037	647
437	458	463	401	350	333	368	369	660	591	612	527
450	405	599	434	427	451	439	441	790	707	958	758
426	354	409	358	363	345	347	309	565	513	655	581
438	494	491	403	342	330	366	366	639	561	637	516
437	487	483	444	338	307	341	332	1082	862	1113	934
460	460	522	380	396	379	375	354	797	752	872	772
485	433	531	422	417	384	468	382	780	694	809	678
399	422	427	349	318	319	318	315	546	507	581	450
477	500	573	479	416	419	434	390	821	679	1019	812
438	382	455	372	336	332	339	329	497	560	603	593
421	383	468	393	368	364	380	344	815	734	867	729
461	448	481	407	331	342	380	350	679	650	792	679
428	373	462	389	311	305	305	300	920	1014	903	815
468	490	556	391	392	369	350	340	895	636	901	633
457	451	443	382	427	396	572	386	874	885	671	718
569	527	574	495	405	401	435	410	858	745	1142	693
491	392	543	412	409	368	511	352	686	584	702	592
487	447	802	404	422	410	411	396	1060	816	912	652
408	376	464	362	359	340	357	334	640	564	502	513
468	481	549	416	352	349	366	334	881	894	1059	762

Experiment 4 Mean% Errors for Numerical, Physical, and Stroop tasks at 25% and 75% congruent

Task	Numerical				Physical				Stroop			
CP	25		75		25		75		25		75	
	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong	Incong	Cong
	4	4	7	2	8	0	4	4	13	9	21	4
	0	0	4	1	0	0	0	0	10	0	0	0
	1	0	7	0	0	0	4	1	4	4	17	3
	12	0	19	4	11	0	4	0	6	5	14	10
	0	0	12	1	0	0	4	0	3	0	8	0
	6	4	19	0	5	4	7	2	7	0	4	1
	9	0	23	5	11	4	7	6	14	13	23	16
	1	0	4	0	3	0	0	1	6	0	0	0
	14	11	48	0	4	0	8	4	10	8	22	12
	2	0	4	0	0	0	0	0	9	0	4	1
	1	0	4	1	1	0	7	0	11	8	4	0
	1	4	11	0	1	0	4	0	3	4	17	3
	3	0	18	1	18	21	14	13	15	17	17	10
	2	11	21	0	4	7	4	6	18	13	17	8
	1	4	4	2	6	0	11	1	8	8	4	3
	11	0	27	1	10	4	4	2	6	0	13	1
	3	0	26	0	4	0	11	1	4	0	4	0
	4	0	19	1	4	4	15	4	20	0	13	7
	10	7	22	8	10	15	19	16	14	8	30	6
	10	4	37	1	3	7	0	0	13	0	8	0
	1	0	7	0	1	7	4	0	10	13	30	4
	1	0	0	0	0	0	0	1	0	5	0	3
	1	0	4	0	0	4	7	0	22	21	29	1
	8	0	19	0	6	4	11	1	9	9	22	6
	6	0	18	1	1	8	4	2	7	0	22	1
	6	0	19	0	8	0	7	1	4	0	17	1
	5	0	0	0	4	7	4	4	3	4	4	0
	4	0	26	0	0	0	7	0	7	0	13	1
	2	0	7	0	0	0	0	0	3	8	4	6
	1	4	7	2	5	4	8	1	9	0	0	0
	14	0	32	0	7	4	11	6	25	21	33	33
	13	0	21	1	4	0	11	5	16	0	21	1
	5	8	18	0	1	0	0	2	6	13	4	6
	1	0	4	2	6	0	4	1	11	0	17	3
	2	0	7	0	1	0	0	0	3	0	8	4
	1	0	7	0	2	0	0	0	3	0	4	1
	7	4	31	0	8	7	19	2	11	0	4	10
	6	0	29	0	0	0	0	1	8	0	8	1
	1	0	4	0	1	0	0	0	1	4	8	0
	10	22	41	4	5	4	29	9	7	14	8	6
	5	0	15	1	0	0	4	0	7	4	0	3
	1	0	4	0	6	0	11	2	4	0	0	0
	4	0	11	0	3	7	15	2	13	21	21	12
	2	0	0	1	0	0	0	0	4	9	0	1
	2	0	8	0	0	4	0	0	3	0	0	0
	2	0	0	0	0	0	0	1	0	0	4	0
	1	0	11	0	0	0	0	1	0	0	0	6

2	0	7	0	0	0	4	1	6	0	5	4
1	0	4	0	1	0	4	0	10	0	17	1
4	0	4	0	1	0	0	1	18	4	21	4
6	0	22	1	1	0	7	0	7	4	0	9
0	0	8	1	1	0	11	1	6	4	0	7
7	4	30	5	4	7	4	3	7	13	8	3
1	0	4	0	0	0	4	0	8	0	9	3
2	0	22	0	5	0	7	1	6	0	9	6
5	0	8	1	5	0	0	3	4	4	0	4
1	4	0	0	4	0	0	2	0	0	0	3
0	0	4	1	1	0	14	1	1	0	9	4
5	0	19	0	1	0	0	4	6	0	10	0
5	4	14	1	4	0	8	2	9	0	4	0
6	4	11	0	0	0	8	0	3	0	9	4
9	0	15	1	4	0	0	0	6	8	8	4
5	0	11	1	8	0	7	1	6	9	26	0
0	0	11	0	0	0	4	0	4	0	0	1
0	0	0	1	1	0	4	0	3	0	4	0
2	0	4	1	4	4	11	0	13	0	8	1
4	0	0	1	1	0	4	0	3	0	17	2
2	0	4	0	1	0	4	0	0	0	4	0
1	4	0	0	1	0	7	0	3	4	0	3
3	0	15	0	0	0	4	1	4	4	17	4
1	0	8	0	0	0	11	1	3	0	4	0
0	0	4	0	1	0	4	0	3	8	4	0
1	4	8	0	4	0	7	0	3	9	9	0
6	0	14	1	3	0	0	2	13	0	0	4
0	0	4	1	1	4	4	1	4	5	0	3
0	0	14	0	0	0	0	0	1	8	4	0
4	4	21	0	6	4	4	3	10	0	29	3
4	4	11	2	11	14	19	3	27	4	33	12
1	0	4	1	0	0	0	0	4	4	13	6
0	0	11	0	0	0	0	0	4	0	0	6
6	4	16	0	5	0	11	2	14	14	21	9
3	0	14	0	1	0	0	1	4	0	9	2
0	4	4	0	4	0	7	1	1	5	4	1
4	0	8	0	1	4	4	2	7	4	19	8
0	0	7	0	2	0	7	0	1	0	0	0
0	0	4	0	1	0	0	0	0	0	0	1
5	4	4	2	1	0	7	0	7	5	17	6
2	0	18	0	1	0	4	1	6	9	13	3
1	0	8	0	4	4	0	0	6	0	8	1
1	0	7	0	1	0	0	0	4	0	17	3
4	0	19	1	2	4	4	0	6	8	9	1
4	0	21	0	2	0	0	0	14	0	17	0
4	4	18	0	4	0	4	2	14	17	9	9
0	0	12	0	2	0	0	0	9	0	13	0
3	0	7	0	4	0	7	0	1	9	8	8
7	7	44	8	4	0	4	3	16	0	23	10
2	0	7	1	0	0	7	0	1	0	5	4
1	0	7	0	0	0	0	0	6	0	13	0

Appendix E

Subject Difference Scores for Experiment 4

Experiment 4: Difference in Proportion effects (in ms, 75%-25%) and survey scores

Numerical	Physical	Stroop	CFQ	NFC
56	56	-8	39	56
49	32	-22	42	62
194	72	212	49	48
-36	18	39	35	44
46	-94	243	41	54
231	94	842	54	48
123	39	-62	17	45
122	16	453	61	42
247	-9	112	31	43
9	-18	64	25	50
59	58	-52	40	57
89	16	38	24	47
100	5	303	41	53
127	7	90	76	62
56	24	-31	40	53
87	-5	-41	27	63
140	-3	-82	44	60
176	-12	76	46	55
15	35	33	63	45
100	45	176	48	54
128	56	132	52	66
59	1	-1	49	54
51	84	278	63	47
-8	2	60	43	43
98	-17	235	45	55
67	9	57	44	52
86	4	-43	44	62
63	53	160	53	52
31	12	178	36	46
129	-17	47	53	52
11	4	-22	47	53
92	46	3	28	61
138	7	198	36	39
14	66	266	38	35
10	-21	22	65	29
59	35	143	58	52
68	-2	61	24	57
97	-10	330	67	42
33	12	359	26	52
-42	111	-100	81	44
42	6	-39	16	36
161	63	118	23	58
35	2	131	41	66
113	4	190	39	46
95	7	144	24	43
20	28	112	41	23
132	19	-9	23	50
92	-14	-55	51	42

97	20	51	61	55
80	9	136	61	47
74	4	56	58	50
57	12	-69	63	65
71	38	316	20	47
106	68	40	33	41
112	-1	-15	22	44
53	125	151	61	60
76	12	-84	34	59
88	88	-4	41	54
53	31	11	51	50
114	46	119	52	55
215	60	-256	60	35
124	14	229	54	47
207	-37	-46	62	41
136	35	87	36	45
80	75	182	38	41
71	-7	8	33	48
66	91	154	58	44
61	-17	72	51	46
47	20	206	46	51
52	62	5	47	36
10	16	51	36	55
40	57	154	43	40
177	50	-198	56	42
101	7	-67	47	39
118	-13	-65	52	49
80	-6	179	54	58
94	36	156	43	52
47	76	286	46	41
83	-18	28	49	43
119	23	117	30	60
-21	20	6	52	36
145	-14	42	31	65
85	-22	-66	43	44
144	5	60	59	50
55	60	51	13	50
101	3	95	38	59
117	48	35	32	42
27	5	73	41	49
38	32	57	19	60
64	42	80	49	46
20	-2	186	43	38
200	-14	13	28	49
56	156	-22	59	52
38	22	312	41	62
27	120	9	41	36
323	2	30	55	43
69	5	-88	29	50
147	30	303	43	47

Appendix F

Component Score Inter-correlations and Reliabilities

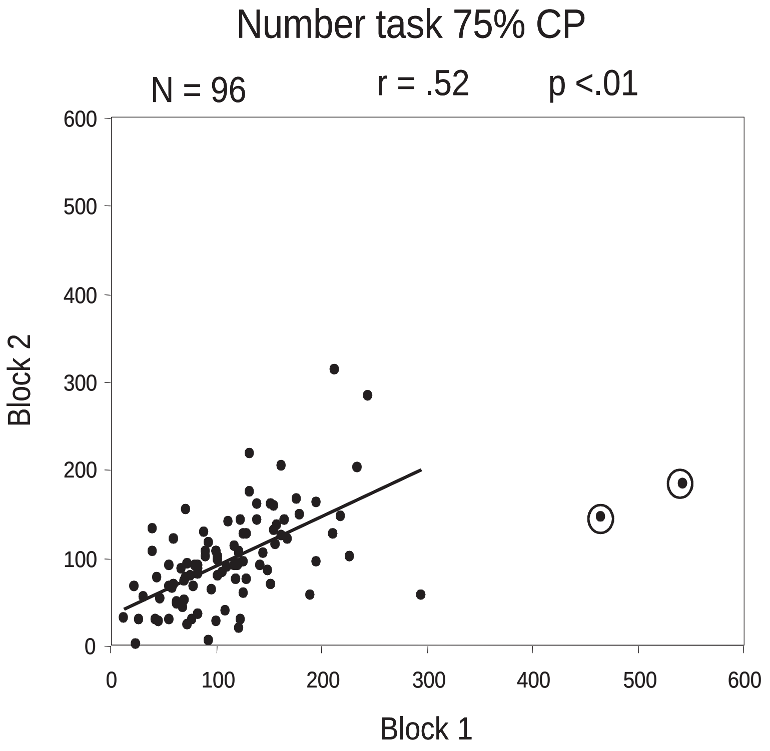
Component Score Reliabilities and Inter -correlations for all three tasks

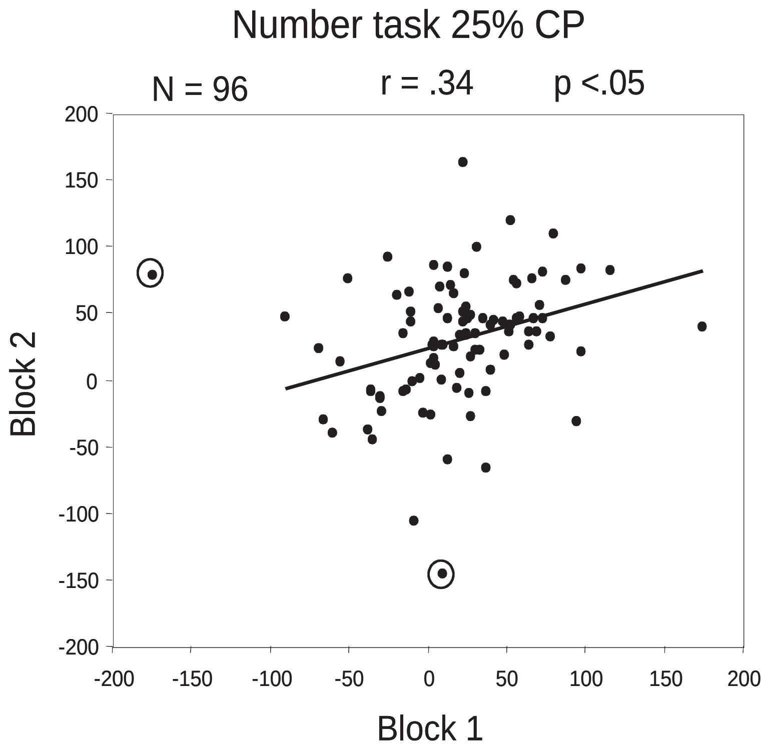
	N CB1 75	N IB1 25	N CB1 25	N IB2 75	N CB2 75	N IB2 25	N CB2 25	P IB1 75	P CB1 75	P IB1 25	P CB1 25	P IB2 75	P CB2 75	P IB2 25	P CB2 25	S IB1 75	S CB1 75	S IB1 25	S CB1 25	S IB2 75	S CB2 75	S IB2 25	S CB2 25
N IB1 75	.706**	.678**	.588**	.740**	.622**	.750**	.570**	.390**	.519**	.566**	.537**	.357**	.512**	.495**	.511**	.464**	.488**	.479**	.301**	.395**	.410**	.405**	.323**
N CB1 75		.769**	.784**	.696**	.858**	.834**	.723**	.544**	.649**	.657**	.675**	.405**	.591**	.622**	.599**	.340**	.447**	.359**	.197	.353**	.402**	.359**	.313**
N IB1 25			.801**	.650**	.747**	.798**	.615**	.478**	.569**	.552**	.593**	.347**	.563**	.513**	.580**	.394**	.412**	.340**	.212*	.285**	.324**	.351**	.341**
N CB1 25				.658**	.797**	.743**	.670**	.445**	.536**	.575**	.591**	.319**	.511**	.545**	.580**	.395**	.455**	.427**	.258*	.317**	.390**	.391**	.360**
N IB2 75					.756**	.764**	.642**	.305**	.451**	.457**	.468**	.221*	.420**	.385**	.455**	.471**	.452**	.473**	.372**	.403**	.375**	.398**	.378**
N CB2 75						.833**	.788**	.453**	.642**	.590**	.622**	.323**	.574**	.541**	.587**	.344**	.483**	.395**	.279**	.359**	.450**	.384**	.368**
N IB2 25							.821**	.472**	.614**	.587**	.618**	.389**	.567**	.536**	.568**	.456**	.526**	.421**	.262**	.370**	.453**	.413**	.394**
N CB2 25								.437**	.620**	.524**	.535**	.332**	.513**	.455**	.473**	.404**	.483**	.457**	.283**	.315**	.451**	.434**	.358**
P IB1 75									.786**	.797**	.721**	.723**	.737**	.741**	.679**	.339**	.378**	.321**	.147	.256*	.382**	.353**	.294**
P CB1 75										.797**	.786**	.615**	.812**	.714**	.752**	.415**	.514**	.480**	.272**	.355**	.476**	.468**	.387**
P IB1 25											.870**	.718**	.783**	.892**	.790**	.351**	.436**	.458**	.255*	.354**	.449**	.414**	.349**
P CB1 25												.611**	.783**	.792**	.801**	.345**	.427**	.405**	.254*	.325**	.412**	.360**	.383**
P IB2 75													.756**	.736**	.645**	.313**	.366**	.338**	.277**	.221*	.337**	.305**	.206*
P CB2 75														.747**	.799**	.437**	.524**	.466**	.411**	.358**	.507**	.442**	.440**
P IB2 25															.826**	.343**	.430**	.415**	.225*	.333**	.429**	.397**	.345**
P CB2 25																.408**	.446**	.458**	.336**	.385**	.417**	.396**	.414**
S IB1 75																	.733**	.798**	.602**	.686**	.579**	.772**	.683**
S CB1 75																		.769**	.706**	.666**	.863**	.721**	.745**
S IB1 25																			.725**	.743**	.644**	.798**	.719**
S CB1 25																				.562**	.604**	.684**	.778**
S IB2 75																					.728**	.639**	.655**
S CB2 75																						.649**	.675**
S IB2 25																							.785**

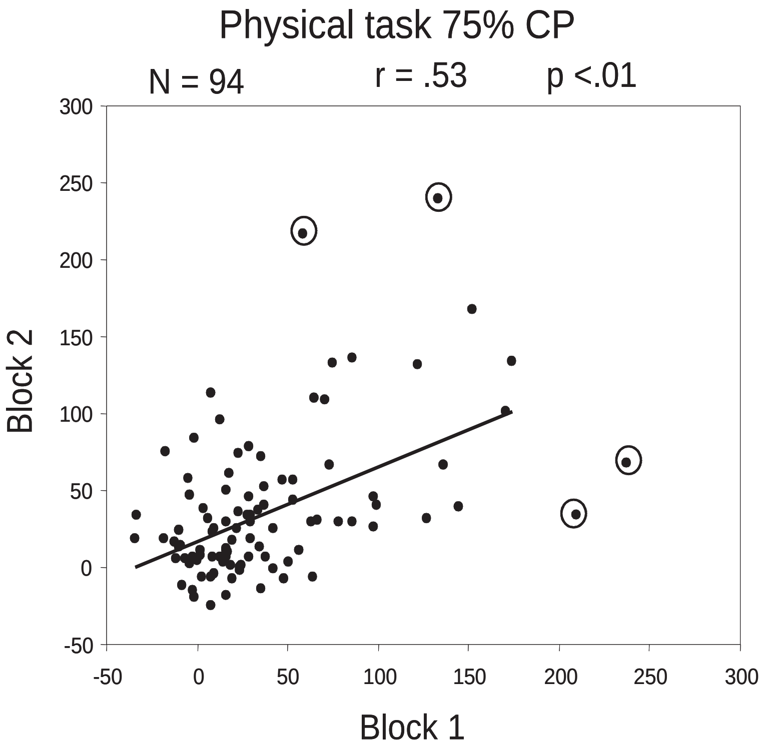
N(Numerical task) P(Physical task) S(Stroop task); I(incongruent) C(congruent)/ B1(Block 1) B2(Block 2); 25(25% Congruent condition) 75(75% Congruent Condition)

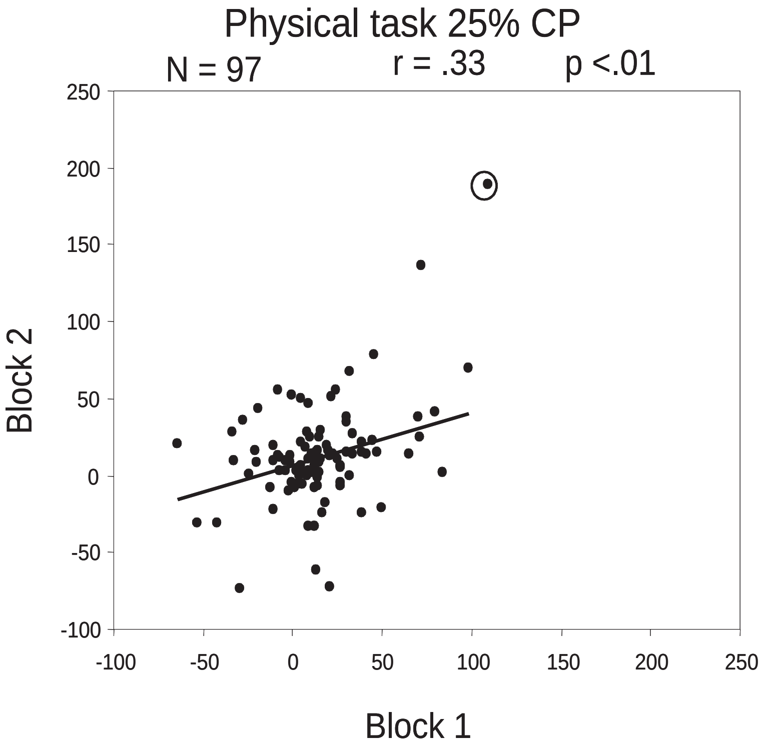
Appendix G

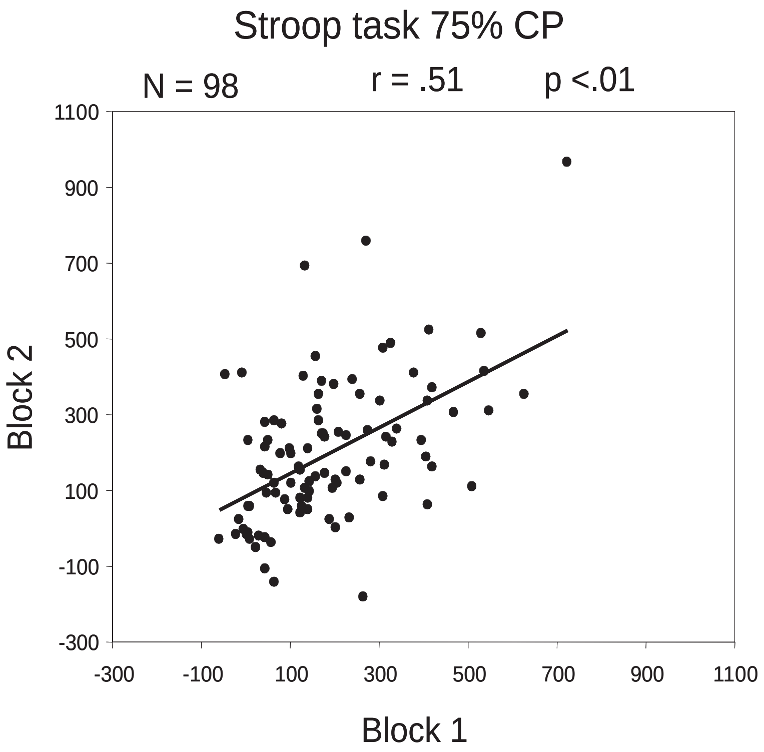
Scatterplots Depicting Task Reliabilities for Experiment 4

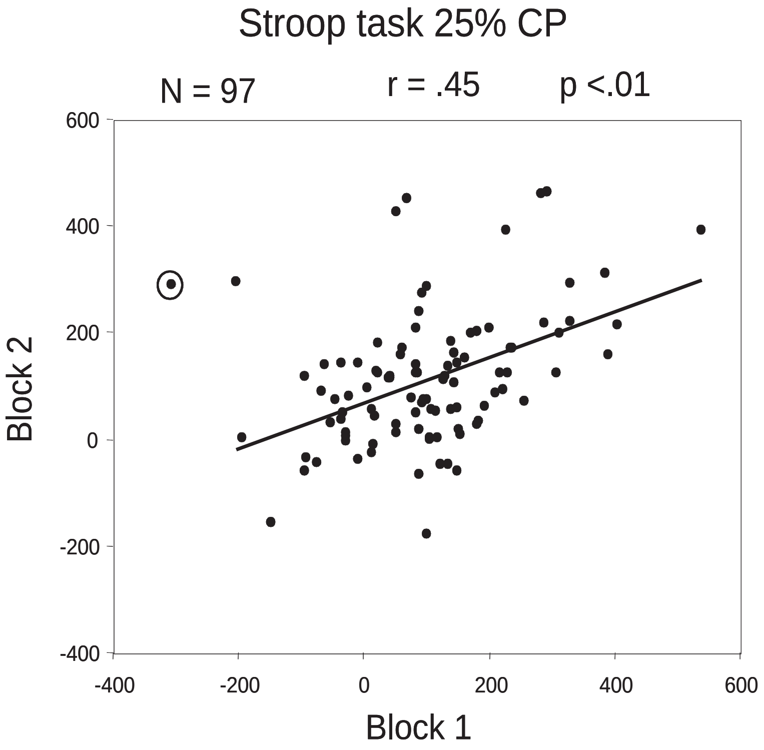





Physical task 75% CP
N = 94
r = .53
p <.01
Block 2
300
250
200
150
100
50
0
-50
-50
0
50
100
150
200
250
300
Block 1

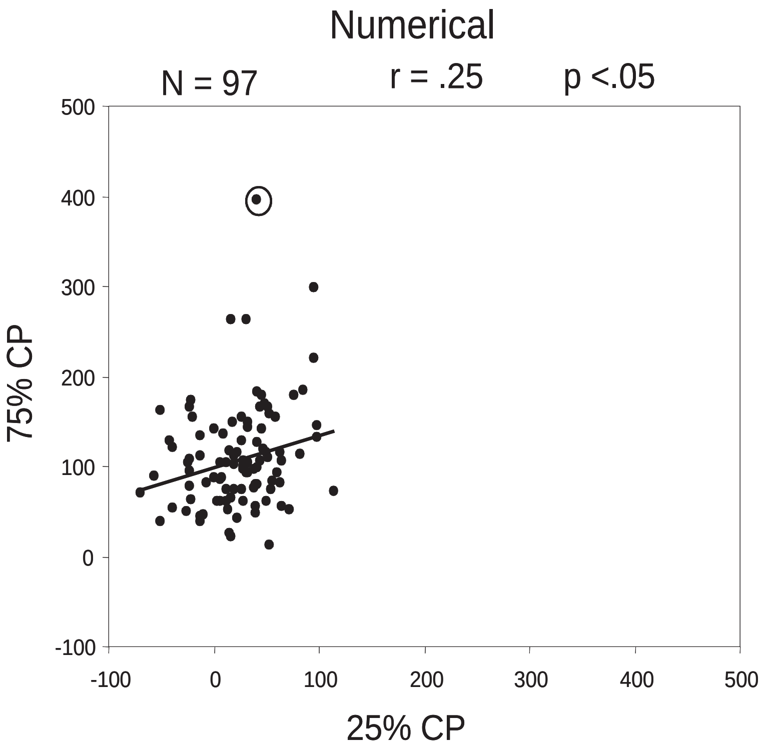

Physical task 25% CP
N = 97
r = .33
p <.01
Block 2
250
200
150
100
50
0
-50
-100
-100
-50
0
50
100
150
200
250
Block 1

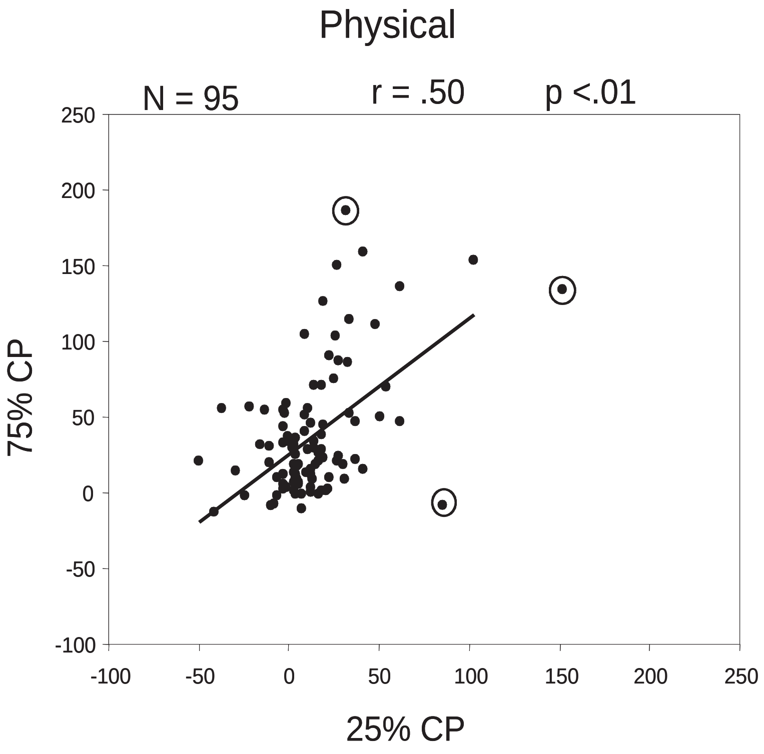

Stroop task 75% CP
N = 98
r = .51
p <.01
1100
900
700
500
300
100
-100
-300
-300
-100
100
300
500
700
900
1100
Block 2
Block 1

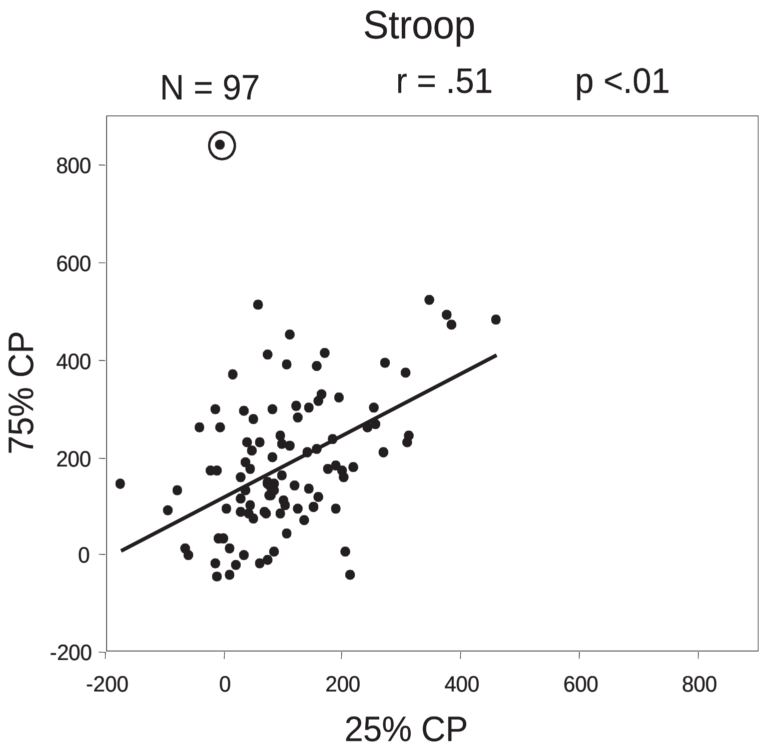

Stroop task 25% CP
N = 97
r = .45
p <.01
600
400
200
0
-200
-400
-400
-200
0
200
400
600
Block 2
Block 1

Appendix H

Scatterplots Depicting Within Task / Cross Congruency Proportion Relations

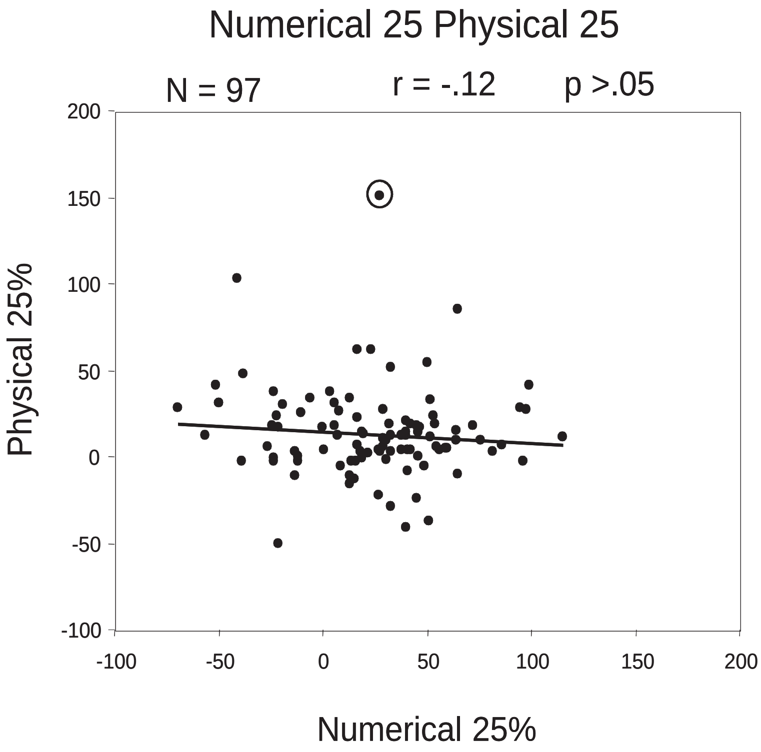


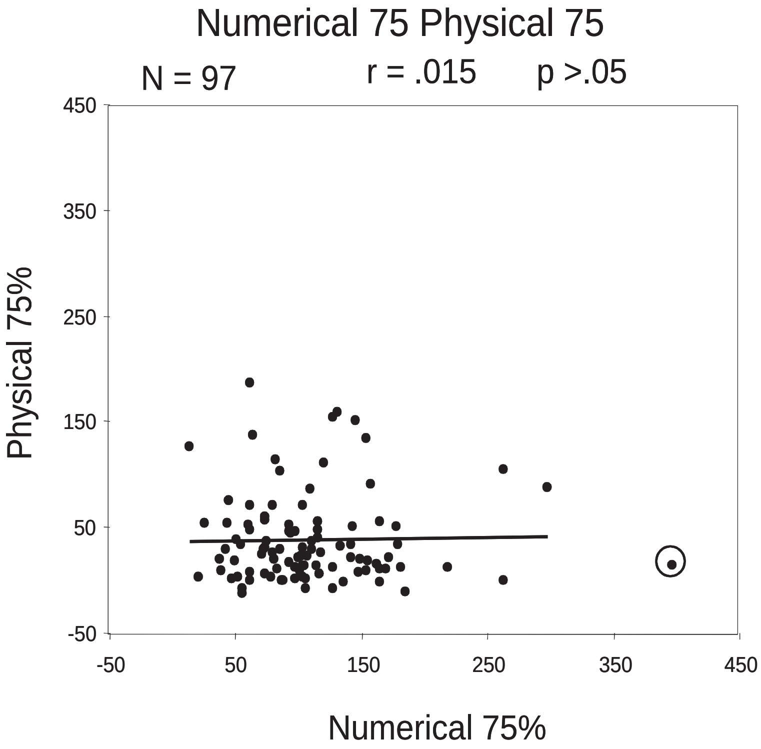


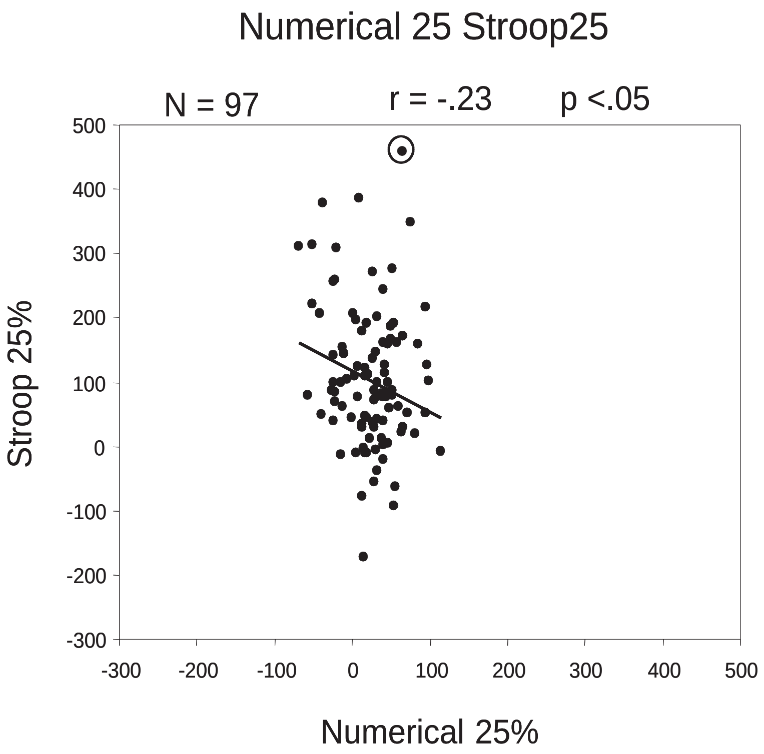

Stroop
N = 97
r = .51
p <.01
800
600
400
200
0
-200
75% CP
-200
0
200
400
600
800
25% CP

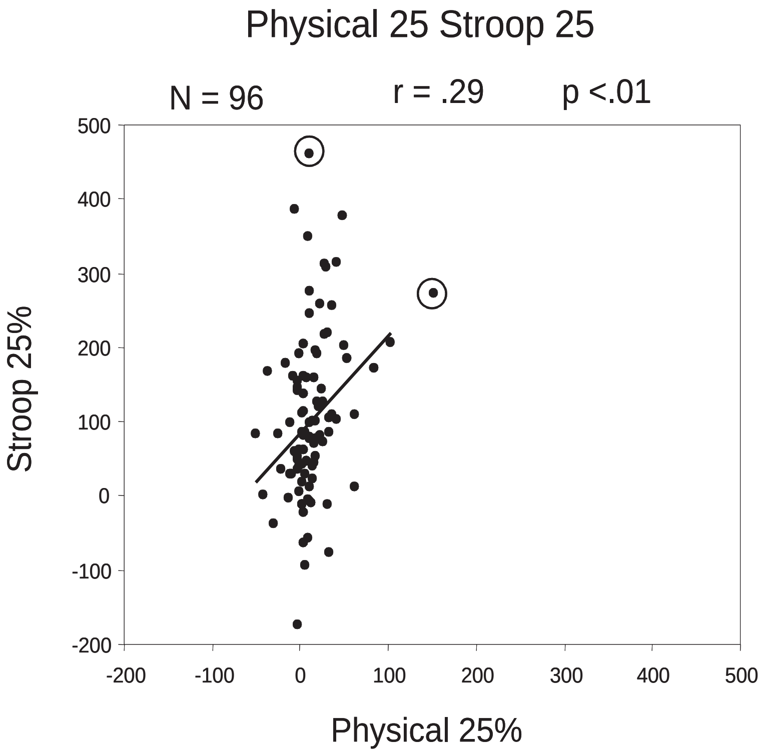
Appendix I

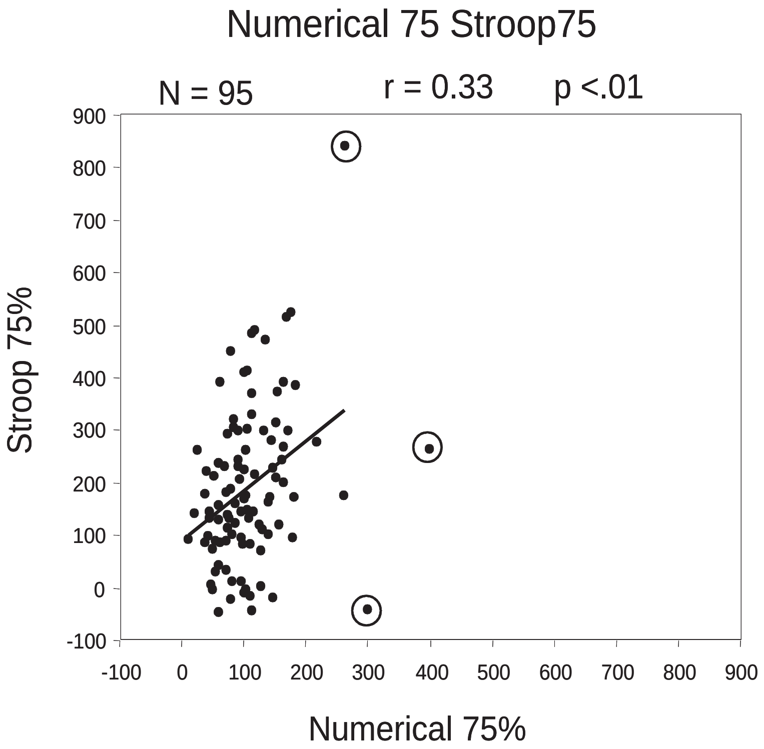
Scatterplots Depicting Cross Task / Within Congruency Proportion Relations

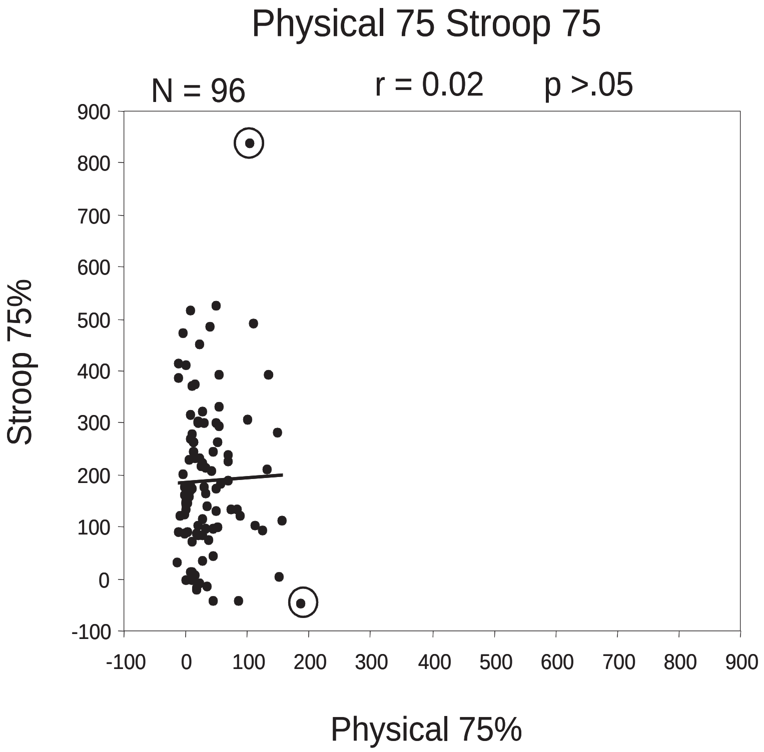





Numerical 25 Stroop25
N = 97
r = -.23
p <.05
500
400
300
200
100
0
-100
-200
-300
Stroop 25%
-300
-200
-100
0
100
200
300
400
500
Numerical 25%

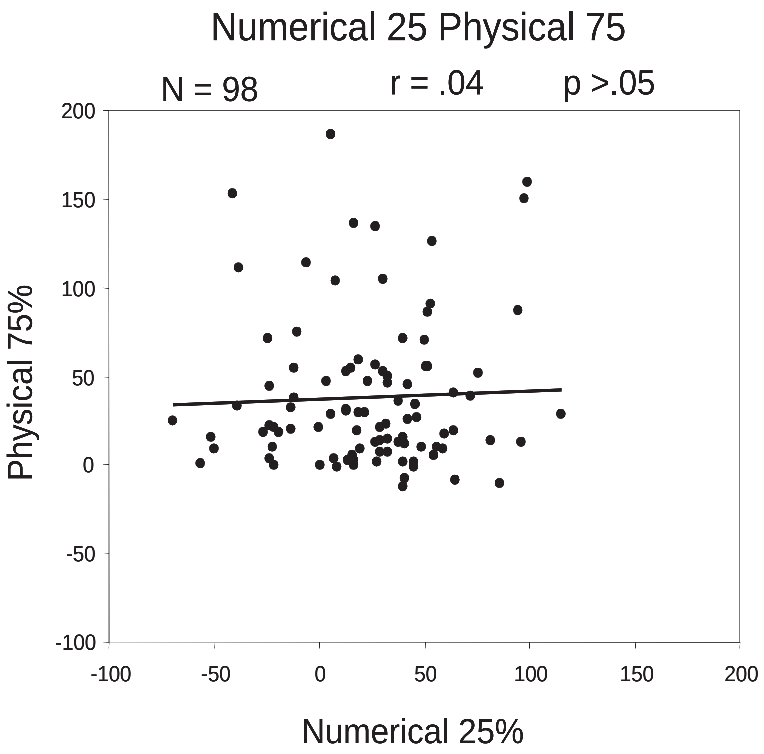

Physical 25 Stroop 25
N = 96
r = .29
p <.01
500
400
300
200
100
0
-100
-200
Stroop 25%
-200
-100
0
100
200
300
400
500
Physical 25%

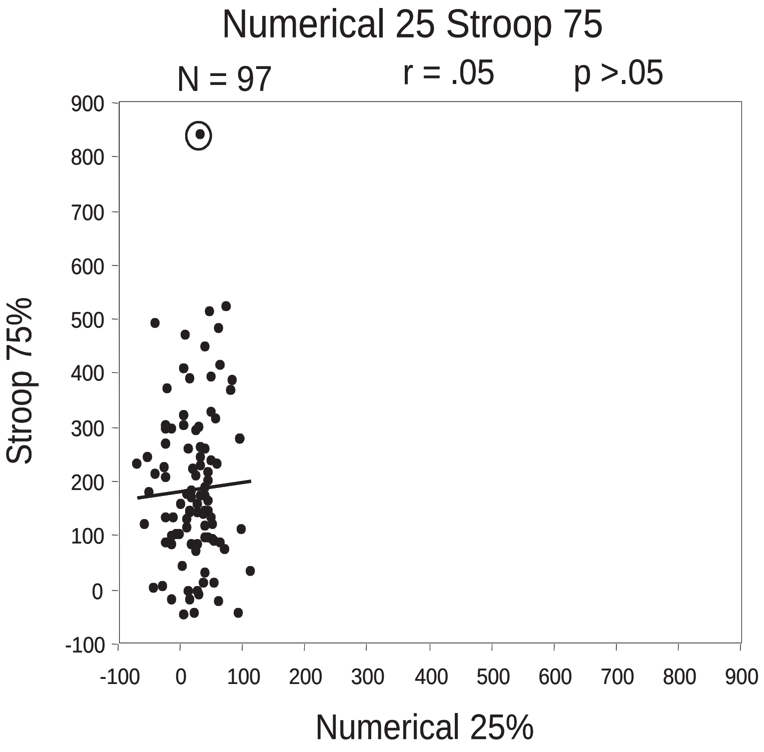

Numerical 75 Stroop75
N = 95
r = 0.33
p <.01
Stroop 75%
900
800
700
600
500
400
300
200
100
0
-100
-100
0
100
200
300
400
500
600
700
800
900
Numerical 75%

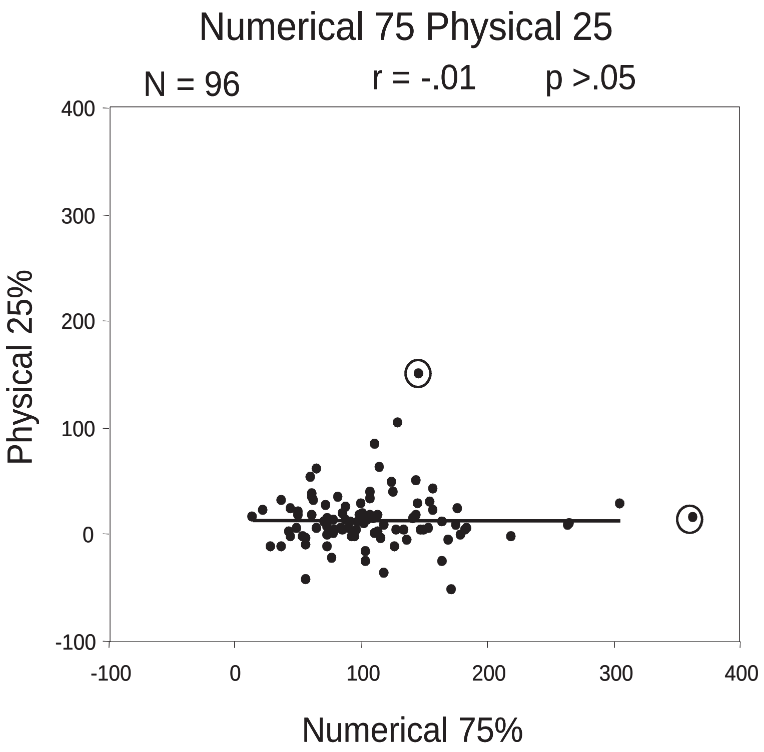

Physical 75 Stroop 75
N = 96
r = 0.02
p >.05
Stroop 75%
900
800
700
600
500
400
300
200
100
0
-100
-100
0
100
200
300
400
500
600
700
800
900
Physical 75%

Appendix J

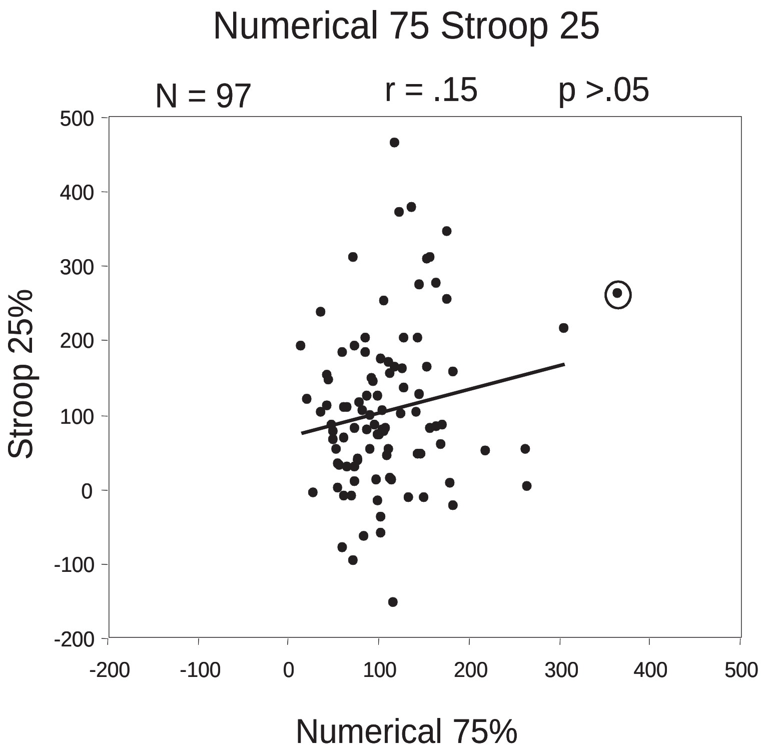
Scatterplots Depicting Cross Task / Cross Congruency Proportion Relations



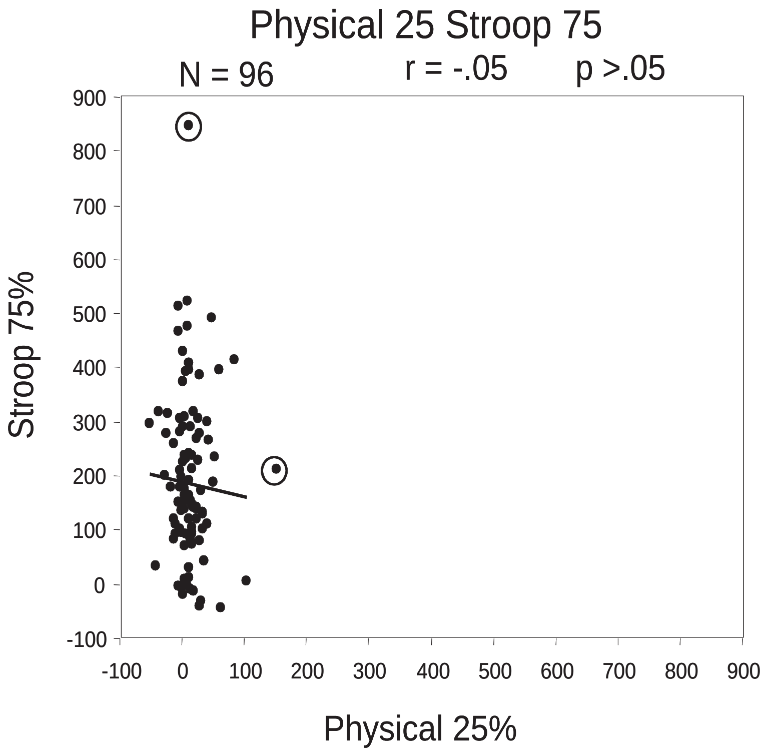


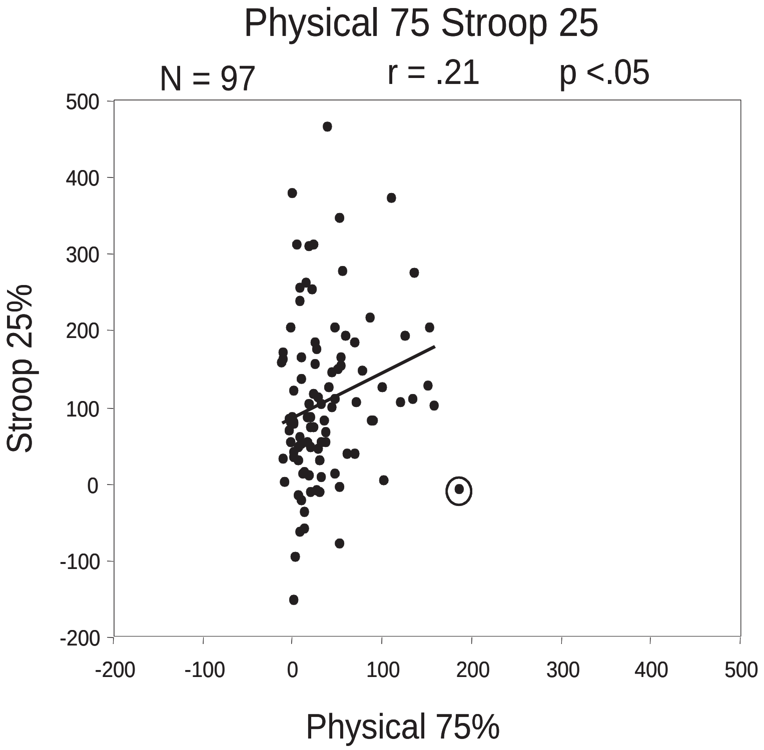

Numerical 75 Physical 25

N = 96 r = -.01 p >.05


Numerical 75 Stroop 25

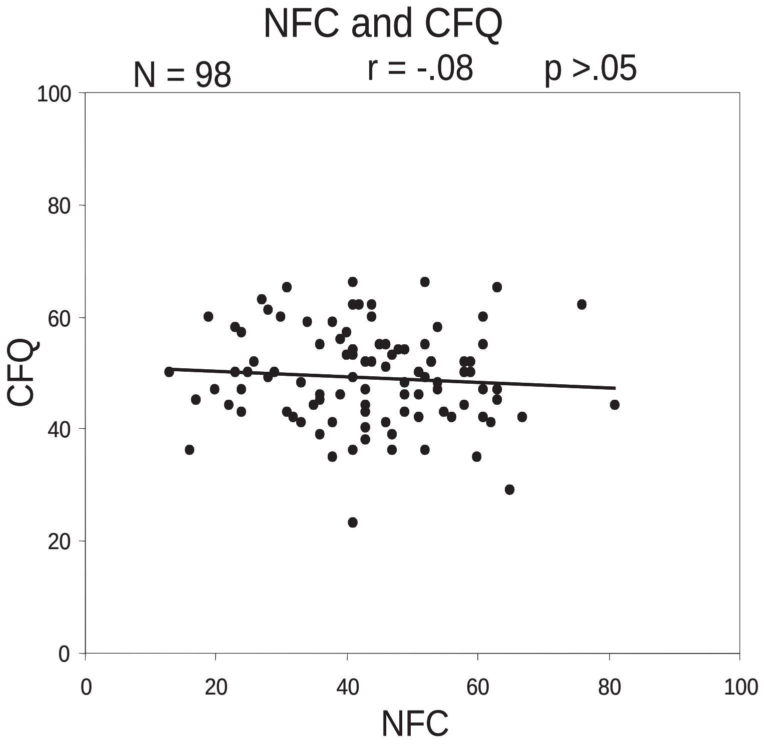
N = 97 r = .15 p >.05

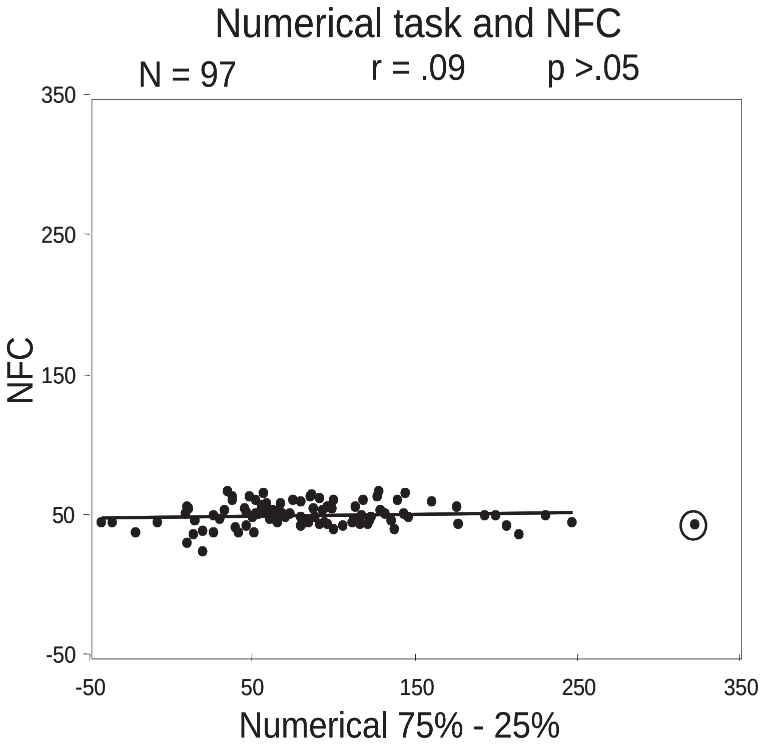

Physical 25 Stroop 75
N = 96
r = -.05
p >.05
Stroop 75%
900
800
700
600
500
400
300
200
100
0
-100
-100
0
100
200
300
400
500
600
700
800
900
Physical 25%

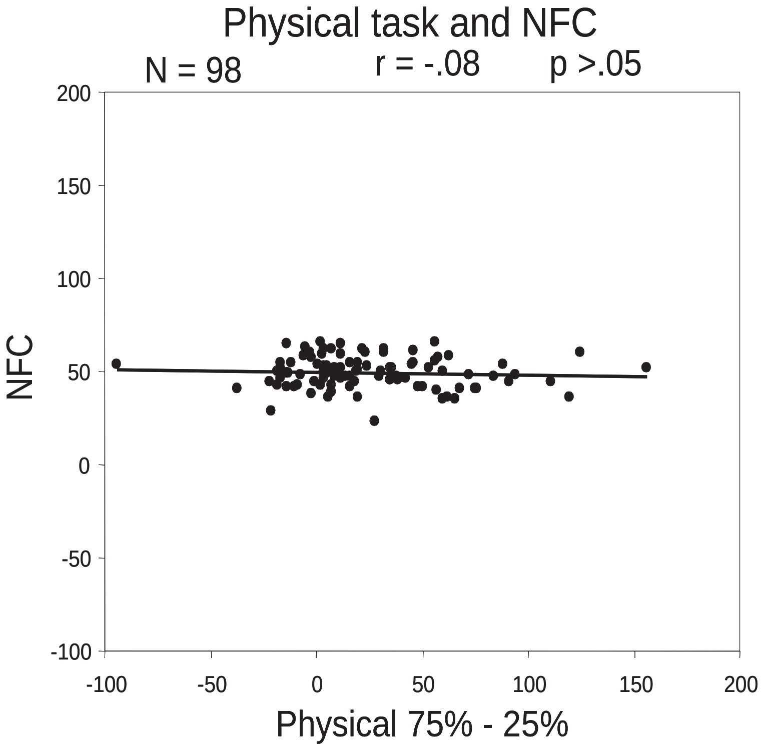

Physical 75 Stroop 25
N = 97
r = .21
p <.05
Stroop 25%
500
400
300
200
100
0
-100
-200
-200
-100
0
100
200
300
400
500
Physical 75%

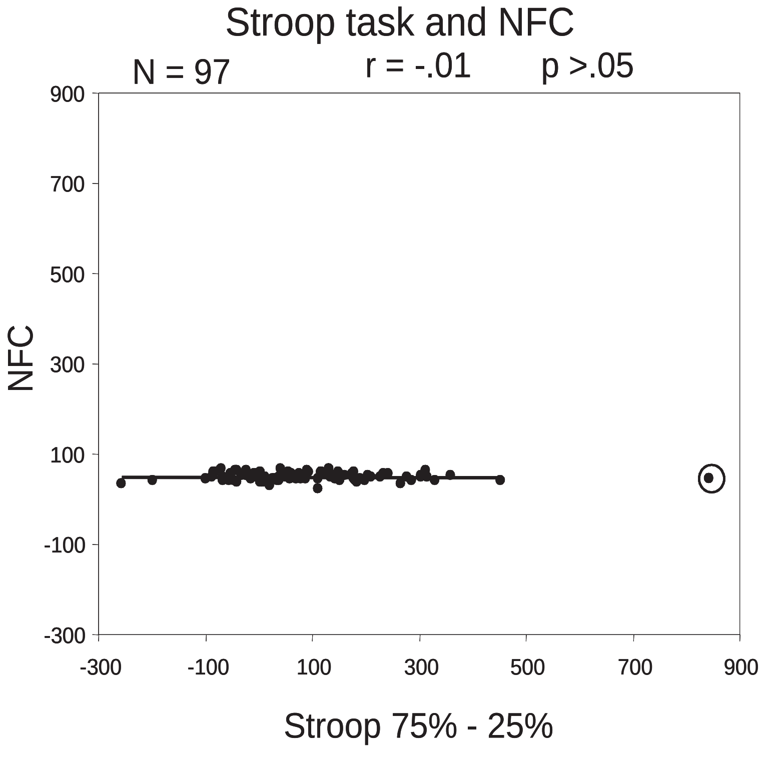
Appendix K

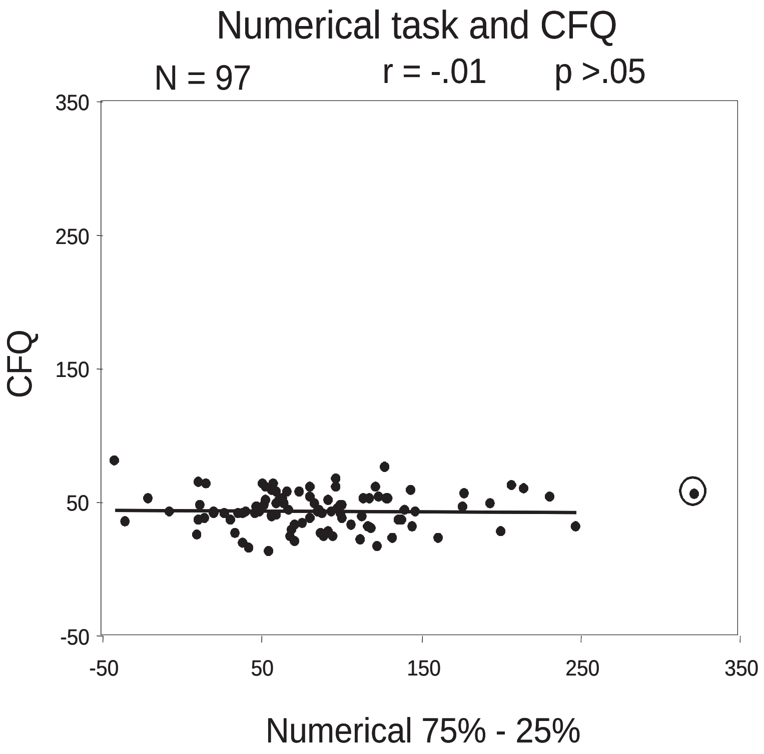
Scatterplots Depicting Relations between CP Difference Scores and NFC and CFQ scales

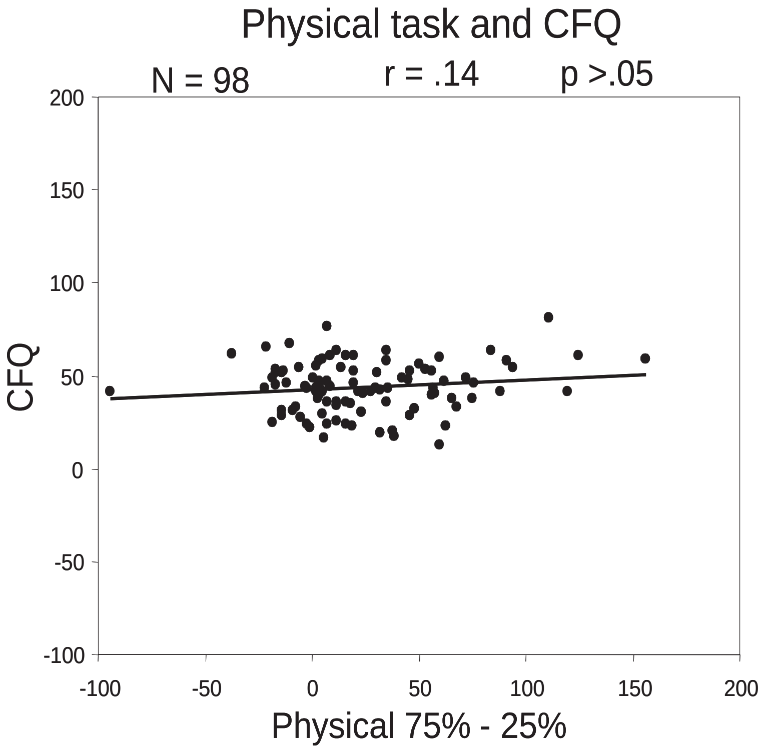


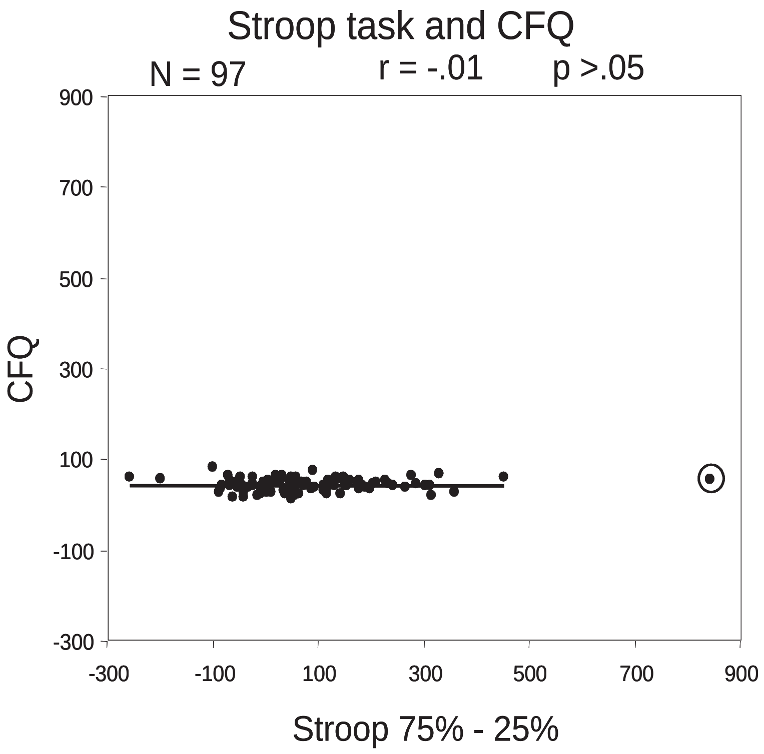


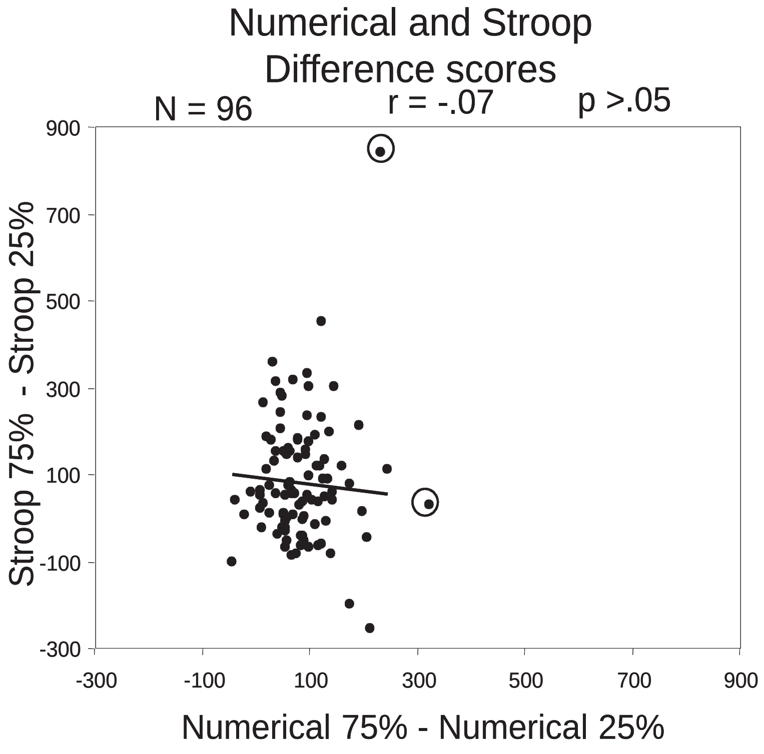

Physical task and NFC
N = 98
r = -.08
p >.05
200
150
100
50
0
-50
-100
NFC
-100
-50
0
50
100
150
200
Physical 75% - 25%

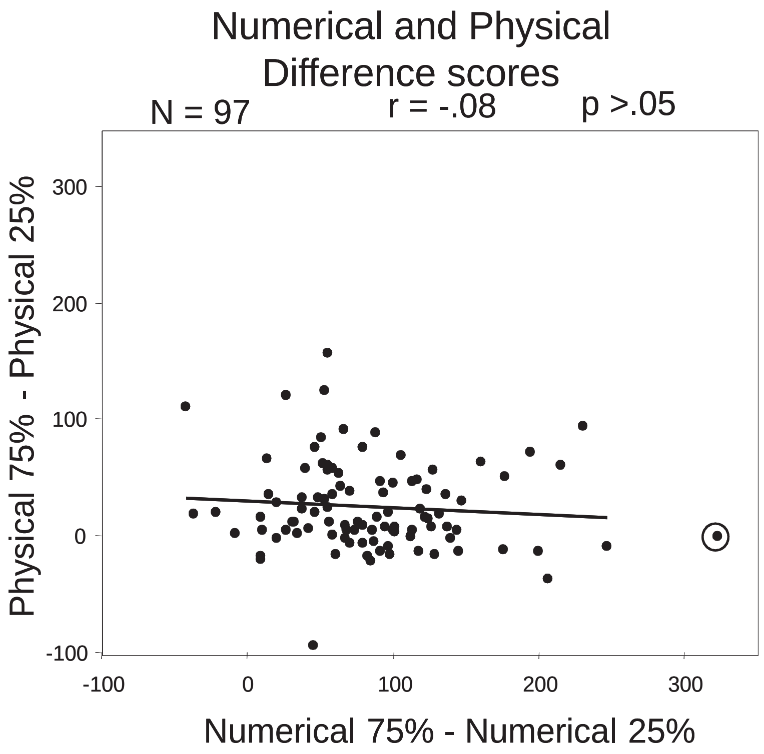

Stroop task and NFC
N = 97
r = -.01
p >.05
900
700
500
300
100
-100
-300
NFC
-300
-100
100
300
500
700
900
Stroop 75% - 25%

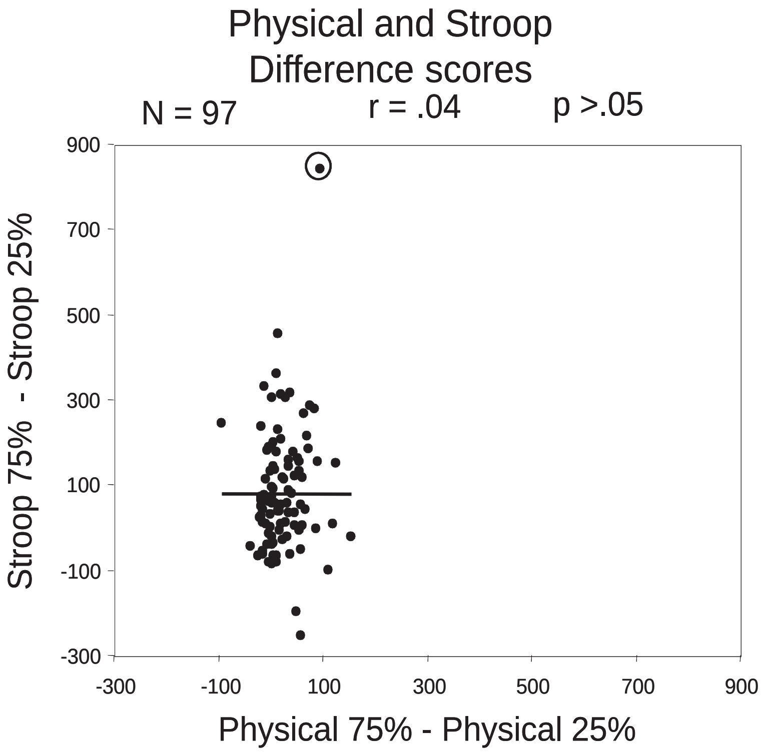

Numerical task and CFQ
N = 97
r = -.01
p >.05
CFQ
350
250
150
50
-50
-50
50
150
250
350
Numerical 75% - 25%


Physical task and CFQ
N = 98
r = .14
p >.05
CFQ
200
150
100
50
0
-50
-100
-100
-50
0
50
100
150
200
Physical 75% - 25%


Stroop task and CFQ
N = 97
r = -.01
p >.05
CFQ
900
700
500
300
100
-100
-300
-300
-100
100
300
500
700
900
Stroop 75% - 25%

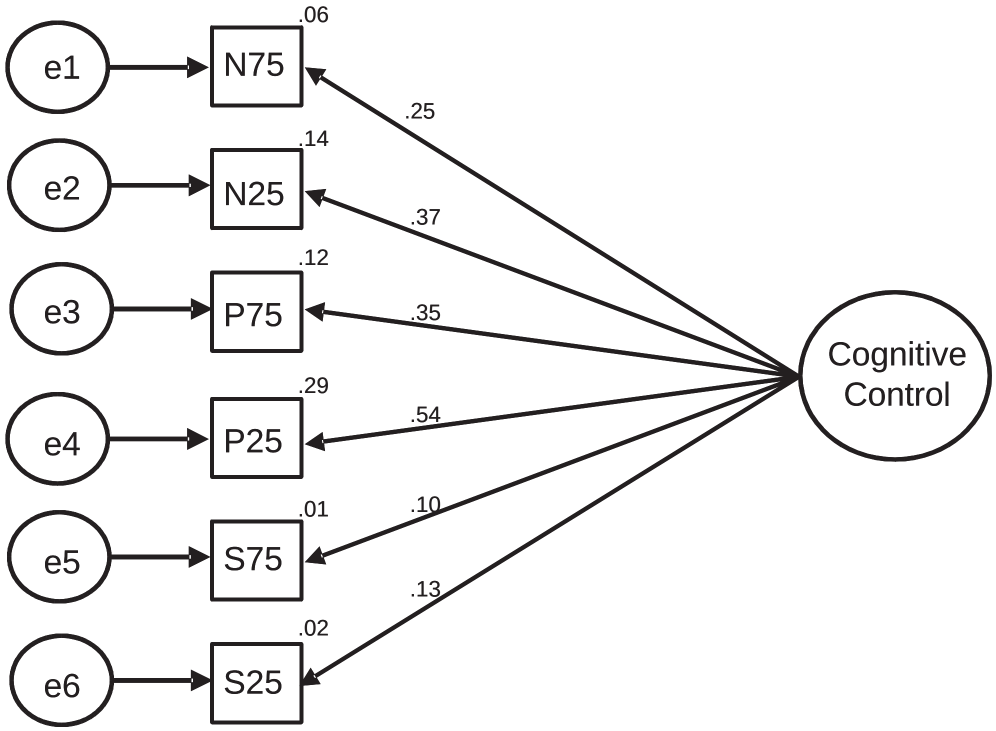

Numerical and Stroop
Difference scores
N = 96
r = -.07
p >.05
Stroop 75% - Stroop 25%
900
700
500
300
100
-100
-300
-300
-100
100
300
500
700
900
Numerical 75% - Numerical 25%


Numerical and Physical
Difference scores
N = 97
r = -.08
p >.05
Physical 75% - Physical 25%
300
200
100
0
-100
-100
0
100
200
300
Numerical 75% - Numerical 25%

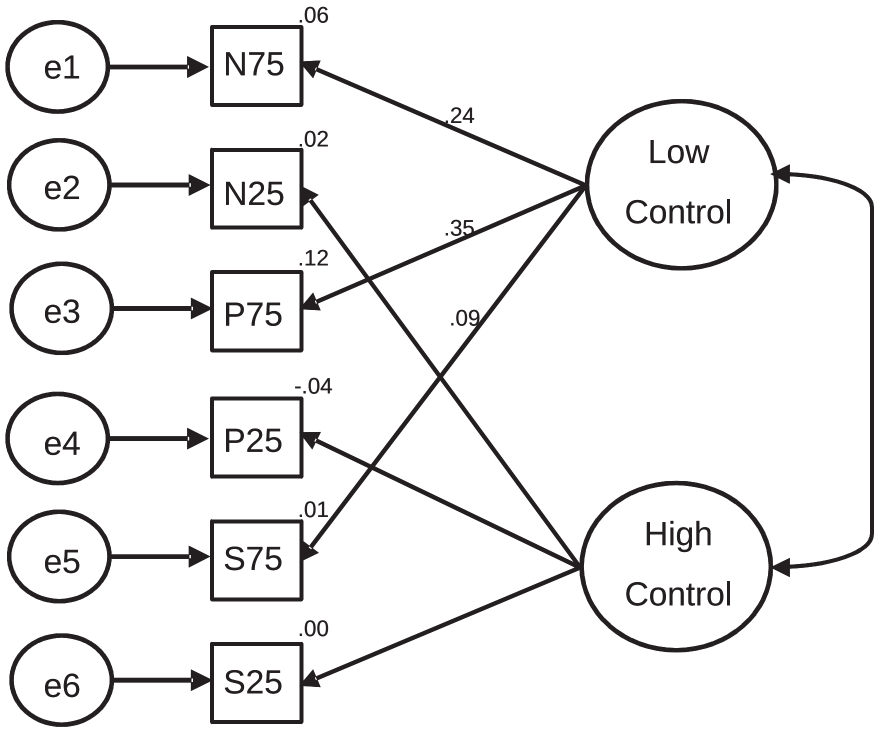

Physical and Stroop
Difference scores
N = 97
r = .04
p >.05
Stroop 75% - Stroop 25%
900
700
500
300
100
-100
-300
-300
-100
100
300
500
700
900
Physical 75% - Physical 25%

Appendix L

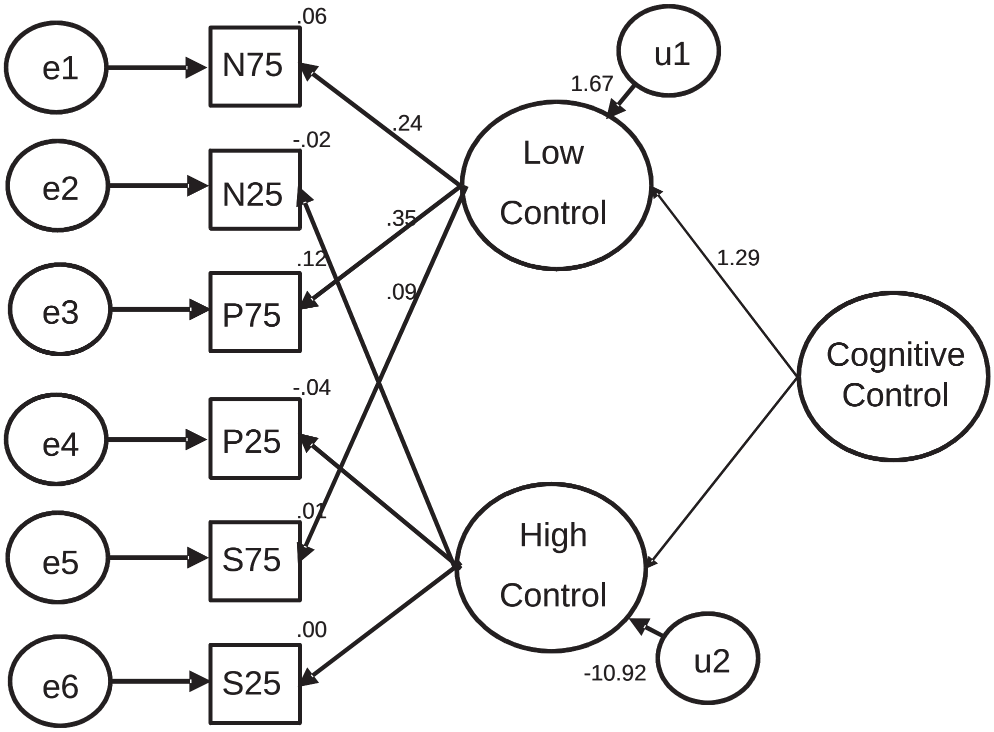
Factor Analysis Models for Experiment 4



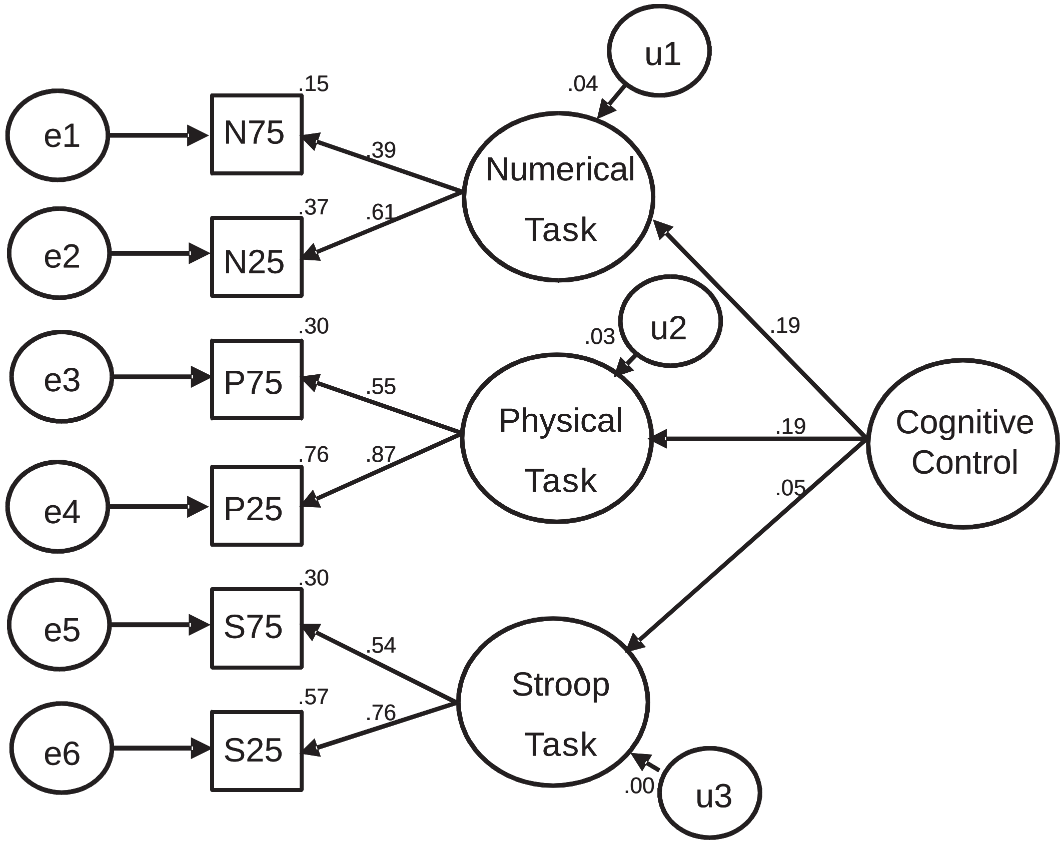
Chi² (14) = 70.78, p < .001 ; **CFI** = 0.155



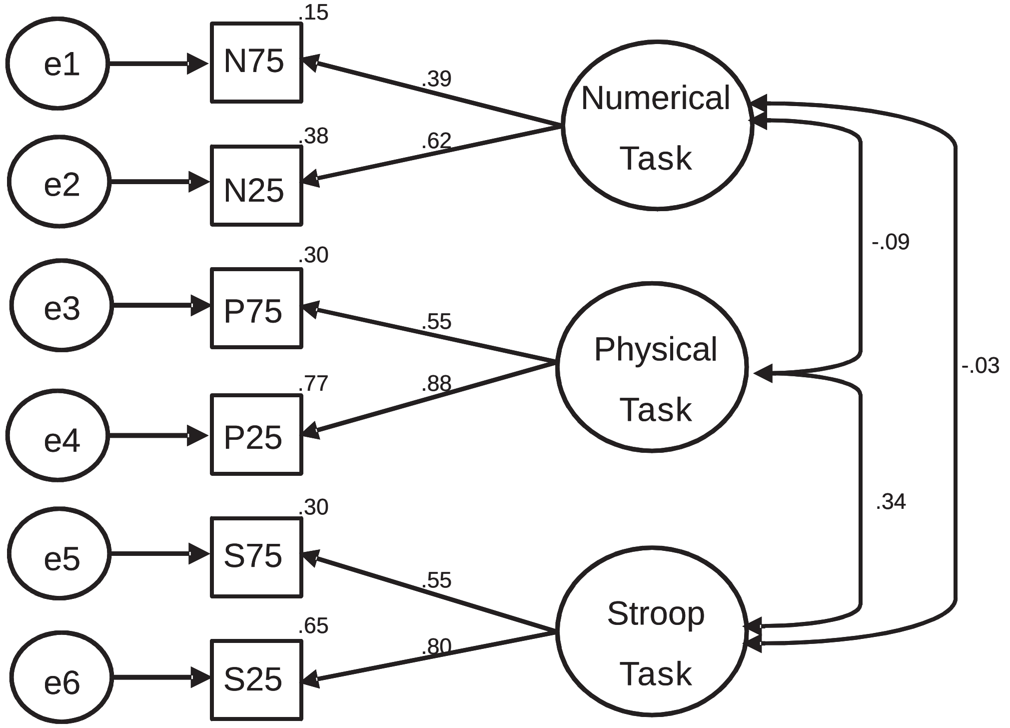
Chi² (12) = 5687, p < .001 ; **CFI** = 0.332



Chi^{2} (12) = 56.87, $p < .001$; **CFI** = 0.322



Chi² (11) = 32.88, p < .001 ; **CFI** = 0.675



Chi² (9) = 26.58, p < .001 ; **CFI** = 0.738