

Running head: INHIBITION IN CHILDREN WITH ADHD

Inhibition in Children with Attention-Deficit/Hyperactivity Disorder

by

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Supervisor: Dr. Kimberly A. Kerns

Abstract

The present study was conducted in an attempt to replicate previous research findings indicating that children with Attention-Deficit/Hyperactivity Disorder (ADHD) have specific inhibitory deficits on tasks requiring the inhibition of irrelevant stimulus characteristics (i.e., stimulus selection), but have preserved ability to inhibit over-learned, inappropriate motor responses (i.e. response selection) compared to normal children (Casey et al., 1997). A Stroop task was also administered to assess the relationships between specific forms of inhibitory processing and the performance on this classic task. A sample of 20 male children previously diagnosed with ADHD and 23 male age-matched controls were tested on computerized stimulus selection and response selection inhibitory tasks and a Stroop task. Results indicated children with ADHD made a higher percentage of errors on tasks requiring inhibitory functions, with a trend towards making more errors on tasks requiring stimulus selection inhibition, indicating a deficit for children with ADHD in tasks requiring stimulus selection, but not response selection inhibition. The high percentage of errors for ADHD children indicated a speed/accuracy tradeoff, thus mean reaction times for conflict conditions did not reflect a different pattern of performance between groups. Implications of the present findings and avenues of future research are outlined.

Supervisor: Dr. Kimberly A. Kerns, (Department of Psychology)

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Dedication

For Ian, my biggest fan, whose unconditional love and support has made this accomplishment all the more rewarding.

Attention-Deficit/Hyperactivity Disorder (ADHD) is the most common clinical disorder diagnosed and treated in children (Brown et al., 2001). Classified as a disruptive behavioral disorder, ADHD affects many levels of a child's everyday functioning and as such is a major clinical and public health problem due to the associated morbidity and disability in children, adolescents, and adults. ADHD not only negatively affects individuals' academic and vocational activities and self-esteem, but also creates a stress on families of these individuals and society as a whole in terms of the financial cost associated with diagnosing and treating this disorder (Wilens, Biederman, & Spencer, 1999). The Diagnostic and Statistical Manual of Mental Disorders, 4th edition, text revised (DSM-IV-TR) states that ADHD is characterized by a pervasive pattern of inattention and hyperactivity-impulsivity, maladaptive to the child and inconsistent with behavior seen in normally developing children (see full diagnostic criteria in Appendix A). In order to receive a diagnosis of ADHD, a child must have shown symptoms before the age of seven years, and the symptoms must be present for a period of at least six months (American Psychiatric Association, 2000). A diagnosis also requires that the maladaptive behaviors of the child be observed in two or more settings (i.e., school, at home, during extra-curricular activities). There are three subtypes of ADHD, based on the predominance of specific symptoms: 1) ADHD, combined type is the most prevalent of the subtypes, and is diagnosed if the child elicits six or more inattentive and six or more hyperactive-impulsive symptoms, 2) ADHD, predominantly inattentive requires six or more symptoms of inattention but fewer than six hyperactive-impulsive symptoms, and 3) ADHD, predominantly hyperactive, is characterized by six or more hyperactive-

impulsive symptoms but fewer than six inattentive symptoms (American Psychiatric Association, 2000).

In terms of prevalence rates, approximately 3-7% of school-aged children have ADHD (American Psychiatric Association, 2000). The prevalence rates regarding sex can vary from 2:1 boys to girls to up to 9:1 based on subtype (i.e., ADHD, predominantly inattentive has a less pronounced gender ratio) and setting (i.e., more male children are likely to be referred to a clinic, due to a higher comorbidity with conduct and oppositional-defiant disorders) (American Psychiatric Association, 2000). ADHD is frequently comorbid with other disruptive behavior disorders, most often oppositional defiant disorder (ODD) and conduct disorder (CD) (Loeber, Burke, Lahey, Winters, & Zera, 2000). However, ADHD is also frequently comorbid with learning disorders (LD), with about 20% to 25% of children diagnosed with ADHD also meeting criteria for LD (Pliszka, 2000).

Etiologically, research has provided support for a genetic and neurobiological basis for ADHD, with a core dysfunction being located in the catecholaminergic (i.e., dopamine) system (Wilens et al., 1999). Psychosocial factors, such as socioeconomic status and parenting, are also believed to interact with or contribute to the manifestation of ADHD symptoms (Lahey, Miller, Gordon, & Riley, 1999; Waschbusch, 2002). However, the cause of ADHD is still unknown, and available treatments, such as pharmacological (i.e., psychostimulants and antidepressants) and psychological treatments, are not a cure, but a method of which to control the symptoms of the disorder (Gaultney, Kipp, Weinstein, & MacNeill, 1999). Stimulant medications such as methylphenidate are the most popular form of medication for people of all ages with

uncomplicated ADHD (Wilens et al., 1999). Psychological treatments for ADHD follow behavioral principles, most often contingency management (McLaughlin, 2002).

Behavioral interventions and the combination of behavioral interventions and pharmacological treatments have received much empirical support in terms of effectiveness (see Pelham & Waschbusch, 1999, for a review).

Historically, psychological theories conceptualized ADHD as arising from such things as defective moral control (Still, 1902) and minimal brain dysfunction (Wender, 1973). Later on, Douglas (1988) proposed a cognitive deficit model in which she identified a pattern of four major deficits believed to account for the cognitive impairments associated with ADHD. These deficits were: 1) lack of investment and maintenance of effort, 2) impaired modulation of arousal to meet situational demands, 3) tendency to seek immediate reinforcement, and 4) difficulties with impulse control. These four deficits were believed to arise from a central deficit of self-regulation resulting in a variety of impairments in planning, organization, executive functions, metacognition, flexibility, self-monitoring, self-correction, and associated deficits of motor control and perceptual-motor performance.

Executive functions have been increasingly examined in an effort to isolate a core deficit underlying ADHD (Pennington & Ozonoff, 1996). Current models of ADHD (Quay, 1988a, 1988b, 1997; Sonuga-Barke, Houlberg, & Hall, 1994; Sergeant, Oosterlaan, & Meere, 1999; Pennington & Ozonoff, 1996; Barkley, 1997a, 1997b, 1997c, 1999, 2003; Nigg, 2001; Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003) emphasize deficits of behavioral or response inhibition and self-regulation, both of which fall within the domain of executive functioning. The focus on inhibitory deficits and a

convergence of evidence from neuroanatomy, neuroimager, neurochemistry, and stimulant medication research has resulted in the view that ADHD is a disorder resulting primarily from the dysfunction of the frontal lobes (Barkley, 1997c; Castellanos, 1997; Felton, Wood, Brown, Campbell, & Harter, 1987; Perugini, Harvey, Lovejoy, Sandstrom, and Webb, 2000).

The frontal lobes play an integral role in human behavior. There has been a vast amount of literature over the past 30 years about the role of prefrontal cortical fields in particular complex behavioral processes. Coinciding with the development of this literature, there have also been anatomical connections linking the prefrontal cortex to the basal ganglia (Johnson & Rosvold, 1971). In particular, Alexander, DeLong, and Strick (1986) identified five circuits that unite specific regions of the frontal cortex with the basal ganglia and the thalamus and serve to mediate motor activity, eye movements, and behavior. More specifically, these five parallel circuits link regions originating in the supplementary motor area, frontal eye fields, dorsolateral prefrontal region, lateral orbitofrontal area, and the anterior cingulate cortex to the striatum, globus pallidus/substantia nigra, and thalamus (Alexander et al., 1986). These circuits are modulated by the basal ganglia via a direct (excitatory) pathway, which facilitates cortically mediated behavior, and an indirect (inhibitory) pathway, which is believed to inhibit cortically mediated behavior. Present in the circuitry of this system are an excitatory neurotransmitter, glutamate, an inhibitory neurotransmitter, GABA, and a neuromodulatory neurotransmitter, dopamine (Cohen & Servan-Schreiber, 1992; Montague, Dayan, & Sejnowski, 1996; Schultz, 1997; Casey, Tottenham, & Fossella, 2001). In terms of cognitive control, if the direct pathways are involved in facilitating

cortically mediated behaviors, then damage to this pathway may result in constantly interrupted behaviors (e.g. behaviors in ADHD or thoughts in schizophrenia). If the indirect pathway is involved in inhibiting cortically mediated behaviors, than damage to this pathway may result in insuppressible repetitive behaviors (e.g., behaviors in Obsessive Compulsive Disorder or Tourette 's syndrome, or ruminative thoughts in depression). Neuromodulatory imbalances could result in hypermetabolic activity in either the direct or indirect pathways leading to difficulties in cognitive control (Casey et al., 2002). The dorsolateral prefrontal circuit, the lateral orbitofrontal circuit, and the 'limbic' circuit, outlined by Alexander and colleagues (1986), are intricately involved in mediating behaviors and have been implicated in a number of neuropsychological syndromes (Mega & Cummings, 1994; Tekin & Cummings, 2002).

The dorsolateral prefrontal cortex (Brodmann's areas 9, 10; Walker's area 46) is on the lateral surface of the anterior frontal lobe and has projections that terminate in the dorsolateral head of the caudate nucleus (Selemon & Goldman-Rakic, 1985). This region of the caudate nucleus has fibers projecting on a direct pathway to the lateral aspect of the mediodorsal globus pallidus interna and rostromedial substantia nigra pars reticula (Parent, Bouchard, & Smith, 1984) or on an indirect pathway to the dorsal globus pallidus externa, which then projects to the lateral subthalamic nucleus (Smith, Hazrati, & Parent, 1990). The lateral subthalamic nucleus then terminates in the globus pallidus interna and substantia nigra pars reticula. The globus pallidus interna and substantia nigra pars reticula project to the parvocellular portions of the ventral anterior and mediodorsal thalamus, respectively (Kim, Nakano, Jayaraman et al., 1976; Ilinsky, Jouandet, & Goldman-Rakic, 1985). The mediodorsal thalamus completes the circuit by looping back

to the dorsolateral prefrontal lobe (Kievit & Kuypers, 1977; Giguere & Goldman-Rakic, 1963).

In terms of function, the dorsolateral prefrontal circuit subserves many executive functions (Cummings, 1993; Mega & Cummings, 1994). Lesions of the dorsolateral prefrontal cortex have resulted in difficulties on tasks requiring spatial memory (Goldman-Rakic, 1987; Fuster, 1989) and may also play a role in various components of short-term memory (Fuster, 1989). In essence, the dorsolateral prefrontal cortex mediates executive functions, such as the ability to organize a behavioral response in order to solve complex problems (which includes learning new information, copying complex figures, and systematically searching memory stores), activate remote memories, self-direct and have the ability to be independent from environmental contingencies, accurately shift and maintain behavioral sets, generate motor programs, and the ability to use verbal skills to guide behaviors (Duffy & Campbell, 1994; Mega & Cummings, 1994). Damage to the dorsolateral prefrontal cortex produces deficits in these executive functions. Patients with dysfunctions in this circuit are typically concrete and perseverative and show impairments in reasoning and mental flexibility. Without the ability to maintain and redirect their attention, these patients are characterized by distractibility and may appear disorganized without guidance (Tekin & Cummings, 2002). For example, the Wisconsin Card Sorting Test (WCST) requires the ability to shift sets, maintain sets, generate strategies, and organize information (Milner, 1963), and as such is a particularly sensitive measure of dorsolateral prefrontal abnormalities. Patients with dorsolateral prefrontal damage also show reduced verbal and design fluency, poor organizational and constructional strategies (Benton, 1968; Jones-Gotman & Milner, 1977), and impairments

in motor sequencing (Cummings, 1985). Other deficits associated with dorsolateral prefrontal cortex damage include stimulus-bound behavior or environmental dependency characterized by poor set shifting, concrete thinking, a 'pull' towards high-stimulus objects, imitation behaviors, reduced design fluency, and poor response inhibition, among others (Mega & Cummings, 1994).

The lateral orbitofrontal circuit has primary projections from Brodmann's areas 10 and 11 to the ventromedial caudate (Selemon, Goldman-Rakic, 1985). The ventromedial caudate sends direct projections to the medial area of the mediodorsal globus pallidus interna and the rostromedial substantia nigra pars reticula (Johnson & Rosvold, 1971) and indirect projections to the dorsal globus pallidus externa to the lateral subthalamic nucleus, which then projects to the globus pallidus interna and substantia nigra pars reticulata (Smith et al., 1990). The medial area of the ventral anterior thalamus and inferomedial sector of the mediodorsal thalamus then receive projections from the globus pallidus and substantia nigra (Selemon & Goldman-Rakic, 1985; Ilinsky et al., 1985). The circuit is closed via projections from these thalamic areas to the lateral orbitofrontal cortex (Ilinsky et al., 1985).

With regards to functioning, the lateral orbitofrontal circuit is believed to mediate socially appropriate behavior. As such, lesions in this region are associated with personality changes characterized by social disinhibition and impulse control disorders (Hesslinger et al., 2002). Patients with orbitofrontal lesions commonly rapidly shift moods from irritability to lability. These patients have been described as tactless, lacking the ability to respond appropriately to social cues, portraying undue familiarity, and as having an inability to empathize with others (Bogousslavsky & Regli, 1990; Hunter,

Blackwood & Bull, 1968; Logue, Durward, Pratt et al., 1968). Utilization and imitation behaviors can also occur with large bilateral lesions (Lhermitte, Pillon, & Serdaru, 1986; Tekin & Cummings, 2002). Patients with orbitofrontal lesions perform card-sorting tasks normally, unlike patients with dorsolateral prefrontal lesions (Tekin & Cummings, 2002). Patients exhibiting more prominent abnormalities in the right orbitofrontal cortex compared to the left have been said to have more marked disinhibition and loss of social behavior (Miller et al., 1993). Difficulty inhibiting inappropriate behaviors is characteristic of patients with damage to the lateral orbitofrontal circuit. Obsessive-compulsive disorder is a psychological disorder characterized by increased metabolic activity in the orbitofrontal cortex and increased caudate metabolism (Baxter, Phelps, Mazziotta, et al., 1987). As well, personality changes that occur in Huntington's disease patients are attributed to abnormality in the orbitofrontal circuit at the level of the medial caudate region (Cummings, 1993).

The limbic circuit originates in the anterior cingulate cortex (Brodmann area 24) and medial orbitofrontal cortex (Walker's area 13) (Alexander, Crutcher, & DeLong, 1990; Mega & Cummings, 1994) and projects to the ventral striatum (Selemon & Goldman-Rakic, 1985), which includes the ventromedial caudate, nucleus accumbens, ventral putamen, and olfactory tubercle. These structures compose the limbic striatum (Heimer, 1978). The ventral striatum has direct projections to the rostromedial globus pallidus interna and ventral pallidum and the rostradorsal substantia nigra and possible indirect projections to the rostral globus pallidus externa (Haber, Lynd, Klein, et al., 1990). Projections from the external pallidum connect to the medial subthalamic nucleus, which then projects to the ventral pallidum (Smith et al., 1990). The limbic circuit is

closed with projections from the dorsal magnocellular mediodorsal thalamus to the anterior cingulate (Giguere & Goldman-Rakic, 1988) and medial orbitofrontal cortex (Alexander et al., 1990).

Both the anterior cingulate cortex and medial orbitofrontal cortex have been implicated in affective or motivational processes (Butter & Snyder, 1972; Butters, Butter, Rosen, & Stein, 1973) and selective attention (Alexander et al., 1990). The dorsal anterior cingulate cortex is believed to play a role in complex cognitive processing such as target detection, response selection and inhibition, error detection, performance monitoring (Bush, Luu, & Posner, 2000), and reward-based decision-making (Bush, Vogt, Holmes et al., 2002). Apathy and decreased motivation are characteristic behaviors associated with damage to the limbic circuit (Mega & Cummings, 1994; Tekin & Cummings, 2002). The most pronounced neuropsychological deficit of patients with abnormalities of the limbic circuit is response inhibition on “go/no-go tasks”. The deficit in performance on such tasks suggests that these patients have difficulty completely inhibiting responses. Patients with damage to the limbic circuit also exhibit a decreased ability to understand new thoughts and participate in creative thought processes (Chow & Cummings, 1999; Tekin & Cummings, 2002).

Convergent evidence from neuroimaging, neuropsychological, genetics, and neurochemical studies have implicated the disruption of frontal-striatal structures, particularly right structures, such as the lateral prefrontal cortex, dorsal anterior cingulate cortex, caudate, and putamen, as contributing to the pathophysiology of ADHD (Bush, Valera, & Seidman, 2005; Giedd, Blumenthal, Molloy, & Castellanos, 2001; Swanson, Castellanos, Murias, LaHoste, & Kennedy, 1998). A recent neuroimaging study

(Motofsky, Cooper, Kates, Denckla, & Kaufmann, 2002) reported ADHD-related reductions in the volume of the dorsolateral prefrontal, lateral orbitofrontal, and medial orbitofrontal cortices, among others, and reduced premotor regions. The large body of literature supporting abnormalities in the frontal lobes in individuals with ADHD and our understanding of the functioning of the frontal cortex suggest that in order to uncover specific inhibitory deficits within children with ADHD, researchers must utilize tasks that tap into the fronto-striatal circuits that subserve different inhibitory components in order to accurately address inhibitory functioning in children with ADHD. The prominence of inhibitory deficits within several of the current models of ADHD and the convergence of evidence suggesting abnormalities in brain regions associated with inhibitory functioning in these children indicates that effective assessment of inhibition is crucial to our understanding of ADHD.

The Stroop task is consistently used as a neuropsychological measure of inhibitory control (MacLeod, 1991), and is reported to be sensitive to executive function problems in ADHD (e.g., inhibition) (Sergeant, Geurts, & Oosterlan, 2002). In the Stroop task, participants are shown color names written in different colors of ink and are required to attend to the color of ink that words are printed in while ignoring the word printed. The objective of the task is to read the ink colors aloud as quickly as possible, trying not to make mistakes. The Stroop interference effect occurs when the words on the page are color words that conflict with the ink colors they are printed in (e.g., RED printed in green ink). Interference is typically measured as the difference between the time taken to name the colors on incongruent items (e.g., BLUE in red ink) versus

naming the ink color on 'neutral' control items (e.g., colored patches, strings of symbols, pseudowords, or non-color words) (Lindsay & Jacoby, 1994).

A review of the Stroop literature revealed mixed results in terms of the ability of the Stroop to differentiate between children with ADHD and normal children. Some studies report significant differences between performance of ADHD children and control children on the Stroop (i.e., children with ADHD reported to have lower inhibitory function than controls, as shown by increased response times in the interference condition) (e.g., Golden & Golden, 2002; Leung & Connolly, 1996; McLaughlin, 2002; Pennington, Grossier, & Welsh, 1993), however some studies report no difference between performance on the Stroop between children with ADHD and control children (e.g., Cohen, Weiss, & Minde, 1972; Gaultney et al., 1999; Seidman, Beiderman, Faraone, Weber, & Oullette, 1997).

However, Barkley, Grodzinsky, and DuPaul (1992) reviewed 22 different neuropsychological studies of frontal functions in ADHD children and found that the Stroop was one of the most reliable and consistent measures to differentiate children with ADHD from normal children. Doyle, Biederman, Seidman, Weer, and Faraone (2000) reported good positive predictive power and specificity, but inadequate sensitivity and negative predictive power for the Stroop Color-Word Association Test. Both Nigg (2001) and Barkley (1997c) utilize the performance of children with ADHD on the Stroop Color Word Task as evidence for a deficit in interference control in ADHD, and subsequently inhibitory control.

Nigg (2001) highlighted that while impairment in inhibitory control is common to many theories of ADHD, how inhibition is defined tends to differ. Inhibition is

conceptualized as a multidimensional construct with different subtypes. For example, Barkley (1997c) defines behavioral inhibition as being composed of three related processes: 1) the ability to inhibit prepotent responses (i.e., responses that receive immediate reinforcement or one that has been reinforced in the past), creating a delay in reflexive or automatic responses, 2) the ability to inhibit an ongoing response, and 3) the ability to ignore internal or external distracting information. The first two processes constitute response inhibition, while the third process characterizes interference control.

The present study aims to continue to investigate the inhibitory deficit in children with ADHD. The multidimensional nature of inhibition has led to many unanswered questions involving the presence of specific inhibitory deficits, when these deficits arise, and how environmental stimuli affect inhibitory control. Therefore, the ability to separate and analyze different forms of inhibition, and the effects of specific stimulus characteristics on inhibitory control, may provide a better understanding of how inhibition and inhibitory deficits develop, and what environmental cues may contribute to difficulties in inhibitory control. Accordingly, the purpose of the present study is to analyze and compare the performance of children with and without ADHD on different types of inhibition tasks.

Casey (2001) proposed a neuropsychological model of inhibitory control suggesting that parallel pathways in the brain, maintained by the frontal cortex, represent information and regulate responding. Utilizing neural information from Alexander and colleagues (1991), Casey (2001) hypothesizes that the basal ganglia are the common inhibitory system across several pathways and serve to inhibit specific actions. Casey separates inhibition into three components based on different stages of attentional

processing: 1) stimulus selection (by inhibition of a salient, but irrelevant stimulus attribute), 2) response selection (by inhibition of a competing incorrect ‘over-learned’ response) and 3) response execution (by inhibition of a compelling response). According to Casey (2001), these inhibition processes map onto the limbic basal ganglia thalamocortical circuits in the brain. More specifically, the dorsolateral prefrontal circuit (i.e., a neural circuit from the dorsolateral prefrontal cortex to the basal ganglia to the thalamus) is thought to represent stimulus information (e.g., object, spatial, verbal, etc.), thus controlling stimulus selection inhibition. The lateral orbitofrontal circuit (i.e., a neural circuit from the lateral orbitofrontal cortex to the basal ganglia to the thalamus) is believed to be involved in the representation and maintenance of a response set, thus controlling response selection inhibition. The limbic circuit (i.e., a neural circuit with primary projections from the anterior cingulate cortex and the medial orbitofrontal cortex to the basal ganglia and the thalamus) is believed to control emotionally relevant information that mediates approach and avoidance behaviors, thus controlling the avoidance or ‘stopping’ behavior for response execution inhibition (see Figure 1). According to Casey, while many children with developmental disorders have ‘inhibition deficits,’ children with different developmental difficulties have different patterns of problems on these various ‘types’ of inhibitory demands.

Figure 1

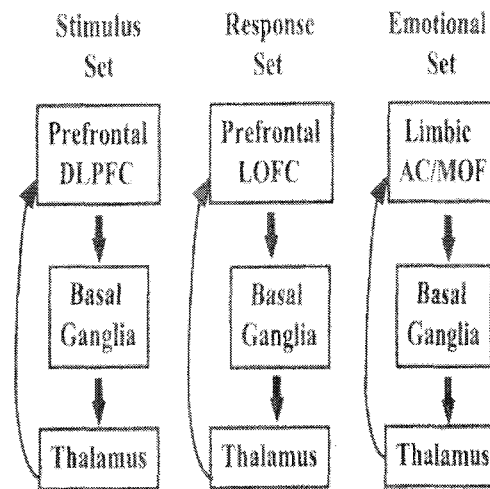


Figure 1. Simplified diagram of parallel basal ganglia thalamocortical circuits adapted from Casey (2001, p.329). Diagram includes the dorsolateral prefrontal circuit (DLPFC), the lateral orbital frontal circuit (LOFC), and the limbic circuit with primary projections areas in the anterior cingulated (AC) and medial orbitofrontal cortex (MOF).

Casey (2001) used different tasks to observe inhibitory processes in four different clinical populations: 1) children with Sydenham chorea, a variant of rheumatic fever, 2) children with Tourette syndrome, 3) children with childhood-onset schizophrenia, and 4) children with ADHD. Casey designed these tasks with the intention of targeting the basal-ganglia thalamocortical circuits described in detail above based on evidence from neuroanatomy, neuroimager, neurochemistry, and lesion studies of these three parallel pathways originating in the frontal lobes. The findings indicated a four-way dissociation in the pattern of performance on these tasks between the populations. Specifically, when compared to controls, children with ADHD revealed deficits on stimulus selection and response execution tasks, but not on response selection tasks, children with schizophrenia revealed a deficit on the stimulus selection task, children with Sydenham chorea

performed poorly on only the response selection task, and children with Tourette syndrome had deficits on only the response execution task.

The different forms of inhibition described by Casey (2001) were assessed using three different computerized conflict tasks. Each task consisted of a *control* and an *inhibition* condition. The *control* condition was always a simple detection version of the task, while the *inhibition* condition was the same task, but required the participant to inhibit attention to salient but irrelevant stimuli or an inappropriate response. As described above, Casey believes that stimulus selection is controlled via the dorsolateral prefrontal circuit. Aforementioned, patients with abnormalities in this area have difficulties with mental flexibility and an inability to redirect and maintain their attention, thus resulting in symptoms of distractibility. Dorsolateral cortex is heavily implicated in executive functions including working memory and ability to ‘shift set’ and attend flexibly to various aspects of a stimulus. Accordingly, Casey’s stimulus selection task is a forced-choice discrimination task requiring participants to respond flexibly to various attributes of a stimulus and inhibit responding to aspects of a stimulus that are no longer relevant for the task at hand. This task targets inhibition at the sensory level of processing the stimulus. In Casey’s task, objects appear on a computer monitor and participants were required to select the one unique object based on stimulus attributes of unique color or shape. For the *control* condition, the unique attribute remained constant across a number of trials (e.g., color), while in the *inhibition* condition the unique attribute changed randomly from trial to trial. Casey hypothesized that her task required participants to inhibit attending to a previously ‘relevant’ stimulus attribute in the *inhibition* condition, in order to attend to the current relevant attribute. When this task was used to compare

children with ADHD to normal children (Casey, Castellanos, Giedd, Marsh, Hamburger, Schubert, Vauss, Vaituzis, Dickstein, Sarfatti, & Rapoport, 1997), results indicated that children with ADHD had longer response times during both *control* and *inhibition* conditions than normal participants. More importantly, children with ADHD had more errors in the inhibition condition of this task than normal children.

As noted earlier, the dorsolateral prefrontal circuit is believed to control stimulus selection inhibition. Casey et al. (1997) correlated performance on this task with magnetic resonance imaging (MRI) data taken from the same participants. The right prefrontal cortex volume was positively correlated with mean accuracy on the stimulus selection task for control participants, but not for children with ADHD. There are no published studies that have replicated the result of stimulus selection inhibition in children with ADHD using Casey's stimulus selection task or similar tasks. Accordingly, the current study proposes to use a novel set of computerized conflict tasks to assess Casey's "stimulus selection" inhibition in children with ADHD in an attempt to replicate the hypothesis that children with ADHD are impaired on some forms of inhibition (i.e., stimulus selection and response execution), but not on response selection inhibition.

The lateral orbitofrontal circuit described in detail above appears to be particularly involved in socially appropriate behaviors. That said, patients with abnormalities in this circuit also have difficulty inhibiting inappropriate behaviors and often exhibit utilization and imitation behaviors. Utilization has been suggested to be due to an 'over-reliance' on response to a visual stimulus. For example, if the persons 'sees' a hammer, activation of their motor system elicits the motor program for use of the hammer, which would be to pick it up and pound. According to Casey, tasks that target

this circuit require the inhibition of prepotent responses, for example, responding towards the source of stimulation or responding with task inappropriate ‘compatible’ responses (e.g., hitting a left button in response to a left pointing arrow or a blue key in response to a blue stimulus). Accordingly, the response selection task (Casey, Gordon, Mannhein, & Rumsey, 1993) consists of selecting responses to target stimuli that are based on ‘compatible’ or ‘incompatible’ mappings. Casey’s task targets inhibition at a level of responding to a stimulus. In the *control* condition, participants complete a compatible mapping task in which they press a “number” button that corresponds to a number (1, 2, 3, or 4) presented on a computer screen. Participants then complete the *inhibition* condition, which is an incompatible mapping task, in which they are instructed to press the buttons in reverse order of the numbers. For example, 1, 2, 3, and 4 correspond to the 4, 3, 2, and 1 buttons, respectively. In this task, each digit is presented centrally in a randomized order an equal number of times. This task was designed to assess inhibition of a competing motor response, or in other words, the tendency to respond with a compatible mapped response when the correct response is an incompatible mapping response. Children with ADHD did not reveal any differences in terms of inhibition or accuracy compared to normal children on this task (Casey et al., 1997). However, in looking at the data it seems that a ceiling effect may have occurred, as children with ADHD and normal children performed almost perfectly on this task. Further research into response selection inhibition may benefit from use of a more complex or cognitively demanding task in order to acquire a more accurate comparison between children with ADHD and normal children. The present study proposes to further investigate response selection inhibition using a set of novel computerized conflict tasks with two types of

target stimuli (i.e., color and location) in which participants will be required to make compatible and incompatible mapping responses to.

As indicated above, the lateral orbitofrontal circuit is believed to control response selection inhibition. Interestingly, it is believed that orbitofrontal functioning can be assessed with the classic Stroop task (Barkley, 1997c), suggesting that the Stroop task may be targeting more than one form of inhibition. A Stroop task is incorporated into the proposed study in order to further assess the relationship between this classic task and the computerized response selection and stimulus selection inhibition tasks.

As described in detail above, the limbic circuit is involved in a variety of motivational processes such as target detection, inhibition of responses, error detection, performance monitoring, and reward-based decision-making. The most pronounced neuropsychological deficit of patients with damage to structures of the limbic circuit is response inhibition on “go/no-go tasks”. Therefore, tasks that target this circuit should require the participant to completely inhibit ongoing responses or to completely inhibit responding after the detection of a particular target stimulus. Accordingly, the response execution task targets the final stage of Casey’s proposed stages of attentional processing and requires participants to inhibit a prepotent ongoing response in response to specific target stimulation, in this case a specific auditory stimulus. In other words, this task requires participants to inhibit the tendency to respond altogether. In this task, participants respond by pressing a button whenever they hear a single tone, but they do not press the button when they hear a double tone. The *control* condition consisted of 25% targets (single tone) and 75% nontargets (double tone), whereas the *inhibition* condition consisted of 75% targets and 25% nontargets. This task is similar to go/no-go

and continuous performance tasks. Casey and colleagues (1997) used this task to compare response execution inhibition in children with ADHD to normal control children and results revealed that children with ADHD performed significantly worse than controls, as shown by longer response times in both inhibitory and control conditions. As indicated above, the limbic circuit is believed to control the avoidance or ‘stopping’ behavior for response execution inhibition. Performance on this task correlated with MRI measures of the volume of the prefrontal cortex. These results are consistent with previous research utilizing variants of the stop signal paradigm. Several studies using the stop-signal paradigm have consistently shown that children with ADHD take longer to inhibit a response, shown by slower stop signal reaction times, than normal control children (see Nigg, 2001 and Oosterlaan, Logan, & Sergeant, 1998 for reviews).

It is interesting to note that although the terminology used to describe inhibitory functions tends to differ across researchers, the underlying theories and contexts used to illustrate different forms of inhibition tend to overlap. For example, the stimulus selection inhibition described by Casey is similar to the interference control proposed by Barkley (1997a), in which participants must inhibit responding to salient, but irrelevant stimuli and respond to the target stimulus. The classic Stroop task has also been described as a task of interference control where the participant must inhibit the interfering irrelevant ‘words’ and respond to the color that the words are printed in (however, alternative theories have been outlined, see MacLeod, 1991). As aforementioned, the Stroop task has been used extensively to assess the inhibitory deficit in children with ADHD and although results have been mixed, many studies indicate that children with ADHD show impaired inhibitory functioning as compared to normal children.

Just as Casey divided inhibition into separate forms and created tasks to assess these inhibitory processes, other researchers have conceptualized various inhibitory processes and created tasks to assess them. Recently, Nassauer and Halperin (2003) proposed that inhibition could be dissociated into two processes: motor inhibition (the inhibition of inappropriate motor responses) and perceptual inhibition (the inhibition of irrelevant stimulus characteristics). The concepts behind these two forms of inhibition closely resemble the response selection and stimulus selection inhibitions, respectively, described by Casey (2001). Nassauer and Halperin (2003) hypothesized that these forms of inhibition utilize independent cognitive resources. To test and support this premise, they designed a set of computerized ‘conflict’ tasks. The tasks were separated into subtests, which required making either “congruent” or “incongruent” responses based on various “perceptual” or “motor” features. Responses and reaction time were recorded, and responses were made by pressing a key depending on the direction or location of the stimulus. “Perceptual” conditions involved a stimulus-stimulus characteristic conflict. For example, participants viewed an arrow pointing in the right direction on the left side of the computer screen. They had to press the key that corresponded to the target stimulus characteristic (i.e., the direction of the arrow point), in this case the right key, while ignoring the interfering irrelevant stimulus characteristic (i.e., the location of the arrow, which would be on the ‘left’ of the screen). Perceptual inhibition was demonstrated by having the participant respond by pressing a button “congruent” to the direction of an arrow on the computer monitor, while inhibiting the location of the arrow on the monitor.

“Motor” based conditions involved stimulus-response conflict. Motor inhibition was illustrated by having the participant inhibit a prepotent response to press a key

congruent to the arrow point and instead respond incongruently or opposite to the direction of the arrow in the center of the computer screen.

The results indicated significant “perceptual” and “motor” main effects, but no perceptual by motor interaction. In other words, the results indicated that participants had significantly greater reaction times to both “perceptual” and “motor” conflict conditions compared to a baseline control task, but that on tasks that demanded both motor and perceptual inhibition the decrement in performance was merely ‘additive’. Although the perceptual by motor interaction was statistically insignificant, the two conflict tasks were significantly correlated with each other. Interestingly, the “perceptual” conflict tasks were significantly correlated with Stroop performance (Nassauer & Halperin, 2003), while the “motor” tasks were not.

As previously mentioned, although the terminology differs, the two forms of inhibition described within the Nassauer and Halperin (2003) paper are indeed very similar to two of the three forms of inhibition described by Casey (2001). More specifically, the “perceptual” inhibition and “motor” inhibition described by Nassauer and Halperin (2003) correspond to the “stimulus selection” inhibition and the “response selection” inhibition proposed by Casey, respectively. According to Casey (2001), the dorsolateral prefrontal circuit is responsible for stimulus selection inhibition, and the lateral orbitofrontal circuit is crucial for response selection inhibition. Thus, according to Casey’s model, these forms of inhibition utilize some of the same neural mechanisms (basal ganglia and thalamus) but differ in terms of their projections from the frontal cortex.

The current study proposes to assess stimulus selection and response selection inhibition using novel computerized tasks based on the conflict paradigm developed by Nassauer and Halperin (2003), and compare the performance between children with ADHD and normal control children on these tasks. The inhibition processes of stimulus selection and response selection will be mixed within the different subtasks, with trials randomly alternating between control and conflict conditions, believed to create a more cognitively challenging task. The response selection tasks created for the current study may more accurately capture the extent of response selection inhibition in children with ADHD and normal children, given it is not likely to suffer from ceiling effects.

In the present study, stimulus selection is analyzed by comparing performance on congruent or neutral items (e.g., blue box appears in center and correct response is to press the blue button) to performance on items where an irrelevant stimulus characteristic interferes or conflicts with the target stimulus characteristic (e.g., participant asked to respond 'same' to color, blue box appears on right and correct response is to press left blue button: color/location conflict). Response selection is assessed by comparing performance on congruent or neutral items requiring a compatible mapping response to performance on items that require an incompatible mapping response (e.g., box appears on left and correct response is press the button 'opposite' to block location).

The present study consists of six computerized tasks, separated based on target stimulus characteristics and response requirements. The present study analyzed stimulus selection and response selection utilizing two different stimulus characteristics: location and color. The purpose of the present study was to assess the performances on stimulus selection and response selection between children with ADHD and control children using

these computerized tasks in an attempt to replicate the findings of Casey et al. (1997). The children will also be administered a standard Stroop task (Golden, 1978) to assess the differences in inhibition between children with and without ADHD and to correlate performance on the computerized tasks to performance on a classic Stroop task. The comparison of the Stroop task to these computerized tasks can help to uncover the inhibitory processes most targeted by this classic task and help bring about a better understanding of the cognitive mechanisms required to complete Stroop tasks.

The use of a color characteristic to the computerized conflict tasks was felt to be important as the classic Stroop effect is 'color' based, and the Stroop task has been shown to be one of the most reliable and consistent measures of inhibition in its ability to differentiate children with ADHD from normal children (Barkley et al., 1992), though not all studies have replicated this finding. Because color plays such an integral role in the classic Stroop task, a closer look at the effect of color on response inhibition in children with ADHD seems relevant to understanding the nature of this inhibitory task. In addition, assessment of different stimulus characteristics (i.e., location and color) within the current inhibitory tasks can help to highlight specific external features in the environment that may be contributing to the inhibitory deficits in children with ADHD.

To summarize, the present study proposes to utilize a variety of computerized conflict tasks consisting of different stimulus characteristics to measure stimulus selection and response selection performance in children with ADHD and normal control children. The computerized conflict tasks are designed to be independent of verbal ability, and instead participants respond manually by pressing a button on a button bar. The lack of verbal ability necessary in the tasks is an attempt to minimize any

interference effects due to extraneous stimulus-response modality conflicts (Virzi & Egeth, 1985). The administration of a standard Stroop task also allows further analysis of the effects of color on different inhibitory tasks through comparison of a verbal color-naming task (Stroop) and non-verbal manual response color tasks (computerized conflict tasks), and also allows for comparison of specific forms of inhibitory processing to this classic task. The use of tasks separating inhibition into specific forms (namely stimulus selection and response selection) while still utilizing the same 'stimuli' will allow a more careful assessment of specific inhibitory deficits in children with ADHD. The manipulation of stimulus characteristics within the tasks also allows for a closer analysis of how perceptual information impacts inhibition.

There are several hypotheses proposed for the present study:

1. Children with ADHD will show greater deficits on stimulus selection tasks than children without ADHD, as indicated by greater error rates and/or larger reaction times on tasks requiring stimulus selection inhibition.
2. Children with ADHD will be comparable to control children on response selection tasks (i.e., children with ADHD will not show a response selection deficit as compared to controls), as shown by comparable reaction time and error rates on response selection tasks.
3. Children with ADHD will show greater interference effects on the Stroop task than children without ADHD.

Method

Participants

A total of 43 male children between the ages of 7 and 12 years ($M = 10.61$ years, $SD = 1.46$) participated in this study. Participants consisted of 20 children with ADHD (combined type only) ($M = 10.69$ years, $SD = 1.52$ years) and 23 children without ADHD ($M = 10.54$ years, $SD = 1.43$ years). The participants did not differ in age between the two groups, $t(41) = -.328, p = .744$. Parents of participants completed a history questionnaire (see Appendix B) and the Computerized Diagnostic Interview Schedule for Children Version IV (CDISC-IV) (Shaffer & Fisher, 1997; Shaffer, Fisher, Lucas, Corner, 2003) to ensure participants met the inclusion criteria for this study. Due to the high comorbidity rates, time restrictions, and to preserve external validity, children with a diagnosis of ADHD who also met criteria for Oppositional Defiant Disorder (ODD) and/or a learning disability (LD) were included in this study. Children with: 1) a diagnosis of a psychiatric disorder other than ADHD combined type, ODD, or LD, 2) a diagnosis of a mental deficiency or a pervasive developmental disorder, 3) a head injury resulting in a loss of consciousness greater than 20 minutes, 4) color blindness, or 5) visual or hearing impairment, were excluded from this study. The children with ADHD who were on medication for this disorder ($N = 11, 55\%$) were required to be off their medication for 24 hours prior to testing. Of the 20 children who were previously diagnosed with ADHD by a pediatrician or psychologist, three failed to meet full criteria for ADHD on the CDISC-IV, and were thus excluded from the analysis. Of the remaining participants with ADHD, 11 (65%) also met the criteria for ODD. Parent reports on the

history questionnaire (see Appendix A) indicated that four of the children diagnosed with ADHD had also been diagnosed with LD (20%).

Participants were recruited with phone calls to parents based on their participation in a previous study of ADHD at the University of Victoria, and through fliers and brochures posted around the University of Victoria and the community at community centers, with local pediatricians, and willing associations. Advertisements were also placed in local Victoria newspapers (i.e., The Island Newsgroup). Participants received five dollars and a small toy worth approximately one dollar as compensation for their time and effort for participating.

Apparatus

Computer conflict tasks

The computerized tasks were designed to evaluate the ability to ignore irrelevant stimulus characteristics (i.e., location or color cues) and to inhibit inappropriate motor responses and respond to specific target stimuli. Participants were required to make responses on a button bar consisting of a large blue button to the left of center and a large green button to the right of center. The plastic blue and green buttons were approximately 6cm in diameter and positioned 27cm apart on a 10cm wide X 40cm long wooden button bar. The button bar was situated on the table directly in front of the participant and approximately 30cm in front of the computer monitor. The button bar response apparatus used in this experiment permitted all of the color information via the large buttons and the stimuli on the screen to be available within a narrow perifoveal region of the participant's visual field. It is believed that this modification prevented participants from retrieving the color of the response buttons from memory during the reaction tasks

(Hasbroucq & Guiard, 1991) and provided greater interference effects in terms of the color tasks due to their large size and subsequent salient visual presence.

The trials of all tasks were randomized in terms of right or left responses in order to factor out the effect of handedness on performance. Before each task, a set of instructions appeared on the computer screen indicating the nature of the task and instructing participants to respond as quickly as possible without making mistakes. Similar to the method used by Hasbroucq & Guiard, (1991), a conventional choice reaction time procedure (pressing either a left-hand or a right-hand button with no substantial displacement of the responding hand) was utilized. This method of response was chosen because previous results have indicated that interference effects are unaltered by the processes occurring while executing response movements (Hasbroucq & Guiard, 1991). Stimuli for the computerized conflict tasks appeared on a 15" color monitor situated approximately 1.5 feet in front of the seated participant.

Tasks One through Four

These tasks consisted of blue or green blocks appearing on the left or right of the computer monitor. There were 80 randomized stimulus items consisting of 20 green blocks on the left, 20 green blocks on the right, 20 blue blocks on the left, and 20 blue blocks on the right, appearing randomly, one at a time, on a black computer screen (see Figure 2).

Task One

In task one, participants were instructed to press the button that was on the 'same' side as the block that appeared on the screen. This task was designed to assess stimulus selection. A stimulus selection conflict is defined as a conflict where the irrelevant

stimulus characteristic interferes with the target stimulus characteristic (i.e., the participant must inhibit responding to the irrelevant stimulus characteristic). This task included 40 neutral items (no conflict) and 40 items with a stimulus selection conflict (where the irrelevant stimulus characteristic ‘color’, interfered with the target stimulus characteristic ‘block location’).

Task Two

In task two, participants were instructed to ignore the color of the block and press the button that was ‘opposite’ to the location of the block on the screen. This task was designed to assess response selection and stimulus selection. A response selection conflict is defined as a conflict where stimulus characteristics and response are incompatible (i.e., when the participant must make an incompatible mapping response to the target stimulus). In this task, 40 items contained a response selection conflict (where participants had to make an incompatible response to block location, thus ‘inhibiting’ the prepotent but inappropriate ‘compatible’ response) and 40 items contain both response selection and stimulus selection conflicts (where participants had to make an incompatible response to block location and the irrelevant characteristic ‘color’ interfered with the target characteristic ‘block location’).

Task Three

In task three, participants were instructed to ignore the location of the block and press the button that was the ‘same’ as the color of the block on the screen. This task was designed to assess stimulus selection. This task included 40 neutral items (no conflict) and 40 items with a stimulus selection conflict (where the irrelevant characteristic ‘block location’ interfered with the target characteristic ‘color’).

Task Four

In task four, participants were instructed to ignore the location of the block and press the button that was 'opposite' to the color of the block on the screen. This task was designed to assess response selection and stimulus selection. In this task, 40 items contained a response selection conflict (where participants had to make an incompatible response to color) and 40 items contained both response selection and stimulus selection conflicts (where participants had to make an incompatible response to color and the irrelevant characteristic 'block location' interfered with the target characteristic 'color').

Task Five

Task five was designed as a baseline task for reaction time to block location. This task contained 40 white blocks randomly displayed on either the left (20 blocks) or right (20 blocks) side of a black computer monitor. Prior to the task, participants were instructed to press the button that was on the 'same' side as the block that appeared on the screen (see Figure 2).

Task Six

Task five was designed as a baseline task for reaction time to color. This task contained 40 randomly displayed blue (20) or green (20) blocks in the center of a black computer monitor. Prior to the task, participants were instructed to press the button that was the 'same' color as the block that appeared on the screen (see Figure 2).

Figure 2

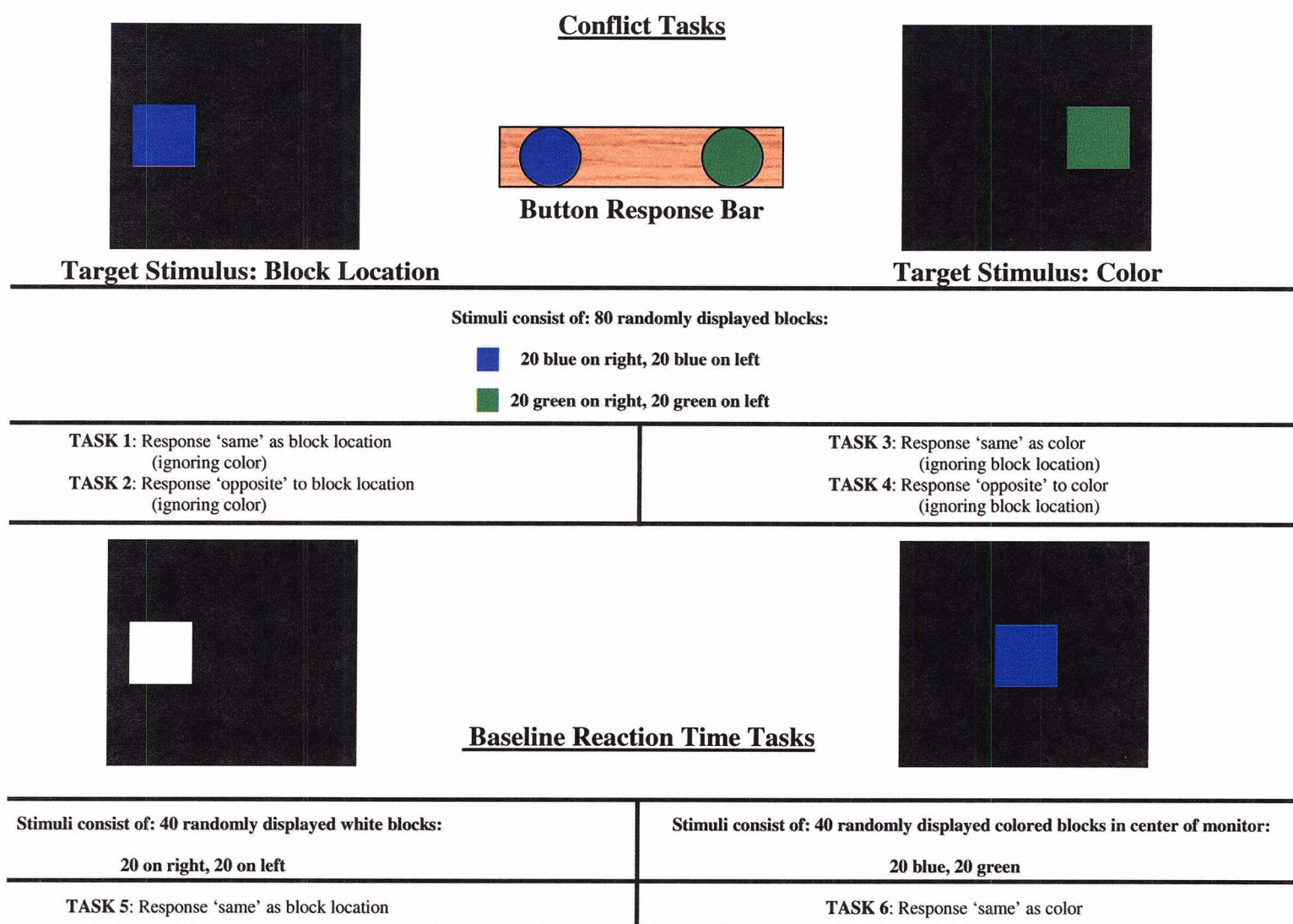


Figure 2. Diagram illustrating computerized conflict and baseline tasks. Tasks 1 and 3 contain random control and 'stimulus selection' conditions. Tasks 2 and 4 contain random 'response selection' and combined 'stimulus selection' and 'response selection' conditions. Tasks 5 and 6 are baseline reaction time tasks to block location and color and do not contain any conflict.

Stroop Color-Word Test (Golden, 1978)

The Stroop Color-Word Test consists of three sections. In the first section, participants were given a sheet of paper in which color words (blue, red or green) were written in black ink. Participants were instructed to read aloud the words down the columns in order as quickly as possible without making mistakes. In the second section, participants were given a sheet of paper in which strings of X's (i.e., XXXX) were printed in red, blue, or green ink. Participants were instructed to read aloud the colors as quickly as possible down the columns on the page. In the third section, participants were given a sheet of paper in which color words (red, blue, or green) were written in different colored ink (red, blue, or green). Participants were instructed to read aloud the color of the ink the words were printed in, ignoring the word. Participants were given 45 seconds for each section.

Procedure

Participants and their parents read and signed a consent form prior to testing (see Appendix C and D). All participants were tested individually. The seven tasks (six computerized tasks and the Stroop Color Word Test) were counterbalanced across subjects in order to control for order effects and also to give the participants a break from the computerized tasks in order to limit possible vigilance effects. Counterbalancing was created by testing each participant with a randomized task order.

Prior to each computer task, instructions appeared on the screen. Participants were reminded to respond as quickly as possible without making mistakes. Each task began with a practice task to familiarize the participants with the nature of the task. Trials were self-initiated with the press of a button on the button bar and each new stimulus appeared

on the screen after a response had been made. Participants responded with either their right or left hand on the corresponding right or left buttons of the button bar. The temporal sequence of tasks was randomized to counteract expectancy or practice effects. Response times for each trial were recorded to the millisecond.

Data Analysis

Error Analyses

Percentage of errors for separate and averaged control conditions, stimulus selection conditions, and response selection conditions were calculated and compared between groups using separate repeated measures between groups ANCOVA while controlling for baseline error rate. The first 2 (Group) X 2 (Conflict Condition) between groups repeated measures ANCOVA compared percentage of errors for averaged conflict conditions (stimulus selection or response selection) between groups controlling for percentage of averaged baseline errors. The within group variable, conflict condition, had two levels, either stimulus selection conflict or response selection conflict. A conflict is characterized by incongruent target and irrelevant stimulus characteristics (stimulus selection) or incongruent stimulus and response (response selection). The between group variable was Group, categorized based on the presence or absence of ADHD. The second ANCOVA assessed the effect of specific target characteristics on error rates using a 2 (Target characteristic: block location or color) X 2 (Conflict condition: stimulus selection or response selection) X 2 (Group) repeated measures between groups ANCOVA controlling for percentage of errors on averaged baseline tasks.

Response Selection X Stimulus Selection

Separate 2 (Group) X 2 (Stimulus Selection) X 2 (Response Selection) repeated measures between subjects analysis of variance (ANOVA) were conducted on tasks where the target stimulus characteristic was location and tasks where the target stimulus characteristic was color. A separate ANOVA was also run on the averaged stimulus selection and response selection conditions for all the tasks. The two within group variables, stimulus selection and response selection, each had two levels, the presence or absence of a conflict (i.e., a 'control' condition and a 'conflict' condition). Repeated measures between subjects analyses of covariance (ANCOVA) were then run on the same data, this time covarying out the baseline reaction times for color and block location (i.e., performance on Tasks 5 and 6).

Cost Score Analysis

'Cost' scores for stimulus selection and response selection conditions were calculated by finding the difference in reaction time between control and conflict conditions where only a single stimulus selection or response selection conflict was present. A 2 (Group: ADHD or controls) X 2 (Conflict: Stimulus Selection or Response Selection) X 2 (Target stimulus characteristic: block location or color) repeated measures between subjects ANOVA was conducted on the cost scores to assess the effect of different target stimulus characteristics and conflicts (i.e., stimulus selection or response selection) on reaction time.

Stroop Analyses

Analysis of the Stroop Color and Word Test (Golden, 1978) involves calculating an interference score. Interference scores can be calculated in one of two ways. In the

classic method (Hammes, 1971), the score on the color-word condition is subtracted from the score on the color condition. The Golden method (Golden, 1978), involves calculating a predicted interference score, which takes into account word reading and color naming speed to predict the score on the color-word condition. This predicted score is then subtracted from the obtained score on the color-word condition to achieve the interference score. Recent research (van Mourik, Oosterlaan, & Sergeant, 2005) suggests that although the latter method is more widely used and is better in differentiating children with ADHD from controls than the classic method, it follows an older sequential model of Stroop interference processing, which suggests that the processing of words must occur prior to, or be completed before, the processing of color naming, thus producing an interference effect. However, parallel processing models are the currently accepted and supported models of Stroop interference, which hold that Stroop stimuli are processed in parallel in a network of brain areas (e.g., Cohen, Dunbar, & McClelland, 1990). Thus, it is suggested that the former, classic method may be a 'purer' method of calculating the Stroop interference effect (van Mourik et al., 2005).

Both methods were used to calculate Stroop interference scores and independent samples t-tests were used to compare interference scores between groups (ADHD vs. controls). For the Golden method, the interference score is negative when word reading actively interferes with color naming and positive when a participant is able to inhibit reading the word.

Pearson Product Moment Partial Correlations were used to analyze the relationships between the different conflict conditions and Stroop interference. Reaction times for stimulus selection and response selection conditions for block location and

color tasks were correlated with Stroop interference scores for the overall sample while controlling for control conditions (i.e., RT for Task 5 or 6). Partial correlations were also run between Stroop interference scores and averaged stimulus selection and response selection conditions while controlling for the averaged control conditions for the overall sample.

Results

Error Analyses

Percentage of errors for separate and averaged stimulus selection and response selection conditions were averaged and compared between groups using a repeated measures between subjects ANCOVA, controlling for percentage of errors for baseline conditions as in general children with ADHD tend to make more errors even on tasks that don't require inhibition. Table 1 provides a summary of means and standard deviations for the percentage of errors obtained on each condition.

Table 1

	Controls		ADHD	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
% Baseline Condition Errors	5.8	5.6	5.6	5.5
% Averaged SS Condition Errors	6.9	6.1	10.9	8.1
% Averaged RS Condition Errors	8.6	6.4	9.5	7.8
% Baseline Condition (Color)	7.7	9.1	6.6	6.7
% SS Errors (Target: Color)	9.2	10.1	15.4	11.9
% RS Errors (Target: Color)	12.1	12.7	12.1	11.0
% Baseline Condition (Location)	3.6	3.5	4.6	6.1
% SS Errors (Target: Location)	4.4	4.5	6.3	6.2
% RS Errors (Target: Location)	6.2	9.1	5.9	9.3

Table 1. Descriptive statistics outlining percentage of errors for averaged and separate task conditions for control and ADHD groups.

For the ANCOVA comparing percentage of errors (averaged across color and location) for stimulus selection and response selection conditions between groups while controlling for percentage of errors on averaged baseline conditions, results revealed no significant effect of condition on percentage of errors ($F(1, 35) = .198, p = .659, \text{partial } \eta^2 = .006$), indicating that for the overall sample, errors did not differ significantly between tasks requiring stimulus selection or response selection. There was, however, a significant between groups effect ($F(1, 35) = 4.29, p = .046, \text{partial } \eta^2 = .109$), characterized by children with ADHD having a higher percentage of errors overall ($M = 10.3\%, SE = 1.0\%$) than normal control children ($M = 7.6\%, SE = 1.0\%$). Though failing to meet traditional significance levels, there was some evidence to support that the groups differed in percentage of errors across the task conditions as substantiated by the ‘trend’ towards an interaction effect between task condition and group ($F(1, 35) = 2.785, p = .104, \text{partial } \eta^2 = .074$). In examination of the data, children with ADHD made more errors on tasks requiring stimulus selection ($M = 11.0\%, SE = 1.3\%$) compared to normal control children ($M = 6.8\%, SE = 1.1\%$) (see Figure 3).

Figure 3

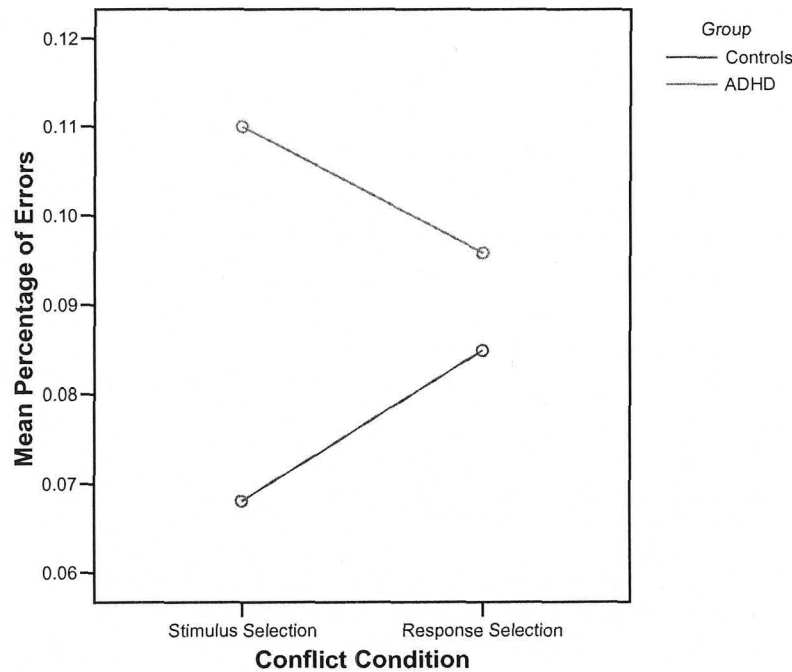


Figure 3. Mean percentage of errors as a function of averaged conflict condition (i.e., stimulus selection or response selection), controlling for errors on averaged baseline condition, between control and ADHD groups. Graph illustrates the significant between groups effect ($F(1, 35) = 4.29, p = .046, \text{partial } \eta^2 = .109$) with a 'trend' for children with ADHD to make more errors on tasks requiring stimulus selection ($M = 11.0\%, SE = 1.3\%$), than normal children ($M = 6.8\%, SE = 1.1\%$), ($p = .104$).

The next ANCOVA assessed the effect of specific target characteristics on error rates using a 2 (block location versus color) X 2 (stimulus selection or response selection) repeated measures between groups ANCOVA controlling for percentage of errors on averaged baseline tasks. Results revealed a significant main effect of target characteristic ($F(1, 35) = 4.377, p = .044, \text{partial } \eta^2 = .111$) for the overall sample, characterized by a larger percentage of errors in conflict conditions where the target characteristic was color ($M = 12.3\%, SE = 1.2\%$), than for conflict conditions where the target characteristic was

block location ($M = 5.7\%$, $SE = 0.6\%$) (see Figure 4). This pattern of performance did not differ between the groups, as indicated by a lack of interaction effect between target characteristic and group ($F(1, 35) = .826$, $p = .370$, partial $\eta^2 = .023$).

Figure 4

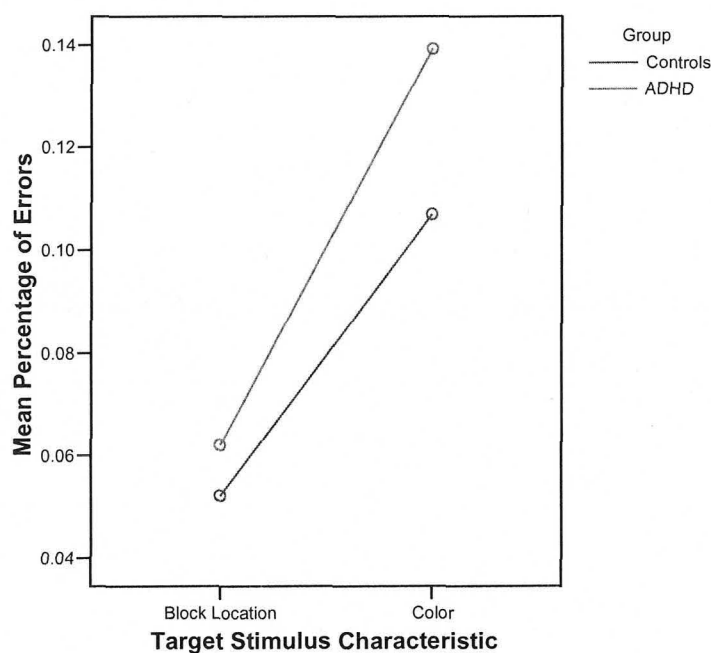


Figure 4. Mean percentage of errors as a function of target stimulus characteristic (i.e., block location or color) for control and ADHD groups. Graph illustrates a significant main effect of target stimulus ($F(1, 35) = 4.377$, $p = .044$, partial $\eta^2 = .111$), but no interaction effect between target stimulus and group ($F(1, 35) = .826$, $p = .370$, partial $\eta^2 = .023$).

There was no significant main effect of conflict condition ($F(1, 35) = .875$, $p = .356$, partial $\eta^2 = .024$), indicating that for the overall sample, percentage of errors did not differ between stimulus selection or response selection conflict conditions. There was a ‘trend’ for the groups to differ in performance across the different conflict conditions as shown by the ‘trend’ for a significant interaction effect between conflict condition and

group ($F(1, 35) = 2.977, p = .093, \text{partial } \eta^2 = .078$). This ‘trend’ for an interaction effect was characterized by children with ADHD tending to make more errors on tasks with a stimulus selection conflict ($M = 11.0\%, SE = 1.3\%$) than normal children ($M = 6.8\%, SE = 1.1\%$). No other interaction effects were revealed. There was also no significant between groups effect ($F(1, 35) = 2.217, p = .145, \text{partial } \eta^2 = .060$).

Reaction Time Analyses

Mean reaction times from correct trials only for each participant were calculated for each condition of the computerized tasks. Descriptive data were then generated on the reaction time data revealing non-normality. Therefore, mean reaction time (MRT) data from all control and conflict conditions were square root transformed to correct for skewness in the data with the exception of the averaged control and conflict task condition data. In this case, once reaction time data from the control and conflict tasks were averaged, only two participants scores (two control participants, both aged 8.75 years) needed to be trimmed from the combined response selection task data due to their extreme scores ($> 2 SD$ from the mean). One control participant (age 8 years, 4 months) was excluded from the analysis due to his extreme scores ($> 2 SD$ from the mean) on the majority of the task conditions. One control participant’s scores on the control and conflict conditions for tasks where block location was the target characteristic were lost (age 11 years, 5 months). Scores from the remaining 22 (21 for block location conditions and 19 for combined task conditions) control children ($M = 10.64$ (10 years, 7.5 months) $SD = 1.38$ (1 year, 4.5 months)) and 17 children with ADHD ($M = 11.00$ years $SD = 1.34$ (1 year, 4 months)) were used in the analyses. Mean age for these participants again did not differ between groups $t(37) = -.828, p = .413$.

Response Selection X Stimulus Selection: Target Stimulus: Block Location

A 2 (Group) X 2 (Stimulus Selection) X 2 (Response Selection) repeated measures between groups ANOVA was conducted on the square root transformed MRT data for the tasks where block location was the target stimulus characteristic.

The analysis revealed a significant main effect of response selection $F(1, 36) = 67.10, p < .001$, partial $\eta^2 = .651$, characterized by faster reaction times in the absence of a conflict ($M = 19.13, SE = .39$) than in the presence of a response selection conflict ($M = 21.43, SE = .47$) for the entire sample. There was no interaction effect between response selection and group ($F(1, 36) = .148, p = .703$, partial $\eta^2 = .004$), indicating that both groups had a similar pattern of performance across both response selection conditions (see Figure 5).

There was also a main effect of stimulus selection ($F(1, 36) = 6.26, p = .017$, partial $\eta^2 = .148$), characterized by faster reaction times in the absence of a conflict ($M = 20.15, SE = .40$) than in the presence of a stimulus selection conflict ($M = 20.41, SE = .43$) for the entire sample. There was also no significant interaction effect between stimulus selection and group ($F(1, 36) = 1.663, p = .205$, partial $\eta^2 = .044$) (see Figure 6). No significant between groups effect ($F(1, 36) = 1.520, p = .226$, partial $\eta^2 = .041$), nor any other interaction effects were revealed.

Figure 5

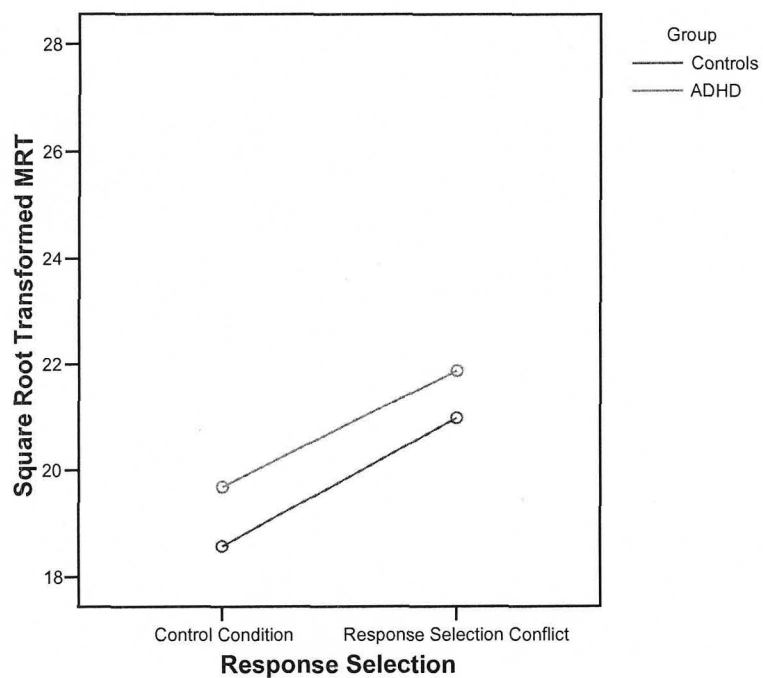


Figure 5. Square root transformed mean reaction time (MRT) as a function of response selection for control and ADHD groups. Target stimulus characteristic = block location. Graph indicates significant main effect of response selection ($F(1, 36) = 67.10, p < .001, \text{partial } \eta^2 = .651$), but no significant interaction effect between response selection and group ($p = .577$).

Figure 6

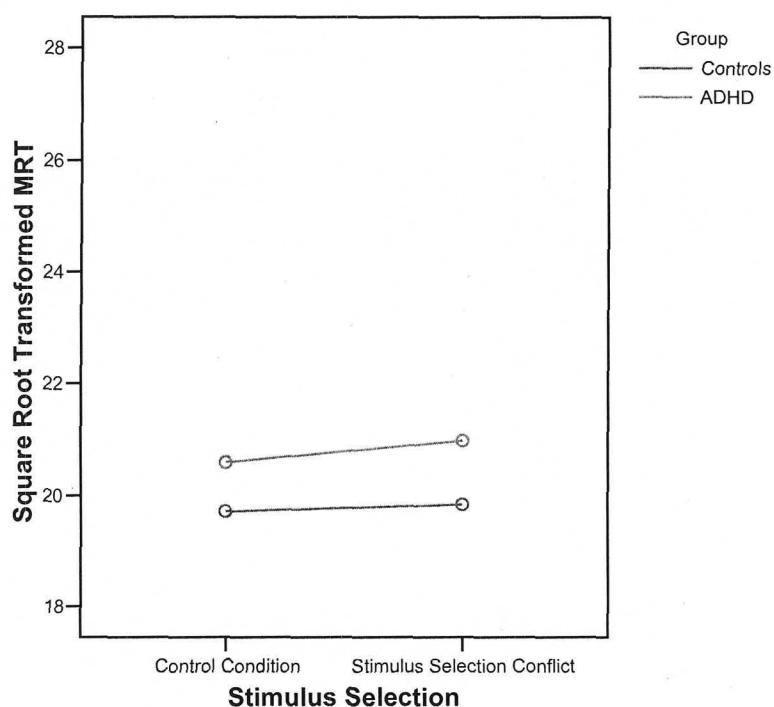


Figure 6. Square root transformed mean reaction time (MRT) as a function of stimulus selection for control and ADHD groups. Target stimulus characteristic = block location, irrelevant characteristic = color. Graph indicates a significant main effect of stimulus selection ($F(1, 36) = 6.26, p = .017, \text{partial } \eta^2 = .148$) but no interaction effect between stimulus selection and group ($p = .205$).

An ANCOVA was run on the same data this time entering the square root transformed MRT for Task 5 (baseline reaction time to block location) as a covariate, thus controlling for baseline reaction time. Interestingly, once the baseline reaction time was controlled for, there was no longer a main effect of stimulus selection ($F(1, 35) = 1.289, p = .264, \text{partial } \eta^2 = .036$) and only a 'trend' for a main effect of response selection ($F(1, 35) = 3.225, p = .081, \text{partial } \eta^2 = .084$) remained. However, an interaction

effect between stimulus selection and response selection was revealed ($F(1, 35) = 4.502$, $p = .041$, partial $\eta^2 = .114$), indicating that reaction times for making a compatible or incompatible response to the target stimulus depended on whether or not the irrelevant stimulus characteristic interfered with the target characteristic. No significant interactions were revealed between group and stimulus selection or response selection. Interestingly, once the baseline reaction time was controlled for, a ‘trend’ for a between groups effect was revealed ($F(1, 35) = 2.965$, $p = .094$, partial $\eta^2 = .078$), indicating a possible tendency for children with ADHD to respond slower ($M = 20.76$, $SE = .42$) than control children ($M = 19.80$, $SE = .37$).

Response Selection X Stimulus Selection: Target Stimulus: Color

A 2 (Group) X 2 (Stimulus Selection) X 2 (Response Selection) repeated measures between groups ANOVA was conducted on the square root transformed MRT data for the tasks where color was the target stimulus characteristic.

The analysis revealed a significant main effect of response selection ($F(1, 37) = 72.834$, $p < .001$, partial $\eta^2 = .663$), characterized by slower reaction time in the presence of a response selection conflict ($M = 27.09$, $SE = .60$) than in the absence of a conflict ($M = 23.78$, $SE = .48$) for the total sample. The lack of an interaction effect between response selection and group ($F(1, 37) = .759$, $p = .389$, partial $\eta^2 = .020$) revealed that both groups had a similar pattern of performance across the response selection conditions (see Figure 7).

Figure 7

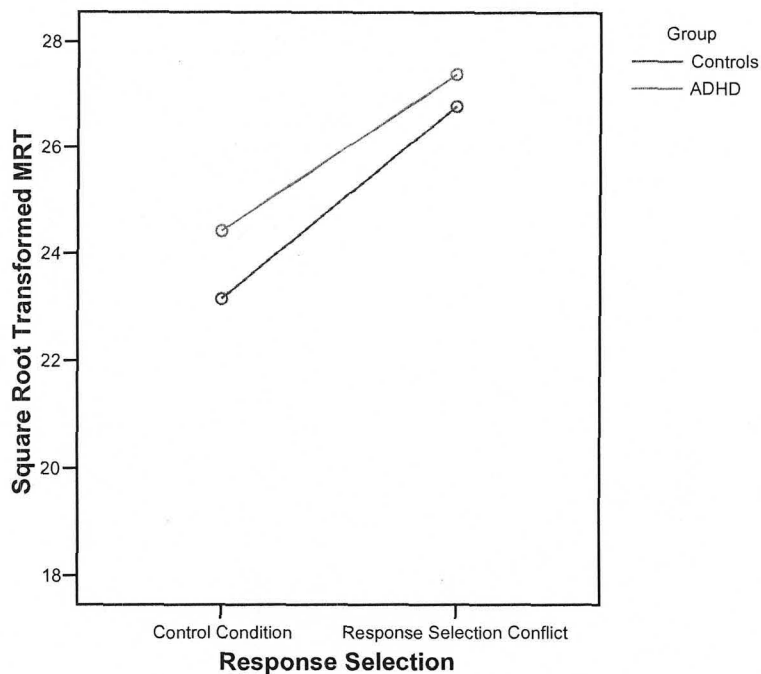


Figure 7. Square root transformed mean reaction time (MRT) as a function of response selection for control and ADHD groups. Target stimulus characteristic = color. Graph indicates significant main effect of response selection ($F(1, 37) = 72.834, p < .001, \text{partial } \eta^2 = .663$), but no significant interaction effect between response selection and group ($F(1, 37) = .759, p = .389, \text{partial } \eta^2 = .020$).

There was also a significant main effect of stimulus selection ($F(1, 37) = 19.833, p < .001, \text{partial } \eta^2 = .349$), characterized by slower reaction time in the presence of a stimulus selection conflict ($M = 25.86, SE = .51$) than in the absence of a conflict ($M = 25.01, SE = .53$) for the total sample. The groups also had a similar pattern of performance across both levels of stimulus selection, as shown by the lack of an interaction effect between stimulus selection and group ($F(1, 37) = .347, p = .559, \text{partial } \eta^2 = .009$) (see Figure 8). No other significant interaction effects were revealed. There

was also no significant between groups effect ($F(1, 37) = .860, p = .360, \text{partial } \eta^2 = .023$), indicating that the groups did not differ significantly in their reaction times across tasks.

Figure 8

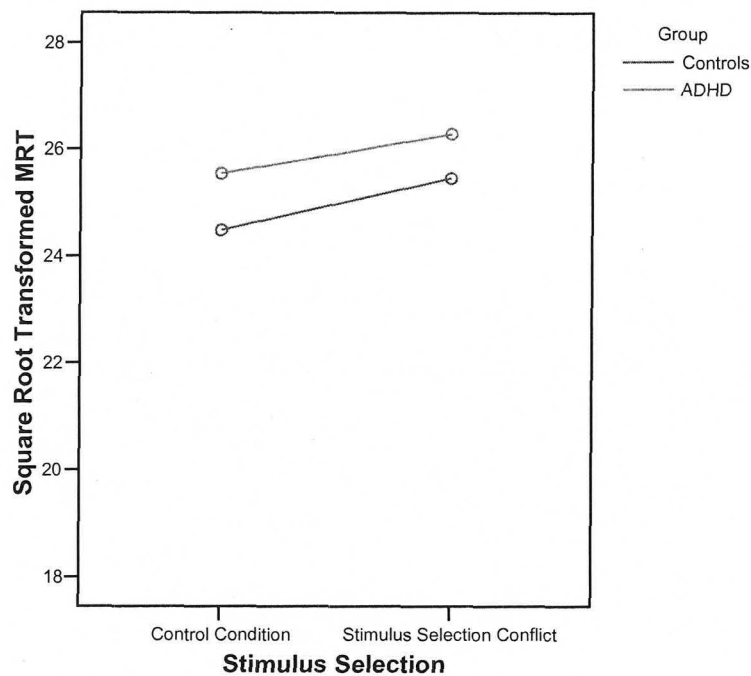


Figure 8. Square root transformed mean reaction time (MRT) as a function of stimulus selection for control and ADHD groups. Target stimulus characteristic = color, Irrelevant characteristic = block location. Graph indicates significant main effect of stimulus selection ($F(1, 37) = 19.833, p < .001, \text{partial } \eta^2 = .349$), but no significant interaction effect between stimulus selection and group ($F(1, 37) = .347, p = .559, \text{partial } \eta^2 = .009$).

An ANCOVA was run on the same data this time entering the square root transformed MRT for Task 6 (baseline reaction time to color) as a covariate, thus controlling for baseline reaction time. Results of this ANCOVA revealed no significant

main or interaction effects for any condition. There was also no significant between groups effect ($F(1, 36) < .001, p = .992, \text{partial } \eta^2 < .001$), indicating that the groups did not differ significantly in their performance across tasks after controlling for baseline reaction time.

Response Selection X Stimulus Selection: Averaged Tasks

Control conditions, stimulus selection conditions, and response selection conditions were averaged across the tasks to assess the overall effect of stimulus selection and response selection. The effect of averaging task conditions helped to normalize the data, thus transformations were not required on this data. Results revealed a significant main effect of response selection ($F(1, 34) = 112.664, p < .001, \text{partial } \eta^2 = .768$), characterized by faster reaction times in the absence of a conflict ($M = 467.94 \text{ ms}, SE = 17.54 \text{ ms}$), than in the presence of a conflict ($M = 587.65 \text{ ms}, SE = 24.08 \text{ ms}$). Groups did not differ in their performance across response selection conditions as shown by the lack of a significant interaction effect between response selection and group ($F(1, 34) = .347, p = .560, \text{partial } \eta^2 = .010$) (see Figure 9).

Figure 9

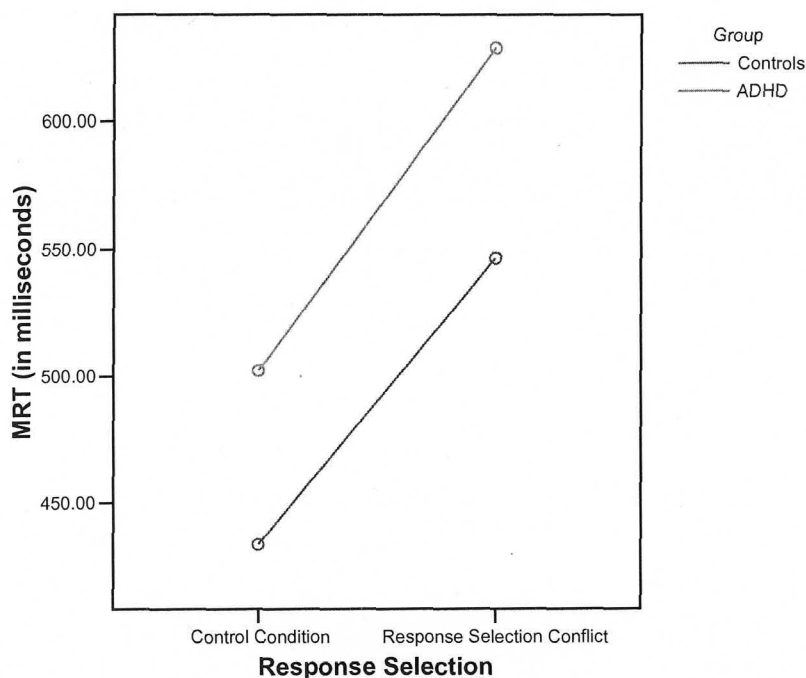


Figure 9. Mean reaction time (MRT) as a function of averaged response selection tasks for control and ADHD groups. Graph indicates significant main effect of response selection ($F(1, 34) = 112.664, p < .001$, partial $\eta^2 = .768$), but no significant interaction effect between response selection and group ($F(1, 34) = .347, p = .560$, partial $\eta^2 = .010$).

Results also revealed a significant stimulus selection main effect ($F(1, 34) = 28.361, p < .001$, partial $\eta^2 = .455$), characterized by faster reaction times in the absence of a conflict ($M = 511.87$ ms, $SE = 19.61$ ms), than in the presence of a conflict ($M = 543.72$ ms, $SE = 21.39$ ms). The groups also did not differ in their performance across stimulus selection conditions as shown by the lack of an interaction effect between stimulus selection and group ($F(1, 34) = .185, p = .670$, partial $\eta^2 = .005$) (see Figure 10). A significant interaction effect between response selection and stimulus selection was revealed ($F(1, 34) = 5.505, p = .025$, partial $\eta^2 = .139$), indicating that reaction times for

making a compatible or incompatible response to the target stimulus depended on whether or not the irrelevant stimulus characteristic interfered with the target characteristic. No other interaction effects were revealed. There was a ‘trend’ towards a between groups effect ($F(1, 34) = 3.453, p = .072, \text{partial } \eta^2 = .092$), indicating that children with ADHD may have a tendency to perform slower on tasks overall ($M = 565.51 \text{ ms}, SE = 29.49 \text{ ms}$) than normal control children ($M = 490.08 \text{ ms}, SE = 27.90 \text{ ms}$).

Figure 10

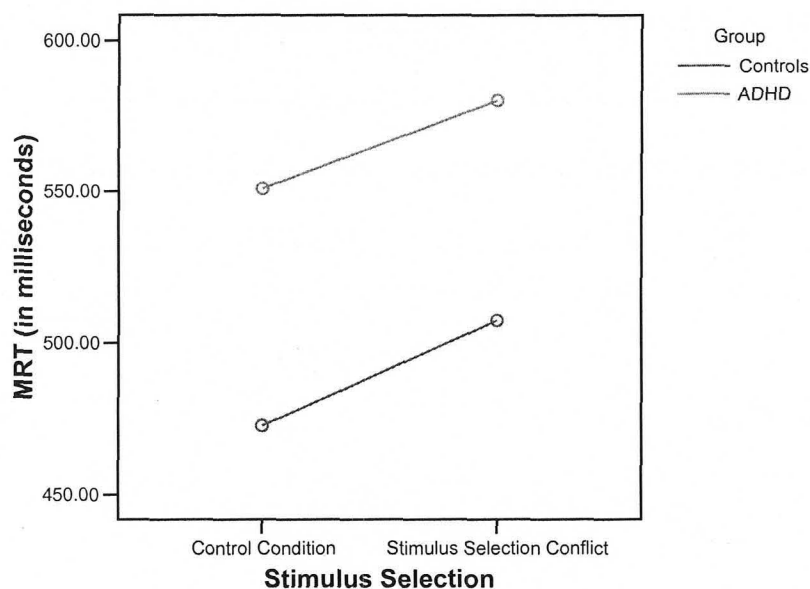


Figure 10. Mean reaction time (MRT) as a function of averaged stimulus selection tasks for control and ADHD groups. Graph indicates significant main effect of stimulus selection ($F(1, 34) = 28.361, p < .001, \text{partial } \eta^2 = .455$), but no significant interaction effect between stimulus selection and group ($F(1, 34) = .185, p = .670, \text{partial } \eta^2 = .005$).

An ANCOVA was run on the same data entering the averaged baseline tasks (Tasks 5 and 6) as a covariate, thus controlling for baseline reaction time. Results of this

ANCOVA revealed no significant main or interaction effects for any condition. There was also no significant between groups effect ($F(1, 33) = 1.893, p = .178, \text{partial } \eta^2 = .054$), indicating that the groups did not differ significantly in their performance across tasks after controlling for baseline reaction time.

Cost Score Analysis

‘Cost’ scores were calculated for the stimulus selection conditions and the response selection conditions using block or color as target characteristics by finding the difference between square-root transformed MRT for baseline and conflict conditions. In other words, these difference scores indicate the ‘cost’ of the presence of a conflict on MRT. ‘Cost’ scores for each group and the overall sample are outlined in Table 1 below.

Table 2

Cost	Target Stimulus	Group	<i>M</i>	<i>SD</i>
SS	Block Location	Controls	-.68	1.74
		ADHD	.47	2.36
		Total	-.17	2.10
SS	Color	Controls	2.15	1.84
		ADHD	1.80	1.93
		Total	2.00	1.87
RS	Block Location	Controls	1.60	1.90
		ADHD	2.27	1.80
		Total	1.90	1.86
RS	Color	Controls	4.69	2.56
		ADHD	4.03	2.94
		Total	4.39	2.72

Table 2. ‘Cost’ scores showing the difference in reaction time between conflict and baseline task conditions. SS = Stimulus Selection, RS = Response Selection. Controls, N = 21, ADHD, N = 17, Total, N = 38.

‘Cost’ scores were then compared using repeated measures between groups ANOVA to assess possible differences in the ‘cost’ on performance created by the different conflict conditions and the different stimulus cues. The results of the repeated

measures between subjects ANOVA revealed a significant main effect of conflict, $F(1, 36) = 97.41, p < .001$, partial $\eta^2 = .730$, characterized by a greater ‘cost’ of square root transformed MRT for the overall sample on tasks with a response selection conflict ($M = 3.15, SE = .29$), than tasks with a stimulus selection conflict ($M = .94, SE = .20$) (see Figure 9). The groups did not differ in ‘cost’ of square root transformed MRT between stimulus selection and response selection conflicts, as indicated by a lack of a significant interaction effect between group and conflict, $F(1, 36) = .786, p = .381$, partial $\eta^2 = .021$. Follow-up paired samples t-tests revealed significant differences between all stimulus selection and response selection cost scores ($p < .001$), characterized by greater ‘cost’ of reaction time for response selection tasks than stimulus selection tasks, with the exception of the cost of response selection where block location was the target stimulus characteristic and the cost of stimulus selection where color was the target stimulus characteristic. In this case, no difference was found between these two cost scores for the overall sample of children ($t(37) = -.219, p = .828$).

A main effect of target stimulus characteristic was also revealed, $F(1, 36) = 26.69, p < .001$, partial $\eta^2 = .426$, characterized by greater ‘cost’ on square root transformed MRT for the overall sample on tasks where color was the target stimulus characteristic ($M = 3.17, SE = .34$), compared to tasks where block location was the target stimulus characteristic ($M = .92, SE = .28$) (see Figure 11). Follow-up paired samples t-tests revealed significant differences between ‘cost’ of stimulus selection for color and block location tasks, and significant differences between ‘cost’ of response selection for color and block location tasks ($p < .001$) for the overall sample, both characterized by a greater ‘cost’ of reaction time when color was the target characteristic than when block location

was the target characteristic. The groups did not differ significantly in the effect of target stimulus characteristic on 'cost' of square root transformed MRT, as shown by the insignificant interaction effect between group and target stimulus characteristic, $F(1, 36) = 2.60, p = .115, \text{partial } \eta^2 = .067$. No other interaction effects were revealed.

Figure 11

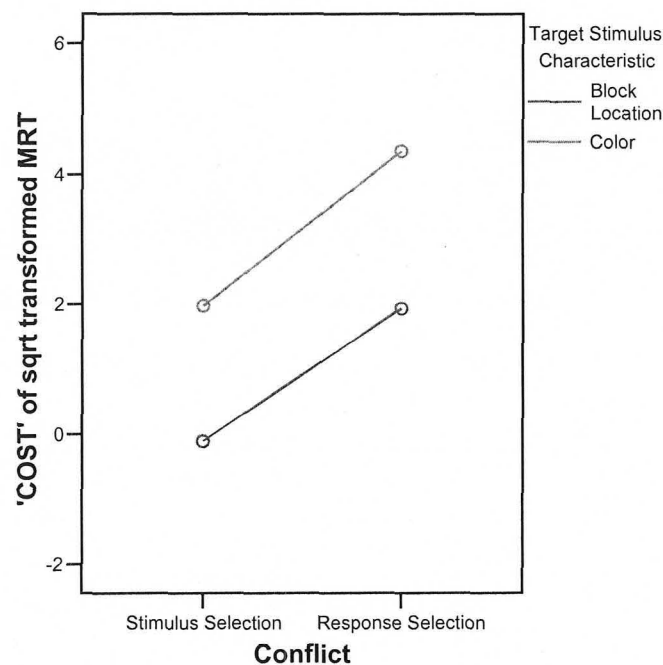


Figure 11. 'Cost' of square root transformed mean reaction time (MRT) for the entire sample as a function of conflict type (i.e., stimulus selection or response selection) for the target characteristics block location and color. Significant main effect for conflict ($F(1, 36) = 97.41, p < .001, \text{partial } \eta^2 = .730$), characterized by greater 'cost' of response selection on MRT than 'cost' of stimulus selection. Also a significant main effect for target stimulus characteristic ($F(1, 36) = 26.69, p < .001, \text{partial } \eta^2 = .426$), characterized by greater 'cost' of reaction time for conditions where color was the target stimulus, than when block location was the target stimulus.

Stroop Analyses

One child with ADHD refused to complete the final two Stroop conditions. All 23 controls completed the Stroop, and 16 children with ADHD completed all Stroop conditions. When assessing the different conditions of the Stroop, children with ADHD achieved significantly less items ($M = 63.71, SD = 12.23$) on the word condition than control children ($M = 75.26, SD = 17.86$), $t(38) = 2.295, p = .027$. Children with ADHD also obtained significantly less items on the color-word condition ($M = 27.00, SD = 5.63$) than control children ($M = 32.39, SD = 8.32$), $t(37) = 2.253, p = .030$. Children with ADHD obtained comparable items on the color condition. However, independent samples t-tests between traditional Stroop interference scores ($t(37) = .110, p = .913$) and Golden Stroop interference scores ($t(37) = 1.132, p = .265$) revealed no significant differences between groups.

Pearson Product Moment Partial Correlations were used to analyze the relationships between the different conflict conditions and Stroop interference scores (Golden or classic). Square root transformed MRT for stimulus selection and response selection conditions for block location and color tasks were correlated with both Stroop interference scores while controlling for square root transformed MRT for control condition. The results of the partial correlation coefficients for the overall sample revealed a significant negative correlation between stimulus selection conflict (target characteristic: block location) and the Golden Stroop interference score ($r = -.349, p = .037$). Recall that for the Golden method, the interference score is negative when word reading actively interferes with color naming and positive when a participant is able to inhibit reading the word. A significant relationship was also found for the overall sample

between response selection conflict (target stimulus: block location) and Golden Stroop interference scores ($r = -.347, p = .038$). No other significant partial correlations were revealed.

For tasks where color was the target characteristic, no partial correlations between conflict conditions and Stroop interference scores for the overall sample were significant.

Partial correlations between averaged stimulus selection and response selection conditions and Stroop interference scores while controlling for averaged control conditions revealed a significant negative relationship between reaction time on averaged stimulus selection conflict conditions and Golden Stroop interference scores for the overall sample ($r = -.415, p = .015$). There was no significant relationship between Golden Stroop interference scores and reaction time performance on averaged response selection tasks for the overall sample ($r = -.283, p = .105$). No other significant correlations were found.

Discussion

Stimulus Selection and Response Selection

The first purpose of the present study was to assess two forms of inhibitory control in children with ADHD, stimulus selection and response selection, using two types of stimulus cues, color and location. Previous research (Casey et al., 1997) has indicated that children with ADHD have more difficulty than normal children on tasks requiring stimulus selection, or the inhibition of processing and responding to irrelevant stimuli in order to respond to target stimuli (i.e., 'interference' control). Whereas stimulus selection was found to be impaired in children with ADHD, Casey and colleagues (1997) concluded that response selection, or the ability to inhibit prepotent, or inappropriate

motor responses, was preserved in children with ADHD compared to normal controls, and to other clinical groups of children reported to suffer from inhibitory deficits (Casey, 2000). The current study utilized different computerized conflict tasks creating stimulus selection and response selection conflict conditions, and compared the performance of children with ADHD to normal controls in an effort to replicate the findings of Casey and colleagues (1997).

Following Casey's findings, the first hypothesis of the present study was that children with ADHD would show deficits on tasks involving stimulus selection conflicts. The current study provided some data that support the previous finding of Casey et al. (1997) that children with ADHD have a deficit in stimulus selection. Error analysis on the averaged stimulus selection and response selection tasks revealed a significant between groups effect, indicating that children with ADHD made more errors on conflict conditions than normal children, even after controlling for baseline error rates. Importantly, results revealed a 'trend' for children with ADHD to make more errors on tasks requiring stimulus selection than tasks requiring response selection. A larger sample size and subsequently more power may have brought this finding into significance. This 'trend' for children with ADHD to make more errors on tasks requiring the inhibition of irrelevant stimulus characteristics parallels the findings of Casey et al. (1997), that children with ADHD show impairments on stimulus selection tasks. Interestingly, the pattern of results across stimulus selection conditions in terms of mean reaction time did not differ between the groups. This suggests that perhaps for children with ADHD, there was a speed/accuracy trade-off. Whereas children with ADHD were able to respond as

quickly to stimuli as normal children, they made more mistakes, indicating an inability to 'inhibit' responses to irrelevant stimuli.

Reaction time findings may have also been impacted by the variability in reaction time for children with ADHD, contributing to the lack of significant findings in the reaction time data. The most consistent finding in the literature on ADHD is that their overall reaction times are slower and considerably more variable than those of control children (Leth-Steenson, Elbaz, & Douglas, 2000). There was some evidence that children with ADHD performed slower than normal children, however, after controlling for baseline reaction time (i.e., baseline reaction time was RT on Task 5 for the conditions with block location as the target stimulus, RT on Task 6 for the conditions with color as the target stimulus, and an average of RT on Tasks 5 and 6 for the averaged task conditions), this between groups effect became insignificant. Again, a larger sample size may have provided enough power for this effect to remain stable.

The results of the present study provide support for the second hypothesis that children with ADHD would perform comparably to control children on tasks requiring response selection, or the inhibition of a competing, but inappropriate, motor response. Both response selection conditions, when block location or color was the target stimulus characteristic, created significant main effects for all participants, at least prior to controlling for baseline reaction time. No group differences were revealed for either response selection condition. These findings indicate that responses for children with ADHD and normal control children were slower in the presence of a response selection condition than for the control condition. In other words, responses were slower for both groups when required to make an incompatible response to either color or block location.

Although children with ADHD appeared to be slightly, but not significantly slower, the 'cost' of reaction time between control and conflict conditions did not differ between the groups. Furthermore, although children with ADHD tended to make more errors overall, they tended to make more errors on stimulus selection tasks compared to normal controls as opposed to making more errors on response selection tasks, where they performed comparably. The finding that children with ADHD perform as well as control children on tasks requiring response selection supports previous findings (Casey et al., 1997) stating that children with ADHD do not have a response selection deficit compared to normal children.

When assessing reaction time for the entire sample, stimulus selection and response selection conflict conditions, whether for individual target stimuli or averaged, created significant main effects. In other words, all children in the present sample had slower reaction times to conflict conditions than to control conditions. Interestingly, however, once baseline reaction time was controlled for, this effect did not remain. It may be that the differences between reaction times once controlling for baseline reaction time were too subtle to create significance. There was certainly a 'cost' of reaction time associated with conflict conditions, as shown by the 'cost' analysis.

Although reaction time is sometimes thought to be a more sensitive measure of performance than error rates, in the present study that was not the case, especially when comparing children with ADHD to control participants. This is not to say that reaction time is not a good measure of performance. However, in this study, children with ADHD responded as fast as normal children, though their performance tended to be more error prone, and reaction time data did not reveal any differences between the groups. Future

research on the performance of children with ADHD using reaction time analysis should also include error analysis in order to ensure that any 'lack' of between groups effects are not due to a speed/accuracy trade-off. In the present study, error analysis proved to be a more sensitive measure of performance in its ability to detect differences in performance on conflict tasks between the groups.

There are a variety of models that attempt to explain the cognitive control required to carry out response inhibition tasks. Parallel-distributed processing (PDP) models (e.g., Cohen et al., 1990) are among the more currently accepted models in the literature today. The PDP model of Cohen and colleagues (1990) is an integrative theory of prefrontal cortex function, which holds that the prefrontal cortex sends 'top-down' signals to configure processing in other parts of the brain in order to represent the goals or rules that correspond with current task demands (Miller & Cohen, 2001). PDP models hold that there are groups of simple information processing units through which information flows. The activation of a given unit is dependent on selective attention, activation, and strength of pathway connections rather than speed of processing (Sugg & McDonald, 1994). PDP models can be feed-forward or feedback depending on which way the information is hypothesized to flow through the system. The PDP model proposed by Cohen and colleagues (1990) is a feed-forward model that is separated into two input and hidden unit pathways containing task-biasing units that affect the activation of the pathways. These 'task-biasing' units provide signals that direct the activity along neural pathways that create the correct mappings between inputs, internal states, and outputs necessary to perform specific tasks (Miller & Cohen, 2001). Weak, but task relevant stimulus-response mappings are favored (or 'biased') by the 'top-down' signals

from the prefrontal cortex when these weak mappings are in competition with stronger, more prepotent or habitual mappings. In other words, the prefrontal cortex functions as a modulator between stimulus and response when there is competition between two neural pathways for the expression of a specific behavior. The ‘winner’ of the pathway is the one with the strongest support. The prefrontal cortex helps to resolve competition and guide activity along the appropriate pathways by providing support for the ‘weaker’ pathway, thus establishing the proper mappings needed to perform specific tasks. Cohen and colleagues (1990) have used this model to help explain the Stroop effect, where the “task-biasing” unit can be described as an attentional bias to process either words or colors (Sugg & McDonald, 1994). This model can be generalized to other tasks requiring cognitive control, such as the stimulus selection and response selection tasks in the current study. In the stimulus selection tasks, participants were required to attend to a specific target stimulus characteristic, either block location or color, and ignore the interfering stimulus characteristic, either color or block location, respectively. For both groups, results indicated a main effect for stimulus selection when color or block location was the target stimulus characteristic, indicating that block location interfered with responding to color, and that color interfered with responding to block location, resulting in a longer reaction time for the stimulus selection conflict condition than for the control condition. Interestingly, the cost score analysis, revealed that for the overall sample, there was a greater ‘cost’ on MRT for stimulus selection tasks where color was the target characteristic (and block location the irrelevant characteristic) than the ‘cost’ of MRT for stimulus selection tasks where block location was the target characteristic (and color the irrelevant characteristic). This result suggests that for both groups, block location was the

more salient stimulus attribute. According to the PDP model (Cohen et al., 1990) the neural pathway that controls responding to block location is stronger, and thus provides competition for the neural pathway that controls responding to color. Competition between two neural pathways requires activation of the prefrontal cortex in order to resolve the conflict and guide activity along the correct pathway required to achieve the task goals. This activation of the prefrontal cortex delays responding as cognitive control is required in order to achieve the proper stimulus-response mapping. In other words, when the participant simply responds the 'same' to a stimulus cue, there is no competition between neural pathways, thus the correct response is carried out without requiring further activation or guidance from other sources, specifically the prefrontal cortex. However, in terms of the computerized conflict paradigm for the stimulus selection conditions, when a stimulus selection conflict is present, signals from the prefrontal cortex are required in order to 'bias' the processing of either location or color, depending on which neural pathway will lead to the correct response. This additional neural activity creates a delay in responding, as competition between neural pathways needs to be resolved before the correct response can be made. For the stimulus selection condition where color was the target and block location was the interfering stimulus cue, the neural pathway required to respond to block location for the overall sample was stronger, and thus interfered with and slowed the processing of the target cue color. In other words, because responding to block location was the more dominant response, it was difficult for all children in the current study to inhibit the tendency to attend to and thus process cues of location and instead process only color cues.

Color also interfered with responding to block location in the other stimulus selection task. Using the PDP model in this case, the competition between the two neural pathways, one to respond to color and one to respond to block location created a delay in responding to the target stimulus, in this case, block location. Even though block location appears to be a more salient stimulus attribute, the presence of a competing stimulus still slows responding, as signals from the prefrontal cortex are required to activate the correct neural pathway. According to Casey's (2001) model of inhibition, signals from the dorsolateral prefrontal cortex helps resolve stimulus selection conflicts. These signals favor task-relevant sensory inputs, either block location or color (depending on the target stimulus), and can thus guide activity along the appropriate pathways that lead to the correct response. The 'task-biasing' signals from the prefrontal cortex that help to guide neural activity along the appropriate pathway thus 'inhibit' activity along the competing, inappropriate pathway.

Whereas both groups of children showed a 'cost' in reaction time for tasks involving stimulus selection conflicts, children with ADHD tended to make more mistakes on these tasks. This result suggests that children with ADHD are less able to inhibit responses to irrelevant stimulus characteristics, thus the 'competing' neural pathway 'wins' and is activated, resulting in the incorrect response. As mentioned, Casey (2001) holds that the dorsolateral prefrontal circuit controls stimulus selection inhibition. Furthermore, Casey and colleagues (1997) found that the right prefrontal cortex volume was positively correlated with mean accuracy on stimulus selection tasks for control participants, but not for children with ADHD. The tendency for children with ADHD to make more errors on stimulus selection tasks than normal children may be a

result of a deficit in prefrontal cortex activation, specifically the dorsolateral prefrontal cortex. Further research is necessary using magnetic resonance imaging with a variety of inhibitory tasks in order to make any conclusive remarks.

The PDP model can also be applied to explain the interference effects created by the response selection conditions for the overall sample. In the response selection conditions, participants were required to make an incompatible response to block location or color. In other words, they had to inhibit a prepotent, over-learned tendency to respond compatibly to the stimuli. While children with ADHD did not differ from control children in their ability to inhibit prepotent responses, reaction times for both groups of children were significantly slower when a response selection conflict was present compared to the control condition, at least before baseline reaction time was controlled for. This was the case for both response selection conditions, as well as for the averaged response selection tasks, indicating that making an incompatible response is more difficult than making a compatible regardless of the target stimulus. Interestingly, cost score analysis revealed that MRT for response selection conditions were slower when the target stimulus was color than when the target stimulus was block location, indicating that for both groups, it was more difficult to make an incompatible response to color than to block location. Using the PDP model (Cohen et al., 1990; Miller & Cohen, 2001), after the initial processing of the target stimulus, and during the second stage of attentional processing (i.e., responding to the stimulus), there is a bias to respond compatibly to the stimulus, as opposed to incompatibly. In other words, there is a tendency to activate the neural pathway required to respond compatibly to the stimulus due to the greater strength of this pathway, thus slowing the completion of an incompatible response during a response

selection condition. Therefore, the neural pathway required to carry out the 'correct' response (i.e., an incompatible response) may not be as strong as the pathway required to carry out the prepotent 'compatible' response. In other words, the stronger pathway used to activate the prepotent 'same' response creates intense competition for the activation of the pathway required to make the correct 'opposite' or 'incompatible' response. Signals from the prefrontal cortex are required to resolve this conflict and bias activation of the correct neural pathway required to establish the correct 'incompatible' response.

This is particularly true when the target stimulus was color, suggesting that the pathway required to conduct an incompatible response to color is perhaps weaker than the pathway required to perform an incompatible response to location. Looked at in another way, the ability to inhibit the prepotent 'same' response to target stimuli was difficult due to the somewhat automatic activation of this pathway. The strength of this pathway is greater than the strength of the pathway required to make an incompatible response due to its relative lack of use. This theory holds for responses of people in everyday tasks, such as driving, where people tend to respond compatibly to cues in the environment, such as location and color, in order to guide them along the correct path towards their destination and keep them from causing accidents. In order to inhibit the 'same' response and carry out the correct 'opposite' response, activation of the prefrontal cortex is required. Casey et al. (1997) hold that the lateral orbitofrontal circuit controls response selection, thus signals from this area of the prefrontal cortex are required in order to resolve response selection competition. The comparable performance between groups on response selection tasks suggests that the functioning of the lateral orbitofrontal circuit is relatively preserved in this sample of children with ADHD.

Stroop Color-Word Test

A second purpose of the present study was to assess the performance of children with ADHD on a classic Stroop task (Stroop Color and Word Test, Golden, 1978) and compare this performance to normal control children. Stroop interference scores were then correlated with performance on the stimulus selection and response selection task conditions to assess the relationships between these different inhibitory tasks. The final hypothesis that children with ADHD would perform more poorly on the Stroop task compared to controls was not supported. While children with ADHD obtained fewer items on the word and color-word conditions of the Stroop task than control children, their Stroop interference scores did not reliably differ. This finding parallels previous studies that have failed to find differences between children with ADHD and normal control children on Stroop tasks (e.g., Cohen et al., 1972; Gaultney et al., 1999; Seidman et al., 1997). Importantly, many previous research studies have indicated significant differences between children with ADHD and control children on Stroop interference scores (e.g., Golden & Golden, 2002; Leung & Connolly, 1996; McLaughlin, 2002; Pennington et al., 1993) and some have even indicated that the Stroop task is one of the most reliable tools to differentiate between children with ADHD and normal children (Barkley et al., 1992). However, although many researchers reveal a deficit on Stroop performance for children with ADHD, results are still mixed, leaving current researchers to conclude that the Stroop test alone is not an adequate tool to differentiate children with ADHD from normal children (van Mourik et al., 2005). The small sample size and heterogeneous sample of children with ADHD (i.e., comorbidity with ODD and LD) in the current study may have influenced the findings. It is apparent that the discrepancies in

the Stroop literature for performance of children with ADHD stress the importance of using a variety of tests to assess possible deficits for children with ADHD on inhibitory tasks. Importantly, the current study and Casey's work suggest primarily using inhibition tasks of stimulus selection and response execution versus inhibition tasks of response selection in order to discriminate between children with ADHD and normal children in terms of inhibitory deficits.

Correlation analyses between Stroop interference scores and reaction time performance on averaged stimulus selection and response selection task conditions revealed a significant relationship between Stroop interference scores and reaction time performance on stimulus selection tasks for the overall sample. No significant relationships were found between averaged response selection and Stroop interference scores for the overall sample. This finding supports previous research that Stroop performance is significantly correlated with reaction time on tasks requiring the inhibition of irrelevant stimulus characteristics but not on tasks requiring the inhibition of over-learned, prepotent responses (Nassauer & Halperin, 2003). The results for the overall sample suggest that similar cognitive processes are required to complete the computerized stimulus selection tasks and the Stroop Color-Word test (Golden, 1978). More specifically, these findings imply that the Stroop task, like the stimulus selection task, targets the first stage of attentional processing that requires the inhibition of irrelevant stimulus characteristics (i.e., color word) in order to attend and respond to the target stimulus characteristic (i.e., name the ink color). The finding that Stroop interference was not related to performance on averaged response selection tasks suggests that the Stroop does not require the inhibition of a prepotent, over-learned, inappropriate

response. According to Casey's model (2001) the dorsolateral prefrontal circuit controls stimulus selection. Thus, because the Stroop task tends to correlate with performance on stimulus selection tasks, this suggests that perhaps similar underlying neural pathways are being targeted in the performance on the Stroop and stimulus selection tasks. More research is needed to assess the relationships between different inhibitory tasks and Stroop tasks to better understand the underlying neural processing required for normal developing children, and children from different clinical populations, to carry out these types of inhibitory demands.

Color was used as a target characteristic in the computerized conflict tasks in an attempt to more closely mimic the stimulus cues used in the interference condition in the classic Stroop task. Interestingly, a significant relationship was found between reaction time performance on the conflict conditions and Stroop interference scores (Golden method) for conditions where block location was the target stimulus characteristic, but not for conflict conditions where color was the target characteristic. This finding suggests that the context in which stimulus cues are presented may affect the way in which people react to them. One would expect that since block location is a more salient, thus a greater interference for color cues, that this task would more strongly correlate with Stroop interference. This lack of correlation between Stroop interference and RT on conflict tasks where color was the target characteristic may be due to a restriction in the range of Stroop inhibition scores compared to the range of scores for performance on the color conflict tasks for the overall sample. The overall sample of children tended to perform faster and more accurately on tasks where block location was the target characteristic, but were more variable and had larger reaction times to tasks where color was the target

characteristic. A larger sample size may have stabilized these scores and created different results. No conclusive remarks can be made for the correlations between Stroop interference scores and reaction time on conflict conditions with specific stimulus characteristics due to the variability in scores. Future research should examine the relationships between Stroop interference scores and reaction time for conflict conditions with a variety of stimulus cues using a larger sample size to assess if stimulus cues affect the relationship between different inhibitory tasks.

Study Limitations

There were a number of limitations to the current study. First, a small sample size and subsequent loss of power may have contributed to the lack of significance between groups on the reaction time and error analyses and the presence of ‘trends’ in the data versus significant findings. Future research should use a larger sample size to reassess the performance of children with ADHD on tasks requiring stimulus selection.

Another possible limitation to the study was the heterogeneous sample of ADHD children. Due to time restrictions, and the high comorbidity rates, children with a diagnosis of ADHD that also had comorbid ODD or LD were included in the current sample. This was believed to preserve external validity, but in turn may have influenced the results. It is possible that a more heterogeneous sample of children diagnosed with ADHD without a comorbid diagnosis may have led to different findings. The small samples of children with comorbid disorders within the group of children diagnosed with ADHD did not allow for further analysis between these groups. In an attempt to address this limitation, all analyses were conducted again separating ADHD from ADHD/ODD groups and comparing these groups to the sample of normal control children (ADHD and

ADHD/LD groups were not separated due to the small sample of children with comorbid LD). Overall, the results did not differ when comparing ADHD to controls or ADHD/ODD to controls, though given the even smaller sample sizes within each group the analyses may have lacked the statistical power to adequately address this question. Another potential research avenue could be to assess the differences between children with ADHD with and without comorbid disorders on these types of inhibition tasks to assess whether differences arise. There is not much research comparing performance on specific inhibitory tasks of children with ADHD or ADHD with comorbid disorders such as CD or ODD or LD. The few studies to date show mixed results. One study using a stop task concluded that response inhibition deficits did not distinguish children with ADHD from children with CD, nor from children with comorbid ADHD + CD (Oosterlaan et al., 1998). A review by Nigg (2001) suggests that individuals with ADHD combined type without comorbid conduct disorder may have executive inhibitory control problems (intentional suppression of a cognition or response to accomplish a later, internally represented objective), whereas individuals with ADHD and comorbid conduct disorder may also have deficits in executive inhibitory processes, but these deficits may be secondary to a primary response modulation deficit or a problem with motivational inhibition (stopping of response or behavior driven by anxiety, uncertainty, or fear). To my knowledge there are no studies that have assessed the three forms of inhibitory processing outlined by Casey (2001) in groups of children with ADHD and ADHD and associated comorbid disorders compared to normal children. The paucity of research comparing ADHD and ADHD and comorbid disorders such as ODD, CD, LD, anxiety and depression with normal children limits knowledge of possible distinctions between

these groups in terms of inhibitory functioning and suggests a need for future research into this area.

A final limitation to the current study was the use of a modified stimulus selection task versus the one used by Casey et al. (1997). Although the premise behind the stimulus selection task used in the current study follows the theory outlined by Casey and colleagues (1997), the tasks used in the current study differed somewhat in stimulus presentation and task requirements. Perhaps a task more similar to that used by Casey et al. (1997) may have led to different results, but then begs the question of whether the difference is then truly one of 'sensory selection' versus 'response selection' versus something specific to her tasks. The fact that the current research findings did not fully support a deficit for children with ADHD on tasks requiring stimulus selection suggests that difficulties on these types of tasks may be context dependent. In other words, children with ADHD may show deficits on some, but not all, tasks requiring the inhibition of irrelevant stimulus characteristics, and these differences may arise due to the context they are set in.

Conclusion

In conclusion, the current study revealed children with ADHD made significantly more errors on conflict tasks, with a tendency to make more errors on tasks with stimulus selection conflict. The results of this research suggest that the inhibition of irrelevant stimulus characteristics may be impaired in children with ADHD. Furthermore, this impairment appears to not be context dependent, as the type of target stimulus characteristic did not alter this finding. This finding supports the first hypothesis, as well as previous research (Casey et al., 1997), that children with ADHD are more impaired on

tasks requiring stimulus selection than normal children. Children with ADHD performed comparably to normal children on tasks requiring response selection, or the inhibition of over-learned, prepotent responses, providing support for the second hypothesis and paralleling previous research suggesting that response selection is relatively preserved in children with ADHD (Casey et al., 1997). Although reaction time performance did not differ between the groups on any of the tasks, the finding that children with ADHD are more error prone on these reaction time tasks suggests a speed/accuracy tradeoff. This finding suggests that for the current study, error analysis was a more sensitive measure of performance than reaction time in its ability to differentiate children with ADHD from normal control children.

Finally, the third and final hypothesis was not supported as children with ADHD performed comparably to normal children on the classic Stroop task. It must be noted that the performance of children with ADHD on the different tasks was variable, indicated by the large standard deviations in performance for all task conditions compared to those of the control group. Large variability in task performance almost inevitably affects the results and makes it more difficult to assess subtle differences in performance. Regardless, the variability in performance for children with ADHD in the current study support the statement made by Castellanos and Tannock (2002) that "Perhaps the most striking clinical characteristics of ADHD include the transient but frequent lapses of intention and attention, and the moment-to-moment variability and inconsistency in performance" (p. 624). Future research with larger sample sizes and perhaps a more heterogeneous sample of children with ADHD may lead to different conclusions. It is clear that more research needs to be carried out on different forms of inhibitory control

within an assortment of contexts with a diversity of clinical populations before any conclusions can be reached regarding the performance of children with ADHD on tasks requiring inhibition.

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Appendix A

DSM IV-TR Diagnostic Criteria for Attention-Deficit/Hyperactivity Disorder (American Psychiatric Association, 2000, pp. 92-93)

A. Either (1) or (2):

- (1) six (or more) of the following symptoms of inattention have persisted for at least 6 months to a degree that is maladaptive and inconsistent with developmental level:

Inattention

- (a) often fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities
- (b) often has difficulty sustaining attention in tasks or play activities
- (c) often does not seem to listen when spoken to directly
- (d) often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (not due to oppositional behavior or failure to understand instructions)
- (e) often has difficulty organizing tasks and activities
- (f) often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework)
- (g) often loses things necessary for tasks or activities (e.g., toys, school assignments, pencils, books, or tools)
- (h) is often easily distracted by extraneous stimuli
- (i) is often forgetful in daily activities

- (2) six (or more) of the following symptoms of hyperactivity-impulsivity have persisted for at least 6 months to a degree that is maladaptive and inconsistent with developmental level:

Hyperactivity

- (a) often fidgets with hands or feet or squirms in seat
- (b) often leaves seat in classroom or in other situations in which remaining seated is expected
- (c) often runs about or climbs excessively in situations in which it is inappropriate (in adolescents or adults, may be limited to subjective feelings of restlessness)
- (d) often has difficulty playing or engaging in leisure activities quietly
- (e) is often “on the go” or often acts as if “driven by a motor”
- (f) often talks excessively

Impulsivity

- (g) often blurts out answers before questions have been completed
- (h) often has difficulty awaiting turn
- (i) often interrupts or intrudes on others (e.g., butts into conversations or games)

B. Some hyperactive-impulsive or inattentive symptoms that caused impairment were present before age 7 years.

C. Some impairment from the symptoms is present in two or more settings (e.g., at school [or work] and at home).

D. There must be clear evidence of clinically significant impairment in social, academic, or occupational functioning.

E. The symptoms do not occur exclusively during the course of a Pervasive Developmental Disorder, Schizophrenia, or other Psychotic Disorder and are not better accounted for by another mental disorder (e.g., Mood Disorder, Anxiety Disorder, Dissociative Disorder, or a Personality Disorder).

Appendix B

**CHILD HISTORY QUESTIONNAIRE:
STUDY OF ADHD IN CHILDREN FROM 7 TO 12**

This questionnaire is designed as a measure to obtain basic information about your child.

Whatever information you may be able to offer will be invaluable in helping us to determine which applicants are most suitable for this phase of the study. We appreciate your participation in what we feel is an exciting and important study.

Date: _____ **ID #:** _____

Parent(s) Name(s): _____

Home Phone: _____ Other Phone: _____

If not scheduling appointment today... What is the best time to reach you? _____

Child's Name: _____ DOB: _____ Age: _____

DEVELOPMENTAL / MEDICAL HISTORY

Has your child been diagnosed with ADHD? Yes No

If no: Do you suspect your child may have ADHD? Yes No

If yes: Date Diagnosed: _____

Who diagnosed your child? _____

ADHD subtype (circle one): Combined Hyperactive Inattentive Don't know

Is your child currently taking medication for ADHD or any other condition?

Yes

<i>Name</i>	<i>Dose (mg)</i>	<i>Frequency</i>

Exclusion criteria = anxiety and antiepileptic meds

No: Has your child ever received medication for ADHD?

No

Yes: How long (months, years)? _____

If child is on psychostimulant medication:

As part of this study, children will need to be off medication for 24 hours prior to coming in.

Would you be ok with taking your child off medication for 24 hours? Yes No

Please contact your child's doctor if you have any questions about taking your child off medication.

Please tell us if your child has any of the following:

- Primary language other than English: _____
- Neurological conditions such as epilepsy, tourette's... _____
- Serious head injury (with >20 mins. loss of consciousness)
- Visual impairment
- Hearing impairment
- Color blindness
- Learning disability

If yes: Is it diagnosed? _____ Did the school help diagnose LD? _____

Is your child receiving learning assistance? _____

- Other medical or psychological conditions: _____

Has your child received or been involved in any of the following?

Grade / Age

- Learning Disabilities/Special Education Class _____
- Behavioral Adjustment Class _____
- Tutoring _____
- Enrichment / Gifted _____
- Language Immersion _____
- Other _____

Testing session scheduled for: Date: _____ Time: _____

Follow up: _____

Appendix C

CHILDREN'S CONSENT FORM FOR PARTICIPATION IN THE STUDY

My name is _____.

Today I will be working with Kate or Karin at the University of Victoria. They are students in psychology and would like me to play some computer games. For some games, I will put on some special goggles and see a classroom in them. There will be teacher there, who asks me to push a button when some colored boxes or words are written on the board. For other games, I will press a colored button or touch a screen. I will try to pay attention and do the best I can. Playing these special games and activities will help researchers to understand more about children who have ADHD, and may also help in the future to figure out if other kids are having problems paying attention.

I am here today because I decided I would like to participate in this study. If I decide at any time today that I no longer want to participate, I just have to tell Kate or Karin and they will let me stop if I want to. Nothing I do here today will affect my grades in school or my health.

I will get some money for my time and effort for coming in today, if that is okay with my parents, and I will get the money even if I decide not to finish participating.

All of my "data" (scores, numbers, and any other information) collected from me today will remain confidential - that means no one (not even Kate, Karin, or Dr. Kerns) will be able to know my name, or what my scores are. In fact, instead of using my name, they will use a "secret code." All of my data will be stored confidentially at the University of Victoria, and they will destroy it all after 3 years.

If I have any questions, my parents or I can call Kate or Karin at 250-472-4339 or their supervisor, Dr. Kimberly Kerns at 250- 721-7553.

Date: _____

My signature: _____

Appendix D

Participant Consent Form

You are being invited to participate in a study entitled “An ADHD investigation of inhibition and working memory” that is being conducted by Dr. Kimberly Kerns. Dr. Kerns is an associate professor in the Department of Psychology at the University of Victoria. You may contact her if you have further questions by phoning (250) 721-7553.

The purpose of this research project is to examine various measures of behavioral inhibition and verbal and nonverbal working memory. Inhibition and working memory will be examined with the use of computer tasks, some of which will use virtual reality or real-world environment technology. These tasks will help researchers to better understand how children with Attention-Deficit Hyperactivity Disorder (ADHD) pay attention, respond to, and remember different stimuli in the environment.

For this study, children will complete a series of computer tasks designed to assess their concentration to specific aspects of their environment when there is interference. In these tasks, the child will view different shapes on a computer screen and respond by pressing a mouse, a colored button, or touching a screen. For the tasks using virtual reality technology, children will put on a head-mounted display that allows them to see a virtual ‘classroom’ where they sit at a desk and see a ‘teacher’ at the front of the classroom. These virtual tasks require the child to click a mouse depending on instructions they receive from the ‘teacher’. The use of virtual reality technology allows researchers to create a more realistic and controlled environment for which to monitor responses and behavior to different tasks.

If you agree to voluntarily participate in this research, your participation as a parent will include the completion of a behavior rating scale to measure the presence or absence of behaviors characteristic of ADHD and other disorders in your child. If your child has ADHD you will be asked to withhold any stimulant medications for 24 hours prior to participating. If you have any concerns regarding this, please consult your prescribing physician. Your child will participate in a series of computer activities in which they respond to different sights and sounds. Most children find these computerized tasks fun and engaging. There are no known or anticipated risks to you by participating in this research. Your participation will benefit the understanding of inhibition and working memory in children with ADHD. Further, it will not be possible to receive specific results of feedback on your child’s test data.

As a way to compensate you for any inconvenience related to your participation, you will be given \$5.00. It is important for you to know that it is unethical to provide undue compensation or inducements to research participants and, if you agree to be a participant in this study, this form of compensation to you must not be coercive. If you would not otherwise choose to participate if the compensation was not offered, then you should decline. Your participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do not withdraw from the study your data will be retained or destroyed, at your discretion.

The University of Victoria abides by the American Psychological Association’s ethics policies, which specifically require informed consent, prohibit duplicate reporting of data, require asking for consent for specific projects, and uses the data collected only for that reason. All data collected from this study will

be handled in a secure, confident manner. After analysis of the collected data is completed, the data will be archived for up to three years, after which it is destroyed in a secure manner. Ensuring that any personal information is secure from people not directly involved in this study will protect your anonymity and confidentiality. Some scientific reports comparing groups of participants on these tasks may be published in appropriate scientific journals. Demographic data provided, as well as other background information will allow us to better understand the results of this study. Rest assured that the information remains confidential.

In addition to being able to contact Dr. Kimberly Kerns at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4362).

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

Name of Participant (Parent)

Parent Signature

Date

A copy of this consent will be left with you, and the researcher will take a copy.