

The Effect of Enhanced Motivation on Time Reproduction  
Abilities in Children with ADHD

by


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### ABSTRACT

Research has shown that children with attention deficit/hyperactivity disorder (ADHD) demonstrate poor performance on time reproduction paradigms and related measures that assess one's sense of time. In Barkley's (1997) model of ADHD, a central deficit in behavioural inhibition is hypothesized to set the occasion for impairments in four subservient executive functions. One of these executive functions, spatial working memory, is hypothesized in turn to underlie a number of complex abilities including one's subjective sense of time. Motivational factors, however, may also impact performance on time reproduction paradigms as these tasks are frequently long and offer no feedback and little inherent reward.


The primary goal of this study was to examine whether children with ADHD have a true deficit in subjective sense of time, or whether their impairment instead reflects a motivational deficit. To test this possibility, 60 children (30 children with ADHD and 30 controls matched by age and gender) between the age of 6 and 13 years completed two versions of a time reproduction paradigm, along with measures of working memory and a measure of behavioural inhibition. On one time reproduction task (the "regular version"), subjects saw a light bulb appear on a computer monitor for a duration that ranged between 3 and 17 seconds, and had to reproduce the duration by turning their own computer-based light bulb on and off for the same amount of time as the computer-generated target duration. The second version of the paradigm (the "enhanced" version) was similar to the first, except that following each trial subjects received feedback that consisted of a sham score, reinforcing graphics, and a verbal accolade, which collectively indicated they had done well on their time reproductions. On the enhanced version, subjects were told that if they did "well enough" and attained a high score, they would be able to choose a prize from a large, attractively-wrapped gift box. They were instructed further that if they did not score as highly, they could still choose a prize, but only from the much smaller prize box, wrapped in white lined writing paper.


Conditions were counterbalanced for presentation and in truth, all children received identical sham feedback so that at the end of the game, all participants “won” the bigger prize. It was hypothesized that if a motivational deficit underlies the poor time reproduction abilities observed in children with ADHD, the deficit might be ameliorated by the increased motivation provided by the enhanced version of the task.

Results indicated that children with ADHD made significantly fewer errors in the enhanced *versus* the regular condition of the time reproduction paradigm. In contrast, control subjects exhibited no reliable change in performance between versions of the task. Despite the improvement shown by children with ADHD, they continued to perform significantly below controls even on the enhanced version of the game. The groups also differed significantly on the measures of working memory and behavioural inhibition.


The impact of self-reported motivation, working memory, and behavioural inhibition on time reproduction, and the relevance of these results in context of Barkley’s theory of ADHD are examined and discussed.

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Dedication

To my parents,  
for boundless love and support.

## Introduction

Attention-Deficit Hyperactivity Disorder (ADHD) is a behavioural disorder characterized by three primary features: poor sustained attention; impulsiveness; and hyperactivity. The disorder arises early in childhood, typically by age seven, and is fairly persistent over development (Barkley, 1994;1997). With an estimated childhood prevalence of 3 to 7 percent (Barkley, 1997), ADHD is one of the most frequently diagnosed disorders in pediatric populations. The disorder occurs much more frequently in males than in females, with male-to-female ratios in the range of 4:1 (American Psychiatric Association [APA], 1994). In childhood and adolescence, those with ADHD are at greater risk for poor academic achievement, poor peer and family relationships, conduct disorders, and delinquency. In adulthood, those with ADHD experience more difficulties with adult social relationships, marriage, and employment (Barkley, 1997; Weiss & Hechtman, 1993).

The Fourth Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; APA, 1994), the current consensual diagnostic manual in North America, combines the three characteristic features of ADHD into two, with hyperactivity and impulsivity considered to be a single impairment. Thus, the current view of ADHD offered by the DSM-IV classifies the disorder into Predominantly Inattentive, Predominantly Hyperactive-Impulsive, or Combined subtypes (children with aspects of both difficulties).

Over the years, and in the absence of a valid and generally accepted hypothesis of ADHD, researchers in the field have conceptualized ADHD in a number of different ways. Before the term ADHD became generally accepted, the features of the disorder

were thought to arise from poor volitional inhibition and defective moral regulation of behaviour (Still, cited in Barkley, 1997). In the 1960s the disorder was termed "Minimal Brain Dysfunction," while later conceptualizations emphasized overactivity or motor restlessness, and the terms hyperkinesis, hyperkinetic reaction of childhood, and hyperkinetic syndrome were applied (Barkley, 1990). The key behaviours included excessive fidgeting, difficulty remaining seated, blurting out answers before questions have been completed, and difficulty awaiting one's turn. By the 1970s, clinicians and researchers began to recognize the presence of attentional deficits in children with ADHD. These deficits included failing to pay attention in school, carelessness or sloppiness in tasks, failing to listen when spoken to directly, distractibility, and difficulty organizing tasks and activities. Having been thrown into prominence these inattentive behaviours overshadowed the hyperactive component, and the latter was seen as a less important factor. In addition, the early view of simple motoric overactivity was reconceptualized as stemming from a more general deficit in self-regulation of behaviour.

At present, there is a reasonable consensus between clinicians and researchers that deficient behavioural inhibition lies at the heart of ADHD (Barkley, 1994, 1997; Quay, 1988; Schachar, Tannock, & Logan, 1993; Schachar, Tannock, Marriott, & Logan, 1995). Several theories and models of ADHD have thus developed with impaired behavioural inhibition viewed as the core deficit; this study will focus on one of these theories more clearly elaborated by Barkley (Barkley, 1997; 1997b).

### Behavioural Inhibition

Barkley (1997; 1997b) contends that successful behavioral inhibition consists of three abilities: (1) the ability to inhibit a prepotent response (one for which immediate

reinforcement is available, be it positive or negative); (2) the ability to interrupt an ongoing response, thereby allowing a delay in the decision to respond; and (3) the ability to protect this delay from competing events and responses, a process termed interference control. He maintains that all three inhibitory processes are impaired in ADHD, and treats them as a single construct.

Evidence for the dissociability of behavioural inhibition into separate components and of their impairment in ADHD comes from a number of studies. At the level of inhibiting a prepotent response, impairments in those with ADHD have been found in studies employing go/no go paradigms, certain versions of the continuous performance test (CPT), and stop signal (stop) paradigms. Go/no go tasks require subjects to perform a simple motoric response to one cue, the *go* stimulus, while inhibiting the response to another cue, the *no-go* stimulus (Barkley, Grodzinsky, & DuPaul, 1992). Those with ADHD tend to perform poorly on this task, often responding more frequently to no-go stimuli (an error of commission) than controls (Iaboni, Douglas, & Baker, 1995; Shue & Douglas, 1992; Trommer, Hoepfner, Lorber, & Armstrong, 1988). Similarly, CPT paradigms, used widely among ADHD researchers, have demonstrated that children with ADHD commit greater errors of commission (i.e., responding to an inappropriate stimulus) than do controls (Barkley, 1991; Barkley et al., 1992; Barkley, Murphy, & Kwasnik, 1996).

Stop paradigms have also proven sensitive to the response inhibition deficits characteristic of ADHD. Subjects are typically presented with two concurrent tasks, a *go task* and a *stop task*. The go task is a choice reaction time task in which subjects must discriminate between two stimuli, often an *X* from an *O* (although any two stimuli will

suffice). Stop trials, which occur randomly on about a quarter of go-task trials, involve presentation of a tone (the stop signal) after the go stimulus appears which directs subjects to inhibit their response to the go task on that trial. Whether or not subjects are able to inhibit has been conceptualized as a race between the stop task and the go task: if they finish the stop task before the go task, they will have inhibited successfully; however, if they finish the go task before the stop task, they will have failed to inhibit, responding much as they would have had no stop signal been presented. Several research groups have found that individuals with ADHD have longer stop-signal reaction times relative to those of controls (Oosterlan & Sergeant, 1996; Schachar & Logan, 1990; Schachar et al., 1993). In other words, children with ADHD have more difficulty stopping an ongoing response secondary to the stop signal, and the stop stimulus must be presented sooner for them to successfully inhibit.

At the second level of inhibition (stopping an ongoing response pattern), deficits have been observed in those with ADHD while performing the Wisconsin Card Sorting Test (WCST). In this task, subjects are required to sort a series of cards according to a target key card; however, the sorting strategy changes periodically throughout the task without explicit notification. To sort the cards successfully, subjects must stop their ongoing response pattern as per their current strategy and shift to a different one. In a review by Barkley et al. (1992), eight of 13 studies in which the WCST was used found that children with ADHD committed more response perseverations (i.e., failing to shift to a new strategy) than those committed by controls.

Deficits at the third level of inhibition (interference control) have also been observed in those with ADHD. For example, on the interference phase of the Stroop

Colour-Word test, subjects are presented with a series of colour names printed in a colour of ink that is incongruent with the name of the colour (e.g., the word "red" printed in blue ink). Rather than reading the word itself, subjects are asked to name the colour of the ink in which the word is printed. To perform successfully, subjects must inhibit their natural tendency to read the name of the colour and instead say aloud the colour of the word despite the interference provided by the name. Barkley et al. (1992) noted that of six studies in which the Stroop test was used, five found children with ADHD to be more impaired than controls on the interference phase.

### Structure of Barkley's Model

Barkley's (1997) model of ADHD is arranged hierarchically and hypothesizes that deficits in behavioural inhibition, at the top of the hierarchy, "set the occasion" for difficulties in several other abilities termed *executive functions*. Collectively, behavioural inhibition along with these executive functions contribute to the self-regulation of behaviour which occurs further down the hierarchy. The executive functions contained in Barkley's model include: (1) working memory; (2) self-regulation of affect, motivation, and arousal; (3) internalization of speech; and (4) reconstitution. By "setting the occasion," Barkley means providing a necessary delay in which these executive functions may occur; however, behavioural inhibition is not hypothesized to cause executive functions but only to be necessary for them to occur. According to Barkley, ADHD disrupts executive functioning because the first self-regulatory act in a behavioural sequence must be to inhibit responding. This permits a delay in the decision to respond in which further self-directed executive functions can occur, and which ultimately control responses. The behavioural features of ADHD, which are hypothesized to stem centrally

from deficient behavioural inhibition, lead one to act immediately rather than creating a delay in which one may “think before one acts.”

Barkley hypothesizes further that these processes are critical in problem-solving situations that require novel responses for their solution and, more importantly, when a response has distant rather than immediate consequences or when a conflict arises between these consequences. In real-world functioning, children with ADHD are influenced by immediate events and their consequences and have substantial difficulty working toward more distant rewards or longer term goals. In contrast, normal executive functioning directs behaviour away from the “temporal now,” bringing it under the control and guidance of internally represented information. These processes allow an individual to work “toward future hypothetical goals, even in the absence of immediate rewards for doing so or in the presence of immediately aversive consequences or self-imposed deprivation.” (Barkley, 1997).

#### Nonverbal Working Memory and Sense of Time

There are two broad kinds of working memory: nonverbal (or spatial); and verbal. Barkley hypothesizes that ADHD is characterized by an impairment in both kinds of working memory, although of particular interest in this study is nonverbal working memory, one of the executive functions that Barkley (1997) hypothesizes as deficient in ADHD. Nonverbal working memory is defined as the capacity to hold events in mind, and the ability to manipulate them “online” to control a response (Goldman-Rakic, 1995). Nonverbal working memory includes, but is not limited to, impairments in the ability to hold events in mind, impaired imitation of complex sequences, defective hindsight and forethought, limited self-awareness, and diminished sense of time. In accordance with

Barkley's model, research suggests that working memory, both verbal and nonverbal, is indeed deficient in children with ADHD. This is reflected in poor performance on tasks such as mental arithmetic, digit span, and the imitation of hand movement sequences (Kemp & Kirk, 1993; Mariani & Barkley, 1997; Pennington, Groisser & Welsh, 1993; Pennington & Ozonoff, 1996), all of which are thought to be heavily dependent on working memory. According to Barkley, the deficits in nonverbal working memory are hypothesized to arise largely because those with ADHD are unable to inhibit a dominant (prepotent) response to an event, and also because of a reduced capacity to protect the contents of working memory from competing sources of interference. As described earlier, the behavioural inhibition system normally preserves the contents of nonverbal working memory through interference control.

The hierarchical organization of Barkley's model suggests that deficits in nonverbal working memory lead to impairments in one's subjective sense of time, an ability subservient to working memory according to the model. It is hypothesized that by retaining a sequence of events in working memory, and by making comparisons among the events in the sequence, a sense of temporal continuity arises (Barkley, 1997; Brown, 1990; Fuster, 1989; Michon and Jackson, 1984). Thus, inherent in current conceptualizations of working memory is the capacity to represent events in their proper temporal order. Working memory must "impart time, timing, and timeliness to behaviour and its cross-temporal organization" (Barkley, 1997b).

Timing and a sense of time are essential to human functioning. Indeed, it is such an important function that for over a century experimental psychologists have studied human abilities to judge and monitor aspects of psychological time such as simultaneity,

successiveness, temporal order, and temporal duration (Zakay, 1992). Of these processes, perhaps duration timing has the most survival value because it is essential for internally representing the immediate external environment (Zakay, 1992). For example, crossing a busy street requires the continual estimation of speed and duration. As people wait in line while shopping, feelings of lengthened duration may determine whether they complete a transaction or abandon it. When planning and organizing events in a hectic day's schedule, an accurate sense of time is required so that enough time is allotted for each activity. Clearly, these abilities become progressively more important throughout development as individuals are required to be increasingly responsible for managing their use of time.

Because working memory capabilities are known to develop with age, Barkley suggests that individuals with ADHD, on account of deficient working memory, should manifest a developmental delay in their psychological sense of time and should therefore perform like younger, normal individuals on tasks that assess sense of time. For example, young normal children appear to perceive time as progressing more slowly than do older children. When asked to wait through a delay period, they perceive it as lasting longer than do older children, display greater impatience and frustration, and may even try to escape from or terminate the delay (Barkley, 1997b). Sonuga-Barke, Taylor, Sembi, and Smith (1992) described individuals with ADHD as being "delay averse"; that is, behaving in ways that seek to terminate delays as early as possible. This is consistent with the opinions expressed by parents of children with ADHD, who often rate their child's use of time in daily life as significantly more impaired than do parents of children without ADHD (Barkley, 1990; Barkley et al., 1996).

### Research Investigating Sense of Time

Three kinds of tasks have generally been used to measure sense of time. In time *estimation* paradigms, subjects are presented with a temporal duration and must verbally report its perceived duration. In time *productions*, subjects are told verbally a length of time, and must produce it in some way by indicating start and end points. In time *reproduction* tasks, subjects are presented with a temporal duration but are not told its length, and must reproduce the duration in some way as required in time production tasks. While time production tasks appear to be the easiest to perform, they are the least likely to assess one's subjective sense of time as the individual is given a verbal numerical standard to use in producing the time interval (Barkley et al., 1997). In contrast, time reproduction tasks are typically the most difficult, and are believed to measure one's subjective sense of time more accurately than the other methods (Zakay, 1990). In general, it has been observed that both children and adults make errors of progressively greater magnitudes when estimating or reproducing time intervals as the target time interval increases (Brown, 1985; Michon, 1985; Zakay, 1990, 1992).

A limited number of studies have found that individuals with ADHD indeed exhibit deficits in their ability to estimate time. For example, children identified as hyperactive have demonstrated impairments in both time production (Senior, Towne, and Huessy, 1979; Walker, 1982) and in time estimation (White, Barratt & Adams, 1979). In those studies it was found that individuals with ADHD produced significantly shorter time estimations than control subjects, a finding consistent with the idea that those with ADHD experience time as progressing more slowly than it does in reality.

Cappella, Gentile and Juliano (1977) compared the time productions of control children with a group of children identified as hyperactive, and found that the latter made more errors at all time intervals. They noted that although all children made more errors as the target time duration increased, hyperactive children made disproportionately greater errors compared to the errors made by control children. A more recent study by Barkley, Koplowitz, Anderson and McMurray's (1997) noted similarly that all children, when reproducing time intervals, displayed errors of increasing magnitude as the target duration increased, but that children with ADHD made more dramatic errors. Barkley and colleagues also noted an interesting trend in which children with ADHD tended to overestimate the target duration at smaller intervals, and underestimate it at larger ones. Dooling-Liftin (1997) reported similar results, but failed to find a directional trend in terms of under- versus over-reproductions.

Although most studies that have investigated sense of time in ADHD have used children, a study by Barkley et al. (1996) found that young adult ADHD subjects performed below controls on a time estimation task, although the difference was only marginally statistically significant. The groups did not differ on a time production task. The authors speculated that the failure to observe a group difference on the latter may have been attributable to low statistical power, and also noted that time productions are the least accurate measure of one's sense of time.

A previous study by Kerns, McInerney, and Wilde (submitted) replicated aspects of Barkley et al's (1997) findings of poor time reproduction in children with ADHD. It was noted in Kerns et al., however, that children in the ADHD group often appeared unmotivated by the time reproduction paradigm, more so than with other paradigms

presented during testing. Children with ADHD became bored with and seemed inattentive to the task; as testing proceeded, off-task behaviours such as fidgeting at the computer and looking around the room became more pronounced. In contrast, similar behaviours were not seen in control children. These observations call into question whether the poor performance on the time reproduction task was attributable to a true deficit in time reproduction abilities or to off-task behaviours stemming from a lack of motivation. To address this issue in more detail, this study will address the impact of motivation on task performance.

#### The Impact of Response Contingencies and Motivational Set in ADHD

Two main lines of research suggest that children with ADHD do not have the same motivational set as normal children. One line suggests that children with ADHD do not expend the effort necessary to perform optimally, while a second line suggests that their performance relies more heavily on the presence of response contingencies and rewards than does the performance of normal children (Oosterlaan and Sargeant, 1998). Research in this area began with Wender (1972) who hypothesized, based on observations that attempts to discipline children with ADHD were often ineffective, that the brains of these children have “anomalous reinforcement centres,” resulting in diminished responses to both reward and punishment. Haenlein and Caul (1987) elaborated on this idea by suggesting that ADHD is characterized in part by a dysfunctional reward system and that those with the disorder, because of an elevated reward threshold, experience lower reinforcement magnitudes than do normal children. To support their theory, they cited evidence that those with ADHD exhibit poorer performance during partial and delayed schedules of reinforcement, the idea being that

these schedules provide lower levels of reward. They suggested further that stimulant medications are effective in treating ADHD symptoms because they lower one's reward threshold which in turn increases perceived reward magnitude.

In contrast, Douglas and colleagues espouse the opposite view, and state that hyperactive children are unusually *sensitive* to rewards. Douglas and Parry (1983) reported that hyperactive children and normal controls reacted in opposite ways to the introduction of non-contingent rewards following a baseline condition in a delayed reaction time task. They observed that the reaction times of controls improved during non-contingent reward and dropped to baseline level during extinction, while hyperactive children deteriorated under non-contingent reward and improved during extinction. They speculated that the presence of non-contingent rewards was arousing and distracting to the hyperactive children, and failed to direct their attention to specific task demands. They suggested further that hyperactive children have an increased tendency to seek immediate rewards, overreact when rewards are withdrawn, and are more vulnerable to the arousing and distracting effects of reward (Douglas and Parry, 1983).

A more recent study by Douglas and Parry (1994) lends support to these earlier findings. These authors set up three schedules of reinforcement (100%, 50%, and 30%) along with an extinction condition (0%), and measured the speed and strength with which subjects pulled a response lever that delivered marbles as rewards. Relative to controls, children with ADHD showed a stronger reaction to the loss of anticipated rewards that was most apparent when the reinforcement schedule changed from 100% to 0%. These children pulled the lever significantly harder during the extinction phase, and continued

to pull harder than controls throughout the extinction trials. Significant group differences were also noted during the 30% schedule.

Douglas and Parry (1994) interpreted these findings as supporting their hypothesis that children with ADHD are prone to significantly higher levels of frustration to the loss of anticipated rewards. This interpretation follows from the work of Amsel (1958, 1962, 1967, 1989, cited in Domjan and Burkhard, 1993), who considered possible emotional effects of reinforcement and extinction. Amsel asserted that subjects on a partial reinforcement schedule develop a reward expectancy when early trials are rewarded. When rewards are subsequently withheld, he believed that subjects experience an emotional response that he termed "primary frustration." Future trials thus are characterized by an expectancy for frustration, which Amsel termed "anticipatory frustration." Subjects experience these two emotions simultaneously, expecting reward and non-reward, a situation that results in a conflict between approach and avoidance. To overcome this conflict, subjects must persist in their responding in light of feeling anticipatory frustration. According to Amsel, this persistence occurs because subjects experience reward for responding in the presence of anticipatory frustration which, in classic learning theorist terms, is known as counterconditioning. This process leads to an increased tolerance against response extinction, an example of the partial reinforcement extinction effect. Amsel surmised that not everyone is able to resolve the approach-avoidance conflict, and that failure to do so results in a failure to develop increased responding persistence. Although Amsel did not apply his research directly to children with ADHD, Douglas and Parry (1983) suggested that Amsel's theory may apply to this

population in that they appear to experience unusual levels of primary or anticipatory frustration, or both, which ultimately interferes with their ability to persist in responding.

Collectively, these and other findings (e.g., Corkum, Schachar, & Siegel, 1996; Tripp and Alsop, 1999) suggest that while response contingencies improve or normalize ADHD children's performance on cognitive tasks, they seem to benefit from rewards only when they are delivered continuously rather than on a partial reinforcement schedule.

Other studies have provided evidence that both reward and response cost contingencies, rather than reward alone, may be more effective in treating children with ADHD. In addition, some authors have suggested that punishment or response costs are more effective than positive rewards in improving on-task behaviour and academic performance (Abramowitz, O'Leary, & Rosen, 1987; Pfiffner & O'Leary, 1987). It also appears that punishments are most effective when delivered immediately rather than after a delay (Abramowitz & O'Leary, 1990). Punishment is often given in the form of time-out or response costs; that is, the child loses opportunity for reinforcers or must give up a portion of tokens or points earned previously. These kinds of response contingencies form the basis of behaviour modification techniques, and have proven effective in behavioural therapy with children with ADHD. For example, a metaanalysis by Baer and Nietzel (1991) demonstrated that behavioural treatment is effective at managing behaviour in the home and at school, and improves academic functioning in the latter.

New lines of research have examined how motivational levels impact cognitive task performance in children with ADHD. In one study, Oosterlaan and Sergeant (1998) reasoned that if a motivational deficit underlies poor response inhibition in children with

ADHD, the deficit should be improved by implementing response contingencies. They tested this hypothesis by using a stop signal paradigm along with both reward and response cost conditions. In the reward condition, successful inhibitions were followed by the word "good!", and children saw one point added to their total credits (which could later be exchanged for presents). In this condition, no feedback was provided after failing to inhibit. The response cost condition was opposite to the reward condition: inhibition failures were followed by the word "wrong!", and children saw one point subtracted from their total credits. Similarly, no feedback was provided following successful inhibitions. In addition, all participants rated their "motivation to complete the task," and task "pleasantness" on a sliding scale.

The most salient finding of Oosterlaan and Sergeant's study is that children with ADHD showed impairments in response inhibition despite the presence of response contingencies, a finding that argues against poor motivation as an explanation for response inhibition deficits. The ADHD group in general exhibited poorer inhibition and slower inhibitory processes relative to controls. Further, there were no group differences with respect to reported level of motivation to complete the task, although both groups reported the reward contingency as more pleasant than the response cost contingency. A major shortcoming of this study, however, was the absence of a condition in which no contingencies were implemented. Thus, although one may conclude that reward did not ameliorate the inhibition deficits that occurred in comparison to controls, it is not possible to ascertain how response contingencies affected inhibition relative to a no-contingency condition.

A study by Iaboni, Douglas, and Baker (1995) also examined the effects of reward and response costs on response inhibition using a go/no go task. These researchers employed four different reward/response cost combinations to examine how response contingencies affected performance on the separate go and no-go components of the task. They observed that relative to controls, children in the ADHD group made a significantly greater number of commission errors and that none of the response contingency combinations improved their performance to the level achieved by normal children. Further, they noted only small differences between the effects of the four reinforcement combinations. In line with Douglas's view that children with ADHD are more prone to frustration effects following response costs or the absence of reward, Iaboni et al. (1995) found that these children responded faster following response costs than following reward. They suggested that this occurred because the absence of reward caused children in the ADHD group to become frustrated or more aroused, or both, resulting in a faster, more impulsive response on the trial following a response cost.

It is worth considering that although Oosterlaan and Sergeant (1998) and, to a lesser extent, Iaboni et al. (1995) manipulated response contingencies under the guise of altering motivational set, it is impossible to establish from these studies how subjectively "motivated" a participant felt by a given task, and whether their motivation was truly altered by implementing response contingencies. Oosterlaan and Sergeant (1998) addressed this issue in part by using a subjective questionnaire that all children completed, but the reliability and validity of that measure are unknown. Taken at face value, the results of both of these studies suggest that the motivational level of children with ADHD does not significantly alter their performance on cognitive tasks of response

inhibition: the underlying deficit remains. A noteworthy study by Tannock (1997) found that children with ADHD attended to and performed better at playing videogames than on control conditions of a CPT task or watching television, but their performance on the videogames was still below that of normal children. This finding is surprising, as parents of ADHD children typically report that their child can play videogames contentedly for hours without interruption, suggesting no lack of motivation. Tannock's study demonstrated that even highly motivating tasks, in which children with ADHD engage more readily, are prone to the disruptive effects of ADHD.

Unlike others, Barkley asserts outright that children with ADHD are neither more nor less sensitive to reward than are other children. Instead, he argues that the working memory deficit characteristic of ADHD causes these children to be less able to bridge the temporal gap between response contingencies and internally represented information. In other words, Barkley contends that these kids have difficulty making the connection over time between specific task demands and the prize or punishment at the end. Barkley refers to this idea as a "temporal myopia," an effective analogy which conveys that the behaviour of those with ADHD is influenced more by immediate events and their consequences rather than by those more distant in time.

In a related line, Barkley hypothesizes that individuals with ADHD have a reduced capacity to induce and regulate emotional, arousal, and *motivational* states when working toward a goal (Barkley, 1997). The longer the delay between a response and its consequence, the less successful these children should be in sustaining the arousal and motivation required to reach a goal. In other words, those with ADHD should be

expected to exert less effort and be less motivated in circumstances that require self-regulation and goal-directed behavior, particularly in the absence of external rewards.

Barkley contends that the internalization of speech, another executive function in his model, is crucial to this process of emotional and motivational self-regulation. As children mature, language shifts from being primarily a means of communication with others to one of communication with the self. Research suggests that language initially is task-irrelevant and perhaps self-stimulating, and progresses through development to self-guiding speech. It then evolves to more private, inaudible speech and finally to fully private, subvocal speech (Berk, 1986, 1994, cited in Barkley, 1997). This shift in language, from public to private, affords reflection and exploration of incoming stimuli, and allows the individual to construct hypothetical messages or responses before one is chosen to voice or perform (Barkley, 1997). Thus, according to Barkley, the progressive shift from public to private speech permits the development of rule-governed behaviour, in turn allowing motor behaviour to come under the control of language. Rule-governed behaviour provides a means of sustaining behaviour across large gaps in time, guiding it toward the attainment of a future goal. As a result, an individual's behaviour becomes less under the control of the immediate context, and more under the control of internally represented information (rules).

To summarize, Barkley maintains that three executive functions in his model – working memory; the self-regulation of affect, motivation, and arousal; and the internalization of speech – allow an individual to persist in cross-temporal behaviours, thereby bridging the delay to future reinforcers when none are immediately at hand. According to Barkley, deficient behavioural inhibition does not allow these executive

functions to occur, and so children with ADHD are less able to persist in responding when reinforcement is delayed, and are more reliant on external forms of immediate reinforcement to remain on task. Accordingly, these children are less able to create positive emotional and motivational states within themselves when experiencing negative affect such as anger, frustration, or disappointment. Indeed, researchers have commented frequently on the difficulties with drive, motivation, and effort in the performance of goal-directed behaviors during tasks that require repetitive responding with little or no reinforcement (Barber, Milich, & Welsh, 1996; Barkley, 1990). Multiple studies have also documented in ADHD children reduced effort and persistence when completing laboratory tasks (Barber et. al., 1996; Douglas & Benezra, 1990).

#### Motivation, Arousal, and Sense of Time

Few if any studies have examined in an ADHD population the effects of motivational level on tasks that assess sense of time. A few studies, however, have looked at the impact of physiological arousal on time estimation abilities. For instance, Shaw and Brown (1999) manipulated arousal levels by showing to a group of attention-disordered teenagers and normal controls either a high arousal video (a police car chase) or a low arousal video (cell division), and then asked subjects to report how long they thought the video lasted, and how long they thought other aspects of the experiment lasted. They found that the attention-disordered teenagers estimated longer times in the low-arousal condition than did normal controls, but not in the high-arousal condition. They also found that self-reported arousal levels correlated significantly with self-reported pulse-rate changes.

A study by Barkley and colleagues (1997) found that Ritalin did not improve the time reproductions of ADHD children, a surprising result given that stimulant medication has been shown in this population to improve performance on cognitive tasks such as vigilance, short-term memory, and visual problem solving (Rapport, Carlson, Kelly, & Pataki, 1993). More importantly, Ritalin has been shown to improve working memory in children with ADHD (Tannock, Ickowicz, & Schachar, 1995). These findings are difficult to understand in light of Barkley's model as it would predict an improvement in measures that assess sense of time secondary to an improvement in working memory. Unfortunately, Barkley et al. (1997) did not obtain any measures of working memory and so it was not possible to examine the time reproduction impairment in relation to working memory performance. Barkley suggested that a small sample size and time of day effects (with respect to peak medication effect) may have figured into his results.

### The Present Study

The time reproduction tasks used in previous studies required repetitive responding with little or no reinforcement. In such a circumstance, one might expect the motivational level of a child with ADHD to be lower than that of a control subject, and that poor motivation may account, at least in part, for the putative deficit in time reproduction abilities. In short, at issue is whether children with ADHD truly have an impaired sense of time or whether, in the words of Sonuga-Barke et al. (1992), they are "delay averse," and lack the persistence to wait through the delay period necessary to perform well on time reproduction paradigms. As described earlier, it was observed in Kerns et al. (submitted) that children with ADHD appeared to grow bored quickly with the time reproduction paradigm, demonstrated progressively greater off-task behaviours

as the task proceeded, and appeared to undershoot the target duration to a much greater extent than controls, as if to “get the trial over with.” Thus, it is difficult to ascertain whether impairments in sense of time are truly characteristic of ADHD, or whether they are an artifact of traditional time reproduction paradigms which may be so intrinsically un motivating that they lead to “delay averse” or impulsive response tendencies.

Disentangling these two possibilities is important because, more generally, attempts to explore the strengths and weaknesses of a child who has ADHD, by engaging the child in specific activities, may be coloured negatively by the child’s motivation toward those activities. In such a case, it is likely that the child’s true deficits would be portrayed inaccurately.

Hypothesis 1. The primary goal of this study was to measure subjective sense of time in children with ADHD and matched controls using a time reproduction task while attempting to manipulate motivation. The time reproduction task was administered twice, once with no reward, and once with the opportunity to earn a “gift” at the end (see below). The latter manipulation was intended to enhance participants’ motivation to perform the task. It was hypothesized that enhanced motivation would reduce, but not eliminate, the time reproduction deficit in children with ADHD. This hypothesis was based largely on the results of Tannock’s study, in which children with ADHD performed more poorly than controls even on a task as engaging as a video game. Additionally, all children were asked to rate how much they liked the games, and how motivated they would feel toward completing the task again if asked to do so.

Hypothesis 2. A secondary goal of this study was to examine the relationships between time reproduction and measures of both working memory and behavioural

inhibition. The purpose of this goal was to further test predictions made by Barkley's model, namely, that deficits in behavioural inhibition set the occasion for deficits in working memory, which in turn cause time reproduction impairments. It was hypothesized that in accordance with Barkley's model, performance on the time reproduction tasks would correlate with measures of both working memory and behavioural inhibition.

It should be noted that Kerns et al. failed to detect a significant relationship between working memory and time reproduction. In addition, a significant relationship between inhibition and time reproduction was found on only one of two measures, namely, the go/no go task, but not the Golden Stroop (Golden, 1978). This pattern of results may have occurred because of the particular working memory tasks employed in that study and, as discussed earlier, because of the hypothesized dissociability of behavioural inhibition into different components. Other possibilities are discussed in Kerns et al. Thus, this investigation employed measures of working memory and behavioural inhibition that differed from those used in the earlier study by Kerns and colleagues.

## Methods

### Participants

Two groups of children, ranging in age from 6 to 13 years, participated in this study. The first group consisted of 30 children (27 males, 3 females) diagnosed with ADHD (combined type). The second group consisted of 30 control children. Children in the ADHD group were admitted to the study based on four criteria. First, children were recruited if they were reported to have been formally diagnosed with ADHD by a health care professional (i.e., a physician, psychiatrist, pediatrician, and/or psychologist). Of the 30 children in the ADHD group, 23 were reported to have a formal diagnosis of ADHD; however, diagnostic information was unavailable for the remaining seven children.

Second, parents were asked to complete The Conners' Parents Questionnaire, which is a well-researched, standardized questionnaire that assesses behavioural difficulties and attention problems at home. Third, each child's teacher was asked to complete The Conners' Teacher's Questionnaire, the counterpart to the parent questionnaire, designed to assess behaviour difficulties and attention problems at school.

A return rate of 73% was achieved for the parent questionnaires, and 67% for the teacher questionnaires. Of the parent forms returned, 91% scored greater than 1.5 standard deviations above the mean (i.e., equal to or greater than the 93<sup>rd</sup> percentile) on both the impulsivity-hyperactivity and ADHD factors. Of the teacher's forms returned, 25% and 65% scored similarly on the impulsivity-hyperactivity and ADHD factors. Of the teacher forms returned, however, 35% indicated that observations of the child's behaviour were available only while he or she was on medication, thereby resulting in lower estimated hyperactivity levels.

Finally, all children met DSM-IV criteria for ADHD (Combined Type) according to the Diagnostic Interview for Children and Adolescents–Fourth Edition (DICA–IV), a structured interview designed to assess psychiatric problems in children and adolescents. The author administered these interviews over the telephone to a prospective child's parent or guardian.

Children with ADHD were admitted to the study only if they met diagnostic criteria for ADHD according to the DICA-IV and at least one of the other three diagnostic methods. These requirements resulted in the loss of 15 children from the original sample, bringing the final sample size to 30. All children in the ADHD group were required to discontinue stimulant medication (e.g., Ritalin) at least 24 hours prior to testing. Of the 30 children in the ADHD group, 18 were reported to be taking stimulant medication, and seven were not. The medication status of the remaining five children was unavailable.

The second group of participants consisted of control children matched to those in the ADHD group based on gender and age (ADHD,  $M = 10.08$  years; Controls,  $M = 10.12$  years;  $t = .080$ ,  $p = .937$ ). Parents and teachers of children in this group completed the questionnaires described above, and parents also completed the DICA–IV. The return rates for the parent and teacher questionnaires were 80% and 67%, respectively. Children qualified as suitable controls only if they did not have a significant history of significant developmental, neurological, and behavioural problems, if they did not meet diagnostic criteria for ADHD, and if their scores fell within one standard deviation of the mean on at least three rating scales.

All children were recruited from a sample that had participated or had expressed interest in a previous study in the lab. This sample originally was recruited from flyers mailed to local schools, advertisements in the *Island Parent Magazine*, and brochures sent to local physicians. Written consent was obtained from the parent (or legal guardian) of each child; each child also gave written consent and verbal assent (see Appendix A). In addition, each child and parent received a lollipop and a \$5.00 honorarium for participating.

Table 1 outlines the demographic features of each group. The groups were equivalent in age ( $t = .080$ ,  $p = .937$ ) and in gender ratio. Two tests were used to assess intellectual ability, Raven's Progressive Matrices (Raven, 1995) and the Vocabulary subtest of the Wechsler Intelligence Scale for Children–Third Edition (WISC-III; Wechsler, 1991). Significant group differences were not present on scores from Raven's Colored Progressive Matrices ( $t = 1.541$ , *ns*), although control children obtained significantly higher scores on the Vocabulary subtest of the WISC-III ( $t = 3.660$ ,  $p = .001$ ). An estimate of general intellectual ability was calculated by averaging each subject's percentile score on both tests. This estimate thereby captured both verbal and nonverbal abilities, respectively, which are traditionally combined to estimate one's full-scale or overall intellectual ability. Significant group differences were observed on this estimated measure of intellectual ability, with control children scoring above children with ADHD ( $t = 3.154$ ,  $p = .003$ ). Of note, however, the average estimated intellectual ability of both groups fell solidly within the average range.

Table 1. Demographic information for children with ADHD and matched controls.

	ADHD		Control	
	<i>M</i>	SD	<i>M</i>	SD
Age (years)	10.09	1.97	10.12	1.87
Gender ratio (male:female)	9:1		9:1	
WISC-III Vocabulary (%ile)	54.00	28.02	76.53	18.76
Raven's Colored Matrices (%ile)	70.67	19.32	77.93	17.14
Estimated IQ (%ile)	62.28	21.32	77.23	14.80

Information was also collected on subjects' medical, behavioural, and educational history via a child history questionnaire (see Appendix B). The groups did not differ significantly in the number of pregnancy or birth complications experienced by a child's mother ( $t = -.628$  and  $t = .293$ , *ns*, respectively). In contrast, children in the ADHD group suffered a higher number of childhood illnesses ( $t = -2.574$ ,  $p = .014$ ) which comprised mainly a higher number of fevers, colds, minor head injuries, and headaches.

The history questionnaire also revealed that children with ADHD had significantly more learning difficulties than control children ( $t = -5.199$ ,  $p < .0001$ ) and were more likely to have been tutored ( $t = -2.085$ ,  $p = .042$ ). Children with a learning disability were not excluded from the study, however, as learning disabilities and ADHD often occur comorbidly (DSM-IV). Thus, their exclusion would alter the representativeness of the ADHD sample. No reliable differences were found in the number of years of education ( $t = .149$ , *ns*).

## Procedure

Participants were tested individually at the University of Victoria in one 75-minute testing session. The testing environment consisted of two rooms. The main testing room contained two tables, a small one with a computer at which the time reproduction paradigms and the computerized working memory paradigms were performed, and a larger table at which the non-computerized activities were performed. On account of space limitations, a second testing room was required to run the measure of response inhibition (the stop paradigm). Participants were assigned randomly to one of two counterbalance conditions that affected only two tasks (the Light Bulb Games; see below). Subjects completed the remaining tasks in an identical order.

## Measures

Light Bulb Game (regular version). In this computerized time reproduction paradigm, participants first were shown a picture of lightbulb on a computer screen that remained visible for a certain number of seconds (the target duration). Immediately following this the screen went blank, and participants were asked to turn their “own lightbulb on and off (by clicking the mouse button) for the same amount of time as what the computer” had just displayed. Children were given a minimum of three practice trials to ensure that they understood the directions. Following the practice session, two trials of one of six target durations (3, 5, 6, 9, 12 or 17 seconds) were presented in a randomized order for a total of 12 trials. No feedback was provided after each trial, and each trial followed immediately the one before it.

Light Bulb Game (enhanced version). The first part of this task was identical to the version described above. It differed, however, in that after each trial a cute, animated

rhinoceros walked across the computer screen, turned to face the subject, and hurled a sham score onto the upper portion of the screen accompanied by a verbal accolade (e.g., “awesome!). Subjects were told that if they did “well enough” and attained a high score, they would be able to choose a prize from a large, attractively-wrapped gift box located plainly in sight. They were instructed further that if they did not score as highly, they could still choose a prize, but only from a much smaller prize box, wrapped in white lined writing paper, located adjacent to the big prize box. The animation, sound effects, and score were designed purposefully to suggest that a child had done well on any given trial in spite of how well they actually performed. In other words, the score and feedback were unrelated to the actual performance on the trial.

The two versions of the Light Bulb Game were counterbalanced for presentation and in truth, all children received identical sham feedback and scores so that at the end of the game, all children “won” the bigger prize. Participants were not told that two versions of the game would be played nor that they would complete the other later. The two versions of the paradigm were separated by a fifteen minute interval during which other cognitive tasks were completed.

Two kinds of summary scores were generated from each trial of both versions of the Light Bulb Game. The first was an absolute discrepancy score which consisted of the absolute value of the magnitude of the discrepancy between a child’s time reproduction and the target duration. The second was an accuracy coefficient which was calculated by dividing the length of the child’s time reproduction by the length of the target duration. As such, scores greater than one reflected over-reproduction of the interval and scores less than one represented under-reproduction of the interval.

Motivation Questionnaire. Following each version of the Light Bulb Game, participants were asked to answer via a computerized sliding scale two questions about the game. The first question read, "How much did you like the Light Bulb Game?", and the response choices ranged from "I did not like it at all!" on the left side of the scale, to "I loved it!" on the right. The second question read, "How much would you like to play the Light Bulb Game again?"; the response choices ranged from "I don't want to play again!" on the left side of the scale, to "I would love to play again!" on the right. Each textual response choice was accompanied by a corresponding graphic (a sleepy guy *versus* a happy guy; a sad face *versus* a smiley face) to facilitate understanding. Further, the questions and response choices were read aloud by the examiner to ensure that a child's reading ability would not interfere with their understanding. Scores were assigned as a function of how much a child moved the computerized sliding scale, and ranged from one point at the left of the scale to 100 points at the right, in increments of one point. Higher numbers reflected a more favourable view of the game.

Stop signal task. This paradigm was modelled after Logan et al. (1997). Children were presented with two concurrent tasks, a go and a stop task. The go task required subjects to discriminate between two stimuli, an X and an O (see below). The stop task, which occurred on a fraction of go trials, involved presenting children with a tone (the stop signal) indicating that they should inhibit their response to the go task on that particular trial. The stimuli for the go task were created using the font Avant Garde at a size of 60 points, presented in the centre of the screen for 1000 ms. Stimuli were preceded by a 500 ms fixation point, also presented in the centre of the screen, and followed by a blank screen exposed for 1000 ms. The stop signal was a 100 ms tone

played through the internal speaker of the computer. The stop signal delay was set initially at 250 ms, and adjusted dynamically depending on the subject's response to a previous stop trial. Specifically, the delay increased by 50 ms if the child inhibited successfully on the previous stop trial, and decreased by 50 ms if the subject failed to inhibit. This made it either harder or easier to respond, respectively, on the next stop trial. The purpose of this tracking procedure was to converge on a "stop-delay" at which subjects would inhibit half of the time (Logan et al., 1997). A total of 128 trials were presented, of which 32 were stop trials.

Children first were instructed on the go task. They were told that they would see one of two letters, either an X or an O, and had to push either the green button or the orange button, respectively, as fast as they possibly could. The stop task was explained by saying that every once in a while they would hear the computer "beep," and when they heard that sound they had to try and not push a button for that particular letter. It was emphasized that the beep would occur at different times, so sometimes they would be able to stop and sometimes they would not. Further, children were instructed that they always had to push the buttons as fast as they could and not to wait for the beep.

Several summary measures were obtained from this task. The first five were measures of the go portion of the task; these included the number of correct go responses, the number of wrong go responses, the number of go omissions (i.e., not responding to a stimulus), the average go reaction time, and the standard deviation of the go reaction time. The last four were measures of the stop portion of the task, and included the number of successful inhibitions, the average stop delay, the standard deviation of the stop delay, and the stop signal reaction time. The most important measure from this task

for the purpose of this study is the stop signal reaction time, and is calculated by subtracting a subject's average stop delay from his or her average go reaction time.

Working Memory Tasks. *Spatial Ordering Game* (see Appendix C). This test was designed by the author to measure spatial working memory without requiring a knowledge of numbers or of the alphabet. Subjects were presented with a list of common objects (e.g., pencil, mountain, train) read aloud and asked to tell them back to the experimenter in order of size from smallest to largest. A minimum of two practice trials first were administered. The actual test began with two items per trial, and became progressively more difficult to a maximum of seven items per trial. All children were administered all trials, regardless of their performance. The summary measure for this task was the total number of pairs of items ordered correctly.

*Sentence Span Measure* (see Appendix D). Devised originally by Daneman and Carpenter (1980), the Sentence Span Measure was adapted by Swanson, Cochran and Ewers (1989) to measure working memory in children and adolescents. Each trial of this task consisted of a series of short sentences read aloud by the examiner, during which children had to "remember the very last word from each sentence in the correct order." After the sentences were read aloud, participants had to answer a short factual question based on the content of one of the sentences in the trial. Next, they had to recall as many of the last words from the sentences as possible. Three practice trials, each containing two sentences, were administered first. The experimental portion consisted of five levels. Each level contained two sets of sentences, the number of which corresponded to the level number (i.e., level 3 contained three sentences per trial, etc.). The task began at

level 2 and discontinued when at least one error was made (either in answering the factual question or in recalling the terminal words) in both sets of sentences within a level.

Two summary scores were generated from this task. The first, a “Level” score generated as per the test instructions, was simply the highest level a child completed successfully. As this scoring method alone might unfairly penalize subjects who progressed to higher levels but could not answer both sets of sentences, and confer an unfair advantage to children who could not answer any questions correctly, a second summary score was calculated by summing the total number of sets of sentences answered correctly regardless of the level from which they came.

*Digit Span Backwards.* This is a portion of a standardized subtest of the WISC-III, and has been used widely among researchers as a measure of spatial working memory (e.g., Pennington & Ozonoff, 1996). Subjects were presented with a series of numbers read aloud and asked to repeat the numbers backward. A minimum of one practice trial was administered first. The experimental portion consisted of eight items, each containing two trials. Item 1 contained two numbers per trial and the test became progressively more difficult, with item 7 containing eight numbers per trial. The test was discontinued when a child committed errors on both trials within any item. The summary measure for this task was the total number of trials answered correctly.

*Children's Paced Auditory Serial Addition Task.* This task was chosen because abundant research has shown that mental arithmetic depends heavily on working memory abilities (Barkley, 1997). In this computerized adaptation of Johnson, Roethig-Johnston, and Middleton's (1988) Children's Paced Auditory Serial Addition Task (CHIPASAT), single digit numbers were presented in five trials of differing speeds. There were 61

digits per trial, presented at speeds of one digit every 2.8, 2.4, 2.0, 1.6, and 1.2 seconds. Subjects were instructed to add the numbers two at a time, by adding each number to the one that came before it, and immediately give the answer aloud. In addition to delivering the instructions orally, a demonstration was provided on paper so that children could see how to add the numbers in pairs. The numbers ranged in magnitude from one to five so that the sum of any number pair never exceeded 10.

Six scores were generated from this task. Each pair of numbers added correctly counted as one point, so that each of the five trials yielded a total score. In addition, a grand total was calculated by summing the scores from individual trials.

## Results

### Intellectual Ability

As reported above, significant group differences were observed in the estimate of intellectual ability. Preliminary analyses revealed that these group differences significantly impacted several of the measures employed in this study. Thus, unless noted otherwise, the following results are expressed after first accounting for the effects of intelligence testing via covariance analysis.

### Effect of Counterbalancing

A multivariate analysis of variance revealed that performance on the two versions of the Light Bulb Game did not differ significantly as a result of counterbalancing their presentation ( $F = .219$ , ns). Further, the absence of an interaction between group membership and counterbalancing suggests that the groups were not differentially influenced by order effects ( $F = .539$ , ns).

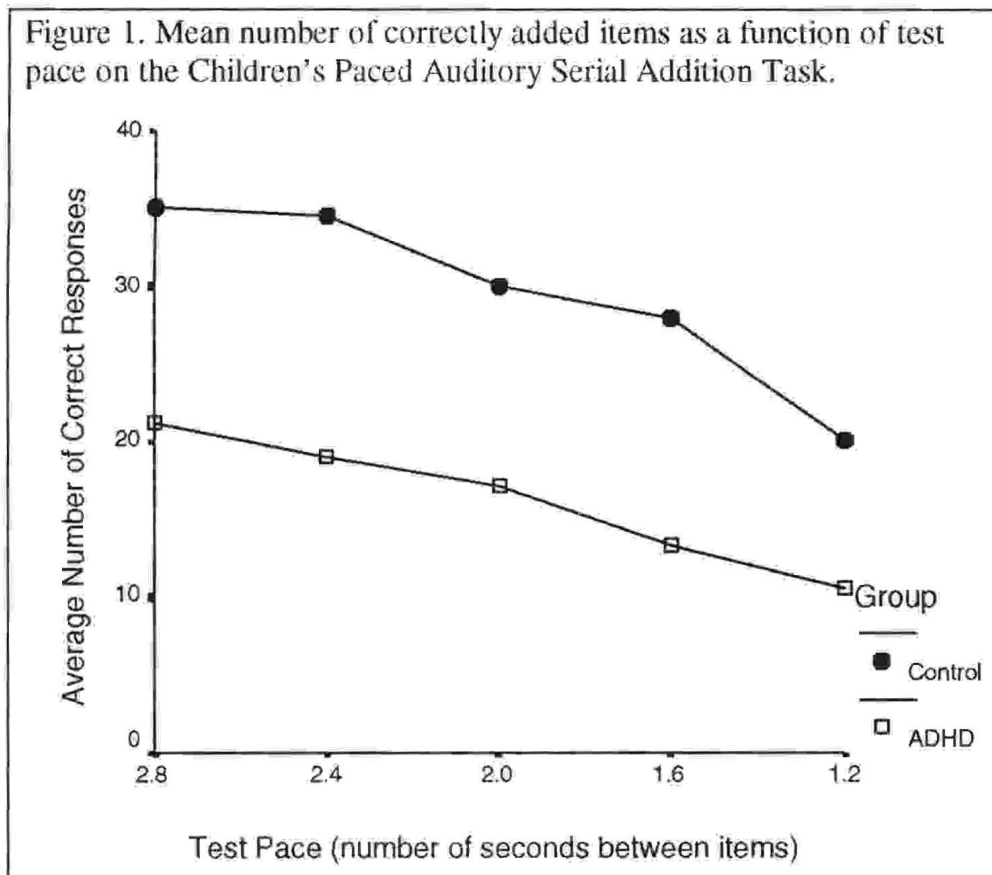
### Working Memory Tasks

Spatial Ordering Game. Children in the control group outperformed children with ADHD on this measure [ $F(1,57) = 10.826$ ,  $p = .002$ ].

Sentence Span Measure. Significant group differences were observed on this task before the effects of intelligence testing were removed. When intellectual ability was accounted for, performance between the groups did not differ significantly [Level score,  $F(1,57) = 1.298$ , ns; Total score,  $F(1,57) = 2.133$ , ns].

Digit Span Backwards. Significant group differences were observed on this task, with control children performing better than children with ADHD [ $F(1,57) = 4.492$ ,  $p = .038$ ].

**CHIPASAT.** An analysis of variance [2 (groups) x 5 (paces)] revealed a significant main effect for group [ $F(1,57) = 22.938, p = .0001$ ], indicating that control children scored significantly higher on the CHIPASAT in comparison to children with ADHD. The main effect for pace was significant, indicating that all children made fewer correct responses as the speed of the test increased [ $F(4,228) = 6.603, p = .0001$ ]. Additionally, there was a significant interaction of group x pace [ $F(4,228) = 4.116, p = .003$ ], indicating that children with ADHD made comparatively fewer correct responses than control children as the pace increased; see figure 1. The main effect for IQ was not significant [ $F(1,57) = .761, ns$ ], nor was its interaction with pace [ $F(4,228) = 2.310, ns$ ].



### Behavioural Inhibition Task

Children with ADHD had more difficulty than controls on the Stop Signal task. They made fewer correct go responses [ $F(1,57) = 8.982, p = .004$ ], more go errors [ $F(1,57) = 4.766, p = .033$ ], and more omissions [i.e., missing a target;  $F(1,57) = 5.674, p = .021$ ]. The groups did not differ with respect to their reaction times on the go portion of the task [ $F(1,57) = .160, ns$ ], although children with ADHD demonstrated much more variability in their reactions times [ $F(1,57) = 10.744, p = .002$ ].

Analysis of the stop portion of the test revealed that the tracking procedure was largely successful. On average, children in the control group inhibited their response on 16.4 trials out of 32, while those in the ADHD group were able to inhibit on 14.4 trials out of 32. Overall, children with ADHD were found to have larger stop signal reaction times than control children [ $F(1,57) = 7.470, p = .008$ ].

The results of the working memory tasks and the measure of behavioural inhibition are outlined in table 2.

Table 2. Means and standard deviations of the working memory and behavioural inhibition tasks.

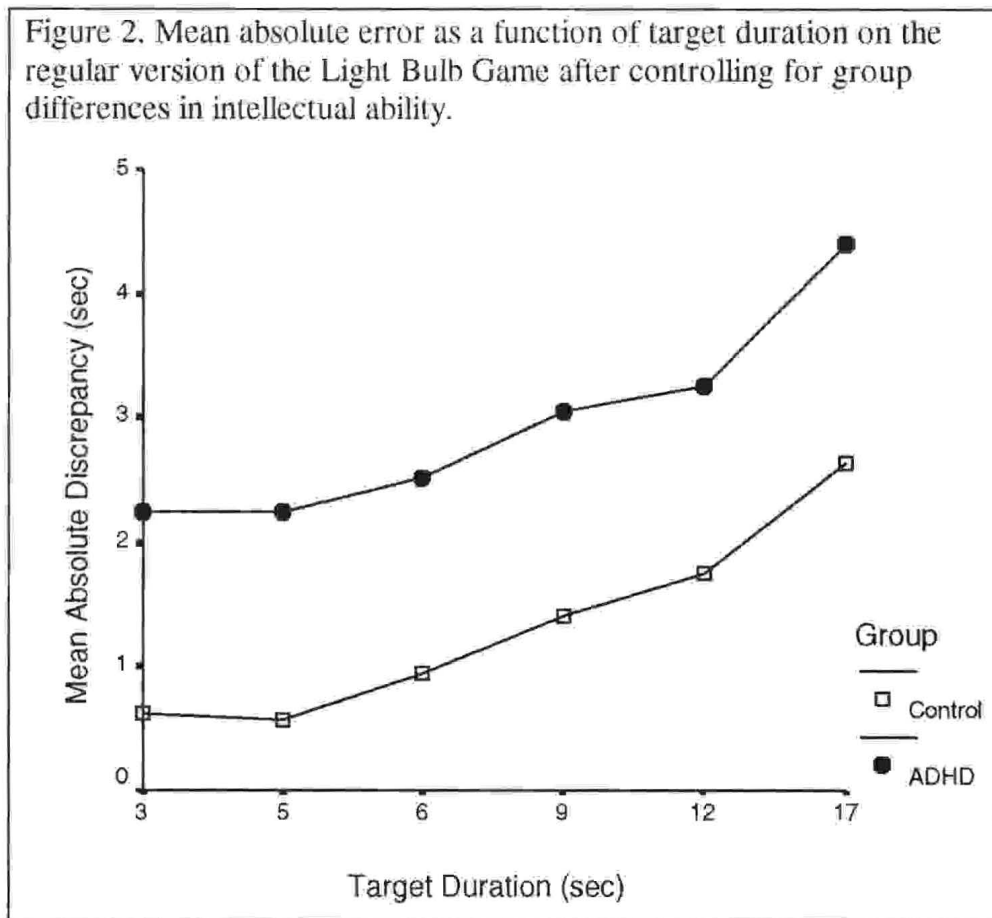
	ADHD		Control	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Spatial Ordering Game Raw Score	17.93	7.89	24.63	4.61
Sentence Span Measure Raw Score	1.40	.62	1.77	.82
Digit Span Backwards Raw Score	4.27	1.60	5.63	1.81
CHIPASAT Total Score	78.93	45.38	150.10	53.49
Stop Signal Reaction Time (msec)	372.11	107.04	279.32	89.34

### Light Bulb Game (regular version)

The results for the regular version of the game were first analyzed using analysis of covariance and a three factor design: 2 (groups) x 6 (time durations) x 2 (trials) with repeated measures on the last two factors and intellectual ability as a covariate. The main effect for the trials factor was not significant [ $F(1,57) = .141$ , ns] nor were any of its interactions. Therefore, the two trials for each time duration were averaged and the trials factor was eliminated from further discussion below.

Absolute Discrepancy Scores. An analysis of covariance [2 (groups) x 6 (time durations)], with intellectual ability as the covariate] revealed a significant main effect for group [ $F(1,57) = 17.627$ ,  $p = .0001$ ], indicating that children in the ADHD sample made significantly larger errors in time reproduction than controls ( $M = 1.23$  versus 3.04 respectively). The main effect for duration was significant [ $F(5,285) = 5.858$ ,  $p = .001$ ], with greater errors being made by children in both groups at longer target durations. The interaction of group x duration was not significant [ $F(5,285) = .027$ , ns] which suggests that children in both groups exhibited poorer performance as the target duration increased; see Figure 2).

Accuracy Coefficient Scores. To determine if the absolute discrepancy scores in time reproduction were likely to be in any consistent direction (i.e., under- vs. over-reproductions), the accuracy coefficients were analyzed as above. An analysis of covariance [2 (groups) x 6 (target durations)] showed a significant main effect of group [ $F(1,57) = 8.486$ ,  $p = .005$ ] but not of duration [ $F(5,285) = 2.129$ , ns]. In addition, a significant two-way interaction was observed between duration x group [ $F(5,285) = 3.152$ ,  $p = .009$ ]. Figure 3 shows that in general, children in the ADHD sample tended to

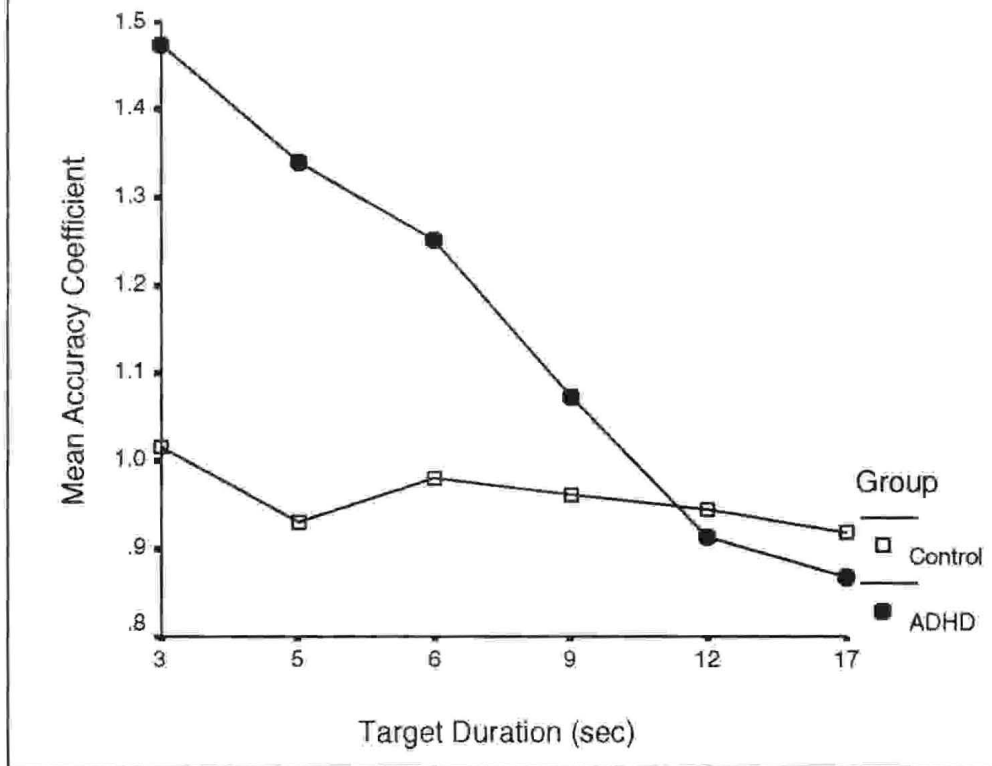


over-reproduce the time durations at shorter time durations, and shifted progressively toward under-reproductions at longer ones. Control children also tended to undershoot the target duration at longer intervals, but their performance was comparatively consistent across trials.

#### Light Bulb Game (enhanced version)

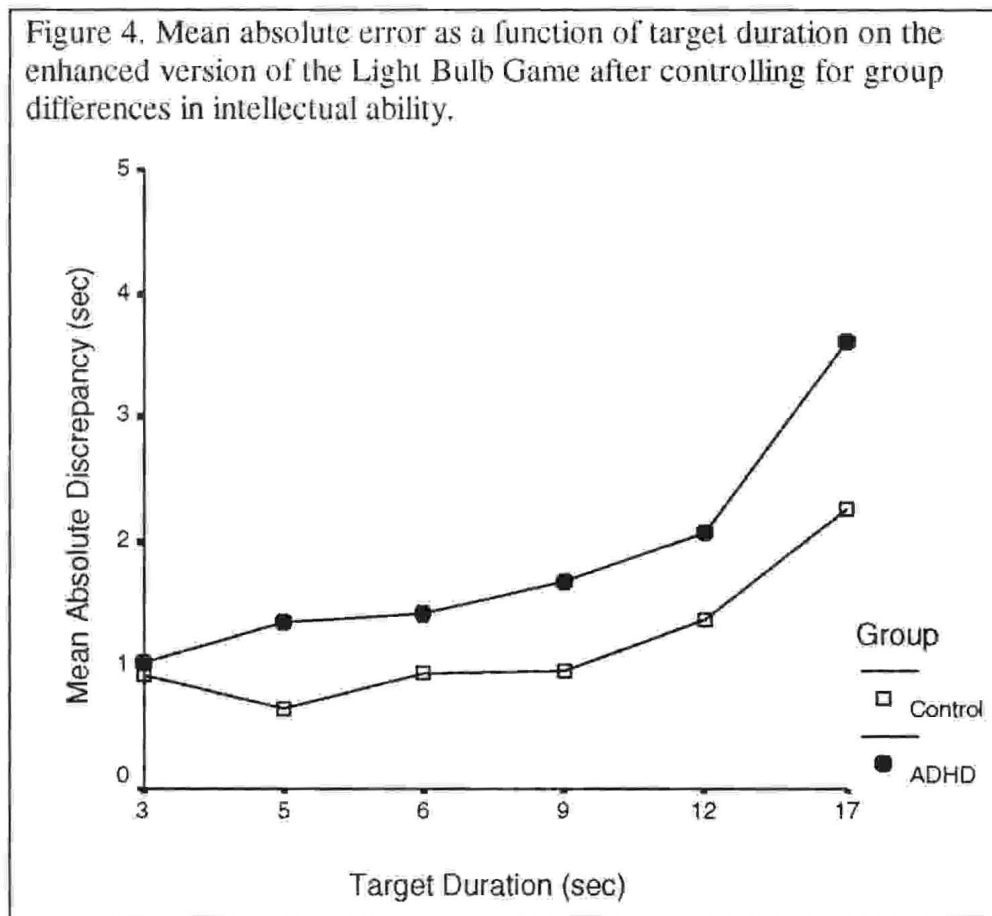
As with the regular version of the Light Bulb Game, the results were first analyzed using analysis of covariance and a three factor design: 2 (groups) x 6 (time durations) x 2 (trials) with repeated measures on the last two factors and intellectual ability as a covariate. The main effect for the trials factor was not significant [ $F(1,57) = .006, ns$ ] nor were any of its interactions. Thus, the two trials for each time duration were

Figure 3. Mean accuracy coefficients (directionality of error) as a function of target duration on the regular version of the Light Bulb Game after controlling for group differences in intellectual ability.

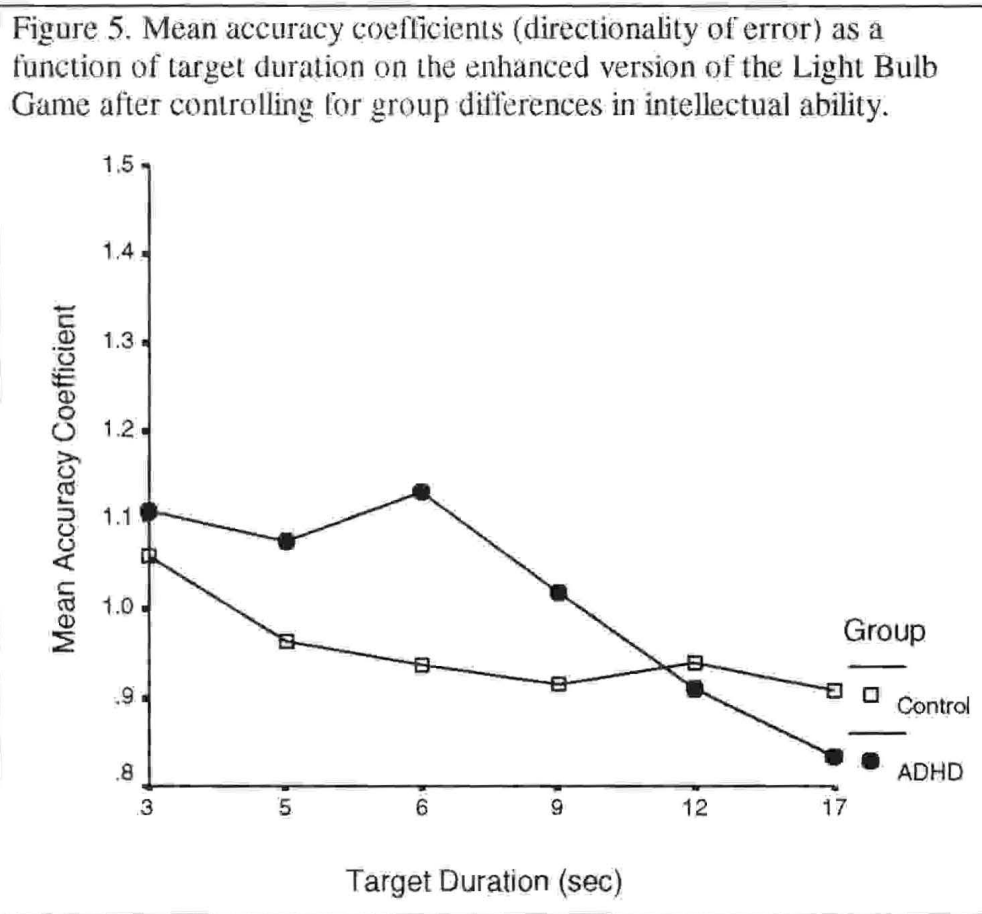


averaged and the trials factor was eliminated from further discussion below.

Absolute Discrepancy Scores. An analysis of covariance [2 (groups) x 6 (time durations)], with intellectual ability as the covariate] revealed a significant main effect for group [ $F(1,57) = 4.379$ ,  $p = .041$ ] indicating that overall, children in the ADHD sample made significantly larger errors in time reproduction than controls ( $M = 1.23$  vs  $3.04$ , respectively). The main effect for duration also was significant [ $F(5,285) = 5.505$ ,  $p = .006$ ], with greater errors being made by children in both groups at longer target durations. The interaction of group x duration was not significant [ $F(5,285) = .027$ ,  $ns$ ] which suggests that children in both groups made comparable errors as the target duration increased; see Figure 4).

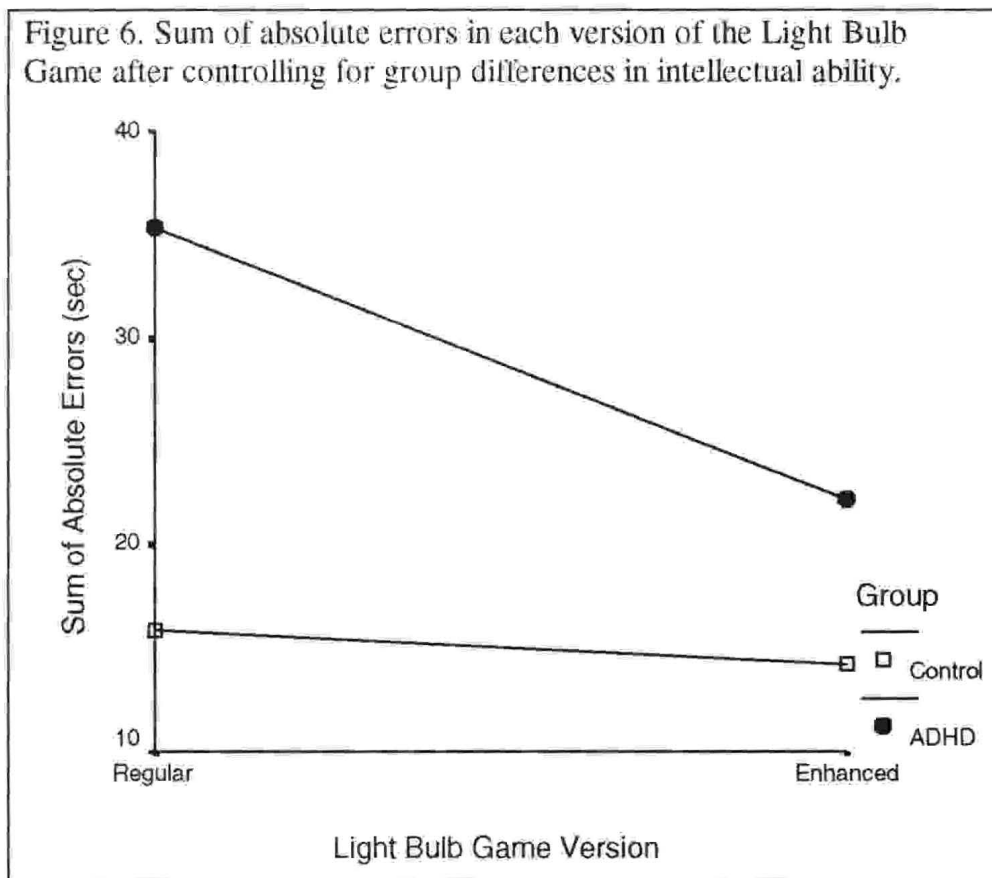


Accuracy Coefficient Scores. Similar to the previous version of the Light Bulb Game, the accuracy coefficient scores from the enhanced version were analyzed to determine if the absolute discrepancy scores in time reproduction were likely to be in any consistent direction. An analysis of covariance [2 (groups) x 6 (target durations)] failed to show a significant main effect of group [ $F(1,57) = 1.618$ , ns] indicating that, overall, the groups did not differ in the direction of their time reproductions. A significant main effect of duration was observed [ $F(5,285) = 3.613$ ,  $p = .003$ ], reflecting in both groups a tendency to over-reproduce the target duration at shorter intervals and under-reproduce it at longer intervals; see Figure 5. The interaction of group x duration was not significant [ $F(5,285) = 1.722$ , ns].



### Comparing Performance Between Versions of the Light Bulb Game

A summary measure of total time reproduction error was calculated for each version of the game by summing the absolute deviations for each trial of all target durations. This measure of total time reproduction error for each game was then analyzed in a 2 (group) x 2 (versions) analysis of covariance with repeated measures on the second factor and intellectual ability as a covariate. The results of this analysis indicated that children with ADHD made significantly fewer errors in the enhanced *versus* the regular version of the Light Bulb Game. In contrast, control subjects exhibited little change in performance between versions of the game [version x ADHD,  $F(1,57) = 7.895$ ,  $p = .007$ ; see figure 6]. As noted previously, however, children in the ADHD group continued to



show significantly poorer time reproduction abilities than controls even on the enhanced version of the Light Bulb Game [ $F(1,57) = 4.358, p = .041$ ].

#### Motivation Questionnaire

Interestingly, in spite of the changes in pattern of performance on the time reproduction paradigms, the groups did not differ significantly in self-reports of how much each version of the Light Bulb Game was liked or how much they wanted to play the game again. As expected, children in both groups reported liking better the enhanced version of the Light Bulb Game ( $M$  Enhanced version = 84.82,  $SD = 14.84$  vs  $M$  Regular version = 55.00,  $SD = 32.23$ ) and reported more willingness to play the game again if asked to do so ( $M$  Enhanced version = 74.24,  $SD = 27.22$  vs  $M$  Regular version = 37.17,  $SD = 33.34$ ). Of note, order effects were observed on the results of only one question

("How much would you like to play the [enhanced] Light Bulb Game again?";  $t = 2.394$ ,  $p = .02$ ); children who played the regular version first were more inclined to report wanting to play the enhanced game again.

Additional analyses were conducted to determine how subjects' responses on the motivation questionnaire related to their performance on each version of the Light Bulb Game. A regression analysis was performed with total time reproduction error regressed onto participants' age and intellectual ability. The two self-report questions for each version of the game were then entered as an additional predictor variable. After controlling for age effects and intellectual ability, self-reports did not significantly predict total time reproduction error on either version of the game [ $R^2$  change on regular version,  $F(2,55) = 2.302$ , ns;  $R^2$  change on enhanced version,  $F(2,55) = .334$ , ns].

#### Relationships among Cognitive Measures and Time Reproduction

Regular Light Bulb Game. To investigate predictions made by Barkley's model, the relationships among behavioural inhibition, working memory, and time reproduction were explored in further analyses. The four main working memory variables (Spatial Order Game, Sentence Span Measure total score, Digit Span Backwards, and CHIPASAT total score) were first submitted to a principal component analysis (PCA) with the goal of creating an overall working memory variable to use in subsequent analyses. Using scree testing and eigenvalues greater than one as indicators of how many factors to retain, the PCA extracted one factor that accounted for 68.24% of the variance. Table 3 displays the factor loadings for the working memory tasks on the factor.

Table 3. Factor loadings for the working memory tasks on the extracted working memory factor.

Working Memory Task	Factor Loading
Spatial Ordering Game	.853
Sentence Span Measure Total Score	.805
Digits Backward Total Score	.823
Total Correct on CHIPASAT	.822

Subsequent regression analyses next were performed to explore aspects of the hierarchical organization of Barkley's model. The first analysis aimed to investigate whether working memory accounted for variation in time reproduction abilities over and above variation accounted for by inhibition, and whether group membership would account for variation in time reproduction abilities over and above both of these variables. To this end, total time reproduction error on the regular version of the Light Bulb Game was regressed onto participants' age and intellectual ability. Stop signal reaction time was entered as a second predictor, followed by the working memory factor scores as a third predictor, and finally by group membership as a fourth predictor. This analysis showed that after controlling for age and intellectual ability, inhibition did not significantly predict total time reproduction error [ $F(1,56) = 3.606$ , *ns*]. Working memory continued to significantly predict total time reproduction error [ $F(1,55) = 14.441$ ,  $p = .0001$ ] as did group membership [ $F(1,54) = 4.866$ ,  $p = .032$ ]; see table 4.

A second analysis, similar to the one above but without including stop signal reaction time as a predictor, showed that working memory significantly predicted total time reproduction error over and above the effects of age and intellectual ability [ $F(1,57) = 18.344$ ,  $p = .0001$ ]. Group membership also significantly predicted total time

	R <sup>2</sup>	ΔR <sup>2</sup>	ΔF	p
Age, IQ	.208	.208	7.476	.001
Age, IQ, SSRT <sup>1</sup>	.256	.048	3.606	.063
Age, IQ, SSRT <sup>1</sup> , WM <sup>2</sup>	.411	.155	14.441	.000
Age, IQ, SSRT <sup>1</sup> , WM <sup>2</sup> , Group	.459	.049	4.866	.032

<sup>1</sup>SSRT = stop signal reaction time  
<sup>2</sup>WM = working memory factor scores

reproduction error over and above the effects of all three variables [ $F(1,55) = 5.530, p = .022$ ].

Enhanced Light Bulb Game. Regression analyses identical to the ones above were also conducted for the enhanced version of the Light Bulb Game. After controlling for the effects of age and intellectual ability, working memory significantly predicted total time reproduction error [ $F(1,56) = 6.399, p = .014$ ]. In contrast, group membership did not predict total time reproduction error after controlling for working memory [ $F(1,55) =$

	R <sup>2</sup>	ΔR <sup>2</sup>	ΔF	p
Age, IQ	.293	.293	11.820	.000
Age, IQ, SSRT <sup>1</sup>	.342	.048	4.115	.047
Age, IQ, SSRT <sup>1</sup> , WM <sup>2</sup>	.386	.045	3.992	.051
Age, IQ, SSRT <sup>1</sup> , WM <sup>2</sup> , Group	.390	.004	.382	.539

<sup>1</sup>SSRT = stop signal reaction time  
<sup>2</sup>WM = working memory factor scores

.770, ns]. When inhibition was entered as a predictor variable before working memory, it was found to relate significantly to total time reproduction error [ $F(1,56) = 4.115, p = .047$ ]. Working memory related only marginally to total time reproduction error [ $F(1,55) = 3.992, p = .051$ ] but, again, group membership did not relate significantly [ $F(1,54) = .382, \text{ns}$ ]; see table 5.

## Discussion

This study explored the impact of motivational levels on time reproduction abilities in children with ADHD and in control children matched by age and gender. The aim was to determine whether the time reproduction deficit observed in children with ADHD stems from poor motivation for completing such tasks, or whether they manifest a true deficit in their subjective sense of time. In addition, working memory and behavioural inhibition were investigated to determine their influence on time reproduction abilities, and to explore the relationships among these constructs to test predictions made by Barkley's (1997) model of ADHD.

As predicted, children with ADHD exhibited on the regular version of the Light Bulb Game significantly less accurate time reproductions than children in the matched control group. Similar to other research studies (Barkley et al., 1997; Dooling-Liftin, 1997; Kerns et al., submitted) both groups of children tended to make larger time reproduction errors as the target duration increased. Unlike those studies, however, disproportionately greater errors at longer target durations were not committed by the sample of ADHD children run in this study. This is evident by the parallel slopes in Figure 2; both groups of children made equivalently greater errors as a function of the target duration.

Of interest is the finding that children in the ADHD group tended to overestimate their reproduction at shorter target intervals and underestimate longer ones. Barkley et al. (1997) noted an equivalent trend, although the target durations used in his study ranged from 12 to 60 seconds. In other words, our sample of children began to under-reproduce the target interval at a point at which Barkley's sample of ADHD children over-

reproduced it. In contrast, Kerns et al. found that all children on average erred toward under-reproductions at all target intervals. It is difficult to account for this difference in findings, given that children of similar ages and identical target intervals were used in this study and in Kerns et al. Behavioural observations made during the regular Light Bulb Game in this study suggest that the errors committed at shorter intervals may reflect inattention, while errors at longer intervals may reflect impulsivity. More specifically, it appeared that on the regular game children in the ADHD group often were inattentive to the task at all intervals. This cost them in terms of response accuracy at shorter intervals, as the trial often “ended before they knew it” resulting in an exaggerated perception of how long the trial took to occur; this would result in over-reproductions at shorter intervals. Conversely, inattentive behaviours at longer intervals would not be detected as readily, as a child could afford not to pay attention while the computer-generated lightbulb was displayed for a greater length of time. When later reproducing a longer interval, impulsivity or “delay averse” behaviours would figure into a child’s hastening to get the trial over with; this would result in under-reproductions at longer intervals.

Also as hypothesized, the enhanced version of the Light Bulb Game improved the performance of kids in the ADHD group, but not to the level achieved by controls. Moreover, the same trend of over-reproductions at shorter target intervals and under-reproductions at longer ones appeared on the enhanced version, but these errors were not as dramatic as on the regular version of the game.

Of principal interest to this study is *why* children in the ADHD group improved on the enhanced version of the Light Bulb Game. Addressing this issue, however, raises one of the limitations of the study. The enhanced Light Bulb Game contained two

differences from the regular version: the opportunity to “earn” a gift; and the presence of positive sham feedback after each trial. As a result of these harmonized manipulations, it is not possible to disentangle these separate influences on the performance improvements that occurred in the ADHD group. The effects of those manipulations applied independently, however, have been researched. For example, it is well established that children with ADHD will expend greater effort to earn tokens, money, or gifts (Abramowitz et al., 1987; Baer & Nietzel, 1991; Kochanska, Murray, Jacques, Koenig, & Vandegest, 1996). As noted earlier, procedures that make use of similar positive reinforcers (in conjunction with punishments) form the basis of behavioural management techniques. The prospect of earning a prize could account alone for ADHD kids’ improvement, as this would presumably foster greater motivation toward completing the task. Although research has found that children with ADHD have difficulty working toward distant rewards (Barkley, 1997), it is likely that the prospect of earning a prize in this study was not so distant so as to seem unattainable. Further, the positioning of the big prize box clearly in sight, and the immediate reinforcement of the sham feedback, would likely have “reminded” children of what they were working toward. Behavioural observations made during both versions of the game support these speculations. On the regular version of the game, task-irrelevant and other disinhibited behaviours abounded; children in the ADHD group often directed their gaze away from the monitor, squirmed in their seat, fidgeted with the mouse, or directed comments to the examiner (e.g., “this game is boring”; “will it be over soon?”). The enhanced game reduced and often eliminated these behaviours. Indeed, children in both groups showed delight when they saw the big prize box. It was noted that many of the kids in the ADHD group applied a

counting-out-loud strategy rather than approaching the task haphazardly or with an ineffective strategy as they had done in the regular version.

On the other hand the effects of the sham feedback, bogus or not, could also account for the improvement seen in children with ADHD. In general, research suggests that instantaneous feedback is more effective than delayed feedback, and any type of feedback is more effective than no feedback at all (Burt & Ryan, 1997). In children with ADHD, positive feedback tends to enhance their performance, whereas negative feedback tends to degrade it through frustration (Burt & Ryan, 1997; Douglas and Parry, 1983, 1994). Indeed, this study capitalized on these last two points by providing only positive (sham) feedback in hopes that frustration effects would be minimized and performance improvements maximized. A critical distinction between authentic and sham feedback is that the former is instructive, whereas the latter is not. Instructive feedback essentially trains a subject on the given task, and he or she can gauge subsequent responses based on feedback provided for earlier ones. In contrast, sham feedback provides false information and does not train one's performance. Nevertheless, that feedback was provided at all could explain the improvement found in this study (Burt & Ryan, 1997). Perhaps the defining feature is not whether the feedback provides real information, but whether the information is *perceived* as real, or some external acknowledgement of performance is obtained.

Another aspect of the enhanced Light Bulb Game is that the feedback occurred after a delay of approximately four seconds, during which the animated rhinoceros walked across the screen. It is plausible that this delay engendered anticipation in a child, anticipation that always came to fruition by a high score and a verbal accolade. This is

tantamount to establishing a continuous reinforcement schedule which, as described above, has been found effective in improving or normalizing ADHD children's performance on cognitive tasks (Corkum et al., 1996; Douglas & Parry, 1983, 1994; Tripp and Alsop, 1999).

Admittedly, a third possibility for the improvement could be that the enhanced version of the Light Bulb Game was simply more interesting or more fun; all children appeared to enjoy watching the animated rhinoceros walk across the screen. It is possible that the rhinoceros simply broke the monotony of an otherwise uninteresting task (which of course would be another kind of continuous reinforcement). This would be consistent with Zentall's optimal stimulation theory (Zentall & Zentall, 1983). If this alone were the reason, however, it would be expected that self reports of motivation would have correlated with improvement in performance.

Considering as a whole the changes present in the enhanced version of the game, the results of this study accord with Tannock's (1997) study, described above, in which a more engaging task (a videogame) elicited in children with ADHD performance improvements and more attentive behaviours than a less interesting task (CPT or watching television), but these children still performed below controls even during the videogames. The results of this study are also congruent with one by Solanto, Wender, and Bartell (1997) in which children were rewarded for improved performance on a CPT task. Although Solanto's group found that reward contingencies altered performance, they did not eliminate the tendency toward impulsive responding characteristic of the children. Solanto's study and the present one are not entirely homologous, though, because Solanto employed reward and response costs that were contingent on subjects'

actual performance. It is also noteworthy that Solanto observed improvements on her task using reward and response costs given that others have found response contingencies ineffective on cognitive task performance in children with ADHD (Iaboni et al., 1995; Oosterlaan & Sergeant, 1998).

Also found in this study was that children in both groups tended to view the enhanced Light Bulb Game more favourably than the regular version; this is not surprising. Despite that, control children performed comparably between the two versions of the game, whereas children with ADHD were influenced much more dramatically and improved their performance significantly on the enhanced version regardless of whether it was administered first or second. It should be noted that children in the control group on average exhibited no reliable change in their performance between versions of the Light Bulb Game. It is unlikely that this finding is due to ceiling effects on the task because, as displayed in figure 6, their performance did contain a measurable amount of error (approximately 15 seconds total error in each version of the game). In other words, there was “room to improve” when playing the enhanced version of the game.

These findings can be interpreted as consistent with Barkley’s model, which hypothesizes that normal executive functioning allows one to self-regulate and even induce emotional states as needed in the service of goal-directed behaviour. In other words, normal executive functioning allows individuals to create more positive emotional and motivation states when bored, frustrated, disappointed, etc. Thus, although control children in this study rated the regular game less favourably than the enhanced game, according to Barkley’s model they performed better because they were able to self-

regulate their drive and affect for the purpose of completing the game as per the examiner's instructions. In contrast, Barkley's model predicts that children with ADHD have a reduced capacity to self-regulate their affect and emotions, and are more dependent on immediate and external sources of motivation. In the absence of emotional or motivational self-regulation, disinhibited behaviours would have abated during the enhanced Light Bulb Game because they came under the control of the immediate environment (i.e., under the control of the positive feedback and the prospect of earning a prize).

Also as hypothesized, significant group differences were observed on three out of four working memory measures and on the measure of response inhibition after controlling for differences in estimated intellectual ability. Specifically, group differences were found on the Spatial Ordering Game, Digit Span Backwards, the CHIPASAT, and the stop paradigm. In contrast, performance on the Sentence Span Measure did not differ between groups after removing group differences in intellectual ability. Several reasons may account for this last finding. First, children from both groups appeared to have difficulty with the Sentence Span Measure, and these results may reflect floor effects. Second, the scoring criteria outlined in the test manual produced scores that ranged from only 1 to 5 points; as a result, there was little variability on which to act statistically. Indeed, the combination of these first two reasons prompted the author to devise the alternative scoring method (see methods section). Using the original scoring criteria, the groups differed by only .37 points; even with the alternative scoring method, however, the groups differed by only .90 points. Third, not all studies have found children with ADHD to be uniformly impaired on measures of frontal lobe

functioning, including measures of working memory (Barkley, et al., 1992; Kerns et al., submitted; Vaughn, 1998).

The regression analyses described in the results section were intended to address predictions made in Barkley's model; that is, whether the time reproduction difficulties are dependent upon working memory or behavioural inhibition, or both. The goal of those analyses was to investigate whether the time reproduction deficit in children with ADHD would disappear after controlling for working memory and/or inhibition. Such a finding would support Barkley's model, as it would suggest that those abilities are indeed related. This study found that on the regular version of the Light Bulb Game, working memory was significantly related to time reproduction abilities, but inhibition was not. Interestingly, group membership related significantly to time reproduction abilities even after statistically controlling for working memory and inhibition. The enhanced version of the game brought a different pattern of results. There, working memory related significantly to time reproduction, but this relationship was diminished when inhibition was controlled for. Further, group membership did not relate to time reproduction abilities when either or both of working memory and inhibition were controlled for.

The pattern of results on the enhanced Light Bulb Game seems most consistent with the hierarchical organization of Barkley's model. Specifically, if subjective sense of time is indeed causally linked to working memory which, in turn, is linked to behavioural inhibition, it would be expected that group differences on measures of time reproduction would go away when the other abilities are accounted for. On the other hand, the pattern of results from the regular version of the game do not entirely fit with Barkley's model,

as the time reproduction deficit persisted despite controlling for working memory and behavioural inhibition. In other words, something in addition to working memory and inhibition was responsible for the time reproduction deficit.

It is likely that the additional factor was motivation level. Barkley's model includes the self-regulation of affect, motivation, and arousal as an executive function commensurate with working memory (and the other executive functions), and predicts that individuals with ADHD should be more dependent on external sources of motivation when working toward a goal. His model may account for the present findings by predicting that enhanced motivation would address only part of the problem with time reproduction; the basic deficits in behavioural inhibition and in working memory remain. This last point is difficult to infer, however, because his model does not expressly predict how external sources of motivation could feed back into the executive system to facilitate working memory and in turn improve sense of time. Alternatively, perhaps the self-regulation of affect, motivation, and arousal would be better suited in a position superior to the other executive functions to reflect the finding that their deployment can be significantly influenced by one's affect or level of motivation.

Given that a more engaging time reproduction task improved time reproduction abilities in this sample of children with ADHD, a promising area of future research would be to enhance motivation to an even greater extent. For example, would the time reproduction deficit persist if children were given the opportunity to earn one hundred dollars or an expensive toy? Or, as found in this study, would their difficulty persist, perhaps suggestive of a fundamental deficit?

### Conclusions and Future Research

The results of this study suggest that children with ADHD manifest a true deficit in time reproduction abilities that may be ameliorated to some extent by increased motivational levels. Group differences on measures of working memory and behavioural inhibition, in conjunction with the time reproduction deficits on the enhanced version of the Light Bulb Game, formed a pattern of results aligned closely with Barkley's (1997) model of ADHD. The same pattern of results was not observed with the normal version of the game which suggests that the executive functions contained in Barkley's model are likely influenced at a more global level by degree of motivation.

Three main practical and clinical implications emerge from this study. First, the results showed that even a small motivational enhancement significantly improved off-task and other associated behaviours characteristic for this sample of children with ADHD. This suggests that in the home or school, the behaviour of children with ADHD may be better managed through structured, consistent rewards (e.g., praise; tokens; television or video game privileges) that reinforce desired behaviours while discouraging inappropriate ones. Second, the results of this study suggest that when working with a child who has ADHD, either in a clinical setting or for research purposes, the child's level of motivation toward a given task should figure into interpreting his or her results. Otherwise, a child with ADHD may appear to have more severe deficits than is actually the case. Thus, it may be that the true abilities of children with ADHD, at the most fundamental level, are examinable only when mediated through a motivational lens. Third, this study confirmed the poor sense of time that is often characteristic of ADHD, a deficit that, in this sample, persisted even when children were motivated. This suggests

that when working with children who have ADHD, it may be necessary to provide them with ways of managing and keeping track of time. For example, a child with ADHD who has been given a certain amount of time to complete an assignment in class, or who is writing a timed test, would likely benefit from periodic updates on how much time has elapsed, how much time is left, and even some suggestions on how to allocate his or her resources so as to achieve a goal or maximize an outcome.

This study warrants future studies in three main areas. Foremost, it would be instructive to disentangle the combined effects of sham positive feedback and the prospect of earning a prize as means by which to increase motivation. This could be accomplished easily by establishing two experimental conditions: one in which a prize is offered at the end of the regular Light Bulb Game without feedback at the end of each trial; and a second condition in which the enhanced Light Bulb Game is run without the prize at the end. Second, on a related line, it would be worthwhile investigating the impact of different kinds of sham feedback on task performance. Third, as described earlier, it would be enlightening to investigate whether the time reproduction deficit could be eliminated by increasing motivational levels even further (e.g., by offering a large monetary reward or an expensive toy).

## References

- Abramowitz, A.J., & O'Leary, S.G. (1990). Effectiveness of delayed punishment in an applied setting. Behaviour Therapy, 21(2), 231-239.
- Abramowitz, A.J., O'Leary, S.G., & Rosen, L.A. (1987). Reducing off-task behaviour in the classroom: A comparison of encouragement and reprimands. Journal of Abnormal Child Psychology, 15(2), 153-163.
- American Psychiatric Association (1994). Diagnostic and statistical manual of mental disorders. (4th ed.). Washington, DC: Author.
- Baer, R.A., & Nietzel, M.T. (1991). Cognitive and behavioural treatment of impulsivity in children: a meta-analytic review of the outcome literature. Journal of Clinical Child Psychology, 20(4), 400-412.
- Barber, M.A., Milich, R., & Welsh, R. (1996). Effects of reinforcement schedule and task difficulty on the performance of attention deficit hyperactivity disordered and control boys. Journal of Clinical Child Psychology, 25, 66-76.
- Barkley, R.A. (1990). Attention-deficit hyperactivity disorder: A handbook for diagnosis and treatment. New York: Guilford Press.
- Barkley, R.A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unified theory of ADHD. Psychological Bulletin, 121, 65-94.
- Barkley, R.A. (1997b). Attention-deficit/hyperactivity disorder, self-regulation, and time: toward a more comprehensive theory. Developmental and Behavioural Pediatrics, 18(4), 271-279.
- Barkley, R.A., DuPaul, G.J., & McMurray, M.B. (1990). A comprehensive evaluation of attention deficit disorder with and without hyperactivity. Journal of Consulting and Clinical Psychology, 58, 775-789.
- Barkley, R.A., Grodzinsky, G., & DuPaul, G.J. (1992). Frontal lobe functions in attention deficit disorder with and without hyperactivity: a review and research report. Journal of Abnormal Child Psychology, 20(2), 163-188.
- Barkley, R.A., Koplowitz, S., Anderson, T., & McMurray, M.B. (1997). Sense of time in children with ADHD: effects of duration, distraction, and stimulant medication. Journal of the International Neuropsychological Society, 3, 359-369.
- Barkley, R.A., Murphy, K., & Kwasnik, D. (1996). Psychological adjustment and adaptive impairments in young adults with ADHD. Journal of Attention Disorders, 1(1), 41-54.

Barkley, R. A. (1994). Impaired delayed responding: A unified theory of attention-deficit hyperactivity disorder. In D. K. Routh (Ed.), Disruptive Behavior Disorders in Childhood (pp. 11-57). New York: Plenum Press.

Brown, J. W. (1990). Psychology of time awareness. Brain and Cognition, 14(2), 144-164.

Burt, K.L. & Ryan, C.L. (1997). An investigation of the effects of medication and the use of computerized feedback in task performance of AD/HD children. Issues in Special Education & Rehabilitation, 12(1), 56-70.

Cappella, B., Gentile, J. R., & Juliano, D. B. (1977). Time estimation by hyperactive and normal children. Perceptual and Motor Skills, 44(3), 787-790.

Corkum, P.V., Schachar, R.J., & Siegal, L.S. Performance on the continuous performance task and the impact of reward. Journal of Attention Disorders, 1(3), 163-172.

Daneman, M., & Carpenter, P.A. (1980). Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behaviour, 19(4), 450-466.

Domjan, M., & Burkhard, B. (1993). The principles of learning and behaviour. (3<sup>rd</sup> ed). Pacific Grove, CA: Brooks/Cole Publishing Company.

Dooling-Litfin, J. K. (1997). Time perception in children with ADHD. ADHD Report, 5, 13-16.

Douglas, V. I., & Benezra, E. (1990). Supraspan verbal memory in attention deficit disorder with hyperactivity, normal, and reading disabled boys. Journal of Abnormal Child Psychology, 18, 617-638.

Douglas, V.I., & Parry, P.A. (1983). Effects of reward on delayed reaction time task performance of hyperactive children. Journal of Abnormal Child Psychology, 11(2), 313-326.

Douglas, V.I., & Parry, P.A. (1994). Effects of reward and nonreward on frustration in attention deficit disorder. Journal of Abnormal Child Psychology, 22(3), 281-302.

Fuster, J.M. (1989). The prefrontal cortex : anatomy, physiology, and neuropsychology of the frontal lobe. New York: Raven Press

Golden, C. J. (1978). Stroop Color and Word Test. Chicago, Illinois: Stoelting Company.

Goldman-Rakic, P. S. (1995). Anatomical and functional circuits in prefrontal cortex of nonhuman primates: Relevance to epilepsy. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), Epilepsy and the functional anatomy of the frontal lobe (pp. 51-62). New York: Raven Press.

Haenlein, M., & Caul, W.F. (1987). Attention deficit disorder with hyperactivity: a specific hypothesis of reward dysfunction. Journal of the American Academy of Child and Adolescent Psychiatry, 26(3), 356-362.

Kemp, S. L., & Kirk, U. (1993). An investigation of frontal executive dysfunction in attention deficit disorder subgroups. In P. Tallal, A. M. Gallaburda, R. R. Llinas, & C. von Euler (Eds.), Annals of the New York Academy of Sciences (Vol. 682, pp. 363-365). New York: The New York Academy of Sciences.

Kerns, K.A., McInerney, R.J., & Wilde, N (2001). Investigation of time reproduction, working memory, and behavioral inhibition in children with ADHD. Manuscript submitted for publication.

Iaboni, F., Douglas, V. I., & Baker, A. G. (1995). Effects of reward and response costs on inhibition in ADHD children. Journal of Abnormal Psychology, 104(1), 232-240.

Johnson, D.A., Roethig-Johnston, K., & Middleton, J. (1988). Development and evaluation of an attentional test for head injured children-1. Information processing capacity in a normal sample. Journal of Child Psychology and Psychiatry, 29(2), 199-208.

Kochanska, G., Murray, K., Jacques, T.Y., Koenig, A.L., & Vandegeest, K.A. (1996). Inhibitory control in young children and its role in emerging internalization. Child Development, 67, 490-507.

Logan, G.D., Schachar, R.J., & Tannock, R. (1997). Impulsivity and inhibitory control. Psychological Science, 8(1), 60-64.

Mariani, M., & Barkley, R. A. (1997). Neuropsychological and academic functioning in preschool children with Attention Deficit Hyperactivity Disorder. Developmental Neuropsychology, 13(1), 111-129.

Michon, J. A. (1985). Introduction. In J. Michon & T. Jackson (Eds.), Time, mind and behavior. Berlin: Springer-Verlag.

Michon, J. A., & Jackson, J. L. (1984). Attentional effort and cognitive strategies in the processing of temporal information, Annals of the New York Academy of Sciences (Vol. 423, pp. 298-321). New York: The New York Academy of Sciences.

Oosterlaan, J., & Sergeant, J. A. (1996). Inhibition in ADHD, aggressive, and anxious children: A biologically based model of child psychopathology. Journal of Abnormal Child Psychology, 24(1), 19-36.

Oosterlaan, J., & Sergeant, J.A. (1998). Effect of reward and response cost on response inhibition in AD/HD, disruptive, anxious, and normal children. Journal of Abnormal Child Psychology, 26(3), 161-174.

Pennington, B.F., Groisser, D., & Welsh, M.C. (1993). Contrasting cognitive deficits in attention deficit hyperactivity disorder versus reading disability. Developmental Psychology, 29(3), 511-523.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. Journal of Child Psychology and Psychiatry, 37(1), 51-87.

Pliszka, S.R., Borcharding, S.H., Spratley, K.L., Leon, S., & Irick, S. (1997). Measuring inhibitory control in children. Journal of Developmental and Behavioural Pediatrics, 18(4), 254-259.

Pfiffner, L.J., & O'Leary, S.G. (1987). The efficacy of all-positive management as a function of the prior use of negative consequences. Journal of Applied Behavior Analysis, 20(3), 265-271.

Quay, H. C. (1988). Attention Deficit Disorder and the behavioral inhibition system: The relevance of the neuropsychological theory of Jeffrey A. Gray. In L. M. B. J. Sergeant (Ed.), Attention Deficit Disorder: III. New research in treatment, psychopharmacology and attention (pp. 176-186). New York: Pergamon Press.

Rappport, M.D., Carlson, G.A., Kelly, K.L., & Pataki, C. (1993). Methylphenidate and desipramine in hospitalized children: I. Separate and combined effects on cognitive function. Journal of the American Academy of Child and Adolescent Psychiatry, 32(2), 333-342.

Raven, J.C. (1995). Colored progressive matrices sets A, Ab, B. Oxford: Oxford Psychologists Press Ltd.

Roizen, N.J., Blondis, T.A., Irwin, M., & Stein, M. (1994). Adaptive functioning in children with attention-deficit hyperactivity disorder. Archives of Pediatric and Adolescent Medicine, 148(11), 1137-1142.

Schachar, R.J., & Logan, G.D. (1990). Impulsivity and inhibitory control in normal development and childhood psychopathology. Developmental Psychology, 26(5), 710-720.

Schachar, R.J., Tannock, R., & Logan, G.D. (1993). Inhibitory control, impulsiveness, and Attention Deficit Hyperactivity Disorder. Clinical Psychology Review, 13(8), 721-739.

Schachar, R.J., Tannock, R., Marriott, M., & Logan, G.D. (1995). Deficient inhibitory control in attention deficit hyperactivity disorder. Journal of Abnormal Child Psychology, 23(4), 411-433.

Senior, N., Towne, D., & Huessy, H. (1979). Time estimation and hyperactivity, replication. Perceptual and Motor Skills, 49(1), 289-290.

Shaw, G., & Brown, G. (1999). Arousal, time estimation, and time use in attention-disordered children. Developmental Neuropsychology, 16(2), 227-242.

Shue, K.L., & Douglas, V.I. (1992). Attention deficit hyperactivity disorder and the frontal lobe syndrome. Brain and Cognition, 20(1), 104-124.

Solanto, M.V., Wender, E.H., & Bartell, S.S. (1997). Effects of methylphenidate and behavioural contingencies on sustained attention in attention-deficit hyperactivity disorder: a test of the reward dysfunction hypothesis. Journal of Child and Adolescent Psychopharmacology, 7(2), 123-136.

Sonuga-Barke, E. J. S., Taylor, E., Sembi, S., & Smith, J. (1992). Hyperactivity and delay aversion-I: The effect of delay on choice. Journal of Child Psychology and Psychiatry, 33(2), 387-398.

Swanson, H.L., Cochran, K.F., & Ewers, C.A. (1989). Working memory in skilled and less skilled readers. Journal of Abnormal Child Psychology, 17, 145-156.

Tannock, R. (1997). Television, videogames, and ADHD: challenging a popular belief. The ADHD Report, 5, 3-7.

Tannock, R., Ickowicz, A., & Schachar, R.J. (1995). Differential effects of methylphenidate on working memory in ADHD children with and without comorbid anxiety. Journal of the American Academy of Child and Adolescent Psychiatry, 34(7), 886-896.

Tripp, G., & Alsop, B. (1999). Sensitivity to reward frequency in boys with attention deficit hyperactivity disorder. Journal of Clinical Child Psychology, 28(3), 366-375.

Tromer, B.L., Hoepfner, J.A., Lorber, R., Armstrong, K.J. (1988). The go-no-go paradigm in attention deficit disorder. Annals of Neurology, 24(5), 610-614.

Walker, N. W. (1982). Comparison of cognitive tempo and time estimation by young boys. Perceptual and Motor Skills, 54(3), 715-722.

Wechsler, D. (1991). Wechsler intelligence scale for children-III. New York: Psychological Corporation.

Wender, P.H. (1972). The minimal brain dysfunction syndrome in children. Journal of Nervous and Mental Disease, 155(1), 55-71.

White, J., Barratt, E., & Adams, P. (1979). The hyperactive child in adolescence: A comparative study of physiological and behavioral patterns. Journal of the American Academy of Child Psychiatry, 18, 154-169.

Weiss, G., & Hechtman, L.T. (1993). Hyperactive children grown up: ADHD in children, adolescents, and adults. (2<sup>nd</sup> ed). New York: Guilford Press.

Zakay, D. (1990). The evasive art of subjective time measurement: Some methodological dilemmas. In R. A. Block (Ed.), Cognitive models of psychological time (pp. 59-84). Hillsdale NJ: Erlbaum.

Zakay, D. (1992). The role of attention in children's time perception. Journal of Experimental Child Psychology, 54(3), 355-371.

Zentall, S.S., & Zentall, T.R. (1983). Optimal stimulation: a model of disordered activity and performance in normal and deviant children. Psychological Bulletin, 94(3), 446-471.

## Appendix A

### CONSENT FORM FOR PARTICIPATION IN THE STUDY ENTITLED: "Time Estimation in ADHD" Control Subjects

We are requesting the participation of your child in a study, under the direction of Robert McInerney (Master's Student) and the supervision of Dr. Kimberly Kerns, which is investigating time estimation abilities in children with Attention Deficit Hyperactivity Disorder (ADHD). Hyperactivity is one of the more obvious and troubling symptoms of ADHD, and we hope that this study will provide better insight in how to understand and manage this symptom.

We are seeking children with a diagnosis of ADHD and children who do not have ADHD. Participants will be asked to complete a number of activities including tasks in which they see a light bulb appear on a computer screen for a certain length of time, and try to reproduce its length by turning on/off their own light bulb. Other tasks will involve pressing a button on a keyboard upon seeing letters on a computer screen. Participation will take place at the University of Victoria and will take approximately 1 hour. We feel the information gained from this study will advance understanding of some of the challenges experienced by children with ADHD, and will also serve to further develop our ability to provide better services and treatment for these children.

I understand that this research project is investigating "time estimation" in children with ADHD. To the best of my knowledge, my child is thought not to have ADHD. For participating in this study, my child and I each will receive \$5.00.

I understand that my child's participation is entirely voluntary and that participation or non-participation will have no adverse consequences in terms of his or her grades or standing in school, or in any current medical treatment he or she may be receiving. I understand that he/she has the right to withdraw from the study at any time without explanation, with the option of having all relevant data destroyed.

I understand that data collected in the study will remain confidential: interview results and other data will be kept in a locked filing cabinet and my child's name will not be attached to any published results. Furthermore, my child's anonymity will be guaranteed by using code numbers to identify the results obtained from individual subjects. The key linking code numbers with individual subjects will be stored in a locked filing cabinet, separate from the other data. Only the primary investigator and supervisor will have access to raw data. All raw data, including the key linking code numbers with individual subjects, will be destroyed one year following completion of data analysis. I understand that my child's teacher may have been approached during the earlier recruitment process to provide information about his/her behavior in class, and thus total anonymity in regards to participation in the study will not be possible in this respect.

I understand that information gathered from this study, if used for publication will not use any individual names or other identifying information.

In order to develop a more holistic view of my child (e.g., likes and dislikes, behaviours at home and at school, brief medical history), I may have been or will be interviewed individually. This may have already been completed in a confidential telephone call when my son or daughter's appointment was scheduled. If not, then I give my consent to be interviewed today or in a future confidential telephone call.

If you have any questions please do not hesitate to contact Robert McInerney at 472-4195 or Dr. Kimberly Kerns at either 472-4195 or 721-7553.

Date: \_\_\_\_\_

Child's Name: \_\_\_\_\_

Signatures: \_\_\_\_\_  
Parent

\_\_\_\_\_  
Experimenter

**CONSENT FORM FOR PARTICIPATION IN THE STUDY ENTITLED: "Time Estimation in ADHD"  
ADHD Subjects**

We are requesting the participation of your child in a study, under the direction of Robert McInerney (Master's Student) and the supervision of Dr. Kimberly Kerns, which is investigating time estimation abilities in children with Attention Deficit Hyperactivity Disorder (ADHD). Hyperactivity is one of the more obvious and troubling symptoms of ADHD, and we hope that this study will provide better insight in how to understand and manage this symptom.

We are seeking children with a diagnosis of ADHD and children who do not have ADHD. Participants will be asked to complete a number of activities including tasks in which they see a light bulb appear on a computer screen for a certain length of time, and are asked to try to reproduce its length by turning on/off their own light bulb. Other tasks will involve responding to stimuli (such as digits) on a computer screen, remembering certain words in a sentence, and adding small numbers. Participation will occur at the University of Victoria and will take approximately 1 hour. We feel the information gained from this study will advance our understanding of some of the challenges faced by children with ADHD, and will also help develop our ability to provide better services and treatment for these children.

I understand that this research project is investigating "time estimation" in children with ADHD. For participating in this study, my child and I each will receive \$5.00.

As the parent of a child with ADHD, I understand that participation in this study will have no impact on the medical treatment of my son or daughter. I acknowledge the risks inherent in withholding his or her ADHD-related medications in order to participate in this study.

I understand that my child's participation is entirely voluntary and that participation or non-participation will have no adverse consequences in terms of his or her grades or standing in school, or in any current medical treatment he or she may be receiving. I understand that he/she has the right to withdraw from the study at any time without explanation, with the option of having all relevant data destroyed.

I understand that data collected in the study will remain confidential: interview results and other data will be kept in a locked filing cabinet and my child's name will not be attached to any published results. Furthermore, my child's anonymity will be guaranteed by using code numbers to identify the results obtained from individual subjects. The key linking code numbers with individual subjects will be stored in a locked filing cabinet, separate from the other data. Only the primary investigator and supervisor will have access to raw data. All raw data, including the key linking code numbers with individual subjects, will be destroyed one year following completion of data analysis. I understand that my child's teacher may have been approached during the earlier recruitment process to provide information about his/her behavior in class, and thus total anonymity in regards to participation in the study will not be possible in this respect.

I understand that information gathered from this study, if used for publication will not use any individual names or other identifying information.

In order to develop a more holistic view of my child (e.g., likes and dislikes, behaviours at home and at school, brief medical history), I may have been or will be interviewed individually. This may have already been completed in a confidential telephone call when my son or daughter's appointment was scheduled. If not, then I give my consent to be interviewed today or in a future confidential telephone call.

If you have any questions please do not hesitate to contact Robert McInerney at 472-4195 or Dr. Kimberly Kerns at either 472-4195 or 721-7553.

Date: \_\_\_\_\_

Child's Name: \_\_\_\_\_

Signatures: \_\_\_\_\_  
Parent

\_\_\_\_\_  
Experimenter

## CHILDREN'S CONSENT FORM FOR PARTICIPATION IN THE STUDY

My name is \_\_\_\_\_.

Today I will be working with Robert McInerney at the University of Victoria. He is a student in psychology and would like me to play some computer games, memory-type games, and a math-type game. For example, I will see a light bulb appear on a computer screen for a short amount of time, and then I will be able to turn my own light bulb on and off for the same length of time. Playing these special games and activities will help researchers to understand more about children who have ADHD, and may also help them get better services and treatment.

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 Robert and he will let me leave without explanation. Nothing I do here today will affect my grades in school or my health.

For coming in today, Robert will pay me \$5.00.

All of my "data" (scores, numbers, and any other information) collected from me today will remain confidential - that means no one (except Robert or his supervisor) will be able to know my name, or know that it was me who participated. In fact, instead of using my name, Robert will use a "secret code." After one year, all of my raw data, and anything with my name on it, will be destroyed.

My teacher may have been asked to provide information about my class behaviour a few months ago, when I first told my parents that I would like to participate in these studies. Because of that, my teacher is another person who may know that I participated here today.

If I have any questions, my parents or I can call Robert McInerney at 472-4195 or his supervisor, Dr. Kimberly Kerns, at either 472-4195 or 721-7553.

Date: \_\_\_\_\_

My signature: \_\_\_\_\_

## Appendix B

**CHILD HISTORY QUESTIONNAIRE:  
DEVELOPMENT OF EXECUTIVE FUNCTIONS STUDY**

This questionnaire was 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.

Child's name \_\_\_\_\_ Sex M \_\_\_\_\_ F \_\_\_\_\_

Address \_\_\_\_\_

Date of Birth \_\_\_\_\_ Age \_\_\_\_\_

**DEVELOPMENTAL/MEDICAL HISTORY**

Pregnancy with this child:

Were there any complications with your pregnancy with the referred child (e.g. anemia, high blood pressure, toxemia, diabetes, infections, hospitalizations etc.)

\_\_\_\_\_

\_\_\_\_\_

Were any medications/drugs used during the pregnancy (If yes, please explain)

\_\_\_\_\_

\_\_\_\_\_

Complications during birth:

Induced \_\_\_\_\_

C-Section \_\_\_\_\_

Forceps \_\_\_\_\_

Fetal Distress \_\_\_\_\_

Breech (feet First) \_\_\_\_\_

Twins \_\_\_\_\_

Other (e.g. breathing problems, cord around neck):

\_\_\_\_\_

Newborn:

Following delivery, was the baby:

Blue at birth \_\_\_\_\_

Require oxygen \_\_\_\_\_

Have jaundice \_\_\_\_\_

Require Phototherapy \_\_\_\_\_

Have seizures \_\_\_\_\_

Other: \_\_\_\_\_

Was medication used? Yes \_\_\_\_\_ No \_\_\_\_\_ If yes, reason.

\_\_\_\_\_

Childhood:

Has your child ever experienced:

Very high fever \_\_\_\_\_ Polio \_\_\_\_\_ Dizzy spells \_\_\_\_\_

Measles \_\_\_\_\_ Whooping Cough \_\_\_\_\_ Frequent colds \_\_\_\_\_

Mumps \_\_\_\_\_ Chicken Pox \_\_\_\_\_ Scarlet Fever \_\_\_\_\_

Seizures \_\_\_\_\_ Asthma \_\_\_\_\_ Freq. Ear infections \_\_\_\_\_

Meningitis \_\_\_\_\_ Encephalitis \_\_\_\_\_ Head injuries \_\_\_\_\_

Heart Disease \_\_\_\_\_ Migraines \_\_\_\_\_ Headaches \_\_\_\_\_

AIDS \_\_\_\_\_ Visual defects \_\_\_\_\_ Hearing defects \_\_\_\_\_

Other: \_\_\_\_\_

Food Allergies: \_\_\_\_\_

Drug Allergies: \_\_\_\_\_

Are there any medical problems currently affecting your child. If yes, please explain.

\_\_\_\_\_

\_\_\_\_\_

Is your child currently receiving medication (specify)?

---

---

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

	Grade/Age
Learning Disabilities/Special Education Class	_____
Behavioural Adjustment Class	_____
Tutoring	_____
Enrichment/Gifted	_____
Language Immersion	_____
Other	_____

## Appendix C

## SPATIAL ORDERING GAME

Subject's Name or ID: \_\_\_\_\_ Date: \_\_\_\_\_

**I am going to tell you the names of some things. Listen carefully, and when I stop, I want you to think about how big the things are, and then say them back to me from smallest to biggest. For example if I say, Mountain–Horse, what would you say?**

**If correct:**

**That's right! A horse is smaller than a mountain, so first you would say horse. A mountain is bigger than a horse, so next you would say mountain. And the whole answer would be Horse–Mountain.**

**If wrong:**

**No, you would say Horse–Mountain. A horse is smaller than a mountain, so first you would say horse. A mountain is bigger than a horse, so next you would say mountain. The whole answer would be Horse–Mountain. Remember, you have to say them back to me from smallest to biggest. *Repeat example, rewording as necessary.***

**Let's try another example. If I say, Apple–Train–Car, what would you say?**

**If correct:**

**That's right! An apple is smaller than a car, so first you say Apple. A car is bigger than an apple but smaller than a train, so next you say car. And last you say train, because it's the biggest one of all. The whole answer would be Apple–Car–Train.**

**If wrong:**

**No, you would say Apple–Car–Train. An apple is smaller than a car, so you say apple first. A car is bigger than an apple but smaller than a train, so next you say car. And last you say train, because it's the biggest one of all. The whole answer would be Apple–Car–Train. Remember, you have to say them back to me from smallest to biggest. *Repeat/reword.***

**OK, we're going to begin the real game now. As the game goes on, I'll be saying more and more things, so listen carefully!**

	Trial	Item/Response	Trial Score	Item Score
1	1	<b>Horse–Apple</b> (Apple–Horse)	/1	/2
	2	<b>Mouse–Football</b> (Mouse–Football)	/1	
2	1	<b>Car–Penny–Shoe</b> (Penny–Shoe–Car)	/2	/4
	2	<b>Cherry–Mountain–House</b> (Cherry–House–Mountain)	/2	
3	1	<b>Socks–Tooth–Person–Elephant</b> (Tooth–Socks–Person–Elephant)	/3	/6
	2	<b>Pencil–Peanut–Island–Giraffe</b> (Peanut–Pencil–Giraffe–Island)	/3	
4	1	<b>Dog–Fire truck–Bed–Finger–Ocean</b> (Finger–Dog–Bed–Fire truck–Ocean)	/4	/8
	2	<b>Clock–Worm–Cow–Chair–Building</b> (Worm–Clock–Chair–Cow–Building)	/4	
5	1	<b>Desk–Airplane–Moose–Apple–Cat–Mountain</b> (Apple–Cat–Desk–Moose–Airplane–Mountain)	/5	/10
	2	<b>Mouse–Horse–Tooth–Building–Shoe–Person</b> (Tooth–Mouse–Shoe–Person–Horse–Building)	/5	
6	1	<b>Pony–Tree–Peanut–Shirt–Baseball–Pencil–Bridge</b> (Peanut–Pencil–Baseball–Shirt–Pony–Tree–Bridge)	/6	/12
	2	<b>Ocean–Cherry–Elephant–Football–Car–Bed–Island</b> (Cherry–Football–Bed–Car–Elephant–Island–Ocean)	/6	
<b>Total Raw Score (Max = 42)</b>				

## Appendix D

## SENTENCE SPAN MEASURE (SSM) RECORD FORM

---

Name or ID: \_\_\_\_\_

Date: \_\_\_\_\_

Say: *In this task, I will be reading some sentences to you. Your job is to remember the last word of each sentence.*

*First, I will read you a set of sentences. Then I will ask you a question about one of the sentences. Then I will say 'Remember' and you are to tell me the last word of each sentence in the correct order.*

*So it's LISTEN, QUESTION, REMEMBER.*

*Let's do some practice ones first. LISTEN as I say the sentences. Then I'll ask you a QUESTION and then you REMEMBER the last word in each sentence in order.*

*Ready for the first set?*

### Practice Set 1 (provide feedback)

LISTEN

1. Many animals live on a farm. *[Pause]*

\_\_\_\_\_ farm

2. People have used masks since early times. *[Pause]*

\_\_\_\_\_ times

QUESTION

What have been used since early times?

\_\_\_\_\_ masks

REMEMBER

### Practice Set 2

LISTEN

1. The baby's toy rolled under the bed. *[Pause]*

\_\_\_\_\_ bed

2. They walked around to the back of the house. *[Pause]*

\_\_\_\_\_ house

QUESTION

What rolled under the bed?

\_\_\_\_\_ toy

REMEMBER

**Practice Set 3**

LISTEN

1. The squirrel hid the acorns in the hollow tree. *[Pause]* \_\_\_\_\_ tree2. It was so cold, the snow crunched under his feet. *[Pause]* \_\_\_\_\_ feet

QUESTION

What crunched? \_\_\_\_\_ snow

REMEMBER

*Say: Now I think you have the idea. Try to remember as much as you can and don't be afraid to guess about the words or the answers to the questions. But LISTEN carefully.*

**START ALL CHILDREN AT LEVEL 2. STOP WHEN TWO SETS WRONG IN A LEVEL.**

**Level 2: Set 1**1. Sarah wants you to give her a pound. *[Pause]* \_\_\_\_\_ pound2. Mary tried to tell her teacher the right street. *[Pause]* \_\_\_\_\_ street

Who did Mary try to tell? \_\_\_\_\_ teacher

**Level 2: Set 2**1. Both of the games were cancelled because of trouble. *[Pause]* \_\_\_\_\_ trouble2. Jennifer says she doesn't have time. *[Pause]* \_\_\_\_\_ time

What was cancelled? \_\_\_\_\_ games

**Level 3: Set 3**1. We waited in line for an hour. *[Pause]* \_\_\_\_\_ hour2. Sally thinks we should give the bird its freedom. *[Pause]* \_\_\_\_\_ freedom3. My mother said she would write an excuse. *[Pause]* \_\_\_\_\_ excuse

Where did we wait? \_\_\_\_\_ in line

**Level 3: Set 4**

- |   |       |         |
|---|-------|---------|
| 1. The captain does not seem to have friends. <i>[Pause]</i>  | _____ | friends |
| 2. Beth can't go because she didn't get shoes. <i>[Pause]</i> | _____ | shoes   |
| 3. Bob doesn't want to tell the teacher. <i>[Pause]</i>       | _____ | teacher |
| Who can't go?   | _____ | Beth    |

**Level 4: Set 5**

- |   |       |            |
|---|-------|------------|
| 1. My little brother went in the wrong restaurant. <i>[Pause]</i> | _____ | restaurant |
| 2. The teacher wanted to see me about my book. <i>[Pause]</i>     | _____ | book       |
| 3. You will be sorry if you break the window. <i>[Pause]</i>      | _____ | window     |
| 4. My friend wants to learn about snakes. <i>[Pause]</i>          | _____ | snakes     |
| Who will be sorry?  | _____ | you        |

**Level 4: Set 6**

- |   |       |           |
|---|-------|-----------|
| 1. If you work hard you can make a discovery. <i>[Pause]</i>  | _____ | discovery |
| 2. We didn't buy the car because of the cost. <i>[Pause]</i>  | _____ | cost      |
| 3. I would like to know your opinion. <i>[Pause]</i>          | _____ | opinion   |
| 4. It is very important to think about safety. <i>[Pause]</i> | _____ | safety    |
| What didn't we buy?   | _____ | car       |

**Level 5: Set 7**

- |   |       |        |
|---|-------|--------|
| 1. The broken doll was not my fault. <i>[Pause]</i>           | _____ | fault  |
| 2. Joe is having problems with his memory. <i>[Pause]</i>     | _____ | memory |
| 3. I have talked to my parents about the idea. <i>[Pause]</i> | _____ | idea   |
| 4. John is not in a very good mood. <i>[Pause]</i>            | _____ | mood   |
| 5. They were all happy to be at the event. <i>[Pause]</i>     | _____ | event  |
| What was broken?  | _____ | doll   |

**Level 5: Set 8**

- |  |                 |
|--|-----------------|
| 1. I can study if you give me a pencil. <i>[Pause]</i>           | _____ pencil    |
| 2. Children like to read books about animals. <i>[Pause]</i>     | _____ animals   |
| 3. I will give Cathy the sweets in a bowl. <i>[Pause]</i>        | _____ bowl      |
| 4. The good news gave Ann a feeling of happiness. <i>[Pause]</i> | _____ happiness |
| 5. Jeff likes to do homework in ink. <i>[Pause]</i>              | _____ ink       |
| What will I give to Cathy?                                       | _____ sweets    |

**SENTENCE SPAN SCORE****(Highest level at which both sets correct) =**

VITA

Surname: McInerney

Given Names: Robert John

Place of Birth: Brampton, Ontario, Canada

Educational Institutions Attended:

University of Victoria	1998 to 2000
McMaster University	1992 to 1996

Degrees Awarded:

B.Sc. (Honours)	McMaster University	1996
-----------------	---------------------	------

Honours and Awards:

The Robert and Douglas Vickery Graduate Award	2000
University of Victoria Doctoral Fellowship	2000 to 2001
University of Victoria Masters Fellowship	1998 to 2000
McMaster University Dean's Honour List	1995 to 1996

Publications:

Kerns, K.A., McInerney, R.J., & Wilde, N. (2001). Investigation of time reproduction, working memory, and behavioral inhibition in children with ADHD. Manuscript submitted for publication.

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Title of Thesis:

The Effect of Enhanced Motivation on Time Reproduction Abilities in Children with ADHD

Author



Robert John McInerney

January 17, 2001

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