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An Examination of Fine Motor Control

In Children with ADHD

By

Vilija M Petrauskas

A Dissertation
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An Examination of Fine Motor Control in Children with ADHD

by

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ABSTRACT

Attention-Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by symptoms of inattention, hyperactivity-impulsivity, or both. Although fine motor difficulties are frequently found in children diagnosed with ADHD, often they are not identified and are undertreated. The present study examined fine motor control in children with ADHD in several ways, including through the use of digitizing technology, and compared it to that of control children. Thirty-eight children with ADHD and 28 control children in grades four through eight were administered a measure of handwriting (Test of Handwriting Skills – Revised; THS-R), a pattern completion task (Repeated Patterns Test; RPT), and a measure of fine motor skills (Bruininks Oseretsky Test of Motor Proficiency – Second Edition; BOT-2) on a digitizing tablet. Groups were compared on peak vertical velocity, variability of peak vertical velocity, normalized jerk, and mean stylus pressure. Results of the present study indicated that better quality of writing was associated with slower writing speed in children with ADHD, whereas in control children better quality writing was associated with greater stylus pressure, slower writing speed, and less variability in writing speed. No group differences were found on either a measure of fluency or stylus pressure when examining children's writing between different levels of constraint. Both groups demonstrated the most fluent writing between 2 cm spaced lines, which appear to represent a level that facilitates the maximal amount of writing fluency in children in grades four through eight. Lastly, results indicated that there were no stylus pressure differences between groups for either novel or motorically complex material.

ACKNOWLEDGMENTS

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CHAPTER 1

Introduction

The frequent co-occurrence of motor problems and Attention Deficit Hyperactivity Disorder (ADHD) has received relatively little research attention compared to psychiatric comorbidities such as depression, autism, oppositional defiant disorder, and conduct disorder. Additionally, in clinical practice there is less attention paid to motor problems in children with ADHD (Fliers et al., 2010). Motor problems are not usually part of assessments for ADHD nor are they typically included in intervention programs (Gillberg et al., 2004; Sergeant, Piek, & Oosterlaan, 2006) despite the estimate that 30 – 50% of children with ADHD exhibit motor problems (Fliers et al., 2008). It is well known that learning disabilities are often comorbid with ADHD (e.g., Mayes & Calhoun, 2006, 2007; Mayes, Calhoun, & Crowell, 2000; Tannock, 2012); reported frequencies of reading disabilities in children with ADHD range from 15 – 44%, while that of math range from 31 – 60% in the studies noted above. One area that has often been overlooked in the learning disabilities research is that of written expression. This is unfortunate since the few studies that do assess reading, math, and writing disabilities indicate that a learning disability in written expression is more common than disabilities of reading or mathematics in clinical samples (Mayes & Calhoun, 2006, 2007; Schuerholz, Harris, Baumgardner, Reiss, Freung, Church, et al. 1995). Specifically, Mayes and Calhoun (2006) reported that 63% of children with ADHD Combined subtype (ADHD-C) and 59% of children with ADHD Primarily Inattentive subtype (ADHD-PI) exhibit deficits in written expression, compared to approximately 20 – 30% who exhibit deficits in reading, mathematics or spelling. Clinical lore and previous research also point to difficulties in the actual production of writing in children with ADHD, often resulting in messy and illegible writing (e.g., Tucha & Lange, 2001, 2004, 2005). It is important to gain a better understanding of why these children experience such difficulties in order to better guide intervention efforts. One new way to examine such problems is through the use of digitizing technology that allows for the quantification of the process variables of writing as opposed to only measuring the end product of writing.

The goal of the proposed study is to investigate fine motor control (e.g., handwriting and drawing) in a sample of children with ADHD. Through the use of

various forms of movement quantification technology (e.g., Mergl et al., 1999; Schoemaker et al., 2005; Schroter et al., 2003; Yan et al., 2008), handwriting movements can be depicted graphically via a velocity profile. A velocity profile is a graphical representation of the amplitude and frequency of writing movements, and allows for the calculation of various quantitative measures of handwriting and drawing.   More specifically, a goal of the present study was to determine whether there is a relationship between handwriting quality and velocity profiles in children with ADHD, and whether the velocity profiles produced by children with ADHD are different from those produced by neurotypical children. Previous research examining handwriting quality in children with ADHD has examined it from subjective ratings across raters, rather than using a standardized and normed test of handwriting quality. A further goal of the present study was to use an objective, standardized measure to examine handwriting in a larger sample than has been typical. Much previous research has consisted of sample sizes of approximately 20 to 25 children per group or less, thus the present study aimed to improve upon this by including a larger sample. Furthermore, handwriting and drawing quality was examined as a function of task novelty and motoric complexity to determine whether cognitive load and task complexity differentially affect fine motor output in children with ADHD and neurotypical children. The results will help clinicians, parents, and educators better understand the nature of fine motor control deficits in children with ADHD, and will help inform and guide future treatment and rehabilitation for these children.

Attention Deficit Hyperactivity Disorder (ADHD)

Diagnostic Criteria

Attention Deficit Hyperactivity Disorder (ADHD), as currently defined, is a clinically heterogeneous developmental disorder characterized by persistent and developmentally inappropriate symptoms of inattention, hyperactivity/impulsivity, or both which cause significant impairment in academic, social, and/or occupational functioning (American Psychiatric Association, 2000; Barkley, 1998, 2000, 2006; Derks, Dolan, Hudziak, Neale, & Boomsma, 2007). Boys are diagnosed with ADHD significantly more often than girls by an average ratio of 3:1 (Barkley, 2006). Additionally, boys are five to nine times more likely than girls to be referred to a clinic

(Barkley, 2006). To be diagnosed with the disorder, an individual must meet 6 of 9 criteria for inattention, or 6 of 9 criteria for hyperactivity/impulsivity, or both (American Psychiatric Association, 2000). Symptoms causing impairment must have been present before the age of seven years, and impairment of functioning must be present in two or more settings (e.g., at school or work and at home). There are presently three forms of the disorder: combined type (ADHD-C; the individual meets criteria for both inattention and hyperactivity/impulsivity symptoms), predominantly inattentive type (ADHD-PI; the individual meets criteria for inattentive symptoms only), and predominantly hyperactive-impulsive type (ADHD-HI; the individual meets criteria for symptoms of hyperactivity/impulsivity only). Although symptoms tend to attenuate during the late teens and adulthood, ADHD persists throughout adolescence in approximately 50 – 80% of cases that were diagnosed in childhood, and 30 – 50% of these cases will continue into adulthood (Barkley, Fisher, Smallish, & Fletcher, 2002; Mannuzza, Klein, Klein, Bessler, & Shrout, 2002).

Prevalence Rates

It is important to gain a better understanding of the deficits associated with ADHD since it is one of the most common neurodevelopmental disorders, with current consensus of expert opinion indicating that approximately 3 – 7% of children are affected (American Psychiatric Association, 2000). Although some prevalence estimates are much higher (e.g., 8% - 12%; Faraone, Sergeant, Gillberg, & Biederman, 2003), many of these differences can be attributed to the criteria used to establish prevalence. Stefanatos and Baron (2007) note that it is difficult to establish accurate prevalence rates due to the lack of:

> (1) an objective diagnostic test for ADHD; (2) a 'gold standard' measure of ADHD that is easily applicable in epidemiologic research; (3) a systematic means to monitor the diagnosis; (4) consistency in case definition and how it is operationalized; and (5) consistency in reporting symptomology across age, gender, and informant source (p. 8).

As such, prevalence rates vary considerably, with some estimates ranging from 1.7 to 17.8% (Brown et al., 2001; Elia, Ambrosini, & Rapoport, 1999; Goldman, Genel, Bezman, & Slanetz, 1998).

Taken together, examination of prevalence rates indicates that rates differ depending on the method used to diagnose the disorder and the age range examined. However, it can be noted that ADHD is truly a worldwide phenomenon since many studies conducted in various countries, using various ways of determining prevalence, have found evidence for the presence of ADHD (Barkley, 2006). Given the large number of children affected worldwide, it is important to attempt to better understand the nature of their various difficulties.

Barkley's Hybrid Model of ADHD

A leading theory in the conceptualization of the deficits exhibited by children with ADHD is Russell Barkley's Hybrid Model (1997). He indicates that his model is a "theory of prefrontal lobe functions (and related networks in the basal ganglia and cerebellum), particularly the executive function system" (Barkley, 2006, p. 300). Behavioural inhibition is the first component in the model and provides a foundation for the other components, namely four different executive functions and motor control. The four executive functions Barkley outlines are nonverbal working memory, internalization of speech, the self-regulation of affect/motivation/arousal, and reconstitution (Barkley, 1997, 2006). Barkley posits that behavioural inhibition affects motor control/fluency/syntax (i.e., the execution of behavioural programs and motor execution systems) through these four executive functions. See Figure 1 below.

Behavioural inhibition. The first component of the model, behavioural inhibition, refers to three interrelated processes: 1) stopping the initiation of a conditioned response; 2) stopping an ongoing response to permit a delay in responding; and 3) protection from competing external and internal events while engaged in another task or while delaying a response (interference control). He argues that inhibition is crucial to creating a delay between an event and one's response to it, and that self-control is not possible without such a delay since it is during this delay period that self-directed actions constituting self-control can occur (Barkley, 1997, 2006). Barkley believes that behavioural inhibition supports the four executive functions, allowing them to act and make behavior goal-oriented.
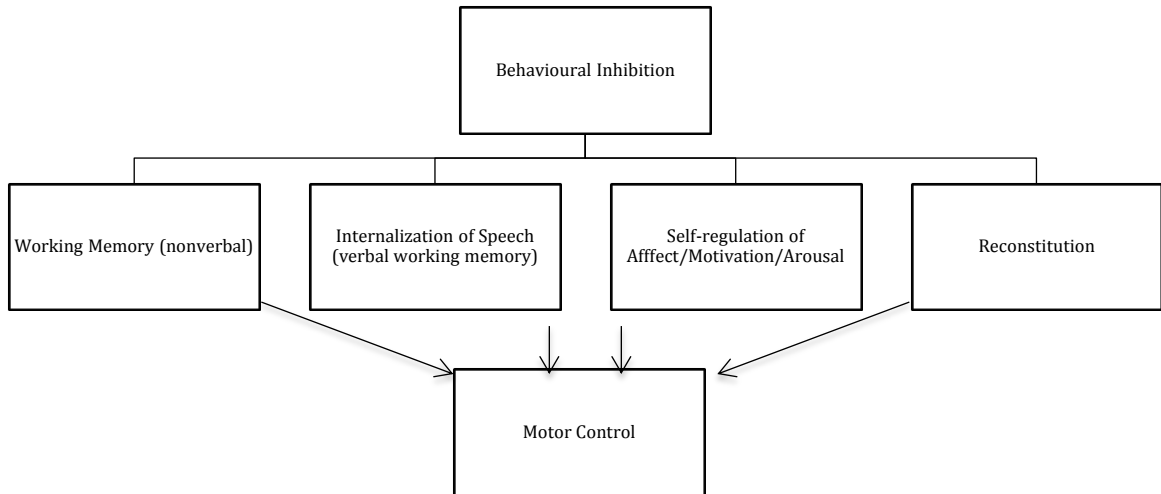
Figure 1. Schematic of Barkley's Hybrid Model of ADHD.

The next level of Barkley's model includes the four executive functions, namely working memory (nonverbal), internalization of speech (verbal working memory), self-regulation of affect/motivation/arousal, and reconstitution (Barkley, 1997, 2006). He proposes that behavioural inhibition does not *cause* the four executive functions, but instead sets the occasion for their performance and protects that performance from interference. Barkley posits that the self-directed actions that occur *during the delay* in the response in fact constitute the executive functions (Barkley, 1997, 2006). He notes that the term 'executive functions' as he uses it, refers to "a specific class of self-directed actions by the individual that are being used for self-regulation toward the future" (Barkley, 2006, p. 304 – 305). Barkley believes that it is the action of the four executive functions that permit and produce self-regulation; deficits in any one executive function will produce a distinct impairment in self-regulation, different from that produced by impairment in self-control produced by deficits in a different executive function. He further proposes that the four executive functions arise at different time points developmentally. More specifically, he posits that behavioural inhibition arises first, likely in parallel with nonverbal working memory. This is then followed by the

internalization of speech, then the internalization of affect and motivation, and lastly by the internalization of play or the 'reconstitution' component of his model (Barkley, 2006).

Nonverbal working memory. Working memory has been defined as the ability to hold an event in mind so as to use it to control a response (Goldman-Rakic, 1995), and it includes both a verbal and nonverbal part. The first of the executive functions in Barkley's model is nonverbal working memory, which Barkley (2006) defines as "the capacity to maintain internally represented information in mind or online that will be used to control a subsequent response" (p. 307). He believes that nonverbal working memory gives rise to mental imagery, hindsight, forethought, a preparation to act, time management, imitation and vicarious learning, and social reciprocity. He posits that this in turn helps to guide behavior through motor control (the final component of his model, discussed in greater detail below).

Internalization of speech. Although Barkley refers to this part of his model as internalization of speech, he regards this as comprising what most researchers refer to as verbal working memory, or the articulatory loop of the working memory system (e.g., Baddeley & Hitch, 1994). Normally, overt private speech emerges around age 3 to 5 and serves a problem-solving function, and becomes increasingly covert during the early school years and is predominantly internalized by ages 9 – 12 (Barkley, 2006). Barkley believes that this provides a means for reflection and description, problem-solving, generating rules, reading comprehension, and moral reasoning.

Self-regulation of affect/motivation/arousal. The development of self-regulation of affect/motivation/arousal, the third type of executive function in Barkley's model, develops in a similar manner as internalization of speech, namely from being expressed purely in its public form to becoming more and more regulated and covert (Barkley, 1997, 2006). Barkley proposes that this executive function supports emotional self-control, objectivity, self-regulation of motivation, and self-regulation of arousal for the purpose of goal-directed action. He believes that this executive function is used to sustain goal-directed behaviour in the absence of external consequences for doing so.

Reconstitution. The final executive function Barkley outlines is planning or reconstitution. He posits that reconstitution aids with analysis and synthesis of behaviour, verbal and behavioural fluency, rule creativity, behavioural simulations, and syntax of

behaviour (i.e., a syntax for assembling units of behaviour into proper sequence; Barkley, 2006). It includes analysis and synthesis, that is, decomposition of sequences of events or messages into their parts, and manipulation of these parts in order to reconstitute new events or messages. Reconstitution is linked to inhibition in that a delay in responding is required in order to mentally organize information, and such a delay is provided by inhibition. It is also linked to working memory in that information has to be retained in memory before any type of manipulation of information can take place.

Elements of Barkley's model are based on Fuster's theories (1997), which posit that by instituting a separation and temporal delay between external forces and behavioural responding, individuals develop a sense of time and the ability to put behaviour in sequential order. Temporal awareness becomes necessary when evaluating past and current demands of the environment and attempting to develop plans for future responding. As such, these executive functions have specific effects on motor control. Firstly, executive functions can be seen in the retention of information about past events and actions already executed that feed forward to influence subsequent responding (i.e., sensitivity to errors). Secondly, effects of executive functioning would be observed in the anticipatory setting of premotor and motor functions (i.e., preparation to act). Lastly, executive functions would influence resistance to interference and the inhibition of motor impulses that are inappropriate to the goal.

Motor control. The final component of Barkley's model is motor control/fluency/syntax. He proposes that the forms of self-directed behaviour that comprise the executive functions come to control the actions of the behavioural programming and execution systems (Barkley, 1997, 2006). As a result of the four executive functions, irrelevant sensory input and motor behaviour becomes suppressed or minimized. Such suppression of prepotent responding (i.e., impulsivity) occurs during the operation of the executive functions as well as during the execution of goal-directed responses (Barkley, 2006). Once a goal-directed action is formulated, the motivation necessary to maintain these sequences of goal-directed behavioural structures must be recruited. This recruitment of motivation for the purpose of goal-directed behaviour, combined with working memory and interference control, drives the intended behaviour (Barkley, 2006). He further explains that while the goal-directed behaviour is being

executed, the self-awareness features of working memory permit for feedback from the last response to be held in mind in order to feed forward in modifying subsequent responses, thus creating sensitivity to errors.

Overall, Barkley's model describes how one's actions are affected by the functioning of four executive functions, all influenced by one's ability to inhibit his/her behaviour. As such, Barkley's model suggests that problems in any of the components of the model may result in the deficits seen in children with ADHD.

Other Impairments Associated with ADHD

Beyond the primary deficits of inattention, hyperactivity, and impulsivity, research has demonstrated various domains of activities and functioning that are impaired in children with ADHD. Such areas include cognitive functioning, language development and expression, motor skills, emotional regulation, academic performance, consistency of task performance, and general health and well-being (Barkley, 2006).

Of particular interest to the present study is the greater variability of task performance. Although not directly included in his Hybrid Model, Barkley (2006) proposes variability of performance as a hallmark feature of ADHD. In recent years, the excessive intraindividual variability in reaction times has been documented in children with ADHD (e.g., Borella, Chicherio, Re, Sensini, & Cornoldi, 2011; Castellanos & Tannock, 2002). Patterns of large within-task intraindividual variability in reaction times have been extended to a variety of tests such as cognitive inhibition (e.g., Christiansen & Oades, 2009), sustained attention (e.g., de Zeeuw et al., 2008), choice reaction time (e.g., Leth-Steensen, Elbaz, & Douglas, 2000), and working memory tasks (e.g., Klein, Wendling, Huettner, Ruder, & Peper, 2006). Intraindividual variability reflects endogenous brain mechanisms, such as higher fluctuations in the connectivity of neuronal pathways and dysfunctional modulation of neurotransmitter systems (e.g., Borella, Chicherio, Re, Sensini, & Cornoldi, 2011). Additionally, the increased temporal and contextual variability in behavioural performance in children with ADHD, stemming from dysfunctional regulatory processes producing fluctuations in attention or response control (Tannock, 2003), has been associated with compromised central nervous system integrity in individuals with ADHD (MacDonald, Nyberg, & Backman, 2006). In particular, dysfunctions of fronto-striatal-cerebellar circuits (e.g., Paus, 2001), the

catecholaminergic and noradrenergic deficiencies (e.g., Krain & Castellanos, 2006), which give rise to arousal modulation deficiencies, and a reduced myelinisation (e.g., Russell et al. 2006) have been proposed to explain increased intraindividual variability in ADHD.

Research in the area of intraindividual variability as it pertains to handwriting specifically is very scarce, with only one study found to date.   Borella and colleagues (2011) asked children with ADHD and typically developing controls to write a cursive sequence of "lele" letters onto a blank sheet of paper. The page was marked at 5 second intervals, and the mean number of "le" repetitions written in 5 seconds was calculated for the overall task duration of 180 seconds. To calculate the intraindividual variability, Borella et al. (2011) divided the individual standard deviation of the number of "le" sequences by the individual mean. They found that children with ADHD had greater intraindividual variability in the production of handwriting movements compared to typically developing controls. No studies to date have examined intraindividual variability of handwriting within a kinematic context.

Motor Systems and Motor Control

Several anatomical areas known to be involved in ADHD are also involved with motor control. Given this, it is not surprising that many children with ADHD exhibit difficulties with gross and fine motor control. Fine motor skills are small movements that are produced by the body's small muscle groups such as the hands, fingers, toes, wrists, and other small muscles (Schmidt & Lee, 2011). Some examples of fine motor skills include writing, picking up objects, drawing, among others. In contrast, gross motor output entails the use of large muscle groups such as the arms, legs, and trunk to move the body and engage in activities (Schmidt & Lee, 2011). Examples of gross motor skills include balancing, bending, walking, catching, and stepping, among others.

In order to better understand these motor difficulties, it is first important to examine how the motor system works in controlling movement. All movements, whether voluntary or involuntary, are elicited by coordinated patterns of muscle contractions orchestrated by the motor neurons of the spinal cord and brainstem. One of the main functions of the brain is to control motor behaviour, which is manifested as coordinated movements of the eyes, mouth, limbs, and body (Rosenbaum, 2010). Consider someone

serving a ball in tennis. In order to serve the ball so that the opponent cannot return it, the player must assess where the opponent is standing, throw the ball in the air, coordinate their arm position so that they can hit the ball, and hit the ball in the predetermined direction so as to make it difficult for the opponent to return the ball. It would not be possible to coordinate all of these movements without the efforts of four hierarchically ordered systems (Michael-Titus, Revest, & Shortland, 2010).

Starting distally, the first of these four systems comprises the lower motor neurons (LMN), which comprises the cell bodies located in the ventral horn of the spinal cord and the brainstem, as well as the axons that form the motor nerves that control skeletal muscles (Lundy-Ekman, 2007). The axons of the LMNs innervate the striated muscle via neuromuscular junctions. Together with other spinal cord and brainstem interneurons, the LMNs receive sensory input from proprioceptors, and act to modulate LMN activity and coordinate the movement of different muscle groups (see Figure 2; Lundy-Ekman, 2007; Michael-Titus et al., 2010).

The second system, which consists of upper motor neurons (UMN) whose cell bodies lie in the cortex and brainstem, modulates LMN activity. The axons of the UMNs form the descending motor pathways and synapse on the cell bodies of either interneurons or LMNs in the brainstem or spinal cord (UMNs never innervate muscles directly; Kolb, & Whishaw, 2003). Upper motor neuron axons are traditionally divided into two descending systems – the pyramidal and extrapyramidal tracts. The pyramidal tract arises from the motor cortex and is essential for planning, initiating, and directing voluntary movements (Kolb, & Whishaw, 2003; Lundy-Ekman, 2007; Michael-Titus et al., 2010). The extrapyramidal tracts arise from the brainstem and play an important role in postural control, selective activation of movements and suppression of others, initiation of movement, as well as coordinating movements (Kolb, & Whishaw, 2003; Lundy-Ekman, 2007; Michael-Titus et al., 2010).

The third and fourth systems are the cerebellum and basal ganglia. They do not project directly to LMNs, instead regulating the activity of UMNs. The basal ganglia and cerebellum receive information from the motor cortex, and both structures send information back to the cortex via the thalamus (See Figure 2). The output from the cerebellum to the motor cortex is excitatory, while that of the basal ganglia is inhibitory

(Kolb, & Whishaw, 2003). These two systems allow for smooth, coordinated movement. The cerebellum acts as a motor performance error detector, whereas the basal ganglia function to suppress unwanted movements as well as prepare the motor cortex for the initiation of movements (Michael-Titus et al., 2010). All systems, with the exception of the basal ganglia, receive information from somatic proprioceptors that continually inform the motor system about the position and movement of the body and limbs.

As described above, the production of movement involves the activation of a complex neuromuscular system made up of several components which are organized both hierarchically and in parallel. The three main components are: 1) cortical areas (i.e., primary motor cortex, premotor cortex, and supplementary motor area, which contain somatotopic maps and receive information from the periphery via sensory relay nuclei; 2) the brain stem, which modulates motor neurons and interneurons in the spinal cord; and 3) the motor neurons, which interact either directly or indirectly with proximal and distal muscles (Plamondon, 1995). As described above, the cerebellum and basal ganglia aid in controlling and regulating motor functions. Lastly, the skeletal muscles actually perform each movement. Taken together, it is through this sensori-motor integration that smooth movements can be produced.
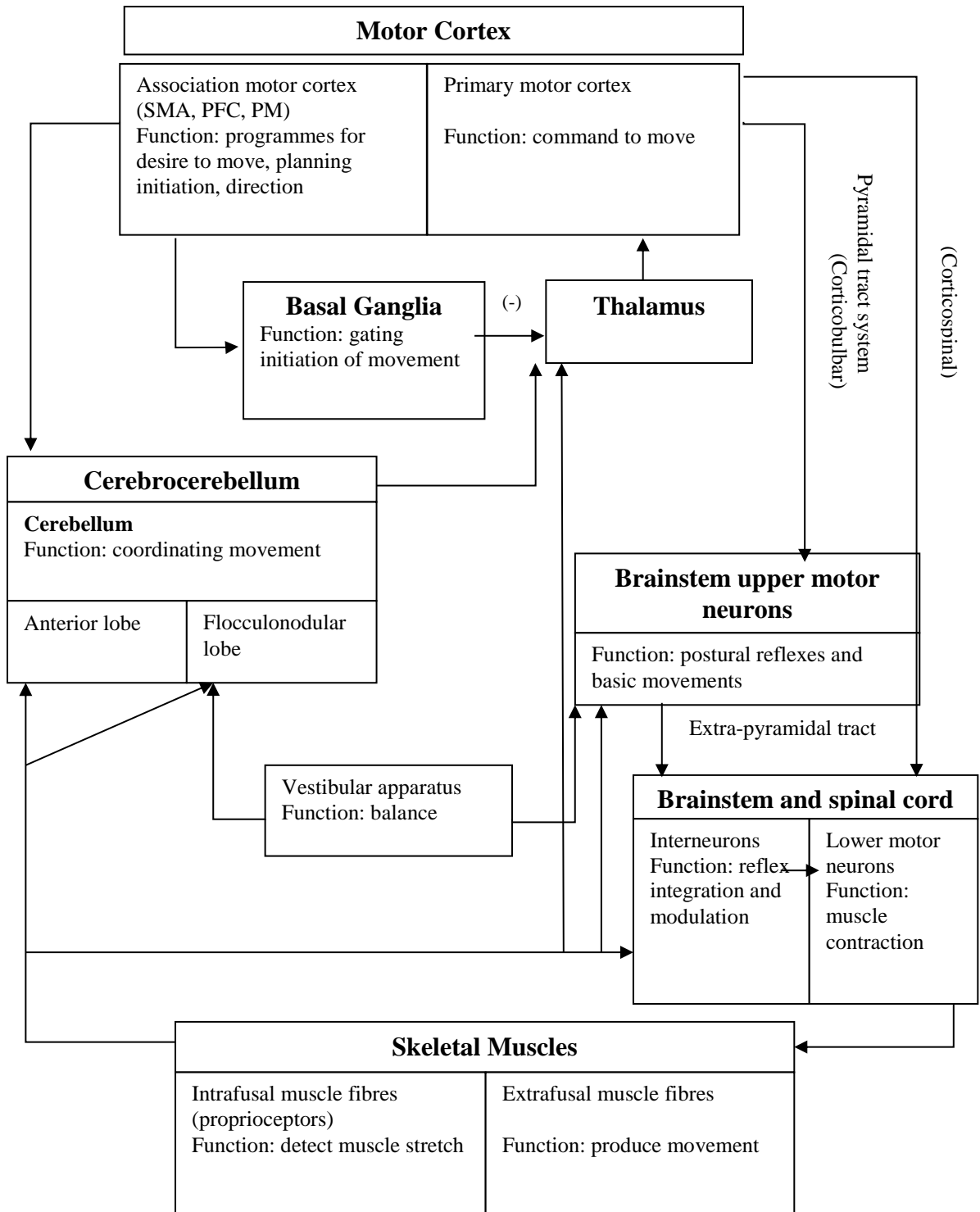
Figure 2. Schematic representation of circuits involved in motor function.

Note: SMA, supplementary motor area; PFC, prefrontal cortex; PM, pre-motor cortex; (-), inhibitory connection. Figure adapted from Michael-Titus, Revest, & Shortland (2010).

Writing

Handwriting is a very important and complex scholastic skill, as it is fundamental in daily activities. Difficulties and poor handwriting quality imply more time needed to carry out writing tasks such as homework assignments, which makes schoolwork even more difficult. Children struggling with handwriting will then often attempt to get around writing related tasks, an attitude that can be considered oppositional to parents and teachers, leading to conflict at home and school (Brossard-Racine, Majnemer, Shevell, & Snider, 2008). Children spend 31 to 60% of their school day performing handwriting and other fine motor tasks (McHale & Cermak, 1992), and difficulties in this area can interfere with academic achievement. Additionally, illegible handwriting can create barriers for higher-order skills such as spelling and writing composition.

The development of handwriting begins with early scribbling, which then becomes more intentional over time (Ajuriaguerra & Auzias, 1975; Oliver, 1990). As the child grows and develops, these design patterns evolve into more precise shapes and then letters (Feder & Majnemer, 2007). Children first learn to print letters by imitating geometric shapes beginning with vertical strokes (age 2), followed by horizontal strokes (age 2 years, 6 months), and circles (age 3; Feder & Majnemer, 2007). The ability to imitate and copy a cross typically occurs at 4 years, copying a square at 5 years, and a triangle at 5 years 6 months (Beery & Buktenica, 1989). Studies of handwriting in typically developing children in grades one to five have found that quality of handwriting develops quickly during grade one, and reaches a plateau by grade two (Feder & Majnemer, 2007). Further development is seen by grade three in that handwriting becomes automatic, organized, and is available as a tool to facilitate the development of ideas (Blote & Hamstra-Bletz, 1991; Karlsdottir & Stafansson, 2002). Speed of writing develops in a somewhat linear fashion throughout primary school, and overall development of handwriting continues during the middle school years (Feder & Majnemer, 2007).

Components Necessary to Produce Handwriting

Handwriting is a very complex perceptual-motor skill that encompasses a blend of visual-motor coordination abilities, motor planning, cognition, and perceptual skills, together with tactile and kinesthetic sensitivities (Maeland, 1992). Lack of fine motor

control is implicated in common writing errors (e.g., incorrect size or placement of letters); isolation, grading, and timing of movements have been reported to be the three aspects of fine motor control that affect handwriting ability (Exner, 1989). For instance, labored, slow, and jerky writing or rapid, haphazard writing is usually a sign of difficulty with movement timing that affects the rhythm and flow of writing (Exner, 1989). Another aspect of fine motor control that may affect writing is in-hand manipulation; this is the process of adjusting objects within the hand after grasp. More specifically, once a pencil is grasped, it must be shifted (i.e., moved linearly) by the fingers in order to adjust its position to an optimal one for writing. Translation is another type of in-hand manipulation task whereby an object is moved from the fingers to palm, or palm to fingers (i.e., pushing the fingers towards or away from the writing point). Lastly, rotation is another in-hand manipulation task whereby the pencil is moved around an axis (e.g., turning the pencil around to erase). Motor planning influences the child's ability to plan, sequence, and execute letter forms, as well as the ordering of letters in words (Amundson, 1992). The ability to motor plan is particularly important for children first learning to write, as it is implicated in their ability to perform novel or unfamiliar movements (Amundson, 1992). Visual-motor integration is also an important variable in handwriting performance (Cornhill & Case-Smith, 1996), and is defined as the ability to coordinate visual information with a motor response, allowing children to reproduce letters and numbers. Several studies have found visual-motor integration to be one of the most significant predictors of handwriting performance (e.g., Maeland, 1992; Tseng & Murray, 1994; Weil & Amundson, 1994). Poor visual memory has also been documented in children who have difficulties with writing tasks (e.g., Bain, 1991; Kurtz, 1994). Proprioception and kinesthesia also play a role in handwriting by influencing pencil grip, the amount of pressure applied to the writing tool, and the ability to write within boundaries (Amundson, 1992; Cornhill & Case-Smith, 1996; Schneck, 1991). Sensory awareness of the fingers also impacts handwriting performance. During writing, tactile/proprioceptive inputs provide information regarding grasp of the writing tool, paper, and surface (Amundson & Weil, 1996). Impaired sensory awareness of the fingers may require more intense visual monitoring of written output, causing increased fatigue and limiting automaticity. Similarly, impaired sensori-motor integration may be reflected

in limited automaticity and therefore increased jerkiness in writing. Lastly, sustained attention is also necessary to enable children to effectively perform a handwriting task for an extended period of time (Amundson, 1992). Lowered attention can limit the practice of handwriting which can lead to poor mastery of letter formation.

As described above, there are many factors that contribute to successful writing. Deficiencies or problems in any one of these areas may manifest in problems successfully writing.

Handwriting and Written Expression

As described above, the act of producing written text is complex and involves several components. In fact, Kellogg (2008) has noted that writing is such a complex and demanding activity that it generally takes more than two decades to achieve writing expertise. There is a difference, however, between the physical act of writing and written expression.

The physical act of writing letters in concert to produce words can also be referred to as 'writing' or 'transcription', and refers to the transformation of language representations in working memory into written text (Berninger, 1999). This requires the retrieval of orthographic symbols and the execution of fine motor movements for producing them (Abbott & Berninger, 1993). Handwriting, and in particular handwriting fluency, has been shown to be causally related to written expression (Graham, Harris, & Fink, 2000). The ability to automatically write letters has been shown to be the best predictor of both text length and text quality for elementary school children (Graham, Harris, & Fink, 2000). Furthermore, converging evidence indicates that improved handwriting automaticity improves children's text generation and composition quality (Berninger et al., 1997, 1998; Graham, Harris, & Fink, 2000, Graham, Harris, & Chorzempa, 2002).

In contrast, written expression is a higher order process whereby written text is planned, and organized, in order to produce goal-directed writing. One of the most influential models of writing was proposed by Hayes and Flower (1987) who stated that mature writers go through a three-step process – they plan, translate, and review or edit what they have written. A lack of adequate foundational skills in text generation or transcription are thought to constrain higher-order skills such as planning and revising,

which are both essential components of written expression (Berninger, 2000; Puranik & AlOtaiba, 2012). When children lack adequate transcription skills, they consciously devote their attention to forming letters and spelling words, taking away considerable attentional and cognitive resources from composing text (McCutchen, 1996; Puranik & AlOtaiba, 2012). Thus, transcription skills by way of handwriting are important elements and play a crucial role in early written expression.

How ADHD Affects Motor Control and Handwriting

When examining how Barkley's hybrid model of ADHD relates to motor control and handwriting in children with ADHD, an examination of the relationship between the executive functions (EF) proposed in the model and motor control is necessary. Of particular relevance are the EFs of working memory and reconstitution. It is well documented that children with ADHD have deficits in both verbal and nonverbal working memory (Barkley, 2006). For instance, children with ADHD have been found to be less proficient in mental computation (e.g., Frazier, Demaree & Youngstrom, 2004), digit span (e.g., Frazier, Demaree & Youngstrom, 2004; Siklos & Kerns, 2004), recall of stories (e.g., Lorch et al., 2000, 2004), and listening comprehension (e.g., McInnes, Humphries, Hogg-Johnson, & Tannock, 2003). Regarding nonverbal working memory, deficits have been documented in visual-spatial working memory (e.g., Frazier et al., 2004; Seidman, Biederman, Monuteaux, Doyle & Faraone, 2001), sequential working memory (e.g. McInnes, Humphries, Hogg-Johnson, & Tannock, 2003), and motor timing (e.g., Rubia, Noorloos, Smith, Gunning, & Sergeant, 2003), among others. Reconstitution, on the other hand, refers to the ability to sequence behaviours, including motor behaviours. Deficits in this area have also been noted in ADHD (Barkley, 2006).

Given the complex nature of the production of writing movements as described above, it is not surprising that children with ADHD would be expected to exhibit difficulties in this area, especially given their well-documented deficiencies in EF. The production of handwriting requires that a specific sequence of motor movements be smoothly executed (Guigon, Baraduc, & Desmurget, 2008). This would require the optimal functioning of both verbal and nonverbal working memory. For instance, verbal working memory would be necessary to maintain the on-line representation of what specifically the child was asked to write, and nonverbal working memory would be

required to correctly keep in mind the spatial organization and production of each letter component (McCutchen, 1996). This can be carried over into the motor system in that the correct sequence of motor movements (i.e., reconstitution) must be executed in order to produce the desired outcome. There is also a link between working memory functioning and motor sequencing in that as more components are added to a required motor action, the greater the load on working memory (McCutchen, 1996). Given that children with ADHD have diminished working memory capacities (Barkley, 1997, 2006), it follows that as a motor movement begins to require more and more components to be executed, their working memory systems will become overloaded more quickly than control children's, resulting in poor execution of the required motor response.

As noted earlier, although not included in his Hybrid Model, Barkley (2006) acknowledges that another key feature of ADHD is that of greater variability of task performance. Extending this to motor control, it may be said that variability would be manifest as poorer control of movements. Barkley's (1997, 2006) primary assertion is that children with ADHD have difficulties regulating their behaviour, which then manifests in their motor output. As such, such children would be expected to generate more motor output than would be necessary to complete a task. In fact, motor overflow movements have been documented in individuals with ADHD (e.g., D'Agati, Casarelli, Pitzianti, & Pasini, 2010; Larson, Mostofsky, Goldberg, Cutting, Denckla, & Mahone, 2007). Extending this to the present study, given the difficulties with behavioural regulation, children with ADHD would be expected to demonstrate more variability in areas such as variability in speed of writing, variability in size of letters, and difficulties maintaining a motor output when constraints are put in place, among others.

Motor Difficulties in ADHD

The role of motor functioning in ADHD has long been of interest, particularly regarding the potential for differentiation of individuals with ADHD from those with a neurologic disorder (Konrad, Gauggel, Manz, & Scholl, 2000). Interest has been renewed through more recent research into Developmental Coordination Disorder (DCD; Gillberg, 2003) and deficits in attention, motor control, and perception (DAMP; Gillberg, 2003). There is general agreement that children with ADHD have diminished gross and fine motor skills, with greater variability in their speed of movement compared to children

without ADHD, difficulties with parameter setting (i.e., one's ability to adjust force or pressure when completing a motor task), and a slower speed of execution of skilled movements (Brossard-Recine, Majnemer, & Shevell, 2011; Pitcher, Piek, & Barrett, 2002; Schoemaker, Ketelaars, van Zonneveld, Minderaa, & Mulder, 2005), demonstrating the wide range of both gross and fine motor problems exhibited by these children.

Comorbidities with Developmental Coordination Disorder (DCD)

ADHD is known to be comorbid with Developmental Coordination Disorder (DCD). Developmental Coordination Disorder is defined by the DSM-IV-TR as a marked impairment in the development of motor coordination that significantly affects activities of daily living and/or academic performance and that cannot be explained by another medical condition (American Psychiatric Association, 2000). The prevalence of DCD in children with ADHD has been estimated at approximately 50% (Blondis, 1999; Pitcher, Piek, & Hay, 2003; Watemberg, Waiserberg, Zuk, & Lerman-Saige, 2007). Reported motor impairments for children with concurrent ADHD and DCD include difficulties with handwriting (e.g., Brossard-Racine et al., 2011, 2012; Fliers et al., 2008; Tervo, Azume, Fogas, & Fiechtner, 2002), fine and gross motor delays (e.g., Fliers et al., 2008; Pitcher, Piek, & Hay, 2003), poor movement programming (e.g., Eliasson, Rosblad, & Forssberg, 2004), and deficits in parameter setting (i.e., adjustments in force or pressure; Jucaite, Fernell, Forssberg, & Hadders-Algra, 2003; Pereira, Eliasson, & Forssberg, 2000; Pitcher, Piek, & Barrett, 2002; Schoemaker et al., 2005).

Pitcher, Piek, and Hay (2003) examined the prevalence of motor problems generally in children with ADHD, as well as the prevalence of DCD in the each of the three different subtypes of ADHD. They found a high percentage of movement problems in all three subtypes: 58% of children with ADHD-PI, 49% of children with ADHD-HI, and 47% of children with ADHD-C as defined by motor performance in the lower 15th percentile on the Movement Assessment Battery for Children (MABC). They also examined the percentage of children with ADHD that also met criteria for DCD (i.e., defined by performance in the lower 5th percentile on a movement assessment battery). Their results demonstrated 42% for the ADHD-PI group, 31% for the ADHD-HI group, and 29% for the ADHD-C group. Such findings clearly demonstrate that children with

ADHD frequently have concurrent difficulties with motor performance, even if they may not meet criteria for DCD.

As outlined above, a large proportion of children with ADHD demonstrate motor problems. Children with comorbid ADHD and DCD exhibit a wide range of difficulties, and include problems with both gross and fine motor control. Additionally, movement problems have been documented in all three subtypes of ADHD.

Gross and Fine Motor Difficulties

Numerous studies have documented the presence of both gross and fine motor problems in children with ADHD without comorbid DCD. As outlined previously, gross motor refers to large movements that are driven mostly by larger muscle groups of the body. Movements of the whole arm, the legs, the trunk, are all gross motor movements. Thus, gross motor skills are skills that develop through using the large muscles of the body in a coordinated and controlled way. In contrast, fine motor control generally refers to control over the small movements of the hands and fingers, as well as the small muscles of the face and mouth and feet.

Some studies that compared children with ADHD who were taking medication with those who were not taking medication found that regardless of medication status, both groups of children with ADHD demonstrated difficulties in fundamental gross movement skills (Harvey et al., 2007). Stray, Ellertsen, and Stray (2010) used a different approach and compared children with ADHD who responded favourably to medication to those who did not respond as well. Their results indicate that medication responders demonstrated greater gross motor problems than non-responders, thus highlighting the likely involvement of the noradrenergic and dopamine systems in motor difficulties.

While many studies have documented the presence of gross motor impairment in children with ADHD (e.g., Buderath et al., 2009; Polderman, van Dongen, & Boomsma, 2011; Stray et al., 2009; Tseng, Henderson, Chow, & Yao, 2004), fine motor problems have been found as well (e.g., Pitcher, Piek, & Hay, 2003; Steger et al., 2001; Tseng et al., 2004; Whitmont, & Clark, 1996). In fact, some researchers have examined the different motor problems by ADHD subtype. For instance, Pitcher, Piek, and Hay (2003) administered the Movement Assessment Battery for Children (MABC) to children diagnosed with various subtypes of ADHD. The MABC is comprised of both fine motor

tasks (i.e., manual dexterity, ball skills), and gross motor tasks (i.e., static and dynamic balance). They found that children with ADHD-HI had less severe total motor problems (as assessed by the Movement Assessment Battery for Children Total Score) compared to either ADHD-PI or ADHD-C subtypes. In contrast, children with either ADHD-PI or ADHD-C subtypes were found to exhibit greater fine motor difficulties compared to gross motor difficulties. Examining motor problems by ADHD subtype has also demonstrated that children with ADHD-C exhibit poor balance, whereas children with ADHD-PI exhibit poor manual dexterity (Piek, Pitcher, & Hay, 1999).

Changing task demands and increasing a task's complexity also affects motor output in children with ADHD. It has been demonstrated that as a task become more complex, children with ADHD exhibit greater difficulties (e.g., Slaats-Willemse, de Sonneville, Swaab-Barneveld, & Buitelaar, 2005; Steger et al., 2001). In their study of children ages 6 – 17 years (25 children with ADHD, 25 non-affected siblings, 48 control children), Slaats-Willemse et al. (2005) demonstrated that children diagnosed with ADHD and their unaffected siblings had relatively more difficulties with a pursuit task (which was considered to be complex) compared to a tracking task. The pursuit tasks required the children to follow a target that moves in random directions across the screen. By comparison the tracking task required the children to trace a mouse cursor between an outer and inner circle presented on the computer. The pursuit task is thought to require higher levels of control compared to the tracking task since the movements of the target in the pursuit task are unpredictable, thus necessitating continuous and online adjustment of movements, whereas movement in the tracking task can be planned in advance and involves the completion of a familiar, more automatized trajectory (circle). They tended to respond more slowly and made more errors since the more difficult pursuit task requires higher levels of flexibility and controlled processing.

Some researchers have attempted to determine what factors are the best predictors of poor gross and fine motor skills in children with ADHD. Fliers et al. (2008) determined that inattention symptoms were predictive of all motor coordination problems, whereas hyperactive-impulsive symptoms were only predictive of fine motor problems. In contrast, Tseng et al. (2004) determined that the best predictor of fine motor difficulties

was attention and impulse control. As such, it is still unclear what factors best differentiate between children who have fine versus gross motor difficulties.

Lavasani and Stagnitti (2011) examined fine motor skills in Iranian children diagnosed with ADHD. Boys between the ages of 6 and 10 were asked to complete nine different fine motor tasks (e.g., cutting, placing dots in a grid pattern, threading beads, drawing lines, finger movements with open and closed eyes, Purdue pegboard test, and others). The researchers found that on eight of the nine tasks there was a significant difference between groups, with boys diagnosed with ADHD performing more poorly than control boys.

Also focusing on fine motor skills, Meyer and Sagvolden (2006) examined differences in such skills in South African children with symptoms of ADHD (no formal diagnosis). In their study, 528 children (264 classified as having symptoms of ADHD and 264 matched controls) of both genders completed the Grooved Pegboard Test, the Maze Coordination Task, and the Finger Tapping Test, with results being analyzed as a function of ADHD subtype, gender, age, and hand dominance. Results indicated that children with symptoms of ADHD performed more poorly on the Grooved Pegboard and Motor Coordination Task, but not the Finger Tapping test. The impairment was noted to be more severe for those children with symptoms of ADHD-C, and less severe for those with symptoms of ADHD-PI or ADHD-HI. Both genders were found to be equally affected, and there were no differences between the dominant and non-dominant hand. Deficiencies in motor control were confined mainly to the younger age group (6 − 9 years).

Overall differences have been found between younger and older children in terms of gross and fine motor performance. Most studies that have examined age have found that older children do not demonstrate as many deficits as younger children (e.g., Harvey et al., 2007; Stray et al., 2009). Not many studies have explicitly examined gender differences in motor performance, but one study that looked at this factor was conducted by Fliers and colleagues (2008). They determined that girls with ADHD were noted to have similar motor coordination problems as boys with ADHD.

Lastly, some researchers have demonstrated greater motor problems in children with ADHD when they were asked to complete a task with their non-dominant hand. For

instance, Rommelse and colleagues (2007) found that when children with ADHD were asked to track a moving target with a mouse on a computer screen, they performed less precisely and less stably (i.e., their movements were more 'jerky') with their non-dominant left hand compared to their dominant right. Similar results were found for greater deficits on the left side by Polderman and colleagues (2011), as well as by Klimkeit and colleagues (2004). These results suggest that children with ADHD have more difficulties completing motor tasks with their nondominant hands, although no speculations have been made as to why this is the case.

In summary, studies examining gross and fine motor performance in children with ADHD have produced some consistent results. In general, children with ADHD have been noted to have difficulties in both gross and fine motor performance. Studies that have examined motor performance in the different subtypes of ADHD generally find that children with ADHD-HI exhibit more fine motor problems, whereas those with ADHD-PI exhibit more problems across all areas. Children with ADHD-HI have also been documented as having less severe motor problems compared to children with ADHD-PI or ADHD-C. Poorer motor performance has also been documented when children are asked to use their nondominant hand.

Motor Programming

Movement programming difficulties have been examined in children with ADHD and found to be deficient, although there are not many studies that examined this aspect of motor control. One study that did examine motor programming in children with ADHD was conducted by Johnson and colleagues (2010) who examined performance on a movement task that tested hand-drawing movement precision. Children were asked to connect circles in either the right or left direction, and Johnson et al. (2010) concluded that children with ADHD demonstrated spatial difficulties when moving towards the right. They were less accurate, tended to overshoot the target, and were more variable in whether or not they reached their target. While Johnson and colleagues (2010) concluded that children with ADHD have a subtle spatial bias towards the right, this may not be the case since the child's hand may have been covering the targets located on the right, thus adding to the difficulty of movements to the right. As such, no definitive statements can

be made regarding any potential spatial biases in children with ADHD and how this may or may not affect their movement planning.

Yan and Thomas (2002) also examined arm movement control in children with ADHD. They determined that children with ADHD had arm movements that were slower, had greater variability in movement timing, and demonstrated longer interstimulus intervals than control children. Another study to examine arm movement control was conducted by Klimkeit, Sheppard, Lee, and Bradshaw (2004) who examined bimanual coordination in children with ADHD. Children were asked to turn two cranks, one with each hand. Results indicated that children with ADHD were significantly more variable in both velocity and coordination, and less accurate in coordination when performing in-phase movements. Children with ADHD were significantly more variable in velocity and coordination for out-of-phase movements. Klimkeit et al (2004) also noted that children with ADHD exhibited greater velocity with their left hands compared to their right hands. As such, these results indicate that children with ADHD have difficulties coordinating bimanual movements, especially evident with the left hand.

Eliasson, Rosblad and Forssberg (2004) examined the ability to program and execute goal-directed arm movements. They compared the performance of 25 boys with ADHD to 25 age-matched control boys on a task that required the boys to move a cursor on a computer screen by moving a stylus on a digitizing tablet. The children were asked to move the cursor from a start position to the target position; the cursor on the computer screen, however, could either be visible throughout the movement or blanked out during the movement (i.e., no visual feedback). Eliasson et al. (2004) reported that movement control was impaired in boys with ADHD, and that these problems were especially pronounced when the cursor was blanked out. In the no-visual-feedback condition, boys with ADHD tended to have large end-point errors and prolonged movement durations. Children with ADHD were also noted to display more 'jerky' movements. The authors concluded that children with ADHD have difficulty programming movements, especially when there is no visual feedback.

Overall, the results of studies examining motor programming have been consistent. Children with ADHD have been found to use online-monitoring of arm

movements that is dependent on visual feedback. Additionally, as the complexity of the task increases, children with ADHD tend to exhibit more difficulties.

Use of Digitizing Tablet Technology to Study Handwriting and Drawing

Another area where deficits have been noted in children with ADHD, and the area of primary interest to the present study, is handwriting and drawing. The most recent research in this area has made use of digitizing tablet technology to study, quantitatively, the production of handwriting movements. Such tablets allow the researcher to examine the kinematic (i.e., movement) aspects of an individual's handwriting or drawing ability quantitatively. For example, variables such as pen pressure, speed of writing (e.g., velocity and acceleration of writing strokes), total movement time, among others, can be gathered by such tablets (a description of variables that can be gathered is provided in Appendix A). These variables circumvent the problem of subjectivity when examining handwriting since various aspects of the handwriting movement can be quantified, instead of examined only by qualitative means. When an individual writes or draws on such a tablet, their movement can be broken down into a velocity profile (i.e., a graphical representation of their movement speed over time), enabling different variables to be extracted. As someone is writing on the tablet, associated software gathers quantitative information about how fast each movement stroke is, how many times the writing changes speed or direction (i.e., shifts from an upwards direction to a downwards direction), how 'fluid' or non-tremulous the movement is, and how variable their strokes are, to name a few.

The greatest advantage for the use of digitizing tablets to study handwriting and drawing is the ability to gather kinematic variables from the data. Such kinematic variables allow for a more 'fine-grained' assessment of an individual's writing or drawing abilities compared to data obtained from paper-and-pencil measures of handwriting alone. Tasks that employ only a paper and pencil can only examine the final *product* of the handwriting or drawing, whereas by comparison the use of a digitizing tablet allows for the examination of the *process* of handwriting or drawing. For example, if an individual's handwriting is characterized by many inversions in their velocity profile (i.e., many more stops and starts to writing each individual stroke resulting in more 'jerkiness'), then such writing would be characterized as dysfluent and non-automatic

(e.g., Adi-Japha et al., 2007; Tucha & Lange, 2001, 2004, 2005). In contrast, examination of only the paper-and-pencil version of a writing task may lead a researcher to conclude that an individual's writing is fluent since qualitatively it looks good, whereas had the task been performed on a digitizing tablet, the same task may show that the individual's writing is dysfluent (it is possible for an individual's handwriting to appear neat and tidy, yet still be dysfluent; e.g., Tucha & Lange, 2001, 2004, 2005). As such, a digitizing tablet can be an invaluable tool in studying handwriting and drawing processes.

Studies of Handwriting and Drawing that use Digitizing Technology

Numerous recent studies have employed the use of digitizing tablets to examine handwriting. One such study was conducted by Tucha and Lange (2001) who examined the effects of methylphenidate (MPH) on kinematic aspects of handwriting in a sample of 21 boys with ADHD-C, and 21 control boys. The boys were asked to write a short dictated text on a sheet of paper placed on top of a digitizing tablet. The text contained numerous words with the "ll" combination of letters, and the text was also presented to the boys on paper to reduce disturbances in writing due to spelling mistakes. Only the letter combination of "ll" was analyzed kinematically since the child did not need to lift the pen from the tablet for this combination of letters. When the boys with ADHD-C were taking MPH, their handwriting did not differ qualitatively from that of control boys in terms of spacing, form, alignment, uniformity, or legibility. Following withdrawal of MPH, the quality of the handwriting of the boys with ADHD-C was poorer than during treatment with MPH and compared to controls. On MPH treatment, hyperactive boys showed lower maximum velocities and acceleration (i.e., they tended to write more slowly). Tucha and Lange (2001) further noted that the MPH resulted in deterioration in handwriting fluency. Since kinematic analysis of the boys' handwriting revealed that hyperactive boys taking MPH displayed more inversions in the direction of velocity and acceleration profiles and lower maximum velocities and accelerations than they did following withdrawal of MPH, Tucha and Lange (2001) posited that handwriting movements of hyperactive boys were less fluent on MPH.

Another study by Tucha and Lange (2004) examined handwriting and attention in children as well as in adults with ADHD. In this study, the writing performance of eight children with ADHD was assessed using a digitizing tablet in a double-blind, placebo-

controlled test. The children were asked to write under three conditions: (1) in cursive as they normally would, (2) with their eyes closed, and (3) faster than normal. Each of these three conditions was repeated both on and off MPH. The children wrote on a blank sheet of paper placed on top of a digitizing tablet. Tucha and Lange (2004) noted that when children with ADHD were asked to write faster than normal, or with their eyes closed, their writing was more fluent and automated, whether or not on medication. In the second part of their study, Tucha and Lange (2004) assessed 10 children with ADHD, 10 control children, 10 adults with ADHD, and 10 control adults. Once again, participants were assessed both on and off medication. Without medication, children with ADHD did not differ from children without ADHD, whereas those on medication were more dysfluent. No differences were found in the adult participants. Consistent with their 2001 results, Tucha and Lange (2004) concluded that since children with ADHD who were on medication gave more attention to the writing process, their writing was less fluent. As such, Tucha and Lange noted that children's writing became more 'jerky' when they were giving more conscious attention to the task of writing. They presumed this was the case since the children demonstrated more 'jerky' writing when taking their ADHD medication compared to when they were not, thus implying that the medication improved their attention to the task. It may be that if children with ADHD are able to dedicate more attention to a complex task such as writing, their motor system becomes overloaded and therefore results in greater dysregulation of the motor output (i.e., more 'jerkiness' in writing).

In a different study, Tucha and Lange (2005) examined the effects of conscious control on handwriting in children with ADHD. Similar to their previous study, two experiments were performed: the first examined whether conscious control of handwriting impairs the fluent execution of handwriting movements in healthy adults; the second examined handwriting movements of children with ADHD on medication under different instructions. For the first study, 26 right-handed university students were asked to write a particular sentence under the following conditions: normal writing, writing with eyes closed, trying to write neatly, writing while visually tracking the pen tip, and writing with closed eyes while mentally tracking the highest position of each letter. Participants wrote on a blank sheet of paper placed on top of a digitizing tablet. Only the letter

combination "ll" was kinematically analyzed. Researchers determined that there were more inversions of velocity (i.e., the writing was less fluent) when participants were asked to write neatly, to write while visually tracking the pen tip, and when asked to write with their eyes closed while tracking the highest position of each letter. Tucha and Lange (2005) reported that such results indicate that automated handwriting movements are independent from visual feedback, and that when conscious attention is given to the writing process it results in less fluent handwriting movements. As such, automated writing processes are disturbed when conscious attention is placed on them, resulting in greater 'jerkiness' in writing.

In the second part of their experiment, Tucha and Lange (2005) asked 12 children ages nine through 12 who were previously diagnosed with ADHD to complete three tasks on a digitizing tablet: (1) write a particular sentence, (2) make repetitive back and forth movements on the tablet, and (3) draw concentric superimposed circles. Each task was performed both on and off MPH. As in the previous study, children completed the task on a sheet of paper that was placed on top of a digitizing tablet. Children were also asked to write the test sentence with eyes closed, and to write faster than normal. Tucha and Lange (2005) reported that medication with MPH resulted in reduced fluency of handwriting of a sentence, but that the children were able to generate fluent back-and-forth motions and automatically draw concentric circles. The researchers suggested that both visual and mental control of handwriting movements affect the automaticity of handwriting movements.

Schoemaker, Ketelaars, van Zonneveld, Minderaa and Mulder (2005) attempted to investigate whether motor planning and parameter setting were impaired in children with ADHD. Sixteen children with ADHD and 16 comparison children (ages seven through 12) were asked to copy figures of increasing complexity on a sheet of paper placed on top of a digitizing tablet under increasing constraint levels. Across all drawing tasks, children with ADHD made slower, more inaccurate strokes with relatively high axial pen force compared to the control group. Deficits in motor planning were not found, but deficits in parameter setting were evident in children with ADHD who made less accurate strokes as constraints increased.

Miyahara, Piek, and Barrett (2006) attempted to parse out whether difficulties in drawing were due to motor or attention deficits. In their study, 21 girls and 39 boys who ranged in age from seven to 13 years were separated into various groups. Three ADHD groups were formed based on the Australian Twin Behaviour Rating Scale which helped to classify children into ADHD-PI, ADHD-C, and control groups. Children were also grouped in a different way, based on the presence or absence of ADHD and inaccurate drawing. Both ADHD-PI and ADHD-C groups were combined into one ADHD group. Additionally, if children scored below the 10th percentile on a Flower Trail task of the MABC they were classified as DCD. Such groupings resulted in 10 children with ADHD only, 16 with DCD only, 11 with ADHD and DCD combined, and 23 who had neither ADHD nor DCD. In the study, children first completed the Flower Trail task at a desk, then moved to another desk with a digitizing tablet. Children completed the Draw a Line Through a Path (DALTAP) task of the Bruininks-Oseretsky Test of Motor Proficiency on a transparency sheet placed on top of the digitizing tablet. The DALTAP task was completed under six different conditions: The first was a baseline condition with no distractions. Conditions two through six involved some form of distraction: 2) background music; 3) a telephone ring in the background; 4) a beeping sound if the pen velocity exceeded 2.5 cm/s; 5) counting aloud from one upwards; 6) naming the animals aloud as their pen passed below each picture on the DALTAP. Miyahara and colleagues (2006) reported that there was no performance decline in all combinations of groups and conditions. No group differences were revealed when impairment scores were compared between the DCD only group and DCD plus ADHD group. Although Miyahara et al. (2006) tentatively concluded that poor manual coordination in children with ADHD is a separate entity from motor deficits, and is not directly linked with either inattention or distractibility, they conceded that perhaps their distractor tasks were not distracting enough, and future studies should establish the cognitive loads of secondary and distractor tasks.

The relationship between attention and handwriting movement was examined by Tucha, Mecklinger, Walitza, and Lange (2006) through two studies. In the first study, the relationship between attentional functioning and kinematic aspects of handwriting movements of 24 adult participants was examined using a digitizing tablet with a blank

sheet of paper placed on top. The position of the pen on the tablet, velocity, and acceleration were measured continuously while participants wrote a simple sentence. Participants also completed a computerized test battery consisting of five tasks measuring various aspects of attention (alertness, divided attention, Go/NoGo, flexibility, and vigilance). When single strokes were analyzed, they revealed velocity profiles with a smooth course, one peak, and a bell shaped course (i.e., the movements were fluent or automated). When kinematic aspects of handwriting were correlated with the attention measures, there were no significant correlations between various measures of attention and both kinematic aspects of handwriting movements and quality of handwriting. Tucha et al. (2006) posited that the fluent execution of handwriting movements is not related to attention functions. In their second study, 20 healthy participants underwent total sleep deprivation for 24 hours. Each participant was examined twice (at 10am on two consecutive days) regarding alertness, vigilance, and generation of handwriting movements. The same handwriting task as in the first study was used. Tucha and colleagues (2006) reported that while attention as assessed through alertness and vigilance tasks deteriorated during sleep deprivation, the execution of handwriting movements improved. Additionally, the quality of handwriting was not affected by sleep deprivation. They proposed that attention and movement generation during handwriting may be independent.

Adi-Japha et al (2007) examined dysgraphia in ADHD. Twenty grade six boys with ADHD and normal reading skills were matched to 20 control boys. Participants completed a spelling test (in Hebrew) and wrote their answers onto a regular sheet of lined paper placed over top of a digitizing tablet. Total writing time, speed of writing, axial pen pressure, time utilization, fluency and consistency were analyzed. Adi-Japha and colleagues (2007) also examined graphemic buffer errors (i.e., letter insertions, substitutions, transpositions, and omissions), allographic errors (which are suggestive of a grapheme retrieval deficit; i.e., a legible upper case letter form of a correctly spelled word is produced in an incorrect location such as the middle of a word, for example 'fRiEnd'), motor patterns of graphemes, and spatial errors on the spelling test. The researchers reported that children with ADHD made more spelling errors overall compared to control children. Children with ADHD were also noted to make more errors in the lexical and

phonologically plausible categories, but there were no differences in their spelling when asked to write nonsense words. In terms of motor programming, children with ADHD made more graphemic buffer letter errors, they confused similar shaped letters, and tended to replace end-of-word letters with simpler and more common middle-of-word letters. Fluency and spatial abilities did not differ between groups. When kinematic aspects of the children's handwriting were analyzed, 'air time' (i.e., the time spent with the pen in the air as opposed to writing) depended on the complexity of the letter, suggesting that complex letters required more time to write. Children with ADHD also required more time to write long words, they did not consistently produce letters (e.g., letter heights varied for the same letters throughout the task), their letters were spatially disproportionate and wider. Children with ADHD were noted to demonstrate a continuum of fluency such that they were most fluent with letters, followed by numbers, followed by drawing (i.e., drawing a circle). When children were asked to repetitively trace an ellipse, children with ADHD were faster but less accurate, suggesting a speed-for-accuracy trade-off compared to control children. Children with ADHD were also noted to use greater pen pressure when writing. Adi-Japha et al. (2007) concluded that the handwriting problems of children with ADHD result from impaired motor processes rather than lack of experience with writing. They explained this was because children with ADHD, despite increasing the mean pen pressure, still had disproportionately sized writing with no effect on fluency.

Rosenblum, Epsztein, and Josman (2008) compared the handwriting characteristics of 12 children diagnosed with ADHD, while on and off medication, with a control group of 12 children. All children were between the ages of eight and 10 years. Children performed a paragraph copying task on a piece of paper covering a digitizing tablet. The Computerized Penmanship Evaluation Tool (ComPET) was used to administer the stimulus paragraph on a computer screen and to collect and analyze the data. The Hebrew Handwriting Evaluation (HHE) was used to assess the overall clarity and legibility of the handwriting sample. Rosenblum and colleagues (2008) reported that when off medication, children with ADHD demonstrated more total time and in-air time as compared to when they were on medication. Although no significant differences were reported in handwriting speed between children with ADHD when on or off medication,

their overall handwriting speed was greater than that of children without ADHD. There were no differences between groups on measures of handwriting product (i.e., spatial arrangement, global legibility). Although children with ADHD performed the handwriting task at a significantly higher speed than children without ADHD, they required more overall time to complete the task. Rosenblum et al. (2008) posited that children with ADHD either perform a greater degree of less-purposeful movements (e.g., greater in-air time) or that they have greater difficulty inhibiting or delaying their responses.

Overall, the results of studies examining handwriting in children with ADHD are fairly consistent. In all studies examined, children with ADHD were noted to have some type of difficulty with handwriting compared to controls. It has been repeatedly demonstrated that children with ADHD have less fluent handwriting if they are taking methylphenidate, but their writing is not qualitatively different from that of controls in this condition. This highlights the need to examine handwriting kinematically, since such technology allows for the quantitative analysis of handwriting movements without potential confounds of subjectivity. Other studies have found that as the complexity of what is to be written or drawn increases, the accuracy of strokes decreases in children with ADHD. Children with ADHD have also been noted to spend more time 'in-air' compared to control children; this is thought to reflect a greater degree of less purposeful movement in such children. Another consistent finding is that children with ADHD write faster than control children.

Purpose of the Present Study

The purpose of the present study is to examine handwriting and drawing through the use of a digitizing tablet in children with ADHD and compare it to that in neurotypical children. Barkley's Hybrid Model of ADHD proposes that the main difficulty in children with ADHD is disinhibition. If children with ADHD have trouble inhibiting, it follows that their handwriting velocity profiles will demonstrate greater variability since they are unable to control their velocity output. Additionally, by changing various parameter constraints on their motor output, children with ADHD will likely demonstrate greater or less variability in their velocity profiles. For instance, if greater constraints are imposed (e.g., smaller distances between lines when asked to write or draw), it would be expected

that children with ADHD would demonstrate more difficulties regulating their output which would result in more dysfluent writing. Similarly, it would be expected that children with ADHD would exhibit greater pen pressure with greater constraint since they would be attempting to stabilize their written output.

It has been documented that children with ADHD have increases in pen pressure when asked to complete complex tasks (e.g., Adi-Japha et al., 2007; Schoemaker et al., 2005). Perhaps it is by increasing pen pressure that children with ADHD attempt to regulate the variability in their velocity profiles. Additionally, it has been demonstrated that children with ADHD have more difficulty with material as complexity increases (e.g., Adi-Japha et al., 2007; Schoemaker et al., 2005), as well as when the material is novel (i.e., the Pursuit versus the Tracking Tasks of the Amsterdam Neuropsychological Tests; Rommelse et al., 2007; Slaats-Willemse et al., 2005). It may be that more familiar material, both motorically and cognitively, would result in more fluent velocity profiles; similarly, more novel material would be expected to result in less fluent velocity profiles and greater pen pressure. In this context, the following research questions and hypotheses were examined:

1. *Is there a relationship between handwriting quality and velocity profiles?* It is hypothesized that in children with ADHD there will be a significant negative correlation between writing quality and measures of writing fluency, writing velocity, and variability in writing velocity. It is also hypothesized that in children with ADHD there will be a significant positive relationship between writing quality and pen pressure. This is because it is hypothesized that in attempts to stabilize their motor movement, children with ADHD will demonstrate greater pen pressure which would result in more fluent writing that is less variable. In contrast, it is hypothesized that in control children better writing quality will be negatively associated with measures of dysfluency, pen pressure, and variability in writing velocity since compared to children with ADHD, control children have not been shown to have difficulties regulating their motor output. Similarly, it is hypothesized that in control children better writing quality will be associated with faster writing. This follows from previous research that has demonstrated that children with ADHD have poor penmanship in general (e.g., Marcotte & Stern,

1997), although no previous studies have used an objective and standardized measure of handwriting quality.

2. *Are velocity profiles of children with ADHD more variable compared to control children?* It is hypothesized that the children with ADHD will demonstrate more variable velocity profiles compared to control children. This follows from previous research indicating that children with ADHD demonstrate greater inversions in the direction of their velocity and acceleration profiles (e.g., Tucha & Lange, 2001).

3. *As motor output is more constrained, do children with ADHD demonstrate less fluent writing?* It is hypothesized that children with ADHD would exhibit greater dysfluency when their motor output is constrained. This follows from previous research indicating that children with ADHD exhibit greater difficulties when their motor output is more constrained (e.g., Schoemaker et al., 2005).

4. *As motor output is more constrained, does pen pressure increase in children with ADHD?* Previous research has been inconclusive in terms of whether children with ADHD increase pen pressure when greater constraints are placed on drawings. For instance, Schoemaker and colleagues (2005) found that children with ADHD *reduced* pen pressure in a highly constrained writing condition, but that their pen pressure was increased in other constrained conditions. On the other hand, Adi-Japha and colleagues (2007) found that children with ADHD demonstrated *greater* pen pressure during writing exercises of greater complexity. It is hypothesized that as there are more constraints placed on motor output, children with ADHD will exhibit greater axial pen pressure.

5a. *As task novelty increases, is there an increase in pen pressure?* Although research regarding task novelty and pen pressure is scarce, the studies that have been conducted (i.e., Adi-Japha et al., 2007) demonstrated that as the handwriting task becomes more difficult, children with ADHD exhibit greater pen pressure. As such, it is hypothesized that children with ADHD will demonstrate increased axial pen pressure with greater task novelty.

5b. *As task motor complexity increases, is there an increase in pen pressure?* There has not been any research conducted previously in this area. As such it is hypothesized that similar to linguistic novelty, motoric complexity will result in greater pen pressure in children with ADHD.

6. *Will there be increased pen pressure with more constrained drawing tasks?* As children complete a motor task that requires them to maintain their stylus between lines that are closer together versus farther apart, it is hypothesized that children with ADHD will demonstrate greater pen pressure.

CHAPTER II

METHODS

Participants

Power analysis using a *p* value of .006 (i.e., .05 ÷ 9 ANOVA analyses) indicated that using the proposed methodological design and statistical analyses, 88 total participants would be needed to detect a statistically significant difference of large effect size using ANOVA. A similar power analysis indicated that for a mixed design ANOVA with four levels of one response variable and two groups, a total of 26 participants would be required to detect differences of large effect size. Although covariates of age and gender were considered given that gender has been shown to be a significant predictor of handwriting legibility (Feder, Majnemer, Boubonnais, Blayney & Morin, 2007), and some studies have found differences in motor performance in older versus younger children (e.g. Harvey et al., 2007; Stray et al., 2009), these studies did not examine motor performance from a kinematic perspective. Genna and Accardo (2011), however, examined the kinematics of writing in children between grades 1 and 8 and found that starting in grade 4 (the start point for the present study), there were no gender or age differences in the kinematic variables pertaining to handwriting. As such, no covariates were used in the present analyses with regard to age or gender.

One hundred children (50 children diagnosed with ADHD, 50 control) in grades four through eight were recruited from the following sources: the private practice of a local physician who specializes in the diagnosis and treatment of ADHD (*n* = 45), the psychology participant pool at the University of Windsor (*n* = 17), summer sports camp for children through the University of Windsor (*n* = 14), word of mouth (*n* = 11), paid advertisements in local publications (*n* = 12), and through a local website for parents (*n* = 1). Recruitment focused on children in grades four through eight as by this time children would have been formally taught cursive writing through their school curriculum (Ontario Ministry of Education, 2006); additionally, previous research has demonstrated that after grade four gender and age no longer influence the kinematics of handwriting (Genna & Accardo, 2011). To minimize confounds related to extraneous visual or motor disturbances, participants included only those with normal or corrected-to normal vision, and those with an estimated IQ of at least 70 (so that cognitive difficulties would not be a

confound), and those who did not have an existing neurological condition that would negatively affect graphomotor performance (e.g., cerebral palsy, motor tic disorder). Two participants were removed from the total sample due to not meeting study requirements; one participant from the ADHD group was removed because he did not meet the estimated IQ requirement (IQ = 63), and one control participant was removed because he had a diagnosed motor tic disorder. The initial total sample size was 98, with equal group sizes of 49. The ADHD group consisted of 40 boys and 9 girls ranging in age from 101 to 171 months ($M = 139.35$, $SD = 17.10$), whereas the control group consisted of 29 boys and 20 girls between the ages of 103 and 167 months ($M = 132.82$, $SD = 18.79$).

Consent was obtained from parents and assent from children prior to participation. Participants were treated in accordance with the Tri-Council Policy Statement, the "Ethical Principles of Psychologists and Code of Conduct" (American Psychological Association, 1992), and the "Canadian Code of Ethics for Psychologists – Third Edition" (Canadian Psychological Association, 2000). Clearance for this study was obtained from the University of Windsor Research Ethics Board.

Sampling Procedures

A local community physician who specializes in the treatment and diagnosis of ADHD was contacted via email to inquire whether she may be interested in helping with the recruitment process. A meeting was scheduled with the physician once she expressed interest, and the study protocol was reviewed along with participant inclusion and exclusion criteria. The community physician had the opportunity to ask questions pertaining to the research. Once the physician expressed interest in helping with recruitment, she was provided with a letter of information (see Appendix B) to be reviewed with her clients. The physician reviewed the study information with clients that met study criteria, and only with the parent's permission was the potential participant's contact information passed on to the researcher. Once the researcher received the contact information from the physician, the researcher telephoned the parent to ensure that his/her child met study criteria, to provide additional information about the study, and to answer any questions the parent may have. Each parent was informed that a requirement of the study is that his/her child refrain from taking their medication for ADHD for 24 hours prior to the study if it is a stimulant based medication, or for 48 hours prior to the study if

his/her child was taking Strattera. Parents were informed that their child could resume taking his/her prescribed ADHD medication immediately after the study. If the parent expressed interest in his/her child participating, a time was scheduled for the parent and child to come and participate in the study. Each parent received a $10 gift card for his/her time and participation, and each child received a small token gift for his/her time and participation.

Participants that were recruited through the psychology participant pool (see Appendix C for the advertisement used) at the University of Windsor had to be parents or family members of a child in the required grade range (4 – 8). The psychology participant pool posting outlined the study requirements including participant inclusion and exclusion criteria. The parent or family member signed up for a study timeslot through the online system, and the researcher emailed each potential participant upon receiving notification of his/her sign up to verify that each parent or family member had a child who met study criteria. If the University of Windsor student who signed up for the study was not the child's parent, then the parent was emailed a copy of the study consent form and letter of information (see Appendices D and E) that had to be signed by the child's parent before the child could participate in the study. The parent or family member received three bonus points based on three hours of participation time, and the child received a small token gift for his/her time and participation.

Participants were also recruited through the University of Windsor Lancer summer sports camps. The researcher set up a table in the main camp registration area with a poster about the study. If a parent approached the researcher, the parent was provided with information about the study. If the parent expressed interest, then a mutually agreeable time was arranged for the parent to bring his or her child in for participation. Following participation in the study, parents received a $10 gift card while the child received a small token gift for time and participation.

Recruitment also involved posting advertisements online (i.e., Mom2Mom website) and in two community publications (i.e., Windsor Parent magazine and the Windsor Activity Guide). See Appendix F for the study advertisement. Following contact, the parent was provided with a detailed description of what would be involved in the study. If the parent expressed interest, a mutually agreeable time was scheduled.

Parents received a $10 gift card while his/her child received a small token gift for time and participation.

Recruitment was also through snowball sampling. For this, parents who had taken part in the study informed individuals they knew about the study and provided them with a letter containing information about the research being conducted. If interested, they were given extra copies of the study advertisement (see Appendix G) to distribute to individuals they thought might be interested in participating. In this case, interested parents contacted the researcher for more information about the study. If the parent expressed interest and the child met criteria, an appointment was arranged. Parents received a $10 gift card for their time and participation and the child received a small token gift.

Apparatus

Digitizing Tablet

A WACOM Cintiq 21UX digitizing tablet was used to record the writing and fine motor movements of participants. The digitizing tablet has an active display area of 17" by 12.75" and spatial resolution of 5080 lines per inch. This tablet provides real-time on-screen visual feedback. A pressure-sensitive, non-inking pen was used by participants.

MovAlyzeR Software

MovAlyzeR software (NeuroScript, LLC; Tempe, AZ, USA) was utilized to quantify handwriting movements with a maximum sampling rate of 200 Hz and x-y coordinates were low-pass filtered at 12 Hz. Handwriting movements were broken down by MovAlyzeR software into strokes using interpolated vertical velocity zero crossings. A stroke can be understood as a half cycle in an ongoing movement, defined by two extreme points (minima/maxima) of the position curves (Mergl, Tigges, Schroter, Moldler, & Hegerl, 1999). Focus was placed on the vertical movement component of each stroke as this is the main movement component in Western cursive handwriting and printing (Caligiuri, Teulings, Dean, Niculescu III, & Lohr, 2010).

Kinematic Variables. For each segmented stroke, the following variables were extracted using MovAlyzeR: (1) peak vertical velocity (PVV; in cm/s; for a pictorial depiction of a velocity profile generated with MovAlyzeR software see Figures 3 and 4); (2) the relative

intraindividual standard deviation of peak vertical velocity (RPVV); (3) normalized jerk per stroke (NJ); and (4) mean stylus pressure (SP).

Figure 3. Pictorial depiction of how the MovAlyzeR software identifies changes in direction of velocity. Each circle represents a point at which the direction of movement was changed.

Sample= 0 Stroke= 1 Segment= 1 Pressure=464 Norm.Jerk=4.5 Vert.Size=-0.6 Loop Surface=4.0

Figure 4. Velocity profile of the handwritten phrase "Michelle fell". Circles represent the point at which the direction of velocity changes. Peaks (i.e., positive velocity values) represent movement upwards, whereas valleys (i.e., negative velocity values) represent movement downwards.

Peak Vertical Velocity (PVV). The peak vertical velocity (PVV) is a measure of how fast the child writes in the vertical direction, with larger values representing faster writing. A related variable of interest given the variability in performance of children with ADHD is the relative intraindividual standard deviation of peak vertical velocity variable (RPVV). The RPVV is a coefficient of variation that was derived by dividing the absolute standard deviation of mean peak vertical velocity of each digitized item by its average peak vertical velocity (i.e., |standard deviation of peak vertical velocity| / peak vertical velocity; Mergl et al., 1999). The RPVV variable reflects stability, coordination, and consistency of an individual's writing with higher values indicating less consistently controlled movements, and lower values reflecting more consistently controlled movements. A RPVV value of 0 would indicate completely identical mean peak vertical velocity across all trials of a task.

Normalized Jerk (NJ). Normalized jerk (NJ) is a measure of writing fluency and smoothness. It is unitless and is normalized for both stroke duration and length; as such it has the advantage of allowing comparison of words or symbols of varying size and

movement durations because it is normalized (Teulings et al., 1997). High NJ scores reflect more dysfluent movement, conversely lower NJ scores reflect smoother, more fluent and more automatized movement (Teulings et al., 1997; Yan et al., 2008). Although the NJ variable is similar to the dysfluency measure used in much of the previous research examining graphomotor difficulties using kinematic measures, namely the "number of inversions of acceleration" (e.g., Flapper et al., 2006; Schoemaker et al., 2005; Tucha & Lange, 2001, 2004, 2005), it has, as noted above, the added advantage of allowing comparison between different sizes of written output and different movement durations. NJ can also be seen as a measure of sensori-motor integration such that higher values of NJ indicate more jerkiness in writing, and poorer integration of sensory and motor information.

   Stylus Pressure (SP). Mean stylus pressure is the amount of force used in the downwards direction when writing on the tablet. It is equivalent to pen pressure.

   The kinematic variables extracted from each measure are outlined in Table 1.

Table 1
Summary of kinematic variables extracted from each task measure

Measure	Study Variables Used in Data Analyses
THS-R Manuscript	NJ, SP, PVV, RPVV
THS-R Cursive	NJ, SP, PVV, RPVV
RPT – loop condition	NJ, SP, RPVV
RPT – square-triangle condition	SP
BOT-2 Crooked Path	SP
BOT-2 Curved Path	SP

Note. THS-R = Test of Handwriting Skills – Revised; RPT = Repeated Patterns Test; BOT-2 = Bruininks Oseretsky Test of Motor Proficiency – Second Edition; NJ = normalized jerk; SP = stylus pressure; PVV = peak vertical velocity; RPVV = relative intraindividual standard deviation of peak vertical velocity.

Measures and Materials

ADHD Symptomatology

   The Conners 3P (2008) is a well-researched and commonly used measure of parent-reported ADHD symptomology. It comprises a 110-item, 4-point (0 = *not true at all*; 1 = *just a little true*; 2 = *pretty much true*; 3 = *very much true*) parent-report

questionnaire designed to assess for ADHD symptoms and the most common comorbid problems and disorders in children and adolescents ages 6 – 18 years. The Conners 3P was standardized on a total sample of 1,200 children and adolescents in the general population, broken down into 13 age groups (one for each year 6 – 16, and one combined 17 – 18). Equal numbers of boys and girls were included in the normative sample. Parents are asked to rate what their child has been like over the past month according to each of 110 items. After completing the full-length questionnaire, six Content Scales, five DSM-IV-TR Symptom Scales, three Validity Scales, and two Indices are computed. The content scales include the following: Inattention, Hyperactivity/Impulsivity, Learning Problems, Executive Functioning, Aggression, and Peer Relations. The DSM-IV-TR Symptoms Scales include: ADHD Inattentive, ADHD Hyperactive-Impulsive, ADHD Combined, Conduct Disorder, and Oppositional Defiant Disorder. Validity scales include measures of positive and negative impression management, as well as an Inconsistency Index. The full-length Conners 3 also includes the Conners 3 ADHD Index (Conners 3AI) and the Conners 3 Global Index (Conners 3GI). The Conners 3AI contains the 10 items that best differentiate youth with ADHD from youth in the general population, whereas the Conners 3GI contains the 10 highest loading items from the original Conners Parent Rating Scale with updated normative data and is often use as a quick measure of general psychopathology (Conners, 2008). Raw scores on the Content Scales and DSM-IV-TR Symptoms Scales are converted to T-scores. According to the manual, T-scores at or above 70 are described as a *very elevated* score, those between 65 – 69 are described as an *elevated score*, those between 60 – 64 are described as a *high average score*, between 40 – 59 are described as *average scores*, and those less than or equal to 39 are considered to be *low scores*.

Internal consistency reliability was reported in the manual to be high, with scores on the Content Scales overall having an internal consistency of .91, and those on the DSM-IV-TR Symptoms Scales overall having an internal consistency of .90. Individual Content Scale reliabilities ranged from .85 (Peer Relations) to .94 (Hyperactivity/Impulsivity). Similarly, the internal consistency reliabilities for the DSM-IV-TR Symptoms scales ranged from .83 (Conduct Disorder) to .93 (ADHD Inattentive). Excellent temporal stability (i.e., test-retest reliability) was also described at .85 and .89,

respectively for the Content and Symptoms Scales overall. Factorial, convergent, divergent, and discriminative validity were all noted to be good in the manual.

Test of Handwriting Skills – Revised (THS-R)

The Test of Handwriting Skills – Revised (THS-R; Milone, 2007) is an untimed assessment of manuscript and cursive handwriting. It can be administered to students aged 6 years 0 months through 18 years and takes approximately 10 minutes to administer. It includes various tasks such as: writing spontaneously from memory the upper- and lower-case letters of the alphabet in order; writing from dictation the upper- and lower-case letters of the alphabet out of order; writing from dictation single-digit numbers out of order; copying selected letters of the alphabet; copying selected words; copying selected sentences; and writing from dictation selected words. The THS-R scores are based on characteristics of individual letters rather than specific letter forms themselves, and thus it can be used to assess handwriting taught using different alphabets and instructional systems (Milone, 2007). When children are asked to produce or copy text they are asked to "use your best handwriting". Each letter that the child produces is rated on a 0 to 3 scale, with 0 being the lowest score (poorly formed letters) and 3 the highest (letters are perfectly formed or nearly perfectly formed). Subtests that contain words or sentences are scored based on the individual letters within the words. Each subtest results in a scaled score ranging in value from 1 to 19 with a mean of 10 and standard deviation of 3. There are two versions of the THS-R – Cursive and Manuscript writing; both versions contain identical items on each scale.

The THS-R was standardized on a sample of 1,608 children in the United States between the ages of 6 years 0 months and 18 years 11 months. The overall internal consistency reliability for the THS-R manuscript format was noted to be .96, and was noted to be .98 for the cursive format. Across the individual subtests, the Cronbach's coefficient alpha were moderate to high for the various age groups with medians of .61 to.85 across all ages for the Manuscript format, and .65 to .92 for the Cursive format. Most reliability coefficients for both formats exceed .80. The overall test-retest reliability was reported to be .80 for the Manuscript format, and .85 for the Cursive format. Lastly, content and construct validity were reported to be satisfactory in the manual.

For the purposes of this study, the overall 'grand mean' normalized jerk, pen pressure, peak vertical velocity, and relative intraindividual standard deviation of peak vertical velocity scores were computed separately for the Manuscript and Cursive formats of the THS-R. For example, each normalized jerk raw score for each of the 10 THS-R Manuscript subtests was averaged to create a 'grand mean' of normalized jerk. By a similar procedure, overall 'grand means' were created for normalized jerk, pen pressure, peak vertical velocity, and relative intraindividual standard deviation of peak vertical velocity for both the Manuscript and Cursive formats of the THS-R.

Bruininks-Oseretsky Test of Motor Proficiency – Second Edition (BOT-2)

The Bruininks-Oseretsky Test of Motor Proficiency – Second Edition (BOT-2; Bruininks & Bruininks, 2005) is an individually administered test that uses engaging, goal-directed activities to measure a wide array of motor skills in individuals aged 4 through 21. It was selected for inclusion in the present study because since its first publication in 1978, the original Bruininks-Oseretsky Test of Motor Proficiency has been the most widely used standardized measure of motor proficiency (Bruininks & Bruininks, 2005). The updated BOT-2 assesses proficiency in four motor-area composites: Fine Motor Control, Manual Coordination, Body Coordination, and Strength and Agility. Of particular interest to the present study is the Fine Motor Control composite, more specifically the Fine Motor Precision subtest. Only this subtest was administered in the present study. This subtest consists of activities that require precise control of finger and hand movement. There are five drawing items, one paper-folding item, and one cutting item. Drawing tasks include filling in shapes, drawing lines through paths, and connecting dots. The objective of each item is to draw, cut, or fold within a specified boundary and performance is evaluated based on how well the examinee remains within the boundary. The raw scores for each of the five items on the Fine Motor Precision subtest are added together to get a total point score, which is then transformed into a scale score with a mean of 15 and standard deviation of 5. Scale scores on the BOT-2 range from 1 to 35. Scale scores 5 and below are classified as *well-below average*; those between 6 and 10 are classified *below average*; those between 11 and 19 are classified as *average*; those between 20 and 24 are classified *above average*; and those 25 or greater are classified as *well-above average*.

The BOT-2 was standardized on a total sample of 1,520 children ages 4 through 21 in the United States. The overall internal consistency reliability for the Fine Motor Precision subtest ranged from .74 in children ages 13 to 14, to .88 in those between 17 and 21 years of age. The test-retest reliability was .75 for the Fine Motor Precision subtest at an average time interval of 19 days. Lastly, construct validity, discriminant validity, and criterion validity are reported to be satisfactory.

Repeated Patterns Test (RPT)

The Repeated Patterns Test (RPT) has been shown to be an efficient and reliable way to assess graphomotor output in children (Marcotte & Stern, 1997; Waber & Bernstein, 1994). It was selected for inclusion in the present study because the patterns mimic cursive writing movements; if a child has not been taught how to cursive write or does not recall how to form letters, administration of the RPT would allow for the gathering of data on fine motor movements that are used in cursive writing. As such, information about fine motor control movements could be gathered both in children who were proficient in cursive writing, and those that were less proficient. According to Waber and Bernstein (1994), the RPT allows for the assessment of graphomotor output independent of linguistic demands, such as spelling, and letter and word formation that are involved in the complex process of writing. In the RPT the child is shown five patterns of increasing complexity on a sheet of paper and is asked to continue the pattern across the page. The five patterns to be repeated are shown below in Figure 5. This test is a laboratory measure and as such does not have any normative scoring criteria.

For the purposes of this study, only kinematic data from the loop and square-triangle conditions were utilized in analyses. The loop condition was chosen since most previous research has focused solely on the cursive "ll" combination of children's writing; as such, the loop condition would mimic the same writing movement. Originally the "mn" condition was chosen to represent the more difficult cursive writing task since it is a real letter combination. Unfortunately the "mn" condition could not be used because most of the children expressed that they did not know how to write in cursive, and qualitative observation of their attempts at writing "mn" in cursive resulted in a written output that did not resemble the required letter combination. As such, the square-triangle condition was used as a more difficult and novel measure of written output.

1. Square condition

2. Loop condition

3. Curve condition

4. MN condition

5. Square-Triangle condition
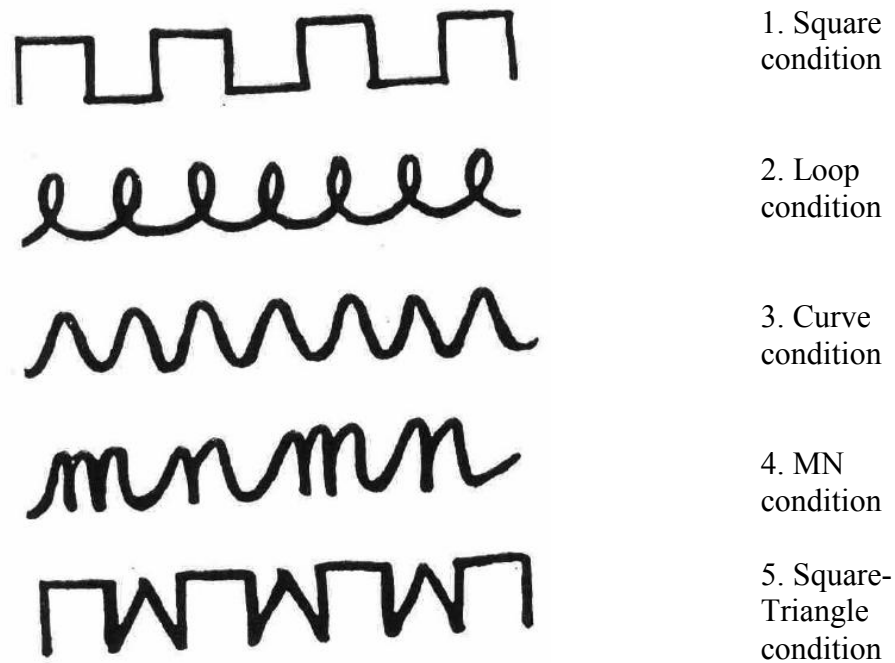
Figure 5. The five patterns comprising the RPT.

Estimate of Intellectual Ability

An estimate of IQ was derived using four subtests of the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV; Wechsler, 2003). Based on practical considerations and the best combination of short form reliability and validity coefficients, the four subtests used for estimating IQ were Block Design (BD), Similarities (SI), Digit Span (DS), and Coding (CD). The BD subtest requires the child to put together blocks to a presented picture; the SI subtest requires the child to indicate how two words or concepts are similar; the DS subtest requires the child to repeat back progressively longer series of digits both forwards and backwards; and the CD subtest requires the child to complete a digit-symbol coding task within a certain time limit. Sattler (2001) recommends this combination of subtests not only because each of the four WISC-IV Indexes are represented, but because the reliability of IQ estimates is greater with more subtests (i.e., a four-subtest short form is a more reliable indicator of IQ that a two-subtest short form). Sattler (2008) reported the reliability and validity coefficients to be .939 and .909, respectively, for this four subtest combination.

Procedures

Upon arrival for the study, consent procedures were explained to both the parent and child. Parents signed a consent form for their own participation in filling out questionnaires, as well as for their consent to allow their child to participate in the study. The letter of information provided and consent form signed varied based on the referral source (see Appendices B and H for the forms used for participants recruited through the physician; see Appendices D and E for the forms used for those recruited through the psychology participant pool; see Appendices I and J for the forms used for those recruited through all other means). Each child also read and signed a child's version of the consent form (see Appendix K); verbal assent was also gained from each child before proceeding. Parents were then given the questionnaires to be filled out (i.e., demographics questionnaire (see Appendix L) and Conners 3P), and the child went to an adjoining testing room. Parents were asked to self-address a stamped envelope so that a summary sheet of their child's results could be mailed to them. While the parent was filling out questionnaires, the child completed the following measures in the following order: 1) abbreviated test of intelligence (i.e., short form of the WISC-IV); 2) Repeated Patterns Test; 3) THS-R Manuscript format; 4) THS-R Cursive format; and, 5) BOT-2 Fine Motor Precision subtest. After completing the abbreviated test of intelligence, and prior to starting any formalized testing on the tablet, each child was allowed to practice writing on the tablet until they felt comfortable with using the non-inking pen and writing on the relatively smooth surface. Once each child indicated that he/she felt comfortable using the tablet, the formalized measures were administered.

The RPT was administered entirely on the digitizing tablet; the stimulus to be continued to the edge of the tablet was presented on the left side, at the mid-point of the screen's height. Each child completed each of the five patterns 5 times on a blank screen, 5 times in between two lines that were 3 cm apart, 5 times in between two lines that were 2 cm apart, and 5 times in between two lines that were 1 cm apart for a total of 100 trials. Before starting the task on the digitizing tablet, each child practiced each of the patterns on paper, and was able to practice writing on the tablet before the task was started in order to familiarize themselves with writing on a tablet. Each condition was completed 5

times in order to get a more reliable indicator of the average for each variable, and to be in line with previous research which has also asked children to complete a task five times each (e.g., Tucha & Lange, 2004, 2005; Tucha, Mecklinger, Walitza, & Lange, 2006). As such, the raw score for each trial was averaged and collapsed across conditions. For example, each child first continued a square pattern across a blank screen five times before the pattern changed. These five raw scores were collapsed and averaged to obtain an average score for the "unconstrained squares" condition. A similar procedure was followed to obtain averages for all conditions of each pattern.

The Manuscript and Cursive formats of the THS-R were also administered entirely on the digitizing tablet. Instructions were presented orally, and the children were not constrained in any way in their writing (i.e., they completed each item on a blank screen and were able to write anywhere on the screen that was comfortable to them). For items that required copying a letter, word, or sentence, the target item to be copied was presented at the top of the screen at the mid-point of the screen's width. Children were asked to use their neatest handwriting, and to write as if they were writing in school. Each item was presented only once on the digitizing tablet.

The Fine Motor Precision subtest of the BOT-2 was first administered on paper, according to the standardized instructions. Following the standardized administration, the first five items (i.e., filling in a circle, filling in a star, drawing a line through a crooked path, drawing a line through a curved path, and connecting dots) were completed 5 times each on the digitizing tablet. The raw scores across all five trials were collapsed and averaged to obtain an average score for each condition (i.e., an average for filling in a circle, an average for filling in a star, etc.).

Children were provided with breaks throughout in order to prevent any cramping of the fingers or hands. Drinks and snacks were offered and provided during the breaks. All participants were given the ability to manipulate the position of the tablet to one that was comfortable for writing and drawing. At the conclusion of testing with the child, the questionnaires filled out by parents were looked over to ensure that all items were filled in; any questions the parents had regarding the questionnaires were answered. Once measures were scored, a summary sheet of each child's performance on all standardized

measures was created and mailed to each parent. A sample, de-identified summary sheet is provided in Appendix M.

Group Assignment

Children were initially assigned to the ADHD group if there was an official diagnosis of any ADHD subtype (i.e., ADHD-PI, ADHD-HI, or ADHD-C). Diagnosis had to have been made by a psychiatrist, psychologist, or physician. However, in order to ensure that the child was indeed experiencing difficulties with symptoms of inattention and/or hyperactivity, and to reduce the potential for sample heterogeneity, only those children who were originally diagnosed with any subtype of ADHD *and* who's T-score(s) on the Conners 3P DSM-IV-TR Inattentive and/or DSM-IV-TR Hyperactive subscales was greater than or equal to 70 were assigned to the ADHD group. The Conners 3P DSM-IV-TR scales were chosen because they correct for both age and gender. This resulted in a total of 38 children assigned to the ADHD group. The children ranged in age from 101 to 170 months ($M = 139.08$, $SD = 17.40$). Thirty children were boys, and eight were girls.

To ensure that medication effects did not mask group differences, all children with a diagnosis of ADHD who were taking medication were asked to refrain from taking their ADHD medication for 24 or 48 hours before participating in the study. Participants taking stimulant based medication at the time of the study (e.g., Vyvance, Adderall, Concerta) refrained from taking their medication for 24 hours prior to the study, and those taking Strattera refrained from taking their medication for 48 hours due to its longer half-life (NIH, 2013). Parents and children were asked to confirm that the child had not taken ADHD medication for the required timeframe upon arriving for the study; if the parent or child indicated that this requirement had not been met, their appointment was rescheduled.

All children whose parents indicated that their child was never diagnosed with ADHD were initially assigned to the control group. In order to reduce sample heterogeneity, only children who did not have a prior diagnosis of ADHD *and* who's T-scores on the Conners 3P DSM-IV-TR Inattentive and DSM-IV-TR Hyperactive subscales were less than or equal to 50 were assigned to the control group. This resulted in 28 children being assigned to the control group. The children ranged in age from 104

to 167 months (M = 137.25, SD = 18.63). Fifteen children were boys and 13 were girls.
See Figure 6 below.
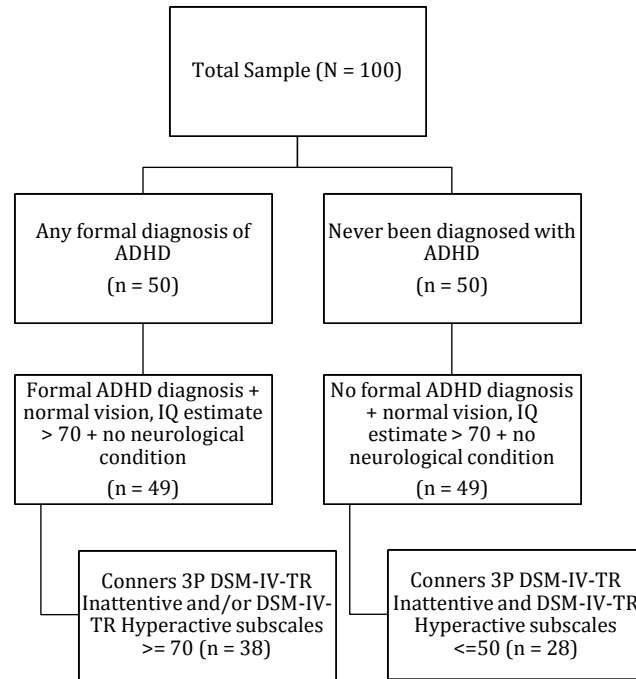
Figure 6. Schematic of how children were assigned to each group.

The present sample is somewhat different from that used in previous research in that
although more overall children are included, both boys and girls are included as well.
Most previous studies have examined kinematic differences only in boys (e.g., Ado-Japha
et al., 2007; Tucha & Lange, 2001, 2004, 2005), although Miyahara, Piek and Barrett
(2006) combined girls and boys together in their sample.

CHAPTER III

RESULTS

Participant Characteristics

Participant demographic information including age, gender, grade, primary language, ethnicity, parental education level, history of head injury resulting in concussion, history of seizure, ADHD diagnosis (and subtype if known), current medications, whether the child had formally be taught handwriting, and if the child experienced any learning difficulties was collected from each participant via a questionnaire (see Appendix L for the questionnaire used). Demographic information for each separate group is presented below in Table 2. It should be noted that qualitative examination of those questionnaires that endorsed a history of head injury in the child revealed that for each of these cases there was no loss of consciousness, and that the child had fallen and "bumped his or her head". As such, these individuals were not removed from analyses. No parent endorsed a history of seizure disorder.   Twenty-seven children in the ADHD group met criteria for ADHD-C, six met criteria for ADHD-PI, and five met criteria for ADHD-HI. In order to preserve power, ADHD subtypes were collapsed into a general ADHD group.

A *t*-test revealed that there were no group differences in age, $t(64) = .409$, $p = .684$, but there was a significant group difference on estimated IQ, $t(64) = -3.586$, $p = .001$, favouring the control group. Given that children with ADHD are known to have more difficulties with process-oriented tasks such as Digit Span and Coding, compared to less process oriented tasks such as Block Design and Similarities, groups were compared on each of the four subtests. As expected, no group difference was obtained on either the Block Design ($t(64) = -.351$, $p = .726$) or Similarities subtests ($t(64) = -1.250$, $p = .216$) whereas the groups differed on Digit Span ($t(64) = -5.278$, $p = .000$) and Coding ($t(64) = -4.122$, $p = .000$). Mean subtest and IQ scores are presented in Table 3. WISC-IV scores were used primarily for descriptive purposes in the present study.

Level of ADHD Symptomology

As an indication of severity of ADHD symptoms, mean Conners 3P scores are presented below in Table 4.

Table 2
Demographic information

	ADHD $n = 38$	Control $n = 28$
Gender:		
Male	30 (78.90%)	15 (53.60%)
Handedness:		
Right	35 (92.10%)	25 (89.30%)
Primary Language:		
English	37 (97.40%)	23 (82.10%)
French	- (0%)	1 (3.60%)
Other	1 (2.60%)	1 (3.60%)
Multiple	- (0%)	3 (10.70%)
Ethnicity:		
Aboriginal	1 (2.60%)	- (0%)
Asian descent	- (0%)	- (0%)
Black/African descent	1 (2.60%)	2 (7.10%)
White/Caucasian	29 (76.30%)	21 (75.00%)
Other	7 (18.40%)	5 (17.90%)
Parent Education:		
< High School	3 (7.90%)	- (0%)
High School graduate	8 (21.10%)	- (0%)
Some college	6 (15.80%)	1 (3.60%)
College graduate	11 (28.90%)	2 (7.10%)
Some university	4 (10.50%)	7 (25.00%)
University graduate	3 (7.90%)	13 (46.40%)
Graduate school	3 (7.90%)	5 (17.90%)
Head Injury:		
No	34 (89.50%)	27 (96.40%)
Other Diagnoses:		
Speech language	- (0%)	1 (3.60%)
Hearing problems	1 (2.60%)	- (0%)
Vision problems	- (0%)	1 (3.60%)
Attention problems	32 (84.20%)	- (0%)
Multiple	5 (13.20%)	1 (3.60%)
Taught Cursive Writing:		
Yes	26 (68.40%)	23 (82.10%)
Learning Disability diagnosis:		
Yes	21 (55.30%)	- (0%)
ADHD Medication:		
Stimulant	28 (73.68%)	- (0%)
Non-Stimulant	5 (13.20%)	- (0%)
Don't Know	2 (5.26%)	- (0%)
No medication	3 (7.90%)	- (0%)
Age in months	139.08[a] (17.40)[b]	137.25[a] (18.63)[b]
Age range in months	101 – 170	104 – 167
Estimated IQ	94.79[c] (12.51)[b]	106.11[c] (12.89)[b]

Note. Stimulant medications included: Vyvance, Concerta, Biphentin, Adderall, and Ritalin. Non-Stimulant medications included: Strattera and Risperdal.
[a] = mean age in months
[b] = standard deviation
[c] = mean standard score

Table 3
Mean subtest and IQ scores

	ADHD $n = 38$ M *(SD)*	Control $n = 28$ M *(SD)*
BD[a]	10.53 (*2.75*)	10.79 (*3.24*)
SI[a]	10.92 (*3.09*)	11.86 (*2.89*)
DS[a]	7.97 (*2.32*)	11.11 (*2.47*)
CD[a]	7.53 (*2.52*)	9.89 (*1.97*)
IQ[b]	94.79 (*12.51*)	106.11 (*12.89*)

Note. BD = Block Design; SI = Similarities; DS = Digit Span; CD = Coding; IQ = Intelligence Quotient.
[a] = scaled score
[b] = standard score

Table 4
Mean scores on the Conners 3P

	ADHD $n = 38$ M *(SD)*	Control $n = 28$ M *(SD)*
Conners 3P[a]		
IN	80.61 (*8.16*)	45.29 (*6.45*)
HY	81.11 (*10.00*)	43.75 (*4.92*)
LP	72.34 (*12.30*)	48.00 (*11.34*)
EF	76.34 (*9.28*)	45.82 (*6.96*)
AG	66.08 (*15.49*)	51.14 (*10.36*)
PR	71.37 (*16.24*)	48.32 (*11.07*)
GI	80.03 (*9.21*)	45.82 (*5.81*)
AN	79.50 (*9.17*)	45.11 (*6.24*)
AH	79.89 (*10.43*)	45.00 (*6.03*)
CD	63.37 (*15.09*)	49.29 (*10.28*)
OD	69.21 (*14.74*)	50.61 (*9.22*)

Note. Conners 3P IN = Inattention scale; HY = Hyperactivity/Impulsivity scale; LP = Learning Problems scale; EF = Executive Functioning scale; AG = Aggression scale; PR = Peer/Family Relations scale; GI = Conners 3P Global Index; AN = DSM-IV-TR ADHD Inattentive scale; AH = DSM-IV-TR ADHD Hyperactive-Impulsive scale; CD = DSM-IV-TR Conduct Disorder scale; OD = DSM-IV-TR Oppositional Defiant Disorder scale.
[a] = Conners 3P scores are presented as T-scores

Manuscript and Cursive Writing Skills

Mean scores on the THS-R Manuscript and Cursive forms are presented in Table 5 below. Independent samples t-tests indicated significant differences between groups on both the THS-R Manuscript and Cursive formats, $t(64) = -3.824$, $p = .000$ and $t(64) = -4.639$, $p = .000$, respectively. In both cases, control children scored significantly higher on the overall standard score of the THS-R Manuscript and Cursive formats.

Table 5
Average THS-R Manuscript and Cursive format scores

| | ADHD $n = 38$ | | Control $n = 28$ | |
	Manuscript M *(SD)*	Cursive M *(SD)*	Manuscript M *(SD)*	Cursive M *(SD)*
1[a]	10.03 *(1.98)*	2.50 *(2.31)*	11.18 *(1.95)*	6.00 *(4.78)*
2[a]	11.84 *(2.43)*	3.74 *(2.65)*	13.46 *(2.46)*	7.21 *(4.56)*
3[a]	9.21 *(2.42)*	5.55 *(1.86)*	10.61 *(2.39)*	7.71 *(3.13)*
4[a]	8.82 *(2.91)*	5.08 *(2.84)*	10.64 *(2.97)*	8.00 *(3.34)*
5[a]	7.87 *(2.87)*	8.32 *(2.29)*	10.14 *(2.83)*	9.86 *(2.16)*
6[a]	10.61 *(2.34)*	8.47 *(3.29)*	12.36 *(3.45)*	11.25 *(3.48)*
7[a]	10.82 *(3.11)*	9.03 *(3.99)*	12.61 *(3.78)*	11.93 *(2.94)*
8[a]	11.05 *(2.35)*	9.00 *(3.34)*	12.36 *(2.68)*	11.46 *(3.92)*
9[a]	9.92 *(2.89)*	8.24 *(4.26)*	12.61 *(3.35)*	12.64 *(4.17)*
10[a]	9.79 *(2.98)*	6.45 *(3.50)*	12.11 *(2.25)*	10.18 *(3.99)*
Overall[b]	99.71 *(8.93)*	82.95 *(10.94)*	108.96 *(10.70)*	97.46 *(14.50)*

Note. 1 = writing all upper case letters of the alphabet from memory; 2 = writing all lower case letters of the alphabet from memory; 3 = writing all upper case letters to dictation (out of alphabetical order); 4 = writing all lower case letters to dictation (out of alphabetical order); 5 = writing numbers to dictation; 6 = copying capital letters; 7 = copying lower case letters; 8 = copying words; 9 = copying sentences; 10 = writing words to dictation; Overall = Overall standard score.
[a] = scaled score
[b] = standard score

Fine Motor Performance

Average scores on the BOT-2 Fine Motor Precision subtest items and overall are presented below in Table 6. For the purposes of this study, only kinematic data from the BOT-2 Crooked Path and BOT-2 Curved Path items was used in analyses. An

independent samples t-test indicated that groups differed on the overall Fine Motor

Precision Scaled Score, $t(64) = -3.083$, $p = .003$.

Table 6
Average raw and scale scores of the BOT-2 Fine Motor Precision subtest

	ADHD M *(SD)*	Control M *(SD)*
Circle[a]	2.97 (*.16*)	2.96 (*.19*)
Star[a]	2.95 (*.23*)	2.93 (.26)
Crooked[a]	6.53 (*.76*)	6.68 (.55)
Curved[a]	4.29 (*1.52*)	5.29 (*1.56*)
Dots[a]	5.84 (*.95*)	6.36 (.78)
Fold[a]	6.26 (*1.33*)	6.25 (*1.46*)
Cut[a]	6.45 (*.95*)	6.75 (*.70*)
Fine Mot. Prec.[b]	11.16 (*3.75*)	14.21 (*4.28*)

Note. Circle = filling in a circle; Star = filling in a star; Crooked = drawing a line through a crooked path; Curved = drawing a line through a curved path; Dots = connecting dots; Fold = folding paper; Cut = cutting a circle out of paper; Fine Mot. Prec. = Fine Motor Precision subtest scaled score.
[a] = raw score
[b] = scaled score

Data Screening

SPSS Statistics Data Editor 21 for Macintosh was used for all statistical analyses. Although an alpha level of .05 has been the convention since 1925 or earlier (Cowles & Davis, 1982), some researchers argue that more conservative cut-offs should be used in studies involving more than one hypothesis (e.g., Bland & Altman, 1995). Others argue that this is unnecessary and deleterious to sound statistical inference (e.g., Perneger, 1998). Given that multiple ANOVA analyses were conducted in the present study, a Bonferroni correction was completed to adjust for Type I error (i.e., 0.05 was divided by the number of analyses (9) for an adjusted significance level of $p = .005$). Notwithstanding, exact p-values are provided for each statistical test, thus allowing the reader to interpret the data using stricter/looser criteria.

This study used correlation, ANOVA, and mixed design ANOVA analyses. As such, the following assumptions were tested: (1) independence of observations; (2)

absence of outliers; (3) univariate normality; (4) equality of population covariance matrices for dependent variables in ANOVA; and (5) sphericity for mixed design ANOVA dependent variables. The testing of each assumption will be described in turn below.

Independence of observations can be assumed based on the design of the study. Only one participant was tested at a time, and only one family at a time was present for the study thus minimizing the likelihood of parents or children discussing the study. Additionally, children attended different schools, came from different backgrounds, and were recruited from multiple sources, also reducing the likelihood that participants would know each other and discuss ratings or experiences.

The data were analyzed for univariate outliers by examining histograms, box-plots, and frequency tables. As suggested by Garson (2012), a univariate outlier was specified as a z-score outside of $\pm$ 3.3. The following variables were found to have univariate outliers: RPVV of the unconstrained RPT loop condition (two individuals in the ADHD group), SP of the BOT-2 Crooked Path condition (one ADHD, two control), SP of the BOT-2 Curved Path condition (three control), NJ of the 1cm RPT loop condition (one ADHD, one control), NJ of the 2 cm RPT loop condition (one ADHD), NJ of the 3 cm RPT loop condition (one ADHD, two control), and NJ of the unconstrained RPT loop condition (one ADHD, one control).

All analyses were completed with and without outliers removed. No differences were found in any of the statistical outcomes if the outliers were removed from the sample; in order to preserve sample size and power all outliers were left in the sample.

The homogeneity of covariances and sphericity assumptions will be discussed in turn for each relevant analysis below.

<div align="center">**Main Analyses**</div>

Hypothesis 1

To address the question of whether there is a relationship between quality of children's manuscript and cursive writing with kinematic variables, Pearson correlations were conducted for THS-R Manuscript and THS-R Cursive format overall standard scores which were correlated with the following variables: THS-R overall mean NJ, THS-R overall mean SP, THS-R overall PVV, and THS-R mean RPVV. Correlations were

performed separately for ADHD and control groups, for both THS-R Manuscript and THS-R Cursive test formats. Results for the THS-R Manuscript and Cursive formats are presented below in Table 7.

Given that children with ADHD have more difficulties regulating their written output, it was hypothesized that as their cursive or manuscript writing quality improved, their NJ, PVV, and RPVV would decrease while their SP would increase. In other words, children with ADHD would require greater stability when writing (i.e., SP) to produce better quality writing, which would in turn result in less variability in writing velocity (i.e., lower RPVV), more fluent writing (i.e., lower NJ), and decreased writing speed (i.e., lower PVV). For control children who do not have difficulties regulating their motor output, it was hypothesized that as their manuscript and cursive writing quality improved their NJ, SP, and RPVV would decrease while their PVV would increase.

Also examined was whether children with ADHD would demonstrate poorer quality handwriting compared to control children using independent samples t-tests. Groups were compared on the overall standard score of the THS-R Manuscript and Cursive formats. Results indicated that children with ADHD had poorer quality manuscript writing ($M = 99.71$, $SD = 8.93$) compared to control children ($M = 108.96$, $SD = 10.70$), $t(64) = -3.82$, $p = .000$. Similarly, children with ADHD had poorer quality cursive writing ($M = 82.95$, $SD = 10.94$) compared to control children ($M = 97.46$, $SD = 14.50$), $t(64) = -4.64$, $p = .000$.

Table 7

Correlations between THS-R Manuscript and Cursive format overall standard scores and kinematic variables

	ADHD					Control				
	1	2	3	4	5	1	2	3	4	5
1. Manuscript SS	-					-				
2. Manuscript Mean Overall NJ	-.06	-				.16	-			
3. Manuscript Mean Overall SP	-.09	.03	-			.26	.16	-		
4. Manuscript Mean Overall PVV	-.42**	-.19	-.12	-		-.52**	-.46**	-.11	-	
5. Manuscript Mean Overall RPVV	-.32	.11	.39*	.18	-	-.27	.48**	-.07	.21	-
1. Cursive SS	-					-				
2. Cursive Mean Overall NJ	.11	-				-.12	-			
3. Cursive Mean Overall SP	-.17	.16	-			-.01	-.14	-		
4. Cursive Mean Overall PVV	-.50**	-.20	-.12	-		-.04	-.36	-.04	-	
5. Cursive Mean Overall RPVV	-.33**	.22	-.05	.41*	-	-.62**	.24	-.04	-.13	-

Note. SS = standard score; NJ = normalized jerk; SP = stylus pressure; PVV = peak vertical velocity; RPVV = relative intraindividual standard deviation of peak vertical velocity.

*p < .05

**p < .01

For children diagnosed with ADHD, the results indicate that as their overall manuscript writing quality increased, their peak vertical velocity decreased (i.e., they wrote more slowly; $r = -.42$). As children with ADHD pressed harder with the stylus, their writing speed was more variable ($r = .39$). When quality of cursive writing improved in children with ADHD, writing speed slowed ($r = -.50$) and writing speed became less variable ($r = -.33$).

Results indicate that for control children, as their overall manuscript writing quality improved, they wrote more slowly ($r = -.52$). With cursive writing, as quality improved writing speed became less variable ($r = -.62$). Additionally, as control children's normalized jerk increased when cursive writing, their writing speed slowed ($r = -.46$) and their variability of writing speed decreased ($r = .48$).

In this regard, the hypothesis that as the quality of children with ADHD's writing improved (as measured by the THS-R overall standard score) their normalized jerk, variability of velocity, and peak vertical velocity would decrease was only partially supported. The only significant correlations were between higher THS-R Manuscript and Cursive scores and lower PVV in the ADHD group indicating that as quality of manuscript or cursive writing improved, children with ADHD tended to write more slowly. Additionally, as cursive writing improved their variability of writing speed decreased. While the other hypothesized correlations did not reach statistical significance, it should be noted that they were found to be in the hypothesized directions.

Similarly to results found in the ADHD group but contrary to what was hypothesized, as the manuscript writing quality in control children improved their writing speed decreased. In the cursive condition, the only statistically significant correlation indicated that as the cursive writing quality of the control group improved, the variability of writing speed decreased.

Hypothesis 2

To determine whether velocity was more variable in children with ADHD when conducting a writing task, an ANOVA was conducted using the unconstrained loops condition of the RPT. Since Levene's test indicated that the assumption of homogeneity of variance was violated, Welch's F statistic was used. There was a significant effect of

group on peak vertical velocity, Welch's F(1, 62.97) = 11.09, *p* = .001, with a medium

effect size (*r* = .36; Cohen, 1992; See Table 8 and Figure 7 below).

Table 8
Variability of Writing Velocity – Summary and Source Table

Source	*M*	*SD*	*SS*	*df*	*MS*	*F*	*p*	*r*
ADHD	.20	.11						
Control	.12	.07						
Between Groups	-	-	.09	1	.09	11.09	.001	.36
Within Groups	-	-	.62	64	.01			
Total	-	-	.71	65				

Note. *M* = mean; *SD* = standard deviation; *SS* = sum of squares; *df* = degrees of freedom; *MS* = mean square; *F* = Welch's F; *p* = significance; *r* = effect size.
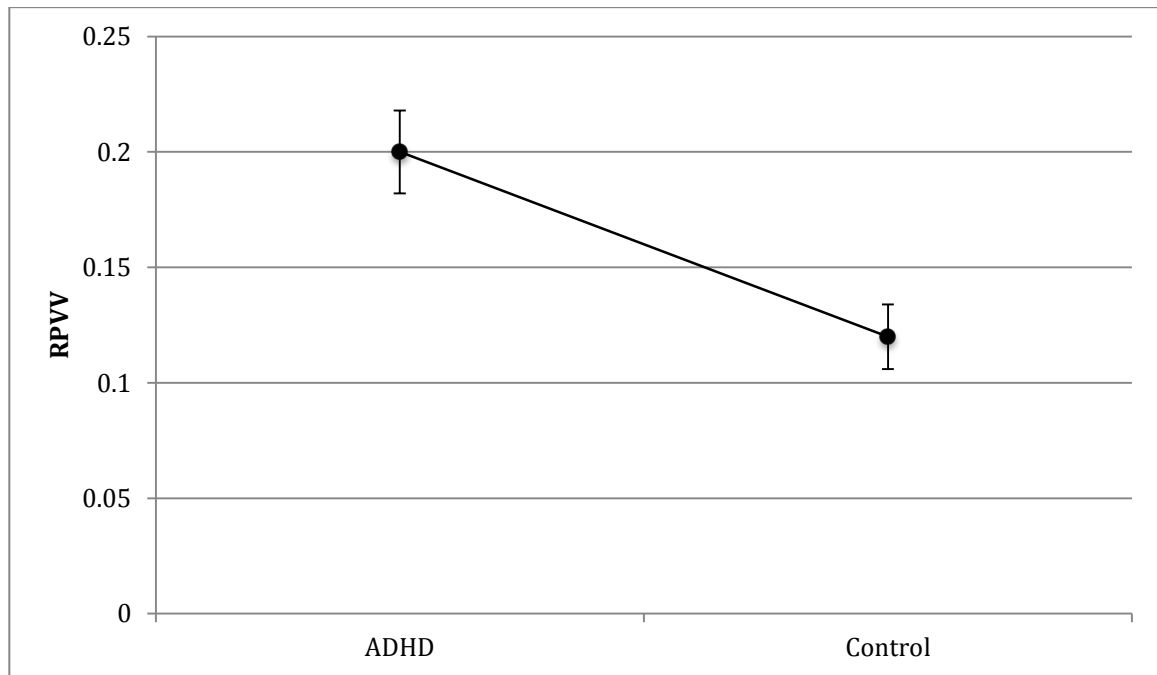
Figure 7. Group means on RPVV for the unconstrained loop condition of the RPT. This figure shows the relative intraindividual standard deviation of peak vertical velocity for the unconstrained loop condition of the Repeated Patterns Test.

Hypothesis 3

To determine whether children with ADHD demonstrate less fluent writing as their writing is more constrained, a two by four mixed ANOVA was conducted with NJ on the loop condition of the RPT as the dependent variable, the level of constraint (no constraint, 3 cm, 2 cm, 1 cm) as the within subject factor, and group as the between subject factor.

Mauchly's test indicated that the assumption of sphericity was tenable, χ^2 (5) = 50.63, p = .00. Given that the standard deviations of NJ across constraint conditions was greater than the respective means for both groups, the NJ variable was log transformed in order to correct for unequal variances. Following the transformation, Mauchly's test indicated that the assumption of sphericity was tenable, χ^2 (5) = 4.68, p = .46. Results showed that there was a significant main effect of constraint, F (3, 192) = 16.22, p = .000. There was no significant effect of group, indicating that children with ADHD and control children had similar NJ overall, F (1, 64) = 3.20, p = .08, r_{group} = .22. Contrasts revealed that there was more NJ on the 1cm condition compared to the 2cm constraint condition, F (1, 64) = 51.583, p = .000, $r_{1cm\ vs\ 2cm}$ = .668; there was less NJ on the 2cm condition compared to the 3cm constraint condition, F (1, 64) = 5.160, p = .026, $r_{2cm\ vs\ 3cm}$ = .273; there was no difference in NJ on the 3cm condition compared to the no constraint condition, F (1, 64) = 2.482, p = .120, $r_{3cm\ vs\ no\ constraint}$ = .215; there was more NJ on the 1cm condition compared to the no constraint condition, F (1, 64) = 7.20, p = .009, $r_{1cm\ vs\ no\ constraint}$ = .318; there was less NJ on the 2cm condition compared to the no constraint condition, F (1, 64) = 21.929, p = .000, $r_{2cm\ vs\ no\ constraint}$ = .505; lastly, there was more NJ on the 1cm condition compared to the 3cm constraint condition, F (1, 64) = 17.025, p = .000, $r_{1cm\ vs\ 3cm}$ = .458. There was no significant interaction effect between constraint level and group, F (3) = 1.094, p = .353. See Figure 8 below. Group means for NJ across constraint levels are presented below in Table 9.
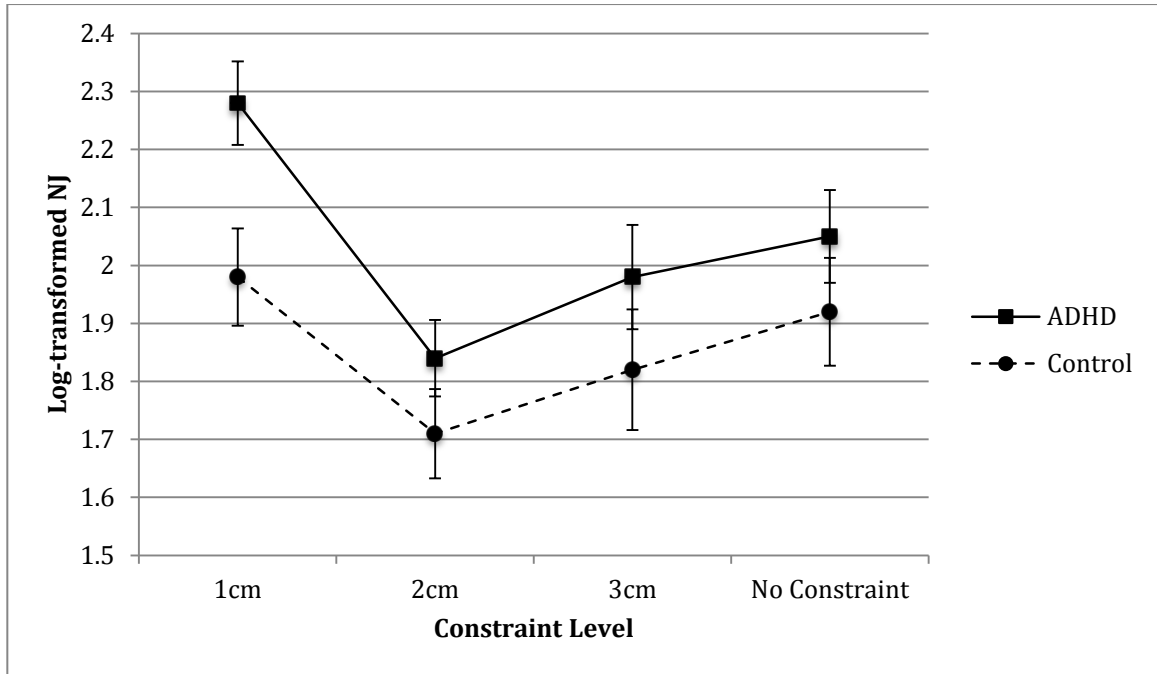
Figure 8. Group log-transformed normalized jerk (NJ) means on each of four constraint conditions of the Repeated Patterns Test loop condition. This figure shows log-transformed group NJ means on each level of constraint.

Table 9
Group normalized jerk means on four levels of RPT loops

	ADHD n = 38		Control n = 28	
	NJ mean M *(SD)*	Log-transformed NJ mean M *(SD)*	NJ mean M *(SD)*	Log-transformed NJ mean M *(SD)*
1 cm RPT loops	331.51 (*366.73*)	2.28 (.*48*)	132.93 (*103.16*)	1.98 (.*38*)
2 cm RPT loops	130.79 (*242.28*)	1.84 (.*44*)	68.90 (*57.54*)	1.71 (.*35*)
3 cm RPT loops	281.71 (*630.12*)	1.98 (.*56*)	190.18 (*472.32*)	1.82 (.*54*)
Uncon. RPT loops	250.22 (*386.53*)	2.05 (.*54*)	144.79 (*240.76*)	1.92 (.*41*)

Note. Uncon. = unconstrained, NJ = normalized jerk, RPT = Repeated Patterns Test.

Hypothesis 4

To determine whether children with ADHD demonstrate greater pen pressure as their writing is more constrained, a two by four mixed ANOVA was conducted with SP on the loop condition of the RPT as the dependent variable, the level of constraint (no constraint, 3 cm, 2 cm, 1 cm) as the within subject factor, and group as the between subject factor.

Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (5) = 28.990, $p < .000$, therefore the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .777$). The results showed that there was no significant main effect of constraint, F (2.332, 149.248) = 1.785, $p = .165$. There was no significant effect of group, indicating that children with ADHD and control children had similar SP overall, F (1, 64) = .212, $r_{group} = .057$. There was no significant interaction effect between constraint level and group, F (2.332, 149.248) = 2.225, $p = .103$. This hypothesis was not supported. Please see Figure 9 below. Group SP means across constraint levels are presented below in Table 10.
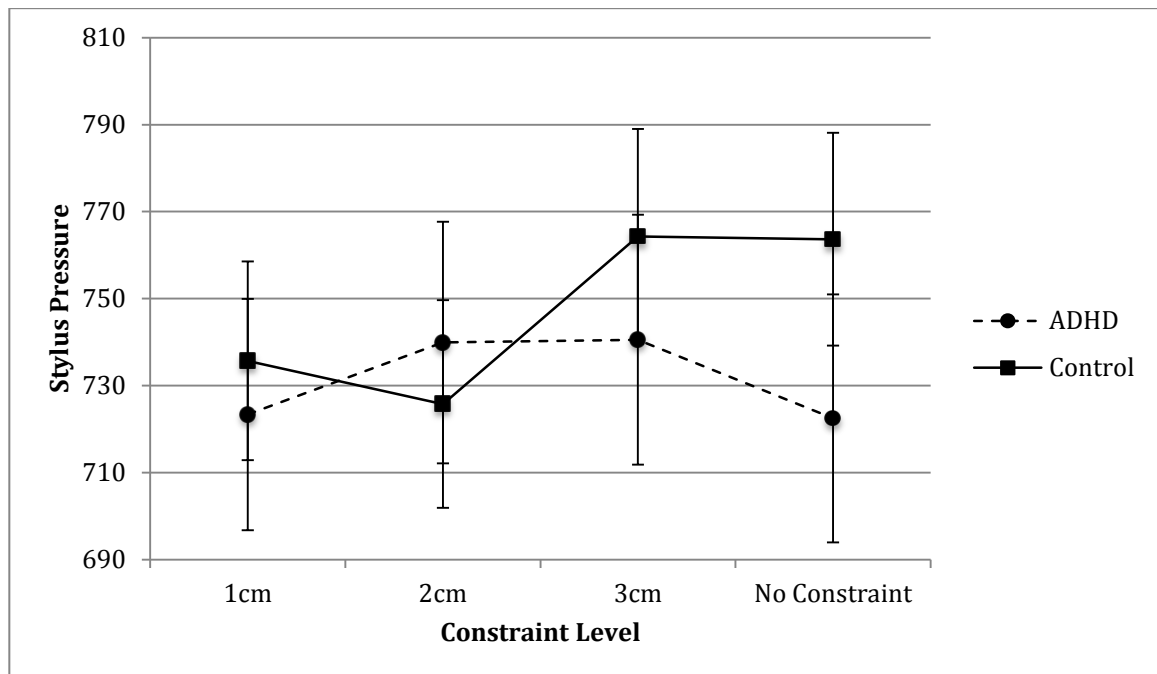
Figure 9. Group stylus pressure (SP) means on each of four constraint conditions of the Repeated Patterns Test loop condition. This figure shows group SP means on each level of constraint.

Table 10
Group stylus pressure means on four levels of RPT loops

	ADHD *n* = 38 M *(SD)*	Control *n* = 28 M *(SD)*
1 cm RPT loops	723.37 (*147.58*)	735.69 (*130.76*)
2 cm RPT loops	739.90 (*146.72*)	725.76 (*147.45*)
3 cm RPT loops	740.56 (*163.12*)	764.31 (*135.71*)
Uncon. RPT loops	722.48 (*156.41*)	763.65 (*142.94*)

Note. Uncon. = unconstrained, SP = stylus pressure, RPT = Repeated Patterns Test.

Hypothesis 5a

To examine whether children with ADHD use greater stylus pressure when copying novel material that involves symbol processing, two separate ANOVAs were conducted where the dependent variable was SP on the THS-R Manuscript word copying task, and the SP on the THS-R Cursive word copying task, respectively. The Cursive word copying task was considered to be more novel than the Manuscript format since writing in cursive is not emphasized in school (Ontario Ministry of Education, 2006).

The first ANOVA examined differences in SP on the Manuscript copying task, which was considered to be the more familiar task. Levene's test of homogeneity of variance indicated that this assumption was met, as such no adjustments were made to the F statistic. There was no significant effect of group on Manuscript SP, $F (1, 64) = .727$, $p = .399$, $r = .106$, indicating that both groups did not differ in their SP when copying printed words. Children with ADHD wrote with a mean stylus pressure of 409.13 ($SD = 103.73$), whereas control children wrote with a mean stylus pressure of 434.25 ($SD = 135.64$). See Table 11 and Figure 10 below.

Table 11

Stylus Pressure on a Manuscript word copying task – Source Table

Source	SS	df	MS	F	p	r
Between Groups	10169.16	1	10169.16	.727	.397	.106
Within Groups	894857.41	64	.01			
Total	905026.57	65				

Note. SS = sum of squares; *df* = degrees of freedom; *MS* = mean square; *F* = F statistic; *p* = significance; *r* = effect size.

Figure 10. Mean stylus pressure in children with ADHD compared to control children on a manuscript word copying task.

The second ANOVA examined differences in SP on the Cursive copying task, which was considered to be a novel task. Levene's test of homogeneity of variance indicated that this assumption was met, as such no adjustments were made to the F statistic. There was no significant effect of group on Cursive SP, F (1, 64) = .592, *p* = .444, *r* = .096, indicating that both groups did not differ in their SP when copying cursive words. Children with ADHD wrote with a mean stylus pressure of 717.59

(*SD* = 128.03), whereas control children wrote with a mean stylus pressure of 690.67 (*SD* = 155.85). Please see Table 12 and Figure 11 below.

Table 12
Stylus Pressure on a Cursive word copying task – Source Table

Source	SS	df	MS	F	p	r
Between Groups	11676.848	1	11676.848	.592	.444	.096
Within Groups	1262366.83	64	19724.482			
Total	1274043.68	65				

Note. SS = sum of squares; *df* = degrees of freedom; *MS* = mean square; *F* = F statistic; *p* = significance; *r* = effect size.

Figure 11. Mean stylus pressure in children with ADHD compared to control children on a cursive word copying task.

Hypothesis 5b

To examine whether children with ADHD use greater stylus pressure on a more complex task, two separate ANOVAs were conducted where the dependent variables were SP on the unconstrained RPT Loop condition, and the SP on the unconstrained RPT

Square-Triangle condition. The Square-Triangle task was considered to be more complex given that there are more changes in writing direction (Christina & Rose, 1985; Henry & Rogers, 1960; Schmidt & Lee, 2011) when writing successive square-triangles compared to loops.

The first ANOVA examined differences in SP on the less complex RPT Loop condition. Levene's test of homogeneity of variance indicated that this assumption was met. There was no significant effect of group on RPT Loop SP, $F(1, 64) = 1.20$, $p = .277$, $r = .136$, indicating that both groups did not differ when writing loops. Children with ADHD had a mean stylus pressure of 722.48 ($SD = 156.41$), while control children had a mean stylus pressure of 763.65 ($SD = 142.94$). Relevant data are presented in Table 13 and Figure 12 below.

Table 13
Stylus Pressure on the RPT Unconstrained Loop condition – Source Table

Source	SS	df	MS	F	p	r
Between Groups	27325.115	1	27325.115	1.200	.277	.136
Within Groups	1456806.64	64	22762.604			
Total	1484131.76	65				

Note. SS = sum of squares; *df* = degrees of freedom; *MS* = mean square; *F* = F statistic; *p* = significance; *r* = effect size.

Figure 12. Mean stylus pressure in children with ADHD compared to control children on the unconstrained RPT Loop condition.

The second ANOVA examined differences in SP on the more complex RPT Square-Triangle condition. Levene's test of homogeneity of variance indicated that this assumption was met. There was no significant effect of group on RPT Square-Triangle SP, $F(1, 64) = .272$, $p = .604$, $r = .065$, indicating that both groups did not differ when writing square-triangles. Children with ADHD had a mean stylus pressure of 767.59 (*SD* = 136.59), while control children had a mean stylus pressure of 785.28 (*SD* = 135.28). These data are presented in Table 14 and Figure 13 below.

Table 14
Stylus Pressure on the RPT Unconstrained Square-Triangle condition – Source Table

Source	*SS*	*df*	*MS*	*F*	*p*	*r*
Between Groups	5041.363	1	5041.363	.272	.604	.065
Within Groups	1184429.07	64	18506.704			
Total	1189470.43	65				

Note. *SS* = sum of squares; *df* = degrees of freedom; *MS* = mean square; *F* = F statistic; *p* = significance; *r* = effect size.
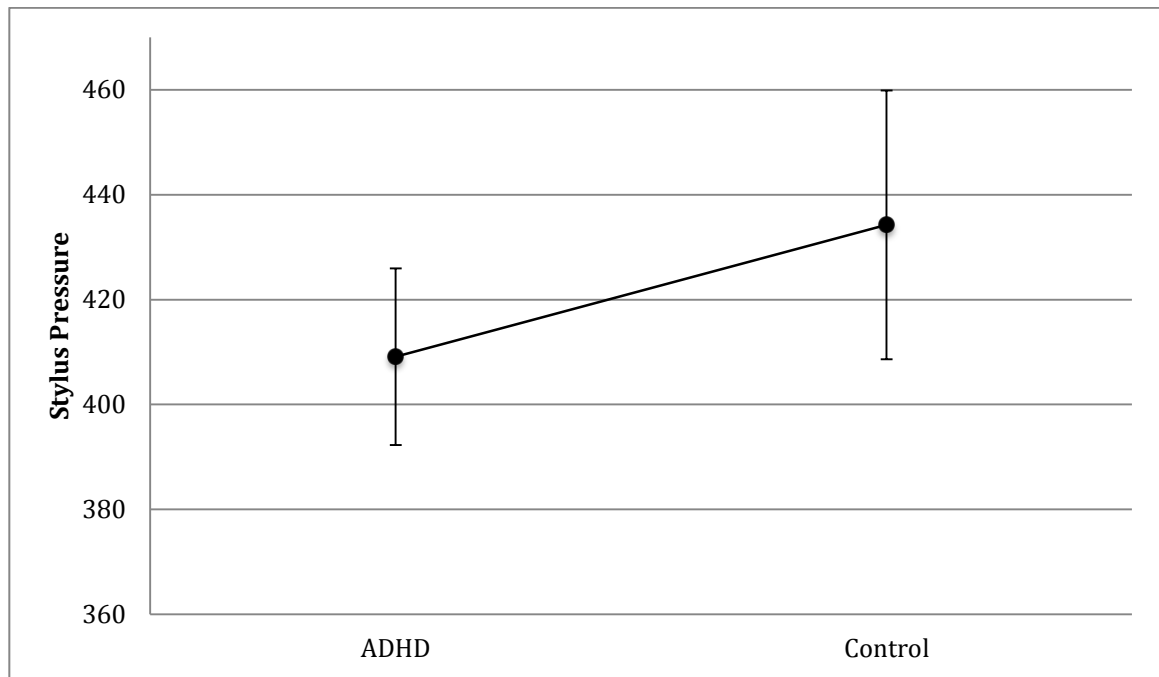
Figure 13. Mean stylus pressure in children with ADHD compared to control children on the unconstrained RPT Square-Triangle condition.

Hypothesis 6

To determine whether children with ADHD demonstrate greater stylus pressure (SP) on a more constrained drawing task, two separate ANOVAs were conducted where SP for the BOT-2 Crooked Path and BOT-2 Curved Path were the dependent variables, respectively.

The first ANOVA examined differences in SP on the less constrained BOT-2 Crooked Path. Levene's test of homogeneity of variance indicated that this assumption was met. There was no significant effect of group on BOT-2 Crooked Path SP, $F(1, 64)$ = .054, p = .817, r = .029, indicating that both groups did not differ when completing this task. Children with ADHD had a mean stylus pressure of 756.61 (SD = 127.87), while control children had a mean stylus pressure of 748.94 (SD = 138.71). Please see Table 15 and Figure 14 below.

Table 15
Stylus Pressure on the BOT-2 Crooked Path – Source Table

Source	SS	df	MS	F	p	r
Between Groups	948.249	1	948.249	.054	.817	.029
Within Groups	1124406.24	64	17568.848			
Total	1125354.49	65				

Note. SS = sum of squares; *df* = degrees of freedom; *MS* = mean square; *F* = F statistic; *p* = significance; *r* = effect size.
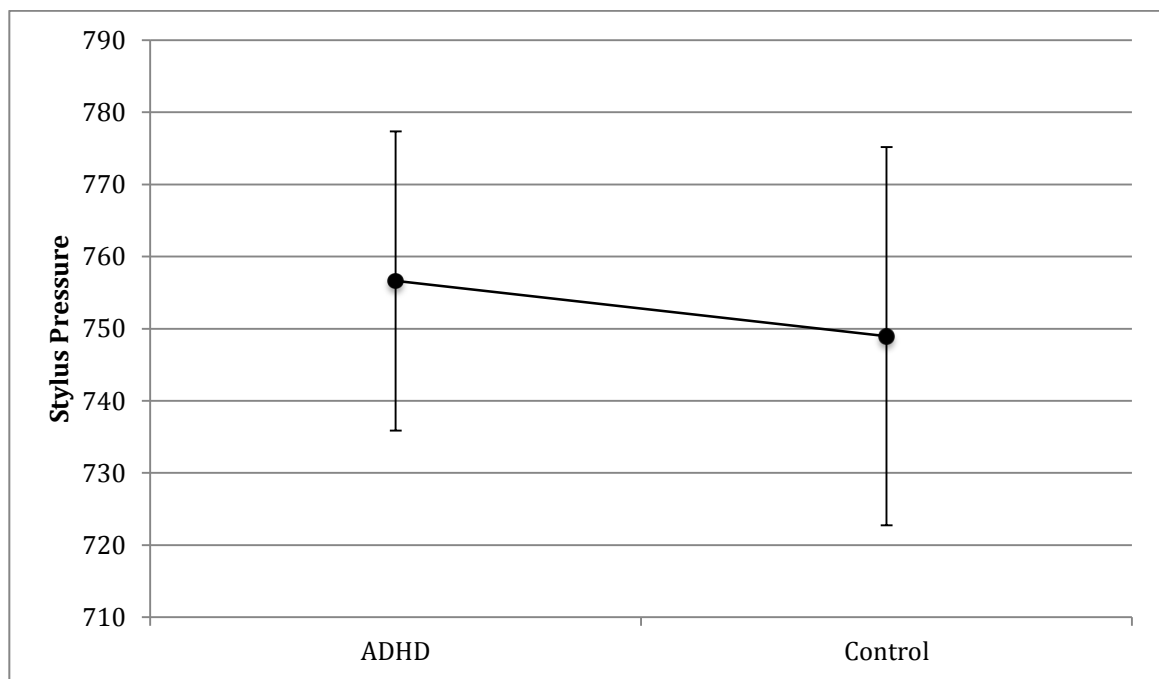
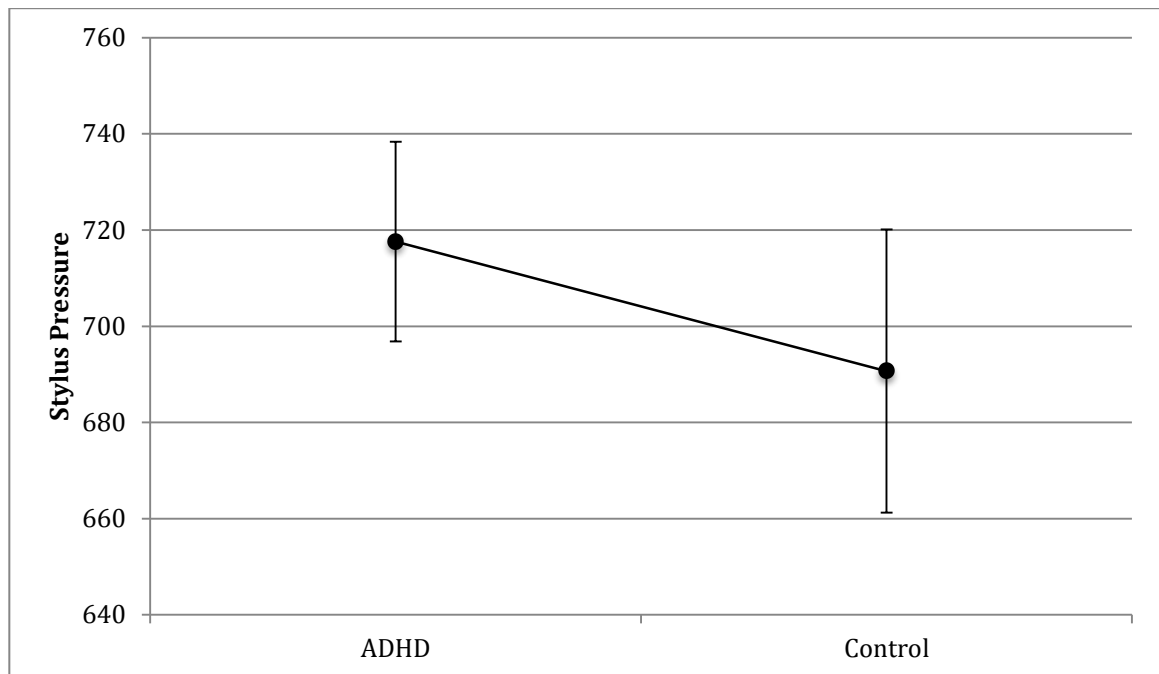*Figure 14*. Mean stylus pressure in children with ADHD compared to control children on the BOT-2 Crooked Path.

The second ANOVA examined differences in SP on the more constrained BOT-2 Curved Path. Levene's test of homogeneity of variance indicated that this assumption was met. There was no significant effect of group on BOT-2 Curved Path SP, F (1, 64) = .224, *p* = .638, *r* = .059, indicating that both groups did not differ when completing this task. Children with ADHD had a mean stylus pressure of 636.75 (*SD* = 148.48), while control children had a mean stylus pressure of 617.60 (*SD* = 179.99). Please see Table 16 and Figure 15 below.

Table 16

Stylus Pressure on the BOT-2 Curved Path – Source Table

Source	SS	df	MS	F	p	r
Between Groups	5911.622	1	5911.622	.224	.638	.059
Within Groups	1690378.88	64	26412.17			
Total	1696290.50	65				

Note. *SS* = sum of squares; *df* = degrees of freedom; *MS* = mean square; *F* = F statistic; *p* = significance; *r* = effect size.

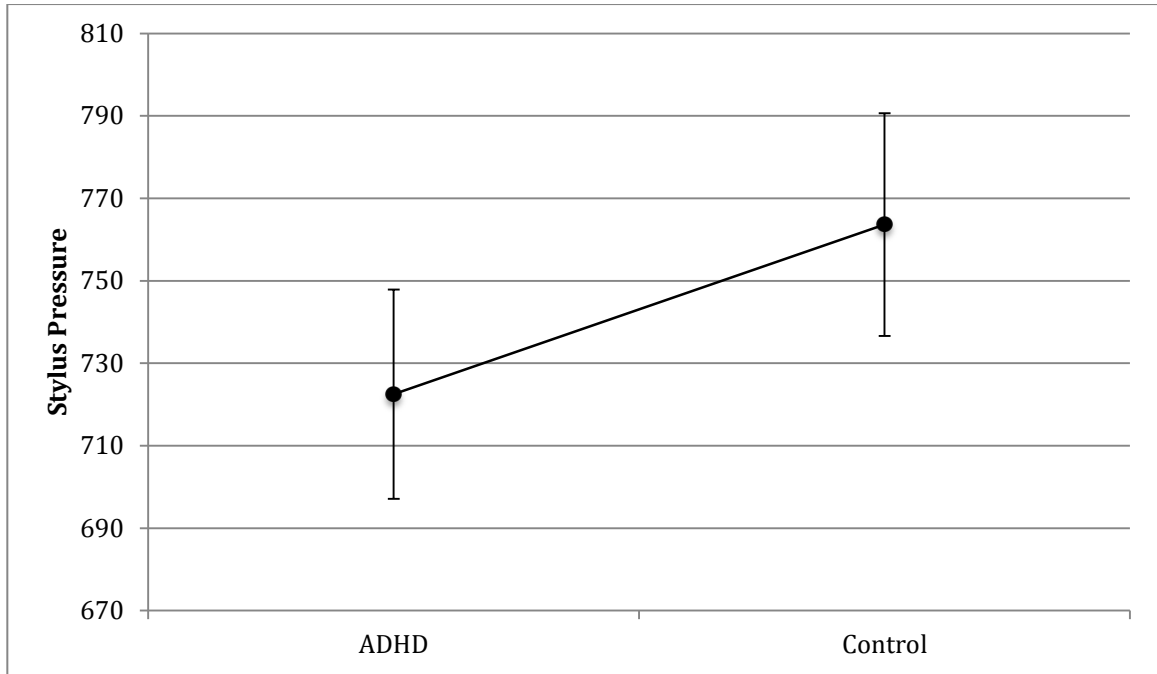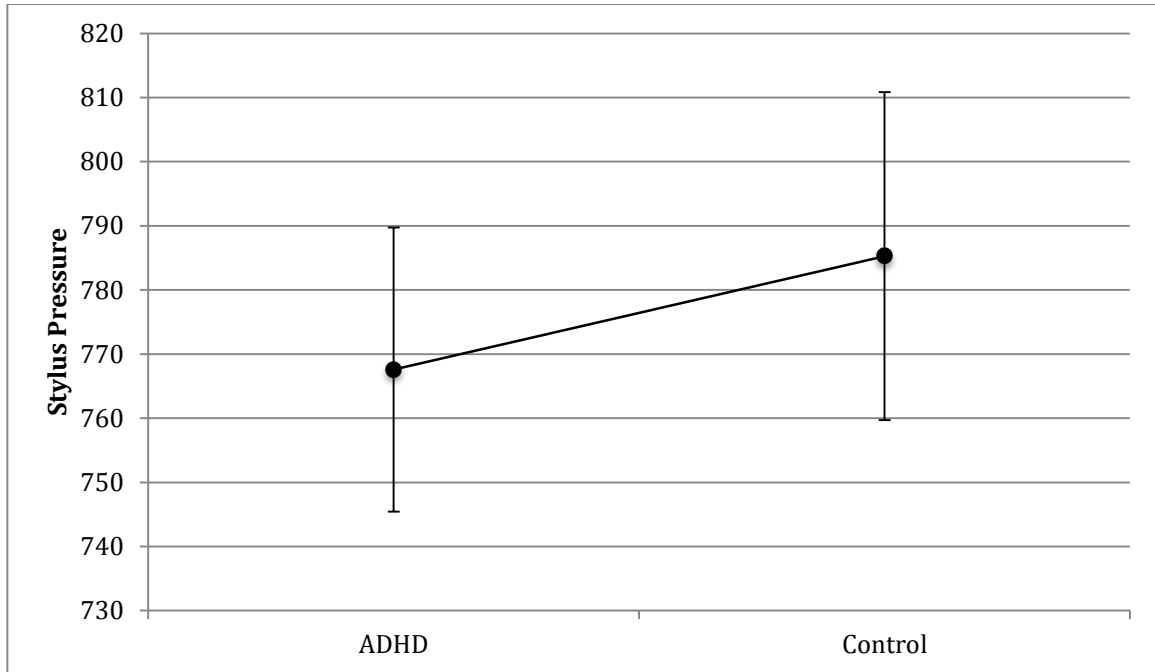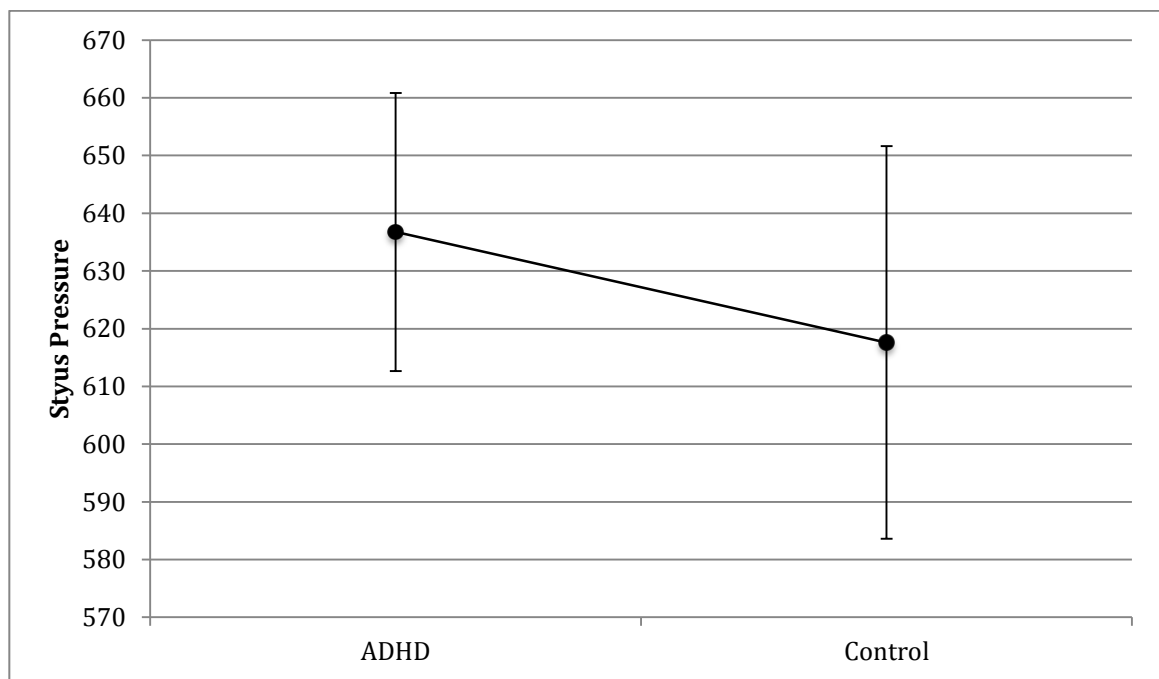*Figure 15*. Mean stylus pressure in children with ADHD compared to control children on the BOT-2 Curved Path.

CHAPTER IV

DISCUSSION

Motor difficulties in children with ADHD have often been overlooked in the past (Fliers et al., 2010), yet difficulties with writing have been noted in approximately two thirds of children with ADHD (Mayes & Calhoun, 2006). The purpose of the current investigation was to examine differences in fine motor control in children with ADHD compared to control children. The advent of digitizing technology has enabled researchers to examine the *process* aspects of a task in addition to the *product* aspects of a task. This was the first study to examine children's manuscript and cursive writing abilities objectively, and correlations were examined between children's quality of manuscript and cursive writing and kinematic variables. Specifically, correlations were examined between overall writing quality and writing fluency, pen pressure, writing speed, and variability of writing speed. Given that variability of performance is a hallmark of ADHD (Barkley, 2006), a second aim of the study was to examine whether children with ADHD would demonstrate more variability in the speed of their writing. The effect of constraining children's writing on both writing fluency and pen pressure was also examined. Additionally, the effect of task novelty and motoric complexity on pen pressure was investigated. Lastly, differences in pen pressure were compared between groups on a drawing task. Below is a summary of the results of each area of research and the implications of these findings. The methodological limitations of this investigation are then discussed, followed by suggestions for future research.

Relationship Between Writing Quality and Kinematic Variables

Barkley's Hybrid Model of ADHD (1997, 2006) outlines the relationship between behavioural inhibition, executive functions, and resultant motor control. The model would suggest that since children with ADHD have difficulties regulating their behaviour, including written output, these children would demonstrate slower writing and greater pen pressure in attempts to stabilize their written output so that they could produce better quality writing. Additionally, better quality of writing should be associated with less jerky writing, and less variable writing speed. Results of the present study only partially supported these predictions.

This was the first study to compare the printing and cursive writing of children with ADHD to that of control children using an objective handwriting measure. Much of the previous research has examined handwriting quality either from a parent or teacher questionnaire perspective (e.g., Shen, Lee & Chen, 2012) or from subjective ratings across multiple raters (e.g., Adi-Japha et al., 2007; Rosenblum, Epszstein & Josman, 2008; Tucha & Lange, 2001, 2004). Regardless of how quality of handwriting was rated, most previous studies did not examine the relationship between handwriting quality and kinematic measures that assess the process of writing. The studies by Tucha and Lange (2001, 2004), Adi-Japha et al. (2007), as well as that by Rosenblum, Epsztein and Josman (2008) were the only previous studies to include both measures of handwriting quality and kinematic variables. Tucha and Lange (2001, 2004) determined that children with ADHD who were off their medication demonstrated poorer quality of handwriting as subjectively rated by independent observers. These results are in line with the present research that also found poorer overall quality of writing in both manuscript and cursive conditions compared to controls. In contrast, Rosenblum, Epsztein and Josman (2008) as well as Adi-Japha et al. (2007) did not find any differences between children with ADHD and control children on subjective measures of writing quality. These differences may be attributable to task demands. For instance, while the studies of Adi-Japha et al. (2007) and Rosenblum et al. (2008) involved the children copying a paragraph in Hebrew, Tucha and Lange (2001, 2004) as well as the present study placed much less demand on the writing output, namely writing a sentence or words. Additionally, the act of writing in Hebrew using block script may be qualitatively and kinematically different from writing using a Latin alphabet as in the present study and those of Tucha and Lange.

Another difference between the present study and those that utilized subjective approaches to examining writing quality was the way in which writing quality was measured. The previous research noted above utilized subjective ratings of variables such as spatial arrangement, global legibility, and number of unrecognizable letters. The present study utilized a standardized assessment of writing quality in which each letter written was scored on a scale from zero to three based on how well executed the letter was; there was no rating of spatial arrangement between letters, or the straightness of the writing. These differences may have also contributed to the different study findings. It

may be that the more rigorous approach to defining writing quality used in the present study affected correlational results and contributed to certain nonsignificant findings. For instance, it is possible that the criteria used in the present study were stricter in defining writing quality since each letter was rated separately. The relationship to writing kinematics could have been affected by this scoring system in that poorer writing quality (e.g., inability to correctly join letter components, leaving gaps, etc.) may be tied to kinematic variables such as writing speed. For instance, if a letter is written poorly in that letter components are not joined correctly and gaps are left, the length of the writing trace will necessarily be longer or shorter than had the child connected the letter segments appropriately. Guigon et al. (2008) point out that faster movements are necessarily more variable. That no relationship was found between writing speed variability and writing quality in manuscript writing, and that quality manuscript writing *was* associated with slower writing speed, suggest that children with ADHD were able to write in manuscript using a steady writing speed. In contrast, when writing cursively children with ADHD demonstrated both slower writing speed and less variable writing speed. Given that cursive writing is less familiar than manuscript writing, it may be that the added lack of familiarity with cursive writing required the children to not only slow down but also stabilize their writing speed output. Although not directly tested in the present study, it may be that the act of completing a less familiar task such as cursive writing focused the children's attention so that they were better able to regulate their writing output, even off medication. This would suggest that children with ADHD are better able to focus their attention and regulate their behavioural output when confronted with less familiar tasks; alternatively, it may be that children with ADHD benefit from requiring to focus on tasks.

Results of the present study indicated that there was a negative relationship between quality of both cursive and manuscript writing and peak vertical velocity in children with ADHD. In children with ADHD, improved manuscript and cursive writing quality was associated with slower writing speed, which only partially supported the hypothesis that as writing quality improved, children with ADHD would demonstrate less writing fluency, slower writing speed, less variability in writing speed, and greater pen pressure. In contrast, improved writing quality was associated with greater pen pressure, as well as slower and less variable writing speed in control children. For cursive writing,

improved writing quality was associated with less variability in writing speed in control children. In their study, Rosenblum, Epsztein and Josman (2008) found that children with ADHD who were not taking medication took longer to copy a paragraph than control children, but that they also wrote at a faster velocity. In contrast, the studies of Tucha and Lange (2001, 2004) found that children with ADHD tended to write more slowly compared to control children, a finding that is in line with the present study. Given that the task demands of the present study (i.e., writing letters, words, and short sentences) more closely align to those in the Tucha and Lange studies (i.e., writing a single short sentence), it may be the task requirement of copying a paragraph that accounts for the different results. Unfortunately, none of the previous research has directly examined the relationship between writing quality and kinematic variables; previous studies have only examined writing quality and kinematics separately. Given the results of the present study, it may be that children with ADHD may need to slow down their writing (manuscript or cursive) in order to produce writing of a higher objective quality. Given the lack of a statistically significant relationship between writing quality and writing fluency, the present study may indicate that for both control children and those with ADHD, the quality of a child's writing (manuscript or cursive) is not related to how fluently they are able to write. While writing fluency was not statistically significantly related to any other kinematic variables for children with ADHD, for control children a significant relationship was found between greater NJ and slower writing speed, and greater NJ and increased writing speed variability. This suggests that as control children slow down, their writing becomes less fluent, but for children with ADHD this is not the case. It may be that control children have automatized the act of writing better than children with ADHD, who's learning of writing was likely interrupted by symptoms of ADHD (Puranik & AlOtaiba, 2012), and therefore as their writing slows it also becomes less fluent. On the other hand, children with ADHD are less likely to have automatized the act of writing due to interference of ADHD symptoms during the learning process and as such their writing fluency may not be as affected.

The present results point to the importance of writing speed when considering quality of written production. For both manuscript and cursive writing in the ADHD group, improved writing quality was associated with slower writing speed. Additionally,

for cursive writing the ADHD group needed to stabilize their writing speed to produce better quality cursive writing. In contrast, for control children slower writing speed was only associated with better quality manuscript writing; control children did not need to slow down when writing in cursive, they only needed to stabilize their writing speed to produce better quality cursive writing. This suggests that control children do not need to adjust their speed when completing a more novel task (cursive writing) compared to a more familiar task (manuscript writing). As such, it may be that children without a diagnosis of ADHD may be better able to adjust to novelty or they may be better able to generalize their motor programs to novel situations.

Although not examined in the present study, the presence of learning disabilities (especially in the ADHD sample) may have affected results. None of the control children had a diagnosis of any type of learning disability, whereas 55% of the ADHD sample had this diagnosis. Difficulties with orthographic processing of letter symbols has been well documented in the learning disabilities literature (e.g., De Jong, Licht, Sergeant, & Oosterlaan, 2012; Galletly & Knight, 2011; Ho, Chan, Leung, Lee, & Tsang, 2005), and such deficits may have affected results of the present study. For instance, given the task of writing both in manuscript and cursive may have been differentially more difficult for those children with learning disabilities, who were concentrated only in the ADHD sample. If a child has difficulty processing letter symbols, they will likely have more problems with retrieving and executing the motor commands to write these symbols.

Although not reported in the results of the present study, additional post-hoc analyses were conducted to examine this possibility. Analyses were conducted examining children with a diagnosis of any type of learning disability (as reported by parents), and comparing them to children without a diagnosis of learning disability. Results did not change from those presently reported. Additionally, including the presence of a learning disability as a covariate did not change the results as reported in the present study. The results of these post-hoc analyses suggest that the difficulties experienced by the children with ADHD were not attributable to a learning disability.

Variability of Velocity on a Writing Task

Barkley (1997, 2006) has noted that variability of performance is one of the hallmark features of individuals with ADHD. Previous research that has examined

variability of performance has not examined the variability of velocity when writing, instead focusing on variability in letter height (e.g., Adi-Japha et al., 2007; Frings et al., 2010), number of over- and under-shoots when writing between lines (e.g., Schoemaker, Ketelaars, van Zonneveld, Minderaa & Mulder, 2005), and accuracy and legibility (i.e.. Tucha & Lange, 2005). The only study to find a difference in variability of velocity was one where the task required the children to trace an ellipse (Adi-Japha et al., 2007); children with ADHD were found to be more variable in their tracing speed. One of the goals of the present study was to examine whether or not variability of performance also extended to variability in velocity.

Consistent with Barkley's (1997, 2006) model, children with ADHD were found to demonstrate greater peak vertical velocity than control children. This points to a problem in the regulation of their behavioural output, more specifically, to deficiencies in regulating writing speed. The findings from the present study suggest that children with ADHD were unable to inhibit their behavioural response and therefore regulate their written output, which manifested in greater variability in writing speed. Tannock (2003) has noted that increased variability in behavioural performance stems from dysfunctional regulatory processes which produce fluctuations in response control, further pointing to deficits in the self-regulation aspect of Barkley's model. Dysfunction in the fronto-striatal-cerebellar circuits have been implicated in arousal modulation difficulties (Russell et al., 2006), thus implicating these circuits in the difficulties associated with regulation of output. Because children with ADHD were not able to regulate and modulate their writing, difficulties were evident by way of an inability to control the speed of writing. The greater variability in children with ADHD in the handwriting task could be associated with a specific problem of motor control producing a dysrhythmia (Ben-Pazi et al., 2007), and it may also be accounted for by attentional control (Barkley, 2006). Greater variability likely reflects multiple neural determinants, and may be due to an attenuated and dysfunctional dopamine modulation, which gives rise to increased neural noise, and may be the basis for difficulty in self-regulation (Sikstrom & Soderlund, 2007)

The only previous study to specifically examine variability of velocity in a kinematic context was that of Adi-Japha et al. (2007). In addition to determining that the mean height of letters was more variable in children with ADHD when writing letters and

words in Hebrew, they also determined that the variability in velocity when tracing an ellipse was twice that of control children. Similarly, although using a different task, the present study also found more variability in writing speed output when writing connected loops. The study of Frings and colleagues (2010) examined megalographia in children with ADHD, children with cerebellar lesions, and control children. They found that children with ADHD and those with cerebellar lesions had more variable letter sizes when writing a sentence. In addition, Guigon, Baraduc and Desmurget (2008) have reported that variability in performance reflects corruption of movement planning and execution processes by noise in sensory feedback and motor commands. Uncertainty in sensory signals directly translates into performance variability, and increased muscle co-contraction during movement results in more variable command signals that then result in more variable output. As such, it may be that the variability of velocity in children with ADHD is due to difficulties in movement planning and execution.

Effect of Constraint on Writing Fluency and Pen Pressure

Barkley's model predicts that children with ADHD will have greater difficulties when asked to constrain their motor output due to difficulties with regulation. Children with ADHD are expected to exhibit problems with motor control as manifested in greater variability when writing (reflected in the normalized jerk variable), together with increased pen pressure in attempts to stabilize written output.

The present study found a significant main effect of normalized jerk when children were asked to write repeating loops between differently spaced lines; no significant main effect for pen pressure was found. No differences between groups were found on either normalized jerk (i.e., fluency) or pen pressure, and no group by constraint interaction was found for either measure. As such, results of the present study demonstrate that constraints affect writing fluency but not pen pressure. Specifically, both groups demonstrated more fluency (i.e., less normalized jerk) when writing between lines spaced 2 cm apart, followed by 3 cm apart, followed by no constraint (i.e., writing on a blank screen). The most dysfluent writing was found when children were asked to write between lines spaced 1 cm apart.

The only previous study to specifically examine constraint effects on various kinematic measures was that of Schoemaker and colleagues (2005). In their study they

asked children with ADHD and control children to write increasingly complex items (where complexity was defined as the number of changes in writing direction) between three lines that were 4 mm apart (total of 0.8 cm between the bottom and top line), 6 mm apart (total of 1.2 cm between the bottom and top line), or just a single underline. The item that the children were asked to write was a single angular peak, compared to two, three, or four peaks (i.e., the more peaks, the more changes in direction and by definition complexity). Schoemaker et al. (2005) found that overall, children with ADHD demonstrated slower and more inaccurate writing as well as higher axial pen pressure compared to control children across all writing tasks. As constraint increased, they found that both groups wrote more slowly, with less pen pressure, and with less accuracy. They also found that children with ADHD wrote more fluently overall.

These results are in contrast to those of the current study that found a significant main effect of constraint on fluency, but no group difference on either fluency or pen pressure. The present study results suggest that all children, regardless of ADHD status, are affected by writing constraint such that they are able to write most fluently at 2 cm, followed by 3 cm, and no constraint; both groups had the most dysfluent writing in the 1 cm condition, which is closest in size to both of the constraint conditions in the Schoemaker et al. study. It may be that the Schoemaker study did not have enough of a difference between their constraint conditions, or conversely, it may be that the present study used constraint conditions that were too different from each other. However, this second explanation is unlikely given that a significant main effect of constraint on fluency was found, suggesting that sufficient differences exist between constraint conditions in the present study.

The current study found no differences between groups on a measure of fluency. That the Schoemaker et al. (2005) study found greater fluency in children with ADHD overall may be related to task demands. Writing angular forms compared to closed loops is a different task process, and as such may affect the kinematics of writing. For instance, in order to write an angular shape the child would need to stop and slightly pause to shift direction when writing an angular shape, compared to writing a loop that does not require a brief stop in order to change direction. Also, given that motoric complexity is defined as the number of times that a movement changes direction (Henry & Rogers, 1960;

Schmidt & Lee, 2001), differences in results may be due to the fact that in the present study children were required to continue writing closed loops until they reached the edge of digitizing tablet surface, compared to the Schoemaker study where the longest item was a total of four peaks. As such, the present study task requirement can be thought of as being more complex than that of the Schoemaker study simply by way of the number of times that each child had to write a loop (with each loop consisting of approximately two changes in direction – once up, and once down).

       Alternatively, given that children in the present study were asked to write a continuous written trace across the tablet surface, it may be that over time the children were able to adapt their written output and automatize it. Since no group differences were found on normalized jerk suggests that this was the case. The five trials of completing the continuous loop pattern across the tablet for each constraint level may have been sufficient for the task to become automatized, and therefore more fluent, to the same extent as that seen in control children. Had the data been compared between the first and fifth trials for each constraint level, group differences may have been elucidated. For instance, since children with ADHD are known to have difficulties with regulating their motor output (Barkley, 2006), they may have had more difficulties with the first trial of each constraint condition; as they had more 'practice' with completing the task across trials two through five, their fluency may have improved to the same level as control children. Since normalized jerk was collapsed across the five trials to get an average fluency score, these effects may have been attenuated.

       The current study found the greatest writing fluency in the 2 cm condition, which is almost double that of the largest constraint condition in the Schoemaker et al. (2005) study. Had they expanded upon their constraint conditions, Schoemaker and colleagues may have found different results. Given that lines in a regular school notebook are approximately 1 cm wide, yet that condition resulted in the greatest dysfluency in both groups in the present study is surprising. It would be expected that since children have the most practice with writing between approximately 1 cm lines, they should demonstrate the most writing fluency in this condition. In fact, qualitatively, most of the children commented that the 1 cm condition was the easiest for them while they completed the task; in contrast, they noted that the 3 cm condition was the most difficult

because they felt that they had to write "too big" and that it "felt weird" to write that large. In examining Figure 7, it appears that there may be an optimal level of constraint for both groups such that as writing approaches the optimal level (i.e., 2 cm), fluency improves, but if the constraint becomes too great (i.e., 1 cm) then writing becomes dysfluent again.

Regarding pen pressure, while the Schoemaker et al. (2005) study found overall greater pen pressure in children with ADHD, the present study found no differences between groups on stylus pressure across constraint conditions. Although there were no statistically significant differences between groups on pen pressure, it is interesting to note that examination of Figure 7 indicates that children with ADHD demonstrated one of the greatest pen pressures in the 2 cm condition, the same condition that elicited the most fluent writing in both groups. The 2 cm condition was also the only condition whereby children with ADHD demonstrated more relative pen pressure compared to control children (although differences were not statistically significant). It may be that in order to produce more fluent writing, children with ADHD need to use greater pen pressure in order to stabilize their writing.

Effect of Task Novelty and Motor Complexity on Pen Pressure

Barkley (2006) has proposed that children with ADHD have problems with movement control, especially complex movement activity that requires planning, self-regulation, and higher-order cognitive processing. As a task becomes more complex, the child is required to hold in mind more 'bits' of information about how to successfully execute that task, and children with ADHD are notorious for having deficits in working memory (e.g., Barkley, 1997, 2006; McCutchen, 1996). Given difficulties with working memory, children with ADHD quickly become overloaded and therefore their execution of motor commands becomes impaired (McCutchen, 1996). Similarly, if a task is novel and unfamiliar, children with ADHD are expected to exhibit more difficulties in executing that task because they must create new motor programs in order to complete the task. As such, task novelty and complexity were hypothesized to affect pen pressure in children with ADHD in that they were expected to use greater pen pressure.

In contrast to what was predicted, the present study did not find any differences between groups in terms of pen pressure when writing short words in manuscript (i.e.,

more familiar task) compared to cursive writing (i.e., more novel task). The effect of task novelty on pen pressure has previously only been examined by Adi-Japha and colleagues (2007). They found that as children wrote more complex single letters in Hebrew, children with ADHD wrote with increased pen pressure. The differences in results may be explained by differences in task demands, or perhaps the task used in the present study was not sufficiently novel. Writing short words in manuscript was thought to be more familiar and less cognitively taxing since the Ontario curriculum (Ontario Ministry of Education, 2006) indicates that cursive writing is only introduced in Grade 3. By comparison, cursive writing the same words was thought to reflect greater novelty of a language-based task since according to the Ontario curriculum, children are merely introduced to cursive writing in Grade 3 (Ontario Ministry of Education, 2006) and are not required to routinely use it. Qualitative observation of the children while writing in cursive appeared to indicate greater difficulty with cursive writing, as many children were observed to utilize a non-systematic approach to the writing of cursive letters. For example, many children in each group wrote the cursive letter 'p' through the connection of multiple separate components (i.e., first drawing a circle, then drawing a line extending below the circle, then drawing a small connector on the left of the circle, followed by a small connector on the right). Children were observed to write many different cursive letters in such a disjointed fashion. As such, it may be that the children in the present study were not thinking of the words as a series of letters, but as a series of connected letter components. In copying the words by connecting a series of letter components, the children in fact likely changed the task demands to one that is more similar to a manuscript writing task. For instance when printing the pencil is lifted from the page for each letter component; similarly, by not continuously connecting the letters when cursive writing, the children tended to lift the pen for each letter component which in effect likely changed the kinematics of the task to ones that are more akin to manuscript writing. In fact, almost all of the children commented that they either had never been taught how to write in cursive, or did not remember how to write in cursive. As such, the nature of the present task was likely very different to that in the study by Adi-Japha and colleagues (2007).

The present study also examined the effect of motoric complexity on pen pressure, a task that was intended to circumvent any potential linguistic components. Results of the current study indicated that there were no differences between groups on a measure of pen pressure for either level of complexity (i.e., repeated loops compared to repeated series of triangle-square-triangle-square). The study by Schoemaker and colleagues (2005) is the only study to have examined the relationship between task complexity and pen pressure. Their task involved children writing a series of connected angular peaks (e.g., ^^) that ranged from one peak to four peaks, between various line constraints. They determined that children with ADHD demonstrated less pen pressure, but only on the most constrained condition. The disparate results to that found in the present study may be explained by the different task demands. For example, the children in the present study wrote both the less complex series of loops and the more complex series of square-triangles on a blank digitizing tablet screen and as such were not constrained in any way. That result is in line with that of Schoemaker and colleagues (2005) since their study only found differences in pen pressure on the smallest level of constraint; no differences were found for the single underline (no constraint) condition. Taken together, it may be that task complexity only affects pen pressure once a certain level of constraint has been reached. In their work relating stress and neuromotor noise to kinematic performance, Van Gemmert and Van Galen (1997) note that as the complexity of a task increases, so does the amount of neuromotor noise. In human task performance the goal is to find an optimum signal-to-noise ratio in a given situation. As such, during task performance the human brain can adapt to increased levels of noise by varying the biomechanical parameters of the active limbs in their interaction with the environment (Van Gemmert & Van Galen, 1997). They posit that in easy conditions, increased friction with the working area will be sufficient to compensate for increased levels of neuromotor noise; in contrast, at higher levels of complexity, further strategic adaptations will become necessary. One strategy is to increase overall speed of motor output since, from a mechanical perspective, higher movement speed is accompanied by higher limb stiffness which may in turn lead to effective inhibition of noise components (Van Gemmert & Van Galen, 1997). Leading from this, when confronted with a situation that is more complex, tonic limb stiffness should increase through the co-contraction of agonist and antagonist muscles which

would subsequently result in increased pen pressure. Given that the present study did not find an increase in pen pressure for either group suggests that perhaps the task was not complex enough to warrant having to generate greater pen pressure. Alternatively, the writing surface may have played a part in the results of the present study. In their study Schoemaker and colleagues (2005) placed a regular sheet of paper over top of the writing surface of the tablet, whereas in the present study children wrote directly on the smooth surface of the digitizing tablet. The increased 'friction' with the paper in the Schoemaker et al. study compared to the lack of 'friction' with the writing surface of the smooth tablet in the present study may have led to the disparate results. As such, it may be that given that children were writing directly on a smooth surface in the present study, no adaptations in their pen pressure were required to stabilize their motor output.

Alternatively, there may have been another factor at play that was not accounted for in the present study. Lee, Chen and Tsai (2013) examined kinematic performance of children with ADHD only, children with ADHD and DCD, and control children on tracking and pursuit tasks directly on the surface of a digitizing tablet. Results indicated children with ADHD demonstrated good fine motor fluency and flexibility, but children with both ADHD and DCD exhibited deficient performance on both measures. Additionally, children with ADHD had more difficulty with the pursuit task (which required a higher level of cognitive processing), compared to typically developing peers. The greatest difficulty was found in children with both ADHD and DCD. It is likely given the high co-existence of ADHD and DCD that the ADHD sample used in the present study contained at least some children with motor difficulties severe enough to constitute DCD. Unfortunately, sufficient data is not available to code for DCD in the present study. Lee et al.'s (2013) results suggest that it might be DCD that accounts for many of the deficits seen in the ADHD groups of this and other studies. For instance, neither Adi-Japha et al. (2007), nor Schoemaker and colleagues (2005) reported whether or not the presence of DCD was assessed in their samples.

Pen Pressure on a More Constrained Drawing Task

The final aim of the present study was to examine the effects of task constraint on a measure of pen pressure. Barkley's (1997, 2006) model proposes that with greater task constraints and cognitive demands, children with ADHD will have greater difficulties

controlling their motor output. As described above, with increasing task demands, as would be the case for increased constraint, the capacity of the working memory system would become overloaded (McCutchen, 1996) and therefore difficulties in motor output regulation would be expected in children with ADHD.

No differences were found between groups on pen pressure in the present study when drawing either a less constrained (BOT-2 Crooked path) or more constrained drawing (BOT-2 Curved path). In their study, Schoemaker et al. (2005) determined that children with ADHD completed patterns with greater pen pressure, but only when their writing was most constrained. The different results of Schoemaker and colleagues (2005) may be due to different task requirements. Whereas the children in the Schoemaker et al. study were required to write self-generated single or multi-peaked lines, children in the present study were required to take into consideration external cues to complete the tasks. For example, in the present study children had to draw a continuous line in between either two crooked lines, or two smooth lines. In contrast, children in the Schoemaker et al. (2005) study were asked to write either one, two, three, or four peaked angular lines without any external cues. Given that poor signal-to-noise ratios result in less fluent writing, which is compensated for by applying a biomechanical noise-filtering strategy of increased limb stiffness (i.e., greater pen pressure; Van Den Heuvel, Van Galen, Teulings, & Van Gemmert, 1998; Van Gemmert & Van Galen, 1997), it would have been expected that greater stylus pressure would have been exhibited by children with ADHD in the more constrained condition. Since children with ADHD tend to have more difficulties with more cognitively demanding tasks that place a greater load on working memory (e.g., Barkley, 1997, 2006), it would be expected that the decrease in working memory capacity for completing more constrained tasks would impact their motor output more so than in control children who are not expected to demonstrate as great a decrease in working memory capacity when completing such tasks. As such, it may be that the BOT-2 Crooked and Curved path tasks were not different enough in their level of constraint to elicit a difference in pen pressure in the two groups.

Limitations of Current Research and Future Directions

Although improvements of the present study over previous ones include the use of a larger sample size for the ADHD group than is typical, and the use of an objective

measure of handwriting quality, this study is not without its limitations. One improvement that could be made in future research is to ask the children to write on a piece of paper positioned over top of the digitizing tablet, and to also use an inking pen. Throughout the course of the study, almost every child commented that it felt very "slippery" when writing directly on the digitizing tablet. Even though children were given the opportunity to practice writing on the smooth surface prior to starting study tasks, eliminating this variable completely in future research is recommended in order to keep the task demands as close as possible to those encountered 'in the real world' (i.e., children usually write on paper, not on smooth surfaced digitizing tablets). Related, it is unclear to what extent a child is compensating in some manner for working on a smooth, relatively frictionless surface. The lack of 'friction' from the tablet surface may have impacted the results looking at pen pressure in particular. As noted above, it is through the sensory feedback gained from 'friction' when writing on a surface that the brain knows to adjust muscle contractions to increase pen pressure in order to stabilize the writing (Van Gemmert & Van Galen, 1998). Given the relatively 'frictionless' surface of the writing tablet, no adjustment in muscle contraction or pen pressure was necessary. As such, future studies should include a piece of paper placed over top of the tablet when examining pen pressure.

Another limitation of the present study is that presentation of RPT items was not randomized. As such, all children completed the patterns first on a blank screen, followed by between 3 cm lines, followed by between 2 cm lines, and finally between 1 cm lines. Greater normalized jerk may have been found in the 1 cm condition merely because it was the last condition administered, and fatigue effects may have impacted performance. This situation may not be the case given that the condition with the least amount of normalized jerk was the 2 cm condition, presented immediately before the 1 cm condition and past the half-way mark of the RPT administration. Additionally, children were given multiple breaks throughout the administration of the RPT, and any time that a child indicated that their hand hurt they were asked to take a break. After completion of the RPT, the researcher reviewed each item to ensure that it had been correctly recorded by the MovAlyzeR program (i.e., the child had not accidently lifted the pen for too long which would have stopped recording), and any items that were not fully

recorded were re-administered, resulting in a quasi-randomized item presentation.
Despite this, to ensure that fatigue effects did not play a role future research should ensure
that items are presented in a randomized fashion.

The present study only examined children with ADHD after a medication washout
period. This was done in order to be able to include more children with ADHD in the
present sample, since not all children with ADHD take medication and to reduce the
incidence of attrition due to the addition of another lab visit. Although this approach
allowed for the inclusion of a greater number of participants (i.e., approximately 7.9% of
the present sample of children diagnosed with ADHD was not taking any medication), it
did not allow for the comparison of children both on and off medication. Previous
research (e.g., Tucha & Lange, 2001, 2004, 2005) has demonstrated differences in several
kinematic variables in children with ADHD off medication compared to on medication.
As such, had children with ADHD been tested both on and off medication different
results may have been found in the present study. Additionally, since the majority of
children diagnosed with ADHD take medication to help manage their symptoms
(Barkley, 2006; Brossard-Racine, Shevell, Snider, Ageranioti Belanger, & Majnemer,
2012), including medication effects would speak to greater generalizability of the present
study results.

Given the lack of findings for several measures used in the present study, it may
be that the specific tasks used in this study may not have been difficult enough. For
instance, differences in kinematic variables for tasks of different complexity may have
been found had the tasks been more difficult. If the two task conditions (less versus more
complex) are not different enough, performance differences between groups may not be
elucidated. As such, future research examining the effects of complexity on kinematic
variables should attempt to ensure that the tasks are sufficiently difficult to elicit group
differences.

Another possibility for the lack of many significant findings may be that there
may be some other variable or variables not measured that are accounting for the lack of
group differences. One such variable discussed above is the presence of learning
disabilities, particularly in the ADHD sample. As described above, learning disabilities
may influence the processing of symbols, and may have affected the ADHD group

preferentially given that there were no control children with a diagnosed learning disability. This hypothesis was actually tested post-hoc by way of adding presence of learning disability as a covariate into the analyses; no change in results was found indicating that controlling for the effects of learning disability, there were no mean differences between the children with ADHD and control children.

Another variable that may have been overlooked is that of response speed. It is well documented in the literature that children with ADHD have a much shorter total time in completing a task than control children (e.g., Barkley, 2006). Unfortunately the present study did not directly evaluate speed of response, and therefore could not statistically control for this variable. It is expected that greater response speed in children with ADHD would influence the variable of peak vertical velocity, as well as the variability of peak vertical velocity. Guigon, Baraduc and Desmurget (2008) note that faster movements are necessarily more variable, therefore it would be expected that by not controlling for this influence, differences between groups on these variables may have been attenuated.

Comorbid psychiatric conditions were not coded in the present study and consequently could not be examined. Given that previous research examining the relationship between comorbidities such as depression (e.g., Mergl, Pogorall, Juckel, Rihl, Henkel, Frodl, et al. 2007; Schrijvers, Hulstijn, & Sabbe, 2008) or anxiety (e.g., Edwards & Rothwell, 2011; Mayes & Calhoun, 2007) have found difficulties with motor tasks in anxious and depressed individuals, future studies should examine the potential effects of such conditions on the kinematics of writing and drawing. For instance, depression has been shown to slow motor performance; as such, depression in the present sample would be expected to decrease writing speed. Future studies should include a broad based measure of psychopathology such as the Behavior Assessment System for Children – Second Edition (BASC-2).

While the present study attempted to improve upon previous research by including a more limited age group, namely children in grades four through eight, it would be interesting to examine age effects in fine motor control. Ideally, future research would include age bands comprised of large numbers of children in each specific age group. In this manner age-related changes in ADHD could be examined in relation to the normative

developmental changes in the neurobiological bases of motor performance that take place during the different ages. It may be that by limiting the age range to essentially four years, results were limited. For instance, a study conducted by Rueckriegel and colleagues (2008) found that the kinematic variables of speed, automation, and pen pressure increase with age when children (n = 177) were asked to draw circles. Age was not included as a covariate in the present study based on a kinematic study of children's handwriting conducted by Genna and Accardo (2011) which indicated no differences in kinematic variables between girls and boys from grade 4 onwards. Post-hoc analyses were conducted with age included as a covariate and no differences in results were found. However, adequate there may not have been adequate power to detect group effects in the present sample.

The ADHD sample in the present study was predominantly male. While this is in accordance with estimated gender differences (American Psychiatric Association, 2000) in ADHD, gender may have played a role. Of particular relevance to the present study, some researchers (e.g., Malecki & Jewell, 2003; Swanson & Berninger, 1996) note that girls write more than boys and are more likely to engage in literacy related activities and have more favourable attitudes towards reading and language than boys (e.g., MacMillan, Widaman, Balow, Hemsley, & Little, 1992; McKenna, Kear, & Ellsworth, 1995). As such, it would be expected for girls to be more proficient at handwriting skills; since the control group had a more equal distribution of girls and boys compared to the ADHD group, the ADHD group may have been disproportionately 'disadvantaged' in the tasks of writing given the lack of girls in the sample. However, post-hoc analyses with gender as a covariate indicated no difference in results. Given that gender was not a statistically significant covariate suggests that there were no differences in the group means for the outcome variables based on gender. However, there may not have been adequate power to detect effects in the present sample. Future research should strive to include samples so that potential gender differences can be examined more systematically.

In a similar vein, it would be interesting to examine whether there are any differences on kinematic variables across the different ADHD subtypes. While research examining fine and gross motor performance has found differences between ADHD subtypes, no previous research has examined kinematic performance differences across

the different subtypes of ADHD. For example Pitcher, Piek and Hay (2003) found that children with ADHD-HI demonstrated less severe motor problems overall, whereas Piek, Pitcher and Hay (1999) demonstrated that children with ADHD-PI and ADHD-C demonstrated greater fine motor difficulties. Since the present study included all subtypes of ADHD together in one group, differences between groups may have been attenuated.

Another model other than Barkley's Hybrid Theory to consider in future research is that of Fitts' Law (Fitts, 1954; Schmidt & Lee, 2011), which indicates that there is an inverse relationship between movement accuracy and movement speed (i.e., speed-accuracy tradeoff). Given that writing performance of children with ADHD on and off medication may be predicted by Fitt's model, it may be a useful and different way of characterizing the deficits seen in ADHD. For instance, Fitts' model posits an Index of Difficulty (Fitts, 1954; Schmidt & Lee, 2011) that could be used to objectively evaluate the complexity of a task and therefore assign a numerical value to the complexity; this would provide an objective way to quantify "complexity" as a variable.

Summary and Major Findings

Both clinical lore and previous research have indicated that children with ADHD experience difficulties with written output (e.g., Mayes & Calhoun, 2006, 2007). The present study aimed to determine some of the reasons why children with ADHD have such problems with fine motor control and writing through the use of digitizing technology. Such technology allows for the examination of the process behind writing, compared to simply examining the product, or outcome of writing. Results of the present study indicated that better quality of manuscript writing was associated with slower writing speed in children with ADHD, whereas better quality cursive writing was associated with both slower and less variable writing speed. In control children, better quality manuscript writing was associated with slower writing speed; better quality cursive writing speed was associated with less variable writing speed. Such differences between groups suggest that children with ADHD tend to slow down their writing when attempting to write neatly both in manuscript and cursive script, whereas control children do not need to slow down their writing for a more novel task (i.e, cursive writing). No group differences were found on either a measure of fluency or stylus pressure when

examining children's writing between different levels of constraint. Both groups demonstrated the most fluent writing between 2 cm spaced lines, which appear to represent a level that facilitates the maximal amount of writing fluency in children in grades four through eight. Lastly, results indicated that there were no stylus pressure differences between groups for either novel or motorically complex material. The fact that few group differences were found on various kinematic measures despite a large sample size raises the question of whether there may be some other variable, or external factors not measured by the present study or other research that contributes to the fine motor difficulties in children with ADHD.

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APPENDIX A

Description of kinematic variables and associated terminology

Kinematics	Time changes of position, velocity, and acceleration.
Stroke	The smallest unit of measurement. A stroke is the half cycle in an ongoing movement, defined by two sequential extreme points (maxima/minima) which are generated with a symmetric bell-shaped velocity profile centered at a given instant in time.
Velocity profile	A graph indicating how fast the participant's up and down component of writing is over time; i.e., time (x axis) by vertical velocity (y axis).
Peak vertical velocity	The maximum speed of movement in the ascending or descending direction.
Speed/Velocity	How fast the child writes or produces movement on the tablet.. This is measured in this study by peak vertical velocity (described above).
Number of changes in acceleration per stroke	Represents the degree of how automated a movement is. The ideal score is 1 (Mergl et al., 1999).
Stylus pressure	The force exerted during the execution of writing.
Relative intraindividual standard deviation of peak vertical velocity	A measure of the variability in movement. The ideal score is 0 (Mergl et al., 1999). It is derived by dividing the absolute standard deviation of the mean peak velocity of a word by its mean peak velocity. Less consistently controlled movements are indicated by higher values, while more consistently controlled movements are indicated by lower values (Mergl et al., 1999).
Normalized jerk	A measure of the smoothness of writing movements. Jerk is the change in acceleration per time. Since jerk level depends on the size and duration of movements, it needs to be normalized. The advantage of normalized jerk is that the coordination difficulties in patterns and different shapes, sizes, and durations can be compared (Teulings et al., 1997). For example, this allows you to compare larger sized writing with smaller sized writing on the same scale.

Fluency	The smoothness of writing movements, often measured by normalized jerk (described above). This is a reflection of the degree of automaticity (described below) of a writing movement, such that movements that are more automatic are more fluent and less 'jerky'.
Automaticity	The degree to which a movement is already a part of a motor program so that conscious control is not necessary to produce the movement.
Novelty	The degree to which a task is familiar. In the context of this study, cursive handwriting was considered more novel compared to manuscript handwriting given the greater emphasis placed on manuscript writing in the Ontario curriculum.
Complexity	The number of changes in direction when writing. The greater the number of changes in direction, the more complex the task; the fewer the changes in direction, the less complex the task.
Accuracy	In the context of the present study, accuracy reflects the ability of the child to: a) produce writing of an objectively high quality (i.e., scores on the THS-R), and b) the ability to maintain a continuously drawn line between two lines without going out of the lines (i.e., as reflected in the BOT-2 Crooked and Curved Path scores).

APPENDIX B

LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Examination of fine motor control in children with and without ADHD**

You are asked to participate in a research study conducted by Vilija Petrauskas from the Department of Psychology at the University of Windsor. Vilija Petrauskas is a doctoral student in the Clinical Neuropsychology track of the Clinical Psychology program, and data for this project will contribute to her doctoral dissertation conducted through the University of Windsor.

If you have any questions or concerns about the research, please feel free to contact Dr. Joseph Casey (Faculty Supervisor) by phone (, extension), or via email (@uwindsor.ca).

PURPOSE OF THE STUDY

The purpose of this study is to compare handwriting and drawing abilities of school-aged children in grades 4 through 8 with and without ADHD through the use of a digitizing tablet (i.e., a large iPad-type device). One of the main difficulties in children with ADHD is disinhibition, therefore it is thought that children with ADHD will have more difficulty controlling their fine motor output (i.e., handwriting and drawing). Such difficulties controlling their movement might result in more variation in the kinematic (i.e., movement) aspects of the child's writing or drawing in the form of more changes in writing/drawing speed (i.e., they speed up and slow down more when writing or drawing). Children with ADHD may also increase their pen pressure when writing or drawing to try and stabilize their movement. In the present study a number of characteristics will be examined and include: quality of handwriting, speed of writing and drawing, number of changes in speed when writing or drawing, as well as pen pressure when writing or drawing. It is anticipated that children with ADHD will demonstrate poorer quality of handwriting, faster writing and drawing, will change writing and drawing speed more than control children, and will write/draw with greater pen pressure, especially as the task becomes more complex. Results of this study will help better target intervention efforts for children with ADHD.

PROCEDURES

If you volunteer to participate in this study with your child, you will be asked to complete the following questionnaires:
- *Research Participant Questionnaire* – This is a form designed to collect information about your child's medical history and their development thus far.
- *Conners 3* – This is a measure of your child's behavioural and emotional difficulties.
- *Barkley Deficits in Executive Functioning Scale* – This is a measure of your child's executive functioning abilities.

We anticipate that you will be able to complete these forms while we work with your child. If you are not able to complete these forms or would feel more comfortable completing them at home, we will be happy to allow you to take these forms home. We anticipate that it will take approximately 45 minutes to complete both questionnaires.

If your child has previously been diagnosed with ADHD, they will need to stop taking their ADHD medication for 24 hours prior to the study (if they are taking stimulant medication such as Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance) or for 48 hours if they are presently taking other medication such as Strattera. Information regarding your child's diagnosis, current management including medication,

will be provided to Vilija Petrauskas and Dr. Casey. Your child is only asked to refrain from taking their ADHD medication for the study and can continue taking any other prescribed medications. While you complete the above questionnaires, your child will be asked to do the following things if he/she participates in this research study:

- Your child will be administered a *brief intelligence screening*, comprised of four short subtests from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV). For these subtests, your child will be asked to put together blocks, indicate how two words/concepts are similar, repeat back a series of digits both forwards and backwards, and copy symbols that are paired with numbers using a key as quickly as possible. This task will be used to get an estimated IQ.
- Your child will be administered a brief measure of *handwriting quality* on a *digitizing tablet*. This digitizing tablet is like a large iPad where your child will write on the screen and a computer will calculate different variables (e.g., how fast your child write, how hard the pen presses on the tablet). This device cannot hurt or cause your child discomfort in any way. For the handwriting quality task, your child will write from memory letters of the alphabet in alphabetical sequence, write from dictation the letters of the alphabet out of alphabetical order, write from dictation 8 numbers out of numerical order, copy 12 uppercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 6 words, copy 2 sentences, and write 6 words from dictation.
- Your child will be asked to *complete 5 different patterns* on a *digitizing tablet*.
- Your child will be administered the *Spelling* subtest of the Wechsler Individual Achievement Test – Third Edition (WIAT-III), and they will be asked to write the dictated words on the *digitizing tablet*.
- Your child will be asked to complete the Fine Motor Precision subtest of the Bruininks Oseretsky Test of Motor Proficiency – Second Edition (BOT-2). For this subtest, your child will be asked to fill in the outlines of two shapes, draw a line through a path (like a maze), and connect four dots on the *digitizing tablet*. Your child will also be asked to fold a piece of paper, and cut out a paper circle.

We anticipate that it will take no more than 180 minutes to complete all of these tasks.
This is the only time that your child will be required to attend, and there will be no follow-up sessions.

Your child will be assigned to either the ADHD or control group, based on whether or not they have previously been diagnosed with ADHD. If your child has never been diagnosed with ADHD, and they do not meet criteria based on your responses on the Conner's Parent Rating Scale-Revised, they will be assigned to the control group. If your child has previously been diagnosed with any of the three ADHD subtypes (primarily inattentive, hyperactive/impulsive, or combined), they will be placed in the ADHD group.

POTENTIAL RISKS AND DISCOMFORTS

There is no foreseeable risk or discomfort associated with your participating in this study. You may experience some mild to moderate distress while completing the questionnaire measures, especially if you are having difficulty with your child. If you experience any distress, please discuss your concerns with Dr. Casey. If you begin to experience distress after you leave the laboratory, please call Dr. Casey in his office (, ext.).

There is no foreseeable risk or discomfort associated with your child participating in this assessment process. Most children will find many of these tasks similar to ones they complete in school (e.g., spelling, writing), and therefore should be familiar with the task requirements. Most children will experience the intelligence screening measure and maze-like tasks as more novel, and may enjoy completing these tasks. Most children enjoy interacting with the digitizing tablet, and there is no foreseeable risk or discomfort in the use of this device. If your child is upset by the assessment or refuses to participate, we will attempt to reschedule the appointment for another time.

If your child is diagnosed with ADHD and is presently taking medication for this condition, they will be asked to refrain from taking their ADHD medication for 24 hours prior to the study if their medication is a stimulant (e.g., Ritalin, Concerta), or for 48 hours if they are taking a medication such as Strattera. This will allow for all of the medication to "wash-out" of your child's system prior to their participation in the study. The only foreseeable risk to your child from not taking their medication for 24 or 48 hours is an increased possibility of school-related difficulties on those days where your child is not taking their medication. To try and minimize this, the research team will try and schedule a time for your child to participate where the withdrawal of medication will have the least effect on their schooling (e.g., on a weekend, during a school holiday). There are no foreseeable risks to not taking ADHD medication for your child, other than the reappearance of ADHD symptoms for the time that they are not taking their medication.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

The main purpose of this study is to better understand fine motor control in children with ADHD and compare it with children who do not have ADHD. Clinicians, educators, and parents of children may benefit from the results of this study in that intervention efforts may be better targeted. Results of this study may also highlight the importance in examining not only symptoms of impulsivity, inattention, and hyperactivity in children with ADHD, but difficulties with fine motor control. This knowledge would help to better target intervention efforts. Society in general may benefit if we better understand fine motor control in children.

COMPENSATION FOR PARTICIPATION

All participants will receive a $10 gift certificate to either Chapter's or Staples upon completion of the study. Parents will also receive a written report of their child's performance on the motor tasks, their performance on a standardized measure of handwriting, as well as results of the IQ screening and academic measures (i.e., WIAT-III Spelling). All participants will receive the $10 gift certificate, whether or not they choose to complete the study in full or choose to withdraw. Individuals who withdraw from the study will receive a written report of their child's performance on all measures that were completed before withdrawing. Your child will receive a small toy for their participation. They will receive this toy regardless of whether they complete all items or choose to withdraw from the study.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. We will not discuss your results with anyone without your written permission. Once your forms are completed, your unique subject identification number will be written on every form and your name will be removed from all forms. These unique subject identification numbers will be used for data entry involving your responses. Consent forms and rating forms will be stored separately in locked cabinets. Only Dr. Casey will have access to your personally identifying information. In the event these data are ever to be destroyed, their destruction will be carried out in a manner to preserve your confidentiality.

There is one set of circumstances that would possibly necessitate a breach in confidentiality. In the event your or your child discloses that you or he/she is imminent danger or that your child is experiencing abuse/neglect, we may disclose this information to the appropriate authorities. Before this disclosure is made, we will discuss our concerns with you. As someone who works with children and families, Dr. Casey is a mandatory reporter for child abuse/neglect and is required by law to protect the right of the child. Confidentiality would only be breached regarding instances of abuse or neglect.

PARTICIPATION AND WITHDRAWAL

You can choose whether or not you and your child participate in this study. If you and your child volunteer to be in this study, you or your child may withdraw at any time without consequences of any kind. You and your child may also refuse to answer any questions you don't want to answer and still remain in the study.

The investigator may withdraw you from this research if circumstances arise which warrant doing so, such as it is discovered that your child does not meet eligibility criteria. In that event, Vilija Petrauskas or Dr. Casey will discuss the reasons your child is not eligible with you. If your child does not wish to participate in this study, they do not have to. In this case, there will not be any penalties to you or your child. If you or your child choose to withdraw from the study, any data collected will be confidentially destroyed and there will be no record of your participation.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

When this study is completed, we hope to publish these results in a scientific journal so other researchers and clinicians may benefit. Results of the present study will be posted on the Research Ethics Board website: www.uwindsor.ca/reb Results are likely to be available after September, 2013.

SUBSEQUENT USE OF DATA

This data will be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____   _____

Signature of Investigator   Date

APPENDIX C

Psychology Participant Pool – Study description

Title: Examination of fine motor control in children with and without ADHD.

Description: Are you the parent of a child in grades 4 through 8? If so, you and your child are invited to participate in a study comparing fine motor control (i.e., handwriting and drawing) in children with ADHD to those of children who do not have ADHD. Your child *need not* have ADHD to participate in this study. As part of this study, your child will complete a screening assessment including a partial IQ test, some paper tasks that examine fine motor control (e.g., folding and cutting), as well as some writing and drawing tasks on a digitizing tablet (e.g., a large iPad-type device). You will complete a background information questionnaire about your child, a questionnaire about their executive functioning (e.g., their ability to plan, organize, regulate themselves) as well as a questionnaire about your child's behaviour. If your child has ADHD and is taking medication, we ask that they not take their ADHD medication for 24 hours before the study if it is a stimulant medication (e.g., Ritalin, Concerta), or for 48 hours before the study if your child is taking Strattera. They may continue taking any other prescription medications.

This study will take no more than 180 minutes of you and your child's time, and is worth 3 bonus points if you are registered in the pool and you are registered in one or more eligible psychology courses. You will also have the option of receiving written feedback regarding how your child performed on the IQ, spelling, writing, drawing, and fine motor tasks. Your child will be able to choose a small toy from a toy chest as a 'Thank you' for participating.

Please sign up for one of the study slots, then email the researcher (Vilija Petrauskas at @uwindsor.ca) to set up a time to come in. You do not necessarily need to come in at the timeslot you sign up at; a mutually agreeable time to bring your child in will be decided via email. You are only signing up for a study timeslot so that study credit points can be awarded.

Eligibility Requirements: Must have a child in grades 4 through 8.

Duration: 180 minutes.

Points: 3

APPENDIX D

University
of Windsor

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Examination of fine motor control in children with and without ADHD.**

You are asked to participate in a research study conducted by Vilija Petrauskas from the Department of Psychology at the University of Windsor. Vilija Petrauskas is a doctoral student in the Clinical Neuropsychology track of the Clinical Psychology program, and data for this project will contribute to her doctoral dissertation conducted through the University of Windsor.

If you have any questions or concerns about the research, please feel free to contact Dr. Joseph Casey (Faculty Supervisor) by phone (, extension), or via email (@uwindsor.ca).

PURPOSE OF THE STUDY
The purpose of this study is to compare handwriting and drawing abilities of school-aged children in grades 4 through 8 with and without ADHD through the use of a digitizing tablet (i.e., a large iPad-type device). One of the main difficulties in children with ADHD is disinhibition, therefore it is thought that children with ADHD will have more difficulty controlling their fine motor output (i.e., handwriting and drawing). Such difficulties controlling their movement might result in more variation in the kinematic (i.e., movement) aspects of the child's writing or drawing in the form of more changes in writing/drawing speed (i.e., they speed up and slow down more when writing or drawing). Children with ADHD may also increase their pen pressure when writing or drawing to try and stabilize their movement. In the present study a number of characteristics will be examined and include: quality of handwriting, speed of writing and drawing, number of changes in speed when writing or drawing, as well as pen pressure when writing or drawing. It is anticipated that children with ADHD will demonstrate poorer quality of handwriting, faster writing and drawing, will change writing and drawing speed more than control children, and will write/draw with greater pen pressure, especially as the task becomes more complex. Results of this study will help better target intervention efforts for children with ADHD.

This form is for you to consent to *you* and *your child* participating in this research project.

PROCEDURES
If you consent to your child participating in this study, it is anticipated that the length of the study will be no more than 180 minutes. If your child has previously been diagnosed with ADHD, they will need to stop taking their ADHD medication for 24 hours prior to the study (if they are taking stimulant medication such as Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance) or for 48 hours if they are presently taking other medication such as Strattera. Your child is only asked to refrain from taking their ADHD medication for the study and can continue taking any other prescribed medications. Your child will be asked to do the following things if he/she participates in this research study:

- Your child will be administered a *brief intelligence screening*, comprised of four short subtests from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV). For these subtests, your child will be asked to put together blocks, indicate how two words/concepts are similar, repeat back a series of digits both forwards and backwards, and copy symbols that are paired with numbers using a key as quickly as possible. This task will be used to get an estimated IQ.
- Your child will be administered a brief measure of *handwriting quality* on a *digitizing tablet*. This digitizing tablet is like a large iPad where your child will write on the screen and a computer will calculate different variables (e.g., how fast your child writes, how hard the pen presses on the tablet). This device cannot hurt or cause your child discomfort in any way. For the handwriting quality task, your child will write from memory letters of the alphabet in alphabetical sequence, write from dictation the letters of the alphabet out of alphabetical order, write from dictation 8 numbers out of numerical

order, copy 12 uppercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 6 words, copy 2 sentences, and write 6 words from dictation.

- Your child will be asked to *complete 5 different patterns* on a *digitizing tablet*.
- Your child will be administered the *Spelling* subtest of the Wechsler Individual Achievement Test – Third Edition (WIAT-III), and they will be asked to write the dictated words on the *digitizing tablet*.
- Your child will be asked to complete the Fine Motor Precision subtest of the Bruininks Oseretsky Test of Motor Proficiency – Second Edition (BOT-2). For this subtest, your child will be asked to fill in the outlines of two shapes, draw a line through a path (like a maze), and connect four dots on the *digitizing tablet*. Your child will also be asked to fold a piece of paper, and cut out a paper circle.

If you volunteer to participate in this study, you will be asked to complete several forms about yourself and your child. These forms will include the following measures:

- *Research Participant Questionnaire* – This is a form designed to collect information about your child's medical history and their development thus far.
- *Conners 3* – This is a measure of your child's behavioural and emotional difficulties.
- *Barkley Deficits in Executive Functioning Scale* – This is a measure of your child's executive functioning abilities.

We anticipate that you will be able to complete these forms while we work with your child. If you are not able to complete these forms or would feel more comfortable completing them at home, we will be happy to allow you to take these forms home.

This is the only time that you and your child will be required to attend, and there will be no follow-up sessions.

POTENTIAL RISKS AND DISCOMFORTS

There is no foreseeable risk or discomfort associated with *your* participation in this study. You may experience some mild to moderate distress while completing these measures, especially if you are having difficulty with your child. If you experience any distress, please discuss your concerns with Dr. Casey. If you begin to experience distress after you leave the laboratory, please call Dr. Casey in his office (, ext.).

There is no foreseeable risk or discomfort associated with *your child* participating in this assessment process. Most children will find many of these tasks similar to ones they complete in school (e.g., spelling, writing), and therefore should be familiar with the task requirements. Most children will experience the intelligence screening measure and maze-like tasks as more novel, and may enjoy completing these tasks. Most children enjoy interacting with the digitizing tablet, and there is no foreseeable risk or discomfort in the use of this device. If your child is upset by the assessment or refuses to participate at the time, we will attempt to reschedule the appointment for another time. If your child absolutely does not want to participate, they do not need to participate. In this case there will be no negative consequences to you or your child.

If your child is diagnosed with ADHD and is presently taking medication for this condition, they will be asked to refrain from taking their ADHD medication for 24 hours prior to the study if their medication is a stimulant (e.g., Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance), or for 48 hours if they are taking a medication such as Strattera. This will allow for all of the medication to "wash-out" of your child's system prior to their participation in the study. The only foreseeable risk to your child from not taking their ADHD medication for 24 or 48 hours is an increased possibility of school-related difficulties on those days where your child is not taking their medication. To try and minimize this, the research team will try and schedule a time for your child to participate where the withdrawal of medication will have the least effect on their schooling (e.g., on a weekend, during a school holiday). There are no foreseeable risks to not taking ADHD medication for your child, other than the reappearance of ADHD symptoms for the time that they are not taking their medication. Your child may continue taking other prescription medications, we only ask that they refrain from taking their ADHD medication.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

Following completion of the study, a brief report will be written summarizing your child's participation. This report will include information about your child's handwriting abilities, results of a brief IQ screen, as well as information regarding your child's spelling ability. In the event this evaluation uncovers a possible clinically significant problem, Dr. Casey will make a referral to a clinician working in the community for further assessment and/or intervention. It is your choice whether or not to pursue additional services. If you have questions about this summary report, please contact Dr. Casey (, ext.).

The main purpose of this study is to better understand fine motor control in children with ADHD and compare it with children who do not have ADHD. Clinicians, educators, and parents of children may benefit from the results of this study in that intervention efforts may be better targeted. Results of this study may also highlight the importance in examining not only symptoms of impulsivity, inattention, and hyperactivity in children with ADHD, but difficulties with fine motor control. This knowledge would help to better target intervention efforts. Society in general may benefit if we better understand fine motor control in children.

COMPENSATION FOR PARTICIPATION
You will receive 3 Psychology Participant Pool bonus points for no more than 180 minutes of your participation in this study. You may also choose to receive a written report of your child's performance on the motor tasks, their performance on a standardized measure of handwriting, as well as results of the IQ screening and academic measures (i.e., WIAT-III Spelling). Your child will receive a small toy for their participation. If you or your child choose to withdraw from the study, you will still receive credit points commensurate with the amount of time spent prior to withdrawal (i.e., if 30 minutes of the study are completed, you will receive 0.5 bonus points; if 1 hour is completed you will receive 1 bonus point, etc.). Individuals who withdraw from the study will receive a written report of their child's performance on all measures that were completed before withdrawing. Your child will receive a small toy for their participation; they will receive this toy regardless of whether they complete all items or choose to withdraw from the study.

CONFIDENTIALITY
Any information that is obtained in connection with this study and that can be identified with you or your child will remain confidential and will be disclosed only with your permission. We will not discuss your child's results with anyone, including school personnel, without your written permission. You and your child will be assigned a unique study identification number, which will appear in place of your names on every form used for this study. These unique subject identification numbers will be used for data entry and you and your child's name will never be included in any of the data entry files. Any public presentation of data from this study will involve only pooled data from all participants, and an individual's data will never be presented in isolation. Consent forms and other materials will be stored separately in locked cabinets in Dr. Casey's office. Only Dr. Casey will have access to your personally identifying information.

There is one set of circumstances that would possibly necessitate a breach in confidentiality. In the event you or your child discloses that you or he/she is imminent danger or that your child is experiencing abuse/neglect, we may disclose this information to the appropriate authorities. Before this disclosure is made, we will discuss our concerns with you. As someone who works with children and families, Dr. Casey is a mandatory reporter for child abuse/neglect and is required by law to protect the right of the child. Confidentiality would only be breached regarding instances of abuse or neglect.

PARTICIPATION AND WITHDRAWAL
You can choose whether or not you and your child participate in this study. If you and your child volunteer to be in this study, you or your child may withdraw at any time without consequences of any kind. You and your child may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so, such as it is discovered that your child does not meet eligibility criteria. In that event, Vilija Petrauskas or Dr. Casey will discuss the reasons your child is not eligible with you. If your child does not wish to participate in this study, they do not have to. In this case, there will not be any penalties to you or your child. If you or your child choose to withdraw from the study, any data collected will be confidentially destroyed and there will be no record of your participation.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

When this study is completed, we hope to publish these results in a scientific journal so other researchers and clinicians may benefit. Results of the present study will be posted on the Research Ethics Board website: www.uwindsor.ca/reb Results are likely to be available after September, 2013.

SUBSEQUENT USE OF DATA
This data will be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS
You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH SUBJECT/LEGAL REPRESENTATIVE

I understand the information provided for the study *Examination of fine motor control in children with ADHD* as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

_____   _____
Name of Child   Name of Parent of Legal Guardian

_____
Signature of Parent or Legal Guardian

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____   _____
  Signature of Investigator   Date

APPENDIX E

University
of Windsor

LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Examination of fine motor control in children with and without ADHD**

You are asked to participate in a research study conducted by Vilija Petrauskas from the Department of Psychology at the University of Windsor.   Vilija Petrauskas is a doctoral student in the Clinical Neuropsychology track of the Clinical Psychology program, and data for this project will contribute to her doctoral dissertation conducted through the University of Windsor.

If you have any questions or concerns about the research, please feel free to contact Dr. Joseph Casey (Faculty Supervisor) by phone (, extension), or via email (@uwindsor.ca).

PURPOSE OF THE STUDY
The purpose of this study is to compare handwriting and drawing abilities of school-aged children in grades 4 through 8 with and without ADHD through the use of a digitizing tablet (i.e., a large iPad-type device). One of the main difficulties in children with ADHD is disinhibition, therefore it is thought that children with ADHD will have more difficulty controlling their fine motor output (i.e., handwriting and drawing). Such difficulties controlling their movement might result in more variation in the kinematic (i.e., movement) aspects of the child's writing or drawing in the form of more changes in writing/drawing speed (i.e., they speed up and slow down more when writing or drawing).   Children with ADHD may also increase their pen pressure when writing or drawing to try and stabilize their movement.   In the present study a number of characteristics will be examined and include: quality of handwriting, speed of writing and drawing, number of changes in speed when writing or drawing, as well as pen pressure when writing or drawing.   It is anticipated that children with ADHD will demonstrate poorer quality of handwriting, faster writing and drawing, will change writing and drawing speed more than control children, and will write/draw with greater pen pressure, especially as the task becomes more complex.   Results of this study will help better target intervention efforts for children with ADHD.

PROCEDURES
If you volunteer to participate in this study with your child, you will be asked to complete the following questionnaires:

- *Research Participant Questionnaire* – This is a form designed to collect information about your child's medical history and their development thus far.
- *Conners 3* – This is a measure of your child's behavioural and emotional difficulties.
- *Barkley Deficits in Executive Functioning Scale* – This is a measure of your child's executive functioning abilities.

We anticipate that you will be able to complete these forms while we work with your child.   If you are not able to complete these forms or would feel more comfortable completing them at home, we will be happy to allow you to take these forms home.   We anticipate that it will take approximately 45 minutes to complete all questionnaires.

If your child has previously been diagnosed with ADHD, they will need to stop taking their ADHD medication for 24 hours prior to the study (if they are taking stimulant medication such as Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance) or for 48 hours if they are presently taking other medication such as Strattera.   Your child is only asked to refrain from taking their ADHD medication for the study and

can continue taking any other prescribed medications. While you complete the above questionnaires, your child will be asked to do the following things if he/she participates in this research study:

- Your child will be administered a *brief intelligence screening*, comprised of four short subtests from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV). For these subtests, your child will be asked to put together blocks, indicate how two words/concepts are similar, repeat back a series of digits both forwards and backwards, and copy symbols that are paired with numbers using a key as quickly as possible. This task will be used to get an estimated IQ.

- Your child will be administered a brief measure of *handwriting quality* on a *digitizing tablet*. This digitizing tablet is like a large iPad where your child will write on the screen and a computer will calculate different variables (e.g., how fast your child write, how hard the pen presses on the tablet). This device cannot hurt or cause your child discomfort in any way. For the handwriting quality task, your child will write from memory letters of the alphabet in alphabetical sequence, write from dictation the letters of the alphabet out of alphabetical order, write from dictation 8 numbers out of numerical order, copy 12 uppercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 6 words, copy 2 sentences, and write 6 words from dictation.

- Your child will be asked to *complete 5 different patterns* on a *digitizing tablet*.

- Your child will be administered the *Spelling* subtest of the Wechsler Individual Achievement Test – Third Edition (WIAT-III), and they will be asked to write the dictated words on the *digitizing tablet*.

- Your child will be asked to complete the Fine Motor Precision subtest of the Bruininks Oseretsky Test of Motor Proficiency – Second Edition (BOT-2). For this subtest, your child will be asked to fill in the outlines of two shapes, draw a line through a path (like a maze), and connect four dots on the *digitizing tablet*. Your child will also be asked to fold a piece of paper, and cut out a paper circle.

We anticipate that it will take no more than 180 minutes to complete all of these tasks.
This is the only time that your child will be required to attend, and there will be no follow-up sessions.

Your child will be assigned to either the ADHD or control group, based on whether or not they have previously been diagnosed with ADHD. If your child has never been diagnosed with ADHD, and they do not meet criteria based on your responses on the Conner's Parent Rating Scale-Revised, they will be assigned to the control group. If your child has previously been diagnosed with any of the three ADHD subtypes (primarily inattentive, hyperactive/impulsive, or combined), they will be placed in the ADHD group.

POTENTIAL RISKS AND DISCOMFORTS
There is no foreseeable risk or discomfort associated with your participating in this study. You may experience some mild to moderate distress while completing the questionnaire measures, especially if you are having difficulty with your child. If you experience any distress, please discuss your concerns with Dr. Casey. If you begin to experience distress after you leave the laboratory, please call Dr. Casey in his office (, ext.).

There is no foreseeable risk or discomfort associated with your child participating in this assessment process. Most children will find many of these tasks similar to ones they complete in school (e.g., spelling, writing), and therefore should be familiar with the task requirements. Most children will experience the intelligence screening measure and maze-like tasks as more novel, and may enjoy completing these tasks. Most children enjoy interacting with the digitizing tablet, and there is no foreseeable risk or discomfort in the use of this device. If your child is upset by the assessment or refuses to participate, we will attempt to reschedule the appointment for another time.

If your child is diagnosed with ADHD and is presently taking medication for this condition, they will be asked to refrain from taking their ADHD medication for 24 hours prior to the study if their medication is a stimulant (e.g., Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance), or for 48 hours if they are taking a medication such as Strattera. This will allow for all of the medication to "wash-out" of your

child's system prior to their participation in the study. The only foreseeable risk to your child from not taking their medication for 24 or 48 hours is an increased possibility of school-related difficulties on those days where your child is not taking their medication. To try and minimize this, the research team will try and schedule a time for your child to participate where the withdrawal of medication will have the least effect on their schooling (e.g., on a weekend, during a school holiday). There are no foreseeable risks to not taking ADHD medication for your child, other than the reappearance of ADHD symptoms for the time that they are not taking their medication.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY
The main purpose of this study is to better understand fine motor control in children with ADHD and compare it with children who do not have ADHD. Clinicians, educators, and parents of children may benefit from the results of this study in that intervention efforts may be better targeted. Results of this study may also highlight the importance in examining not only symptoms of impulsivity, inattention, and hyperactivity in children with ADHD, but difficulties with fine motor control. This knowledge would help to better target intervention efforts. Society in general may benefit if we better understand fine motor control in children.

COMPENSATION FOR PARTICIPATION
You will receive 3 Psychology Participant Pool bonus points for no more than 180 minutes of your participation in this study. You may also choose to receive a written report of your child's performance on the motor tasks, their performance on a standardized measure of handwriting, as well as results of the IQ screening and academic measures (i.e., WIAT-III Spelling). Your child will receive a small toy for their participation. If you or your child choose to withdraw from the study, you will still receive credit points commensurate with the amount of time spent prior to withdrawal (i.e., if 30 minutes of the study are completed, you will receive 0.5 bonus points; if 1 hour is completed you will receive 1 bonus point, etc.). Individuals who withdraw from the study will receive a written report of their child's performance on all measures that were completed before withdrawing. Your child will receive a small toy for their participation; they will receive this toy regardless of whether they complete all items or choose to withdraw from the study.

CONFIDENTIALITY
Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. We will not discuss your results with anyone without your written permission. Once your forms are completed, your unique subject identification number will be written on every form and your name will be removed from all forms. These unique subject identification numbers will be used for data entry involving your responses. Consent forms and rating forms will be stored separately in locked cabinets. Only Dr. Casey will have access to your personally identifying information. In the event these data are ever to be destroyed, their destruction will be carried out in a manner to preserve your confidentiality.

There is one set of circumstances that would possibly necessitate a breach in confidentiality. In the event you or your child discloses that you or he/she is imminent danger or that your child is experiencing abuse/neglect, we may disclose this information to the appropriate authorities. Before this disclosure is made, we will discuss our concerns with you. As someone who works with children and families, Dr. Casey is a mandatory reporter for child abuse/neglect and is required by law to protect the right of the child. Confidentiality would only be breached regarding instances of abuse or neglect.

PARTICIPATION AND WITHDRAWAL
You can choose whether or not you and your child participate in this study. If you and your child volunteer to be in this study, you or your child may withdraw at any time without consequences of any kind. You and your child may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so, such as it is discovered that your child does not meet eligibility criteria. In that event, Vilija Petrauskas or Dr. Casey will discuss the reasons your child is not eligible with you. If your child does not wish to participate in this study, they do not have to. In this case, there will not be any penalties to you or your child. If you or your child choose to withdraw from the study, any data collected will be confidentially destroyed and there will be no record of your participation.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS
When this study is completed, we hope to publish these results in a scientific journal so other researchers and clinicians may benefit. Results of the present study will be posted on the Research Ethics Board website: www.uwindsor.ca/reb Results are likely to be available after September, 2013.

SUBSEQUENT USE OF DATA
This data will be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS
You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____   _____
Signature of Investigator   Date

APPENDIX F

University
of Windsor
thinking forward

ARE YOU THE PARENT OF A CHILD IN GRADES 4 – 8?

We are seeking children in grades 4 – 8 to participate in a research study examining fine motor control in children with ADHD and comparing it to children who do not have ADHD. **Your child does NOT need to have been diagnosed with ADHD to participate!**

For your time, you will receive a $10 gift card to Chapter's or Staples. You will also receive a brief report of your child's performance on all of the measures. This report will include information about results of an intelligence screening, measures of handwriting quality, fine motor control, and spelling ability. Note that this report does not replace an official psychological assessment.

If you are interested in participating, or would like more information, please contact Vilija Petrauskas (███████████████████████████).

*This study has been approved by the University of Windsor Research Ethics Board

APPENDIX G

ARE YOU THE PARENT OF A CHILD IN GRADE 4 – 8?

We are seeking children in grades 4 through 8 to participate in a research study examining fine motor control in children with ADHD and comparing it to children who do not have ADHD. ***Your child need not have been diagnosed with ADHD to participate***.

If you choose to participate you, the parent, would be asked to complete the following:
1. Demographics questionnaire
2. Questionnaire about executive functioning (i.e., organization, planning)
3. Questionnaire about your child's behaviour

Your child would be asked to do the following:
1. A brief intelligence screening
2. Various measures on a digitizing tablet (similar to a large iPad):
   a. Complete some patterns
   b. Do some printing and cursive writing
   c. Complete a spelling test
   d. Complete a measure of fine motor control (e.g., mazes, connecting dots)

For your time you will receive:
✓ A $10 gift card to Chapter's or Staples!
✓ Your child will also receive a $10 gift card!
✓ A brief summary of your child's results on all standardized measures (i.e., intelligence screening, measures of handwriting quality, spelling ability, and fine motor ability)
➢ *Note that this report does not replace an official psychological assessment*

If you are interested in participating, or would like some more information please contact Vilija Petrauskas (; @uwindsor.ca)

*This study has been approved by the University of Windsor Research Ethics Board

APPENDIX H

University
of Windsor

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Examination of fine motor control in children with ADHD.**

You are asked to participate in a research study conducted by Vilija Petrauskas from the Department of Psychology at the University of Windsor.   Vilija Petrauskas is a doctoral student in the Clinical Neuropsychology track of the Clinical Psychology program, and data for this project will contribute to her doctoral dissertation conducted through the University of Windsor.

If you have any questions or concerns about the research, please feel free to contact Dr. Joseph Casey (Faculty Supervisor) by phone (, extension), or via email (@uwindsor.ca).

PURPOSE OF THE STUDY

The purpose of this study is to compare handwriting and drawing abilities of school-aged children in grades 4 through 8 with and without ADHD through the use of a digitizing tablet (i.e., a large iPad-type device). One of the main difficulties in children with ADHD is disinhibition, therefore it is thought that children with ADHD will have more difficulty controlling their fine motor output (i.e., handwriting and drawing). Such difficulties controlling their movement might result in more variation in the kinematic (i.e., movement) aspects of the child's writing or drawing in the form of more changes in writing/drawing speed (i.e., they speed up and slow down more when writing or drawing).   Children with ADHD may also increase their pen pressure when writing or drawing to try and stabilize their movement. In the present study a number of characteristics will be examined and include: quality of handwriting, speed of writing and drawing, number of changes in speed when writing or drawing, as well as pen pressure when writing or drawing. It is anticipated that children with ADHD will demonstrate poorer quality of handwriting, faster writing and drawing, will change writing and drawing speed more than control children, and will write/draw with greater pen pressure, especially as the task becomes more complex. Results of this study will help better target intervention efforts for children with ADHD.

This form is for you to consent to *you* and *your child* participating in this research project.

PROCEDURES

If you consent to your child participating in this study, it is anticipated that the length of the study will be no more than 180 minutes. If your child has previously been diagnosed with ADHD, they will need to stop taking their ADHD medication for 24 hours prior to the study (if they are taking stimulant medication such as Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance) or for 48 hours if they are presently taking other medication such as Strattera.   Information regarding your child's diagnosis and current management including medication will be provided to Vilija Petrauskas and Dr. Casey. Your child is only asked to refrain from taking their ADHD medication for the study and can continue taking any other prescribed medications.

Your child will be asked to do the following things if he/she participates in this research study:
- Your child will be administered a *brief intelligence screening*, comprised of four short subtests from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV).   For these subtests, your child will be asked to put together blocks, indicate how two words/concepts are similar, repeat back a series of digits both forwards and backwards, and copy symbols that are paired with numbers using a key as quickly as possible. This task will be used to get an estimated IQ.

- Your child will be administered a brief measure of *handwriting quality* on a *digitizing tablet*. This digitizing tablet is like a large iPad where your child will write on the screen and a computer will calculate different variables (e.g., how fast your child writes, how hard the pen presses on the tablet). This device cannot hurt or cause your child discomfort in any way. For the handwriting quality task, your child will write from memory letters of the alphabet in alphabetical sequence, write from dictation the letters of the alphabet out of alphabetical order, write from dictation 8 numbers out of numerical order, copy 12 uppercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 6 words, copy 2 sentences, and write 6 words from dictation.
- Your child will be asked to *complete 5 different patterns* on a *digitizing tablet*.
- Your child will be administered the *Spelling* subtest of the Wechsler Individual Achievement Test – Third Edition (WIAT-III), and they will be asked to write the dictated words on the *digitizing tablet*.
- Your child will be asked to complete the Fine Motor Precision subtest of the Bruininks Oseretsky Test of Motor Proficiency – Second Edition (BOT-2). For this subtest, your child will be asked to fill in the outlines of two shapes, draw a line through a path (like a maze), and connect four dots on the *digitizing tablet*. Your child will also be asked to fold a piece of paper, and cut out a paper circle.

If you volunteer to participate in this study, you will be asked to complete several forms about yourself and your child. These forms will include the following measures:

- *Research Participant Questionnaire* – This is a form designed to collect information about your child's medical history and their development thus far.
- *Conners 3* – This is a measure of your child's behavioural and emotional difficulties.
- *Barkley Deficits in Executive Functioning Scale* – This is a measure of your child's executive functioning abilities.

We anticipate that you will be able to complete these forms while we work with your child. If you are not able to complete these forms or would feel more comfortable completing them at home, we will be happy to allow you to take these forms home.

This is the only time that you and your child will be required to attend, and there will be no follow-up sessions.

POTENTIAL RISKS AND DISCOMFORTS

There is no foreseeable risk or discomfort associated with *your* participation in this study. You may experience some mild to moderate distress while completing these measures, especially if you are having difficulty with your child. If you experience any distress, please discuss your concerns with Dr. Casey. If you begin to experience distress after you leave the laboratory, please call Dr. Casey in his office (, ext.).

There is no foreseeable risk or discomfort associated with *your child* participating in this assessment process. Most children will find many of these tasks similar to ones they complete in school (e.g., spelling, writing), and therefore should be familiar with the task requirements. Most children will experience the intelligence screening measure and maze-like tasks as more novel, and may enjoy completing these tasks. Most children enjoy interacting with the digitizing tablet, and there is no foreseeable risk or discomfort in the use of this device. If your child is upset by the assessment or refuses to participate at the time, we will attempt to reschedule the appointment for another time. If your child absolutely does not want to participate, they do not need to participate. In this case there will be no negative consequences to you or your child.

If your child is diagnosed with ADHD and is presently taking medication for this condition, they will be asked to refrain from taking their ADHD medication for 24 hours prior to the study if their medication is a stimulant (e.g., Ritalin, Concerta), or for 48 hours if they are taking a medication such as Strattera. This will allow for all of the medication to "wash-out" of your child's system prior to their participation in the study. The only foreseeable risk to your child from not taking their ADHD medication for 24 or 48 hours is

an increased possibility of school-related difficulties on those days where your child is not taking their medication. To try and minimize this, the research team will try and schedule a time for your child to participate where the withdrawal of medication will have the least effect on their schooling (e.g., on a weekend, during a school holiday). There are no foreseeable risks to not taking ADHD medication for your child, other than the reappearance of ADHD symptoms for the time that they are not taking their medication. Your child may continue taking other prescription medications, we only ask that they refrain from taking their ADHD medication.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

Following completion of the study, a brief report will be written summarizing your child's participation. This report will include information about your child's handwriting abilities, results of a brief IQ screen, as well as information regarding your child's spelling ability. In the event this evaluation uncovers a possible clinically significant problem, Dr. Casey will make a referral to a clinician working in the community for further assessment and/or intervention. It is your choice whether or not to pursue additional services. If you have questions about this summary report, please contact Dr. Casey (, ext.).

The main purpose of this study is to better understand fine motor control in children with ADHD and compare it with children who do not have ADHD. Clinicians, educators, and parents of children may benefit from the results of this study in that intervention efforts may be better targeted. Results of this study may also highlight the importance in examining not only symptoms of impulsivity, inattention, and hyperactivity in children with ADHD, but difficulties with fine motor control. This knowledge would help to better target intervention efforts. Society in general may benefit if we better understand fine motor control in children.

COMPENSATION FOR PARTICIPATION

All participants will receive a $10 gift certificate to either Chapter's or Staples upon completion of the study. Parents will also receive a written report of their child's performance on the motor tasks, their performance on a standardized measure of handwriting, as well as results of the IQ screening and academic measures (i.e., WIAT-III Spelling). All participants will receive the $10 gift certificate, whether or not they choose to complete the study in full or choose to withdraw. Individuals who withdraw from the study will receive a written report of their child's performance on all measures that were completed before withdrawing. Your child will receive a small toy for their participation. They will receive this toy regardless of whether they complete all items or choose to withdraw from the study.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you or your child will remain confidential and will be disclosed only with your permission. We will not discuss your child's results with anyone, including school personnel, without your written permission. You and your child will be assigned a unique study identification number, which will appear in place of your names on every form used for this study. These unique subject identification numbers will be used for data entry and you and your child's name will never be included in any of the data entry files. Any public presentation of data from this study will involve only pooled data from all participants, and an individual's data will never be presented in isolation. Consent forms and other materials will be stored separately in locked cabinets in Dr. Casey's office. Only Dr. Casey will have access to your personally identifying information. All study data will be destroyed 5 years following the completion of the study. When these data are destroyed, their destruction will be carried out in a manner to preserve you and your child's confidentiality.

There is one set of circumstances that would possibly necessitate a breach in confidentiality. In the event you or your child discloses that you or he/she is imminent danger or that your child is experiencing abuse/neglect, we may disclose this information to the appropriate authorities. Before this disclosure is made, we will discuss our concerns with you. As someone who works with children and families, Dr. Casey is a mandatory reporter for child abuse/neglect and is required by law to protect the right of the child. Confidentiality would only be breached regarding instances of abuse or neglect.

PARTICIPATION AND WITHDRAWAL

You can choose whether or not you and your child participate in this study. If you and your child volunteer to be in this study, you or your child may withdraw at any time without consequences of any kind. You and your child may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so, such as it is discovered that your child does not meet eligibility criteria. In that event, Vilija Petrauskas or Dr. Casey will discuss the reasons your child is not eligible with you. If your child does not wish to participate in this study, they do not have to. In this case, there will not be any penalties to you or your child. If you or your child choose to withdraw from the study, any data collected will be confidentially destroyed and there will be no record of your participation.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

When this study is completed, we hope to publish these results in a scientific journal so other researchers and clinicians may benefit. Results of the present study will be posted on the Research Ethics Board website: www.uwindsor.ca/reb Results are likely to be available after September, 2013.

SUBSEQUENT USE OF DATA

This data will be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH SUBJECT/LEGAL REPRESENTATIVE

I understand the information provided for the study *Examination of fine motor control in children with ADHD* as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

_____   _____
Name of Child   Name of Parent of Legal Guardian

_____
Signature of Parent or Legal Guardian

Phone Number: _____

Best time to contact you: _____

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____   _____
Signature of Investigator   Date

APPENDIX I

University
of Windsor

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Examination of fine motor control in children with and without ADHD.**

You are asked to participate in a research study conducted by Vilija Petrauskas from the Department of Psychology at the University of Windsor. Vilija Petrauskas is a doctoral student in the Clinical Neuropsychology track of the Clinical Psychology program, and data for this project will contribute to her doctoral dissertation conducted through the University of Windsor.

If you have any questions or concerns about the research, please feel free to contact Dr. Joseph Casey (Faculty Supervisor) by phone (, extension), or via email (@uwindsor.ca).

PURPOSE OF THE STUDY
The purpose of this study is to compare handwriting and drawing abilities of school-aged children in grades 4 through 8 with and without ADHD through the use of a digitizing tablet (i.e., a large iPad-type device). One of the main difficulties in children with ADHD is disinhibition, therefore it is thought that children with ADHD will have more difficulty controlling their fine motor output (i.e., handwriting and drawing). Such difficulties controlling their movement might result in more variation in the kinematic (i.e., movement) aspects of the child's writing or drawing in the form of more changes in writing/drawing speed (i.e., they speed up and slow down more when writing or drawing). Children with ADHD may also increase their pen pressure when writing or drawing to try and stabilize their movement. In the present study a number of characteristics will be examined and include: quality of handwriting, speed of writing and drawing, number of changes in speed when writing or drawing, as well as pen pressure when writing or drawing. It is anticipated that children with ADHD will demonstrate poorer quality of handwriting, faster writing and drawing, will change writing and drawing speed more than control children, and will write/draw with greater pen pressure, especially as the task becomes more complex. Results of this study will help better target intervention efforts for children with ADHD.

This form is for you to consent to *you* and *your child* participating in this research project.

PROCEDURES
If you consent to your child participating in this study, it is anticipated that the length of the study will be no more than 180 minutes. If your child has previously been diagnosed with ADHD, they will need to stop taking their ADHD medication for 24 hours prior to the study (if they are taking stimulant medication such as Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance) or for 48 hours if they are presently taking other medication such as Strattera. Your child is only asked to refrain from taking their ADHD medication for the study and can continue taking any other prescribed medications. Your child will be asked to do the following things if he/she participates in this research study:

- Your child will be administered a *brief intelligence screening*, comprised of four short subtests from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV). For these subtests, your child will be asked to put together blocks, indicate how two words/concepts are similar, repeat back a series of digits both forwards and backwards, and copy symbols that are paired with numbers using a key as quickly as possible. This task will be used to get an estimated IQ.
- Your child will be administered a brief measure of *handwriting quality* on a *digitizing tablet*. This digitizing tablet is like a large iPad where your child will write on the screen and a computer will calculate different variables (e.g., how fast your child writes, how hard the pen presses on the tablet). This device cannot hurt or cause your child discomfort in any way. For the handwriting quality task, your child will write from memory letters of the alphabet in alphabetical sequence,

write from dictation the letters of the alphabet out of alphabetical order, write from dictation 8 numbers out of numerical order, copy 12 uppercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 6 words, copy 2 sentences, and write 6 words from dictation.

- Your child will be asked to *complete 5 different patterns* on a *digitizing tablet*.
- Your child will be administered the *Spelling* subtest of the Wechsler Individual Achievement Test – Third Edition (WIAT-III), and they will be asked to write the dictated words on the *digitizing tablet*.
- Your child will be asked to complete the Fine Motor Precision subtest of the Bruininks Oseretsky Test of Motor Proficiency – Second Edition (BOT-2). For this subtest, your child will be asked to fill in the outlines of two shapes, draw a line through a path (like a maze), and connect four dots on the *digitizing tablet*. Your child will also be asked to fold a piece of paper, and cut out a paper circle.

If you volunteer to participate in this study, you will be asked to complete several forms about yourself and your child. These forms will include the following measures:
- *Research Participant Questionnaire* – This is a form designed to collect information about your child's medical history and their development thus far.
- *Conners 3* – This is a measure of your child's behavioural and emotional difficulties.
- *Barkley Deficits in Executive Functioning Scale* – This is a measure of your child's executive functioning abilities.

We anticipate that you will be able to complete these forms while we work with your child. If you are not able to complete these forms or would feel more comfortable completing them at home, we will be happy to allow you to take these forms home.

This is the only time that you and your child will be required to attend, and there will be no follow-up sessions.

POTENTIAL RISKS AND DISCOMFORTS
There is no foreseeable risk or discomfort associated with *your* participation in this study. You may experience some mild to moderate distress while completing these measures, especially if you are having difficulty with your child. If you experience any distress, please discuss your concerns with Dr. Casey. If you begin to experience distress after you leave the laboratory, please call Dr. Casey in his office (, ext.).

There is no foreseeable risk or discomfort associated with *your child* participating in this assessment process. Most children will find many of these tasks similar to ones they complete in school (e.g., spelling, writing), and therefore should be familiar with the task requirements. Most children will experience the intelligence screening measure and maze-like tasks as more novel, and may enjoy completing these tasks. Most children enjoy interacting with the digitizing tablet, and there is no foreseeable risk or discomfort in the use of this device. If your child is upset by the assessment or refuses to participate at the time, we will attempt to reschedule the appointment for another time. If your child absolutely does not want to participate, they do not need to participate. In this case there will be no negative consequences to you or your child.

If your child is diagnosed with ADHD and is presently taking medication for this condition, they will be asked to refrain from taking their ADHD medication for 24 hours prior to the study if their medication is a stimulant (e.g., Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance), or for 48 hours if they are taking a medication such as Strattera. This will allow for all of the medication to "wash-out" of your child's system prior to their participation in the study. The only foreseeable risk to your child from not taking their ADHD medication for 24 or 48 hours is an increased possibility of school-related difficulties on those days where your child is not taking their medication. To try and minimize this, the research team will try and schedule a time for your child to participate where the withdrawal of medication will have the least effect on their schooling (e.g., on a weekend, during a school holiday). There are no foreseeable risks to not taking ADHD medication for your child, other than the reappearance of ADHD symptoms for the time that they are not taking their medication. Your child may continue taking other prescription medications, we only ask that they refrain from taking their ADHD medication.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY
Following completion of the study, a brief report will be written summarizing your child's participation. This report will include information about your child's handwriting abilities, results of a brief IQ screen, as well as information regarding your child's spelling ability. In the event this evaluation uncovers a possible clinically significant problem, Dr. Casey will make a referral to a clinician working in the community for further assessment and/or intervention. It is your choice whether or not to pursue additional services. If you have questions about this summary report, please contact Dr. Casey (, ext.).

The main purpose of this study is to better understand fine motor control in children with ADHD and compare it with children who do not have ADHD. Clinicians, educators, and parents of children may benefit from the results of this study in that intervention efforts may be better targeted. Results of this study may also highlight the importance in examining not only symptoms of impulsivity, inattention, and hyperactivity in children with ADHD, but difficulties with fine motor control. This knowledge would help to better target intervention efforts. Society in general may benefit if we better understand fine motor control in children.

COMPENSATION FOR PARTICIPATION
All participants will receive a $10 gift certificate to either Chapter's or Staples upon completion of the study. Parents will also receive a written report of their child's performance on the motor tasks, their performance on a standardized measure of handwriting, as well as results of the IQ screening and academic measures (i.e., WIAT-III Spelling). All participants will receive the $10 gift certificate, whether or not they choose to complete the study in full or choose to withdraw. Individuals who withdraw from the study will receive a written report of their child's performance on all measures that were completed before withdrawing. Your child will receive a small toy for their participation. They will receive this toy regardless of whether they complete all items or choose to withdraw from the study.

CONFIDENTIALITY
Any information that is obtained in connection with this study and that can be identified with you or your child will remain confidential and will be disclosed only with your permission. We will not discuss your child's results with anyone, including school personnel, without your written permission. You and your child will be assigned a unique study identification number, which will appear in place of your names on every form used for this study. These unique subject identification numbers will be used for data entry and you and your child's name will never be included in any of the data entry files. Any public presentation of data from this study will involve only pooled data from all participants, and an individual's data will never be presented in isolation. Consent forms and other materials will be stored separately in locked cabinets in Dr. Casey's office. Only Dr. Casey will have access to your personally identifying information. All study data will be destroyed 5 years following the completion of the study. When these data are destroyed, their destruction will be carried out in a manner to preserve you and your child's confidentiality.

There is one set of circumstances that would possibly necessitate a breach in confidentiality. In the event you or your child discloses that you or he/she is imminent danger or that your child is experiencing abuse/neglect, we may disclose this information to the appropriate authorities. Before this disclosure is made, we will discuss our concerns with you. As someone who works with children and families, Dr. Casey is a mandatory reporter for child abuse/neglect and is required by law to protect the right of the child. Confidentiality would only be breached regarding instances of abuse or neglect.

PARTICIPATION AND WITHDRAWAL
You can choose whether or not you and your child participate in this study. If you and your child volunteer to be in this study, you or your child may withdraw at any time without consequences of any kind. You and your child may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so, such as it is discovered that your child does not meet eligibility criteria. In that event, Vilija Petrauskas or Dr. Casey will discuss the reasons your child is not eligible with you. If your child does not wish to participate in this study, they do not have to. In this case, there will not be any penalties to you or your child. If you or your child choose to withdraw from the study, any data collected will be confidentially destroyed and there will be no record of your participation.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

When this study is completed, we hope to publish these results in a scientific journal so other researchers and clinicians may benefit. Results of the present study will be posted on the Research Ethics Board website: www.uwindsor.ca/reb Results are likely to be available after September, 2013.

SUBSEQUENT USE OF DATA
This data will be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS
You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH SUBJECT/LEGAL REPRESENTATIVE

I understand the information provided for the study *Examination of fine motor control in children with ADHD* as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

_____   _____
Name of Child   Name of Parent of Legal Guardian

_____
Signature of Parent or Legal Guardian

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____   _____
Signature of Investigator   Date

APPENDIX J

University
of Windsor

LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Examination of fine motor control in children with and without ADHD**

You are asked to participate in a research study conducted by Vilija Petrauskas from the Department of Psychology at the University of Windsor. Vilija Petrauskas is a doctoral student in the Clinical Neuropsychology track of the Clinical Psychology program, and data for this project will contribute to her doctoral dissertation conducted through the University of Windsor.

If you have any questions or concerns about the research, please feel free to contact Dr. Joseph Casey (Faculty Supervisor) by phone (, extension), or via email (@uwindsor.ca).

PURPOSE OF THE STUDY
The purpose of this study is to compare handwriting and drawing abilities of school-aged children in grades 4 through 8 with and without ADHD through the use of a digitizing tablet (i.e., a large iPad-type device). One of the main difficulties in children with ADHD is disinhibition, therefore it is thought that children with ADHD will have more difficulty controlling their fine motor output (i.e., handwriting and drawing). Such difficulties controlling their movement might result in more variation in the kinematic (i.e., movement) aspects of the child's writing or drawing in the form of more changes in writing/drawing speed (i.e., they speed up and slow down more when writing or drawing). Children with ADHD may also increase their pen pressure when writing or drawing to try and stabilize their movement. In the present study a number of characteristics will be examined and include: quality of handwriting, speed of writing and drawing, number of changes in speed when writing or drawing, as well as pen pressure when writing or drawing. It is anticipated that children with ADHD will demonstrate poorer quality of handwriting, faster writing and drawing, will change writing and drawing speed more than control children, and will write/draw with greater pen pressure, especially as the task becomes more complex. Results of this study will help better target intervention efforts for children with ADHD.

PROCEDURES
If you volunteer to participate in this study with your child, you will be asked to complete the following questionnaires:
- *Research Participant Questionnaire* – This is a form designed to collect information about your child's medical history and their development thus far.
- *Conners 3* – This is a measure of your child's behavioural and emotional difficulties.
- *Barkley Deficits in Executive Functioning Scale* – This is a measure of your child's executive functioning abilities.

We anticipate that you will be able to complete these forms while we work with your child. If you are not able to complete these forms or would feel more comfortable completing them at home, we will be happy to allow you to take these forms home. We anticipate that it will take approximately 45 minutes to complete both questionnaires.

If your child has previously been diagnosed with ADHD, they will need to stop taking their ADHD medication for 24 hours prior to the study (if they are taking stimulant medication such as Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance) or for 48 hours if they are presently taking other medication such as Strattera. Your child is only asked to refrain from taking their ADHD medication for the study and can continue taking any other prescribed medications. While you complete the above questionnaires, your child will be asked to do the following things if he/she participates in this research study:

- Your child will be administered a *brief intelligence screening*, comprised of four short subtests from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV). For these subtests, your child will be asked to put together blocks, indicate how two words/concepts are similar, repeat back a series of digits both forwards and backwards, and copy symbols that are paired with numbers using a key as quickly as possible. This task will be used to get an estimated IQ.
- Your child will be administered a brief measure of *handwriting quality* on a *digitizing tablet*. This digitizing tablet is like a large iPad where your child will write on the screen and a computer will calculate different variables (e.g., how fast your child write, how hard the pen presses on the tablet). This device cannot hurt or cause your child discomfort in any way. For the handwriting quality task, your child will write from memory letters of the alphabet in alphabetical sequence, write from dictation the letters of the alphabet out of alphabetical order, write from dictation 8 numbers out of numerical order, copy 12 uppercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 10 lowercase letters out of alphabetical sequence, copy 6 words, copy 2 sentences, and write 6 words from dictation.
- Your child will be asked to *complete 5 different patterns* on a *digitizing tablet*.
- Your child will be administered the *Spelling* subtest of the Wechsler Individual Achievement Test – Third Edition (WIAT-III), and they will be asked to write the dictated words on the *digitizing tablet*.
- Your child will be asked to complete the Fine Motor Precision subtest of the Bruininks Oseretsky Test of Motor Proficiency – Second Edition (BOT-2). For this subtest, your child will be asked to fill in the outlines of two shapes, draw a line through a path (like a maze), and connect four dots on the *digitizing tablet*. Your child will also be asked to fold a piece of paper, and cut out a paper circle.

We anticipate that it will take no more than 180 minutes to complete all of these tasks.
This is the only time that your child will be required to attend, and there will be no follow-up sessions.

Your child will be assigned to either the ADHD or control group, based on whether or not they have previously been diagnosed with ADHD. If your child has never been diagnosed with ADHD, and they do not meet criteria based on your responses on the Conner's Parent Rating Scale-Revised, they will be assigned to the control group. If your child has previously been diagnosed with any of the three ADHD subtypes (primarily inattentive, hyperactive/impulsive, or combined), they will be placed in the ADHD group.

POTENTIAL RISKS AND DISCOMFORTS
There is no foreseeable risk or discomfort associated with your participating in this study. You may experience some mild to moderate distress while completing the questionnaire measures, especially if you are having difficulty with your child. If you experience any distress, please discuss your concerns with Dr. Casey. If you begin to experience distress after you leave the laboratory, please call Dr. Casey in his office (, ext.).

There is no foreseeable risk or discomfort associated with your child participating in this assessment process. Most children will find many of these tasks similar to ones they complete in school (e.g., spelling, writing), and therefore should be familiar with the task requirements. Most children will experience the intelligence screening measure and maze-like tasks as more novel, and may enjoy completing these tasks. Most children enjoy interacting with the digitizing tablet, and there is no foreseeable risk or discomfort in the use of this device. If your child is upset by the assessment or refuses to participate, we will attempt to reschedule the appointment for another time.

If your child is diagnosed with ADHD and is presently taking medication for this condition, they will be asked to refrain from taking their ADHD medication for 24 hours prior to the study if their medication is a stimulant (e.g., Ritalin, Concerta, Adderall XR, Dexadrine, Biphentin, Vyvance), or for 48 hours if they are taking a medication such as Strattera. This will allow for all of the medication to "wash-out" of your child's system prior to their participation in the study. The only foreseeable risk to your child from not taking their medication for 24 or 48 hours is an increased possibility of school-related difficulties on those

days where your child is not taking their medication. To try and minimize this, the research team will try and schedule a time for your child to participate where the withdrawal of medication will have the least effect on their schooling (e.g., on a weekend, during a school holiday). There are no foreseeable risks to not taking ADHD medication for your child, other than the reappearance of ADHD symptoms for the time that they are not taking their medication.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY
The main purpose of this study is to better understand fine motor control in children with ADHD and compare it with children who do not have ADHD. Clinicians, educators, and parents of children may benefit from the results of this study in that intervention efforts may be better targeted. Results of this study may also highlight the importance in examining not only symptoms of impulsivity, inattention, and hyperactivity in children with ADHD, but difficulties with fine motor control. This knowledge would help to better target intervention efforts. Society in general may benefit if we better understand fine motor control in children.

COMPENSATION FOR PARTICIPATION
All participants will receive a $10 gift certificate to either Chapter's or Staples upon completion of the study. Parents will also receive a written report of their child's performance on the motor tasks, their performance on a standardized measure of handwriting, as well as results of the IQ screening and academic measures (i.e., WIAT-III Spelling). All participants will receive the $10 gift certificate, whether or not they choose to complete the study in full or choose to withdraw. Individuals who withdraw from the study will receive a written report of their child's performance on all measures that were completed before withdrawing. Your child will receive a small toy for their participation. They will receive this toy regardless of whether they complete all items or choose to withdraw from the study.

CONFIDENTIALITY
Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. We will not discuss your results with anyone without your written permission. Once your forms are completed, your unique subject identification number will be written on every form and your name will be removed from all forms. These unique subject identification numbers will be used for data entry involving your responses. Consent forms and rating forms will be stored separately in locked cabinets. Only Dr. Casey will have access to your personally identifying information. In the event these data are ever to be destroyed, their destruction will be carried out in a manner to preserve your confidentiality.

There is one set of circumstances that would possibly necessitate a breach in confidentiality. In the event your or your child discloses that you or he/she is imminent danger or that your child is experiencing abuse/neglect, we may disclose this information to the appropriate authorities. Before this disclosure is made, we will discuss our concerns with you. As someone who works with children and families, Dr. Casey is a mandatory reporter for child abuse/neglect and is required by law to protect the right of the child. Confidentiality would only be breached regarding instances of abuse or neglect.

PARTICIPATION AND WITHDRAWAL
You can choose whether or not you and your child participate in this study. If you and your child volunteer to be in this study, you or your child may withdraw at any time without consequences of any kind. You and your child may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so, such as it is discovered that your child does not meet eligibility criteria. In that event, Vilija Petrauskas or Dr. Casey will discuss the reasons your child is not eligible with you. If your child does not wish to participate in this study, they do not have to. In this case, there will not be any penalties to you or your child. If you or your child choose to withdraw from the study, any data collected will be confidentially destroyed and there will be no record of your participation.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

When this study is completed, we hope to publish these results in a scientific journal so other researchers and clinicians may benefit. Results of the present study will be posted on the Research Ethics Board website: www.uwindsor.ca/reb Results are likely to be available after September, 2013.

SUBSEQUENT USE OF DATA
This data will be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS
You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____   _____
Signature of Investigator   Date

APPENDIX K

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Assent

I am a student researcher, and I am doing a study on children's drawing. I would like to ask you to write some letters and numbers, finish some patterns, connect some dots, and do some mazes on a computer screen using a special pen. I would also like to ask you some questions and have you put some blocks together.

When I am finished working with all the kids who agree to be in my study, I will write a report on what I have learned. My teachers will read it, and it might be put in a book, but no one will know who the kids are that helped me with my study.

I want you to know that I will be telling your parents how well you did the drawings, wrote the letters and numbers, finished the patterns, connected the dots and did the mazes. I will only be telling them how you did overall, and I won't tell them what you answered for each question. Your parents may also want to tell your teacher how well you did. I also want you to know that if you tell me that someone has been hurting or abusing you I will need to tell your parents or someone else who can help you.

Your mom and/or dad have said it is okay for you to answer my questions and do the drawings on the computer. Do you think that you would like to answer the questions and do the drawings? You won't get into any trouble if you say "no." If you decide to answer the questions and do the drawings, you can stop answering the questions at any time and you can stop doing the drawings at any time. You don't have to answer any question you don't want to answer, and you don't have to do any drawing you don't want to do. It's entirely up to you. Whether you decide to answer any questions or do the drawings or not, I will give you a small prize when you leave. Would you like to try answering the questions and do some drawings?

I understand what I am being asked to do to be in this study, and I agree to be in this study.

_____

Signature

_____

Date

_____

Witness

APPENDIX L

ID: _____

RESEARCH PARTICIPANT QUESTIONNAIRE
BASIC INFORMATION

Child's Name: _____

      Gender: _____

Child's Birth Date (mm/dd/yyyy): _____

      Age:_____

Today's Date (mm/dd/yyyy): _____

      Grade:_____

Your relationship to the child (please check all that apply):
☐ Parent   ☐ Legal Guardian

      Please specify (e.g., grandparent) _____

Home address: _____

_____

_____

_____

Home phone number: _____

Other phone number: _____

Email: _____

Instructions: *The items in this questionnaire address issues pertaining to your child's developmental history and family background. For questions that include numbered choice options, please circle the number(s) that best describes your child and/or family. Other items will provide you with space(s) to provide a written response. Be sure to read each item carefully, and direct any questions to a member of the research staff. Try to answer each item as best you can, however, if you feel uncomfortable with any question, you do not need to answer it. Please know that your answers will be kept completely confidential.* ***Please do not write your child's name on any page but this front page. (This cover page will be detached and stored with your consent forms to protect your and your child's confidentiality.)***

GENERAL CHILD INFORMATION

Child's Birth Date (mm/yyyy): _____   Age: _____

Today's Date (mm/dd/yyyy): _____   Grade: _____

Gender: _____

Child's primary language: [1] English   [2] French   [3] Other: _____

Racial/Ethnic Background of child (Please circle all that apply):
[1] Aboriginal
[2] Asian descent
[3] Hispanic/Latina
[4] Black or of African descent
[5] Non-Hispanic White/Caucasian
[6] Other: _____

What is the highest grade you, **the guardian**, have completed?
[1] Did not complete grade 12
[2] High School Graduate
[3] Some College
[4] College Graduate
[5] Some University
[6] University Graduate
[7] Graduate Degree
[99] Don't know

Has the child ever had any kind of head injury? [1] NO   [2] YES

      If **yes**, what happened? _____

      _____

      If **yes**, was there a loss of consciousness? [1] NO   [2] YES

      If **yes**, for how long (in minutes)? _____

Has the child ever had a seizure?   [1] NO   [2] YES

If **yes**, specify type:
      [1] Febrile
      [2] Petit mal/absence
      [3] Grand mal/tonic-clonic
      [4] Other
If **yes**, has the child ever been medicated for seizures? [1] NO   [2] YES

      Specify type of medication: _____

Has the child ever been diagnosed with any of the following (please check all that apply):
      [1] speech language disorder
      [2] hearing problems
      [3] vision problems
      [4] Autism spectrum
      [5] oppositional defiant disorder/conduct disorder
      [6] attention problems (e.g., ADHD)

Has the child ever been diagnosed with ADHD? [1] NO   [2] YES
      If **yes**, what type: [1] ADHD-PI (primarily inattentive)
               [2] ADHD-HI (primarily hyperactive/impulsive)
               [3] ADHD-C (combined)
               [4] Don't know

      If **yes**, who made the diagnosis of ADHD?
           [1] Family physician
           [2] Psychologist
           [3] Psychiatrist
           [4] Other: _____

Is the child currently taking any medication? [1] NO   [2] YES

      If **yes**, what medication are they taking? _____

      How often do they take it? _____

      What is the dosage? _____

      Why is it taken? _____

Has the child been formally taught how to handwrite (i.e., cursive writing)?
[1] NO   [2] YES

In your opinion, does the child have any learning problems? _____

_____

_____

Has the child ever been diagnosed with a learning disability? [1] NO   [2] YES

    If **yes**, what type:_____

Has the child ever been identified by the school system as having an exceptionality?
[1] NO   [2] YES

Does the child have an Individual Education Plan (IEP)? [1] NO   [2] YES

    If **yes**, what is it for?
        [1] reading
        [2] writing
        [3] arithmetic
        [4] learning skills
        [5] Other: _____

Has the child ever received any special help at school (e.g., special class placement,
tutoring, speech/language therapy)?

_____

_____

Has the child received any additional (outside of school) reading instruction, tutoring, or
extra help (e.g., Kumon, Oxford, Sylvan)?

_____

_____

Is there any additional information you feel should be included?

_____

_____

_____

   THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE

APPENDIX M

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SUMMARY OF YOUR CHILD'S RESULTS

[CHILD'S NAME] participated on [DATE] in a dissertation research study entitled "*Examination of fine motor control in children with and without ADHD"*. These results are provided for information purposes only. If you have any questions, please contact the Primary Investigator, Vilija Petrauskas (@uwindsor.ca).

Intellectual Screening:
[CHILD'S NAME] was administered a short form of the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV). Results indicate that HIS/HER overall current intellectual functioning is in the [X] range. HIS/HER Full Scale Intellectual Quotient is estimated to be XX (X percentile). On the measures that make up this intellectual screener, [CHILD'S NAME] scored in the [X] range on a measure emphasizing visual-constructional abilities (Block Design subtest; [X^{th}]percentile), in the [X] range on a measure that emphasizes verbal abstract reasoning (Similarities subtest; [X^{th}] percentile), in the [X] range on a measure emphasizing attention and short term memory (Digit Span subtest; [X^{th}]percentile), and in the [X] range on a measure emphasizing digit-symbol coding (Coding subtest; [X^{th}]percentile).

Spelling:
On the Spelling subtest of the Wechsler Individual Achievement Test – Third Edition (WIAT-III) [CHILD'S NAME] scored in the [X] range ([X^{th}]percentile).

Handwriting:
On the Test of Handwriting Skills – Revised (THS-R), [CHILD'S NAME] overall manuscript writing (i.e., printing) ability across all subtests was [X] ([X^{th}] percentile). HIS/HER cursive writing (i.e., handwriting) skills were [X] ([X^{th}] percentile).

Fine Motor Precision:
[CHILD'S NAME] performance on the Fine Motor Precision scale of the Bruininks-Oseretsky Test of Motor Proficiency – Second Edition (BOT-2) was [X] ([X^{th}] percentile).

Conners 3-Parent Form:
The Conners 3 – Parent Form was completed by [CHILD'S NAME] [PARENT]. Scores are as follows:

Conners 3 Scale	T-Score	Description
Inattention		
Hyperactivity/Impulsivity		
Learning Problems		
Executive Functioning		
Defiance/Aggression		
Peer Relations		
Conners 3 Global Index Total		
DSM-IV-TR ADHD Inattentive		

DSM-IV-TR ADHD Hyperactive-Impulsive		
DSM-IV-TR Conduct Disorder		
DSM-IV-TR Oppositional Defiant Disorder		

Barkley Deficits of Executive Function – Parent Form:
The BDEFS-PF was completed by [CHILD'S NAME] [PARENT]. Scores are as follows:

BDEFS-PF Scale	Percentile	Description
Self-Management to Time		
Self-Organize		
Self-Restraint		
Self-Motivate		
Self-Regulate Emotions		
EF Summary Score		
ADHD-EF Index		
EF Symptom Count		

VITA AUCTORIS

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