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The Automaticity and Mean Stylus Pressure Profile of Handwriting in Adults with ADHD

By

Marc Demers

A Thesis
Submitted to the Faculty of Graduate Studies
through the Department of **Kinesiology**
in Partial Fulfillment of the Requirements for
the Degree of **Master of Human Kinetics**
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Windsor, Ontario, Canada

2014

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ABSTRACT

ADHD is a neurobiological disorder typically developed and diagnosed in childhood (Faraone et al., 2003). Impaired motor function is commonly observed in individuals with ADHD, but often overlooked (Brossard-Racine et al. 2011; Meyer and Sagvolden, 2006). Deficits in movement accuracy and increased movement variability can have a profound impact on fine motor skills, such as handwriting (Adi-Japha et al., 2007). The purpose of this study was to determine if automaticity during a handwriting task is impaired in adults with ADHD. The results of this study indicated that adults with ADHD do not have reduced automaticity in their handwriting, but do have significantly increased mean stylus pressure was observed while writing. This suggests that individuals with ADHD may have simple, or dystonic, writer's cramp. Further research should be conducted to determine if simple or dystonic writer's cramp occurs in individuals with ADHD. If so, appropriate treatment methods should be determined.

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1. INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is a neurobiological disorder developed and typically diagnosed in childhood (Faraone, S. V., Sergeant, J., Gillberg, C., & Biederman, J., 2003). *The Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM–5*; American Psychiatric Association, 2013) states that ADHD prevalence is estimated to occur in about 5% of children and 2.5% of adults, although some recent studies indicate that over-diagnosis may occur and that diagnostic criteria are difficult to interpret (Bailey & Owens, 2005; Bruchmüller, K., Margraf, J., & Schneider, S., 2012; LeFever, G.B., Arcona, A.P., & Antonuccio, D.O., 2003).

The diagnostic symptoms of ADHD include: severe inattention, and in most cases hyperactivity and impulsivity, that impair development or functioning; onset of hyperactive-impulsive and inattentive symptoms before the age of 12 years of age; the hyperactive-impulsive and inattentive symptoms are present in two or more settings; strong evidence that these symptoms reduce the quality of academic, work-related, or social functioning (American Psychiatric Association, 2013). ADHD can be divided into 3 subtypes: ADHD – Predominantly Inattentive (ADHD-PI), ADHD – Hyperactive Impulsive (ADHD-HI), and ADHD – Combined (ADHD-C), based on the presence of inattentive and hyperactive-impulsive symptoms (American Psychiatric Association). Current research has indicated that ADHD-C is correlated with the greatest motor control deficits, followed by ADHD-PI and finally ADHD-HI (Schweitzer, Hanford, & Medoff, 2006). Impaired motor function is commonly observed in individuals with ADHD but often overlooked (Brossard-Racine, M., Majnemer, A., Shevell, M., Snider, L., & Belanger, S. A., 2011; Meyer and Sagvolden, 2006). Approximately 50% of individuals with ADHD are reported to have a comorbid Developmental Coordination Disorder

(DCD), which is characterized by severely inhibited acquisition and execution of motor skills based on an individual's age (American Psychiatric Association, 2013; Watemberg, Waiserberg, Zuk, & Lerman-Sagie, 2007).

Hyperactive-impulsive symptoms appear to be caused by a lack of motor inhibition, with associated symptoms of severe fidgeting, tapping, or talking at inappropriate times (American Psychiatric Association (2013)). This inhibition also appears to manifest itself at a micro level in fine motor control. Common motor control deficits reported in kinematic and psychological literature are decreases in fine movement accuracy and increased movement variability (Hurks et al., 2005; Kalff et al., 2003; Meyer & Sagvolden, 2006). Deficits in movement accuracy and increased movement variability can have a profound impact on fine motor skills, such as handwriting (Adi-Japha et al., 2007). Although methylphenidate, a stimulant medication prescribed to approximately 70% of individuals with ADHD, may assist in increasing handwriting legibility, a reduction in handwriting fluency has been reported with its use (Bart, Podoly, & Bar-Haim, 2010; Flapper, Houwen, & Schoemaker, 2006; Olfson, Gameroff, Marcus, & Jensen, 2003; Rubia, Noorloos, Smith, Gunning, & Sergeant, 2003). Although a number of studies have examined motor control deficits in individuals with ADHD, little of this research has examined the mechanisms causing the deficits in handwriting legibility. Because deficits in handwriting legibility can impact test scores, note taking, and potentially self-esteem in students (Cornhill & Case-Smith, 1996), identifying the mechanisms responsible could help in developing treatments to address poor handwriting and potentially other fine motor control deficits associated with ADHD, such as movement variability, and reduced fine movement accuracy.

1.1 Fine Motor Control Deficits - Speed, Accuracy and Variability

There have been a number of studies documenting motor control deficits in individuals with ADHD (Brossard-Racine et al., 2011; Goulardins, J. B., Bilhar Marques, J. C., Casella, E. B., Nascimento, R. O., & Oliveira, J. A., 2013; Meyer & Sagvolden, 2006; Shiels Rosch, Dirlikov, & Mostofsky, 2013). The deficits that occur are typically in areas of movement accuracy, and movement variability (Hurks et al., 2005; Kalff et al., 2003; Meyer & Sagvolden, 2006; Rommelse et al., 2008; Shiels Rosch et al., 2013). Research examining the effect of ADHD on movement speed reveals conflicting results; some studies have indicated individuals with ADHD move at a slower pace, others have yielded no significant differences. (Cole, W. R., Mostofsky, S. H., Larson, J., Denckla, M. B., & Mahone, E. M., 2008; Kalff et al.,2003; Steger et al., 2001).

Variability of movements, or "inability to replicate the same movement pattern", is a deficit often associated in individuals with ADHD (Hurks et al., 2005; Kalff et al., 2003). A study by Hurks et al. (2005) was conducted to determine if visuomotor preparation was affected by ADHD. The study compared 19 ADHD positive children with 124 healthy subjects, and 120 psychiatric controls. Hurks et al. (2005) used the finger pre-cuing test to measure movement speed, speed variability, and accuracy. The finger pre-cueing test is a three stage task. The first stage has four plus (+) signs appear on a screen, corresponding to four fingers (two on each hand) available for responding. The second stage is the pre-cue stage in which two, or four plus signs appeared, indicating either one of two or one of four fingers were to be used to respond. The final stage presented the target stimulus, in which participants responded with the corresponding finger. The results indicated that speed variability was increased among the ADHD group when compared to the healthy control subjects, as well as the psychiatric control group. This suggested that children with ADHD may have difficulty organizing their movements to repeat the same pattern and timing.

The previous results were similar to those found by Kalff et al. (2003) in a study conducted on 1317 children aged 5 to 6 years. The researchers had the children perform a tracking task and a pursuit task. The tracking task required the participants to trace circles on a computer monitor with a mouse with their dominant and non-dominant hand. The pursuit task required them to follow a target on the monitor with the mouse. The children with ADHD had greater movement variability, especially in the dominant hand. The results also indicated movement accuracy was impaired in the ADHD group.

A study conducted by Eliasson, Rösblad, and Forssberg (2004) analysed goal directed arm movements in children with ADHD. The participants in the study were 25 male students with ADHD, aged 8-15 years, and 25 age matched controls. Students were required to aim and move a cursor on a horizontally-oriented digitizing tablet screen with a hand held indicator from one point to another. After eight practice trials the visual cursor was removed. After the participants completed each trial the cursor became visible to show them how successful they were to reaching the target on their attempt. The results indicated that the children with ADHD had significantly reduced accuracy compared to the control group. Additional analysis indicated a significant decrease in accuracy during the non-visual feedback when compared with visible feedback trials of the ADHD group. Interestingly, their movement time significantly increased when there was no visual feedback. Movement time deficiencies have not typically been recorded in studies conducted on ADHD and motor control. Similar results were found by Johnson et al. (2009) in a study analyzing hand drawing movement precision in children with ADHD. The results of this study indicated children with ADHD have a greater difficulty moving accurately towards targets to the right, which appears manifest during a handwriting task (i.e., from left to right).

The published research findings addressing the effect of ADHD on movement speed is less consistent. Steger et al. (2001) reported slower hand and foot movements in children (mean age = 10.93) with ADHD when compared to an age matched control group during a neuromotor assessment battery. Similar results were seen in a study conducted by Cole et al. (2008) in which children with ADHD displayed slower movement time when compared to a control group using the Physical and Neurological Examination for Soft Signs (PANESS). Conversely, Kalff et al. (2003) found no differences in movement speeds during tracking and pursuit tasks. Meyer and Sagvolden (2006) also found no significant differences in movement speeds between children and adolescents with ADHD during a finger tapping task.

Several studies have reported a correlation between age and motor control impairments seen in individuals with ADHD (Ayaz, A.B., Ayaz, M., Yazgan, Y., & Akin, E., 2013; Fliers et al., 2008). A study conducted by Ayaz et al. (2013) compared a group of 64 participants with ADHD against an age matched control group of 69 children between the ages of 12-15 years of age. Their study found a correlation between age and score on the Purdue Pegboard subtests of “both hands” and “assembly” tasks, in which participants are instructed to insert pins, washers and collars onto the pegboard. The study found no correlation between age and the dominant hand subtest. Similar results were reported by Fliers et al. (2008) in a study measuring motor control in children using the Developmental Coordination Disorder Questionnaire (DCD-Q) and Groningen Motor Observation Scale (GMO). The study included 486 participants with ADHD, and 269 controls. The GMO was filled out by the children's teachers, and the DCD-Q by their parents. Both the DCD-Q and GMO scores correlated with age adjusted scores, indicating motor control increases linearly with age in individuals with ADHD. The results of the GMO test showed a greater difference between younger children with ADHD and the control participants than the DCD-Q. The researchers suggested that this discrepancy might be due to the GMO not differentiating between an average rating and good rating of motor performance as well as the DCD-Q. Cole et al. (2008) found slightly conflicting results in a study using the PANESS. Their results indicated that only females with ADHD had increased improvement in motor control as a function of age. The researchers hypothesized that this was possibly due to earlier development in brain areas responsible for motor control, and that boys display more hyperactive and impulsive symptoms than girls (Cole et al., 2008). While fine motor control in children and adolescents has been well documented, little research has been conducted on motor control in adults with ADHD.

All three ADHD subtypes have had motor control deficits associated with them, though not at equal rates. Meyer and Sagvolden (2006) conducted a study to determine if there are different motor control issues between the subtypes of ADHD. Participants with ADHD-C performed the poorest on the Grooved Pegboard and Maze Coordination Tasks. The ADHD-PI only performed poorly on the Maze Coordination Task, which the researchers discuss is likely due to the increased complexity of motor planning required. Mei, Henderson, Chow, and Yao (2004) also reported the greatest correlation between motor control deficits and their ADHD-C participants. Piek, Pitcher, & Hay (1999) reported a correlation between inattentive symptoms and fine motor control skills as assessed by the Movement Assessment Battery for Children (MABC). Similarly both, Fliers et al. (2008) and Pitcher, Piek, & Barrett, (2002) found that inattentive symptoms seem to be a significant predictor of poor motor control.

Research has been conducted to determine whether or not sex has an impact on the motor control deficits associated with ADHD. Current research has been conflicted regarding the effects of sex on motor control in individuals with ADHD (Cole et al., 2008; Fliers et al., 2008; Uebel et al., 2010; Rucklidge, 2008). Fliers et al. (2008) reported similar deficits in motor control between boys (*n* = 375) and girls (*n* = 111) with ADHD on both the DCD-Q and GMO. In the study conducted by Cole et al. (2008), using the PANESS, the results indicated that girls (*n* = 33) with ADHD had similar motor control to age matched controls. Conversely, Meyer & Sagvolden (2006) reported that girls (*n* = 75) with ADHD performed worse on the Purdue Pegboard Test than boys with ADHD (*n* = 189) using either their dominant or non-dominant hand.

There are a few possible explanations for these discrepancies in the literature. Studies examining sex effects of ADHD typically have a substantially greater number of male participants than female participants, as presented in the prior examples. A possible reason for this is the disproportionate prevalence of ADHD in the female population; estimates of the male to female ratio range from 2:1 to 9:1 (Rucklidge, 2008). Another possible explanation for the discrepancies seen literature factoring for sex effects is the lack of factoring for ADHD subtype.

Rucklidge (2008) reported that females tend to have a greater occurance of inattentive symptoms in their presentation. Most current studies examining the effects of sex have lacked factoring for ADHD subtype within their analysis. The study conducted by Uebel et al. (2010) was the only study available that included only participants with the same subtype of ADHD (ADHD-C), and they found no significant effect of sex, thus indicating that sex likely has no impact once ADHD is diagnosed.

1.2 Impact of Fine Motor Deficits on Handwriting

With the observation of increased movement variability, reduced accuracy, and decreased movement speed in individuals with ADHD, it can be hypothesized that deficits associated with motor control are responsible for illegible handwriting associated with ADHD. In a study conducted by Brossard-Racine et al. (2011) researchers analysed the handwriting ability of 40 unmedicated children (aged 6-11 years) with ADHD by using the Evaluation Tool of Children's Handwriting-Manuscript (ETCH-M). The results of this study were compared to results previously collected from typically developing children. Between-subjects analysis indicated that children with ADHD wrote faster than the typically developing children, but had decreased legibility in their handwriting during a copying task. Intrasubject analysis indicated significant variability of their handwriting. The intrasubject analysis of ADHD participants also revealed that increased handwriting speed was associated with increased legibility. Although researchers suggested that the decreased legibility and variability could be attributed to age, it should be noted that variability of fine motor movements, including handwriting, has been associated with ADHD in several other studies with varying age groups (Borella, E., Chicherio, C., Re, A. M., Sensini, V., & Cornoldi, C., 2011; Hurks et al., 2005; Kalff et al., 2003). It should also be noted that results observed by Adi-Japha et al. (2007) suggest that intrasubject variability in handwriting associated with ADHD cannot be attributed to insufficient experience.

A similar study was conducted by Shen, Lee, & Chen (2012) using the Tseng Handwriting Problem Checklist. Twenty-one unmedicated children (aged 8-9 years) with ADHD had their writing compared to 21 age matched controls. Writing legibility was decreased in the ADHD group; however, handwriting speed of the ADHD participants was found to be decreased when compared to control participants in this study. Rosenblum, Epsztein, & Josman, (2008) also reported a lower handwriting speed in children with ADHD when compared to age matched controls. These discrepant results may be attributed to task variation, or not using age matched participants for both of the studies. However, the most likely reason is due to task variation. Brossard-Racine et al. (2011) reported the slowest handwriting speed of ADHD participants in the most similar task (in which the participants had to copy words displayed at a distant location) to Shen et al.'s (2012). The discrepancy could also be attributed to the fact that Brossard-Racine did not use age matched controls in their study. The neurotypical control data they used was taken from a younger sample than the ADHD participants. Therefore their ADHD participants would have more experience with handwriting. The reduction of copying speed in a far-point copying task could possibly due to visual-spatial working memory (Rapport et al., 2008; Shen et al., 2012).

As stated previously, variability in handwriting has been associated with ADHD. A study conducted by Langmaid, Papadopoulos, Johnson, Phillips, and Rinehart (2012) analyzed stroke height and duration during a repeated cursive writing task completed by an ADHD-C group and typically developing group of children. The results of the study indicated that the ADHD-C group had greater variability in stroke length and duration than the typically developing group**.** A study conducted by Frings et al. (2010) examined letter size written by 10 boys with ADHD aged 10-15yrs, 6 boys and girls with cerebellar lesions aged 11-15yrs and a control group of 11 boys and girls aged 10-15yrs. Cerebellar lesions have been associated with macrographia (large handwriting), and the researchers hypothesized that cerebellar dysfunction may account for irregular writing associated with ADHD (Frings et al., 2010). Although the results of the study indicated that all three groups had a similar mean letter height, the ADHD and cerebellar lesion groups had greater intrasubject letter height variability throughout their sentences. Another noteworthy finding was that the ADHD and cerebellar lesion groups increased mean letter height each time they repeated the same sentence. The study indicates that illegible handwriting associated with ADHD may be caused by cerebellar dysfunction.

1.3 Effects of Methylphenidate on Handwriting

Methylphenidate is a psychostimulant medication often prescribed to reduce the negative effects of ADHD (Klein & Abikoff, 1997). Although current literature indicates that methylphenidate increases legibility of writing, it appears to reduce fluency of handwriting skills (Bart et al., 2010; Flapper et al., 2006; Rubia et al., 2003).

Although Flapper et al. (2006) observed increased motor function in a group of ADHD positive individuals after administration of methylphenidate, their performance was still impaired when compared to a control group. Similarly, Bart et al (2010) found that with methylphenidate administration, only 33% of their study participants had clinically significant increases in motor control on the MABC.

While writing legibility may increase with use of methylphenidate, its use appears to have a negative impact on writing fluency. Tucha & Lange (2004) conducted a study examining the fluidity of movements during a writing task. Their subjects were children with a mean age of 10.5 years (SEM = .42 years), currently taking methylphenidate at a mean dose of 23.75mg/day. The participants were required to write a phrase while on their medication, and then write it again at 3 different stages of withdrawal from the drug. The researchers found that while writing legibility was better when the children were on medication, their movements became less fluent. The authors speculated that this was likely due to increased conscious attention (i.e., cognitive effort) to writing patterns, and less reliance on automated motor control processes. Because fluent movements occurred when participants used less cognitive effort during the writing task, writing fluency appears to be a sensitive measure of automaticity.

A follow-up study conducted by Tucha & Lange (2005) was conducted to expand on their prior research. This study included participants aged 9-12 years, taking an average methylphenidate dosage of 11.7mg. The children were asked to write a sentence while on their medication, or off their medication, and then following a 5-7 day withdrawal or loading period, asked to write the sentence again. A digitizing tablet was used to assess writing fluency. A secondary measure of this study was to assess whether or not increasing the speed of handwriting would increase the fluency of the children while on medication. The results of this study corresponded with their prior study, and indicated that writing fluency was reduced with use of methylphenidate. A significant difference was also found on measures of writing fluency when children were asked to speed up their handwriting, indicating that writing speed is associated with automaticity.

These results correspond with a study conducted by Flapper et al. (2006), where they found that children with ADHD who were taking methylphenidate had improved quality and accuracy of handwriting, but reduced fluency. The study conducted by Adi-Japha et al. (2007) indicated that medication-naïve children with ADHD were not significantly different from typically developing children on measures of writing fluency, so this reduction is likely linked to methylphenidate administration.

While the increases in writing legibility associated with methylphenidate are important, the increase in attention devoted to the writing process should not be overlooked as it can decrease attention devoted to other tasks (McCutchen, 1988; Peverly, 2006). A lack of automaticity in handwriting can cause individuals to devote their working memory to the simplistic task (Lienemann & Reid, 2008; Medwell & Wray, 2007). Due to cueing from teachers to focus on writing neatly, students' attention can become fixated on producing legible writing causing them to miss important facts given in lectures, and become less focused on what they are writing as opposed to how they are writing (Gathercole, Pickering, Knight, & Stegmann, 2004; Peverly, Ramaswamy, Brown, Sumowsky, Alidoost, & Garner, 2007). Reduced automaticity has also been associated with decreased of speed of writing (Medwell & Wray, 2007). If children write at a slower speed, note taking production can decrease and therefore miss taking important notes, miss assignment deadlines, and complete homework at a slower pace.

1.4 The Previous Study

A previous study, conducted by Duda (2012), analysed handwriting in adults using normalized jerk as its primary measure. Normalized jerk was used to determine smoothness and fluency of writing. The objectives of this study were 1) to determine if the variable performance of individuals with ADHD observed in psychological domains such as task persistence, emotion, and attention would also be seen in kinematic variables (in this case handwriting); and 2) to assess the effects of a novel task on the consistency of measures in graphomotor performance between adults with ADHD and without ADHD (Duda, 2012). This study's results indicated that adults with ADHD while both on and off medication produced similar measures of fluency when compared to neurotypical adults. The results did reveal a significant difference when comparing normalized jerk of the fluent and novel tasks.

The measurement of Normalized jerk analyzed the "change of acceleration per time" (Duda, 2012); thus, it analyzed the fluency of direction changes during the automatized and normal tasks. The present study will use data collected from this study to analyze displacement over time (tremor) occurring between these direction changes to measure for a possible reduction in automaticity.

1.5 Fast Fourier Transform

A reduction of movement automaticity can be related to joint/muscle stiffness, which can be analyzed using a Fast Fourier Transform (FFT) (McNevin & Wulf, 2002). A FFT yields the frequency components of a movement by parsing it into its spatial-temporal characteristics, yielding a Mean Power Frequency (MPF). This method has been used previously by Wulf, McNevin, & Shea (2001) to evaluate the predictions of the constrained action hypothesis. The constrained action hypothesis proposes that if an individual is performing a novel motor task (dynamic balance on an unstable platform), and focuses their attention on their actions (e.g., “try to keep your feet parallel”, they will inhibit their performance on the task. All of the participants were told the purpose of the task was to keep the platform of the stabilometer they were balancing on horizontal for as long as possible over the duration of each 90-sec trial. Participants in the internal focus group were instructed to focus on keeping their feet horizontal during the balance task, while participants in the external focus group were instructed to focus on markers attached to the platform of the stabilometer. The higher MPF of the external focus group suggested greater sensory and motor coherence during the dynamic balancing task, in that each perturbation of the platform resulted in a rapid correction. In contrast, the lower MPFs of the internal focus group suggested slower reactions to platform perturbations, and as such compromised automaticity of the control processes associated with dynamic balance.

Similar to dynamic (and static) balance, handwriting is a rhythmic activity that involves coordination of wrist and finger flexors/extensors to manipulate a writing implement, which in turn produces movement through the x plane, with inflections occurring in the y plane. As such, both x and y components in cursive writing were analyzed simultaneously. In the present study, FFT was used to assess the automaticity in handwriting. Based on previous research examining dynamic balance, high frequency components in an FFT analysis of handwriting should indicate a higher degree of coupling, or coordination, between the agonist and antagonist muscles and provide a window for assessing the degree of automaticity associated with producing cursive writing (Thompson & Stewart, 1986; Newell & Slifkin, 1996). That is, although increased attention on the task of writing improves legibility as a result of psychostimulant medications, FFT analysis will allow us to assess whether this legibility was gained at the expense of automaticity.

1.6 Mean Stylus Pressure and Writer's Cramp

While a FFT can analyze the x and y movement components of handwriting, mean stylus pressure (pen pressure) can analyze what is happening in the z-plane. Adi-Japha et al., (2007) observed a significantly higher mean pen pressure when comparing un-medicated children with ADHD to an age matched neurotypical control group. Schoemaker, Ketelaars, van Zonneveld, Minderaa, and Mulder, (2005) has similar results in a study conducted to determine if motor planning was impaired in adolescents with ADHD. Sixteen participants with ADHD (mean age = 8 years, 4 months, SD = 1 year, 1 month) were compared to age matched neurotypical control participants. Participants were instructed to copy a series of shapes on a digitizing tablet using a stylus. Stylus pressure information was recorded by software on the digitizing tablet. The results of the study indicated children with ADHD used significantly greater pen pressure. While elevated pen pressure has been reported in children with ADHD, to our knowledge, prior to this study, it has not been analyzed in adults with ADHD

Significantly elevated pen pressure can lead to writer's cramp; uncontrollable muscle hyperactivity and co-contraction during handwriting (Schneider et al., 2010). Writer's cramp can lead to pain while writing, and squashed, tremulous, and variable letter production (Sheehy and Marsden, 1982; Mai and Marquardt, 1994). Writer's cramp can be classified as simple writer's cramp, or dystonic writer's cramp. Writer's cramp is considered simple if symptoms only occur during writing or drawing movements, and dystonic if muscle hyperactivity occurs during other fine movement tasks, such as using a knife or fork (Sheehy & Marsden, 1982).

Many of the symptoms associated with writer's cramp have also been associated with ADHD, thus analyzing mean stylus pressure can provide a measure of agonist and antagonist co-contraction in addition to a FFT. It can also be used to measure if writer's cramp is a comorbid disorder with ADHD.

1.7 Summary and Predictions

ADHD has been heavily correlated with reduced motor function; specifically, reductions in movement accuracy and increases in movement variability (Hurks et al., 2005; Kalff et al., 2003; Meyer & Sagvolden, 2006). These fine motor skill deficits are presumably responsible for the illegible handwriting associated with individuals with ADHD (Brossard-Racine et al., 2011; Rosenblum et al., 2008; Shen et al., 2012). Studies conducted to analyze the effects of methylphenidate on handwriting of individuals with ADHD indicate that it increases the legibility of their handwriting by increasing cognitive effort on the skill (Bart et al., 2010; Flapper et al., 2006; Rubia et al., 2003), but as suggested by the constrained action hypothesis (Wulf et al., 2001), at the cost of reduced automaticity.

The present study examined handwriting differences between adults with ADHD (on and off medication) and controls to determine if reduced automaticity, as a function of medication status, is responsible for deficits in fine motor control tasks. It is expected that the control group will yield the highest MPF, suggesting greater synergy in the agonist and antagonist muscles involved in writing (greater automaticity), while individuals with ADHD on medication will yield the lowest MPF (reduced automaticity) despite medication improving attention to the task of writing. It is expected that the ADHD-ON and ADHD-OFF groups will have a significantly higher pen pressure than the control group.

2. METHODS

2.1 Participants

This study involved the secondary analysis of previously collected data, using new dependent measures. The participants for the original study were recruited by Duda (2012). In total, forty-four participants were recruited from three sources. The participants with ADHD (n = 14) were recruited through the University of Windsor's Student Disabilities Centre, and through a local physician. The control group (n = 30) was recruited using the University of Windsor's Psychology Participant Pool.

Participants were excluded if they had a condition that could potentially impact their graphomotor performance (e.g. cerebral palsy, tendonitis or carpal tunnel syndrome). The participants included were currently taking their prescribed dosage of stimulant medication (e.g. methylphenidate).

The participants recruited from the Psychology Participant Pool were awarded course bonus points for volunteering in the study. The control participants were given 1 course bonus point for 1 hour of work, and the clinical participants were given 2 course bonus points for 2 hours of work. The participants recruited from The University of Windsor's Student Disabilities Services, and the local psychiatrist were awarded a $10 gift card, and entered into a draw for a $50 debit card.

2.2 Participant Demographics

The participants' age, sex, handedness, neurological status, official ADHD diagnosis and current medication (type and dosage), were collected through an in-person interview. ADHD diagnosis, and specific subtype, was further reviewed and recorded if official documentation was available.

All of the participants were required to complete the Barkley Adult ADHD Rating Scale-IV (BAARS-IV). The BAARS-IV is a self-reporting questionnaire designed to assess ADHD symptoms, based on the DSM-IV diagnostic criteria. Upon completion of the BAARS-IV a total ADHD score, ADHD subtype score, symptom count and subscale scores for childhood and current ADHD symptoms can be calculated. If no official diagnostic documentation was available regarding a participant's ADHD subtype, they were categorized based on the information given using the BAARS-IV.

2.3 Digitizing Tablet and Software

The WACOM Cintiq 21UX tablet was used to record the subject's handwriting. The tablets display area is 17" by 12.75", which provides a real time workspace for the participants. As the participant writes, their strokes appear on the screen just as they would with a pen and paper. The stylus used with the system is pressure sensitive, allowing for further measures to be recorded.

MovAlyzer Software created by NeuroScript, LLC, was used to collect handwriting data. The software used a sampling rate of 200Hz, and the x-y coordinates were low-pass filtered at 12Hz. A sample rate of 200Hz was also used through a 2048 point "z-unit" location to determine stylus pressure. 200Hz is industry standard for analyzing handwriting, and has been utilized in previous studies (Thomassen, A. J. & Teulings, H, 1985).

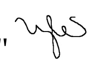
Figure 1. Wacom cintiq 21UX

2.4 Dependent Measures

The prior study conducted by Duda (2012), analyzed normalized jerk to determine fluency of writing. Although normalized jerk is a good indicator of handwriting fluency, it is not a sensitive measure of the spatial-temporal relationship underlying the control of fine motor movements. For this purpose, the mean power frequency (MPF) (Hz) of x and y stylus displacement, which provides an index of muscle stiffness was the primary measure of this study. MPF was used as the measure of the degree of constraint imposed by each participant while engaged in the task of producing a familiar and novel graphomotor pattern.

Mean stylus pressure (z-units) was the secondary measure of this study. As previously discussed, there has been evidence that individuals with ADHD taking medication apply a greater amount of pressure on their pen when writing than typically developing control groups. The data collected for this study builds on that literature. This data offers additional insights into the effect medications play in ADHD graphomotor skill, suggesting that improved legibility in handwriting may also be attributed to changes in motor control (and not only to improved attention to the task).

2.5 Procedures

Each participant session took place in the following sequential order; 1) participants took part in an interview to provide medical and demographic information; 2) participants answered further questions to determine ADHD symptoms; 3) participants took a test of generalized IQ; 4) participants wrote their signature 10 times on the digitizing tablet; 5) participants wrote “hello” 30 times in lower-case cursive writing; 6) participants wrote a novel symbol "  " created for this procedure 30 times (See appendix A for a figure of the symbol provided to participants). The 10 signature trials were used to familiarize the participants with the equipment. The word “hello” was used to represent an automatic/fluent written task, and the novel symbol was designed to represent a non-automated task which will provide a baseline for each group. Instructions for the task were read to participants throughout the testing procedure, as well as displayed on the digitizing tablet screen. A visual example of both the cursive “hello” and novel word were provided throughout the tasks. For detailed instructions given to participants, see Appendix B.

Control participants were only required to complete one testing session. There were two testing sessions for the ADHD group; one session was completed while on medication, and another while off medication. For the off medication session, participants were instructed to abstain from their prescribed dosage between 24 and 48 hours. The withdrawal period was based on the U.S. Food and Drug Administration's (2007) product information, which states that there are extremely low blood plasma concentrations following a 24 to 48 hour withdrawal period.

2.6 Data Analysis

A Fast Fourier Transform was performed, using the MovAlyzer software, comparing the resultant of the X and Y displacements (vector sum) of the cursive writing stylus strokes over the duration of the first 3 and last 3 trials of the writing task. The MPF for the first 3 and last 3 trials of the "hello" and the novel symbol tasks was calculated, and averaged. Three separate ANOVAs were performed using SPSS software to determine if a significant difference in MPF occurred between the groups. The first ANOVA was a 2 (ADHD-ON vs. ADHD-OFF) x 2 (hello vs. novel task) comparing the MPF of the ADHD group on medication vs. the ADHD group off medication trials, with repeated measures performed on the two factors. The second ANOVA was a 2 (ADHD-ON vs. Control) x 2 (hello vs novel task) comparing the MPF of the ADHD on medication vs. control with repeated measures performed on the final two factors. The third ANOVA was a 2 (ADHD-OFF vs. Control) x 2 (hello vs. novel task) comparing the MPF of the ADHD off medication vs. control with repeated measures performed on the final two factors. Statistical significance was assessed at alpha = 0.05.

The mean stylus pressure during stylus strokes was recorded during initial trials by the MovAlyzer software, and placed in a spreadsheet. Mean stylus pressure of all 30 trials of the "hello" and novel writing task were calculated for each group. The same 2x2 ANOVAs mentioned previously were performed using SPSS software, replacing MPF with mean stylus pressure. Statistical significance was assessed at alpha=.05.

3. RESULTS

One control participant withdrew their participation from the study and their data was excluded from all subsequent analysis. Data analyses were performed using IBM SPSS statistics 20.0. An alpha level of .05 was used to determine statistical significance.

Group	**Participants**	**Male**	**Female**	**Mean Age (in years)**
Control	30	27	3	27.5
ADHD-ON	15	9	6	30.8
ADHD-OFF	14	8	6	30.8

Table 1. Participant Demographics and Sample Size for Each Group

The ADHD positive participants included all three ADHD subtypes; 8 participants were diagnosed with ADHD-Combined Type, 4 participants were diagnosed with ADHD-Primarily Inattentive, and 2 participants were diagnosed with ADHD-Hyperactive-Impulsive.

3.1 Mean Power Frequency

A 2 (medication status: drug vs no drug group) X 2 (task: hello vs novel task) factorial ANOVA with repeated measures on both factors was used to assess Mean Power Frequency as collected by the MovAlyzer software. Two additional 2 (group) X 2 (task) factorial ANOVAs with repeated measures on the “hello” vs “novel” task was used to assess the ADHD-ON vs Control trials, and ADHD-OFF vs Control trials.

The 2 X 2 factorial ANOVA comparing the ADHD-ON vs ADHD-OFF yielded no main effect of medication status, $F(1, 13) = 0.735$, $p = .407$, suggesting that for a familiar word (hello), performance was mediated by the same degree of automaticity regardless of medication status. A significant main effect of task $F(1, 13) = 59.925$, $p = .000$, however, suggested that when required to produce a novel pattern, performance was mediated by greater cognitive effort (reduced automaticity). The interaction between medication status and task failed to reach significance $F(1, 13) = .255$, $p = .622$ (see Figure 1).

The 2 X 2 factorial ANOVA comparing the ADHD-OFF vs Control groups yielded no main effect of group, although it did approach significance $F(1, 42) = 196.672$, $p = .066$. This result indicated a similar level of automaticity mediated the handwriting performance of both un-medicated adults with ADHD and neurotypical adults with ADHD. There was a main effect of task, $F(1, 42) = 196.672$, $p = 0.000$, suggesting that for an unfamiliar pattern, performance was mediated by greater cognitive effort (decreased automaticity) compared to the familiar “hello” pattern. There was no interaction observed when analyzing group by task $F(1, 42) = 1.232$, $p = .273$.

The 2x2 factorial ANOVA comparing the ADHD-ON vs Control groups yielded no main effect of group, $F(1, 42) = 1.636$, $p = 0.208$. The failure to find a difference suggests a similar level of automaticity between groups regardless of medication status. There was a main effect of task, $F(1, 42) = 152.318$, $p = 0.000$, suggesting significantly more cognitive effort was required to generate the unfamiliar pattern across both medicated ADHD and control groups. There was no interaction observed when analyzing group by task $F(1, 42) = .003$, $p = .959$.

Taken together, these results suggest that the handwriting performance of adults with ADHD was mediated by the same level of automaticity as control participants, and did not appear to be affected by medication status. The pattern of results for the novel task suggests that for both ADHD and control groups, greater cognitive effort (decreased automaticity) was required to generate an unfamiliar (i.e., un-automatized) pattern. Examples of the FFT profiles across each condition can be found in Appendix C.

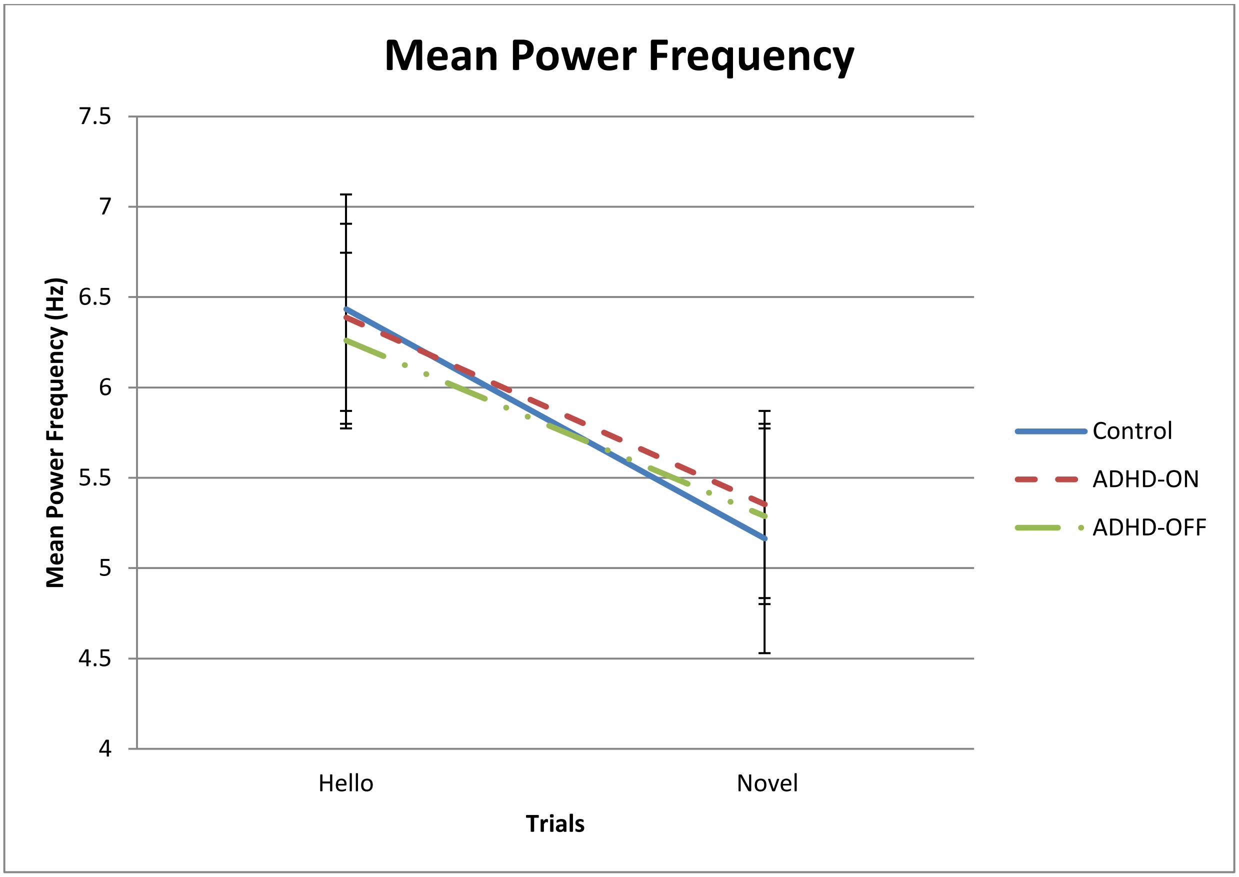


Figure 1. Mean Power Frequency for Control, ADHD-ON, and ADHD-OFF groups for First and Final 3 Hello, and First and Final 3 Novel Symbol Trials

Group	Mean Hello	Standard Deviation Hello	Mean Novel	Standard Deviation Novel
Control	6.42	.52	5.14	.62
ADHD-ON	6.39	.41	5.35	.76
ADHD-OFF	6.26	.62	5.28	.85

Table 2. Mean Power Frequency and Standard Deviation for Hello and Novel Symbol trials for Control, ADHD-ON and ADHD-OFF groups.

3.2 Mean Stylus Pressure

A 2 (medication status: drug vs no drug group) X 2 (task: hello vs novel task) factorial ANOVA with repeated measures on both factors was used to assess Mean Stylus Pressure as collected by the MovAlyzer software. Two additional 2 (group) X 2 (task) factorial ANOVAs with repeated measures on the “hello” vs “novel” pattern task was used to assess the ADHD-ON vs Control trials, and ADHD-OFF vs Control trials.

The 2 X 2 factorial ANOVA comparing the ADHD-ON vs ADHD-OFF yielded no main effect of medication status, $F(1, 13) = 0.091$, $p = .768$. The failure to reach significance suggests that ADHD medication may not have a significant impact on the pressure exerted by adults with ADHD. There was a significant main effect of task $F(1, 13) = 10.323$, $p = .007$, suggesting that when required to generate a novel pattern, more stylus pressure was exerted. The interaction between medication status and task failed to reach significance, $F(1,13) = 3.785$, $p = .074$, however, the trend suggests that more pressure was exerted while medicated (see Figure 2).

The 2 X 2 factorial ANOVA comparing the ADHD-OFF vs Control groups yielded a main effect of group, $F(1, 42) = 10.128$, $p = .003$. This result indicated that un-medicated ADHD participants pressed significantly harder while writing both familiar and novel patterns compared to a control group. The main effect of task, $F(1, 42) = 21.098$, $p = 0.000$ indicates that significantly more stylus pressure was exerted by both the ADHD-OFF and Control groups when generating unfamiliar patterns. There was no interaction of task by group, $F(1,42) = 1.232$, $p = 0.273$, suggesting that un-medicated ADHD did not alter task stylus pressure.

The 2x2 factorial ANOVA comparing the ADHD-ON vs Control groups yielded a main effect of group, $F(1, 42) = 10.505$, $p = .002$, suggesting that medicated ADHD participants exerted greater stylus pressure across both familiar and unfamiliar writing pattern tasks when compared to a control group. There was also a main effect of task, $F(1, 42) = 37.134$, $p = 0.000$ suggesting more stylus pressure was exerted by both the ADHD-ON and Control groups when producing the novel pattern. There was no interaction observed when analyzing task by group, $F(1,42) = 0.016$, $p = 0.901$, indicating that medicated ADHD did not alter task stylus pressure.

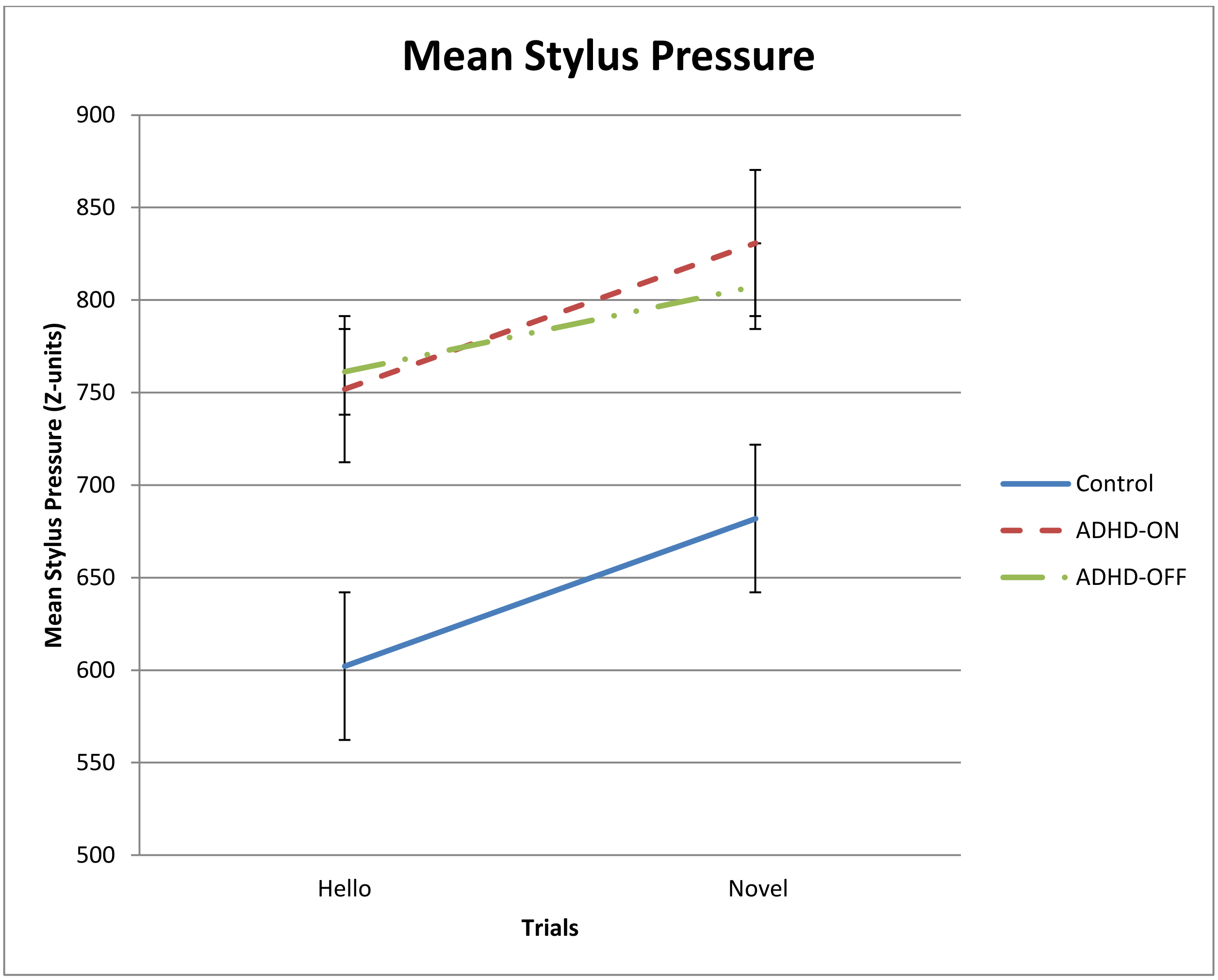


Figure 2. Mean Stylus Pressure for Control, ADHD-ON, and ADHD-OFF groups for all Hello, and Novel Symbol trials.

Group	Mean Hello	Standard Deviation Hello	Mean Novel	Standard Deviation Novel
Control	606.75	151.39	682.56	139.91
ADHD-ON	751.82	145.74	830.81	142.13
ADHD-OFF	761.19	138.28	807.49	125.74

Table 3. Mean Stylus Pressure and Standard Deviation for Hello and Novel Symbol trials for Control, ADHD-ON and ADHD-OFF groups.

4. DISCUSSION

The present study sought to determine if automaticity of handwriting is compromised in individuals with ADHD as a function of medication status. It was expected that the ADHD-ON group would have significantly lower frequency of responding (i.e., MPF) than a neurotypical control group, but more importantly that because the medication was associated with a reduction in automaticity, that ADHD-ON would yield lower frequency of responding when compared to ADHD-OFF conditions. A similar pattern of results was expected for stylus pressure, suggesting that a possible unintended consequence of improved legibility in ADHD handwriting was a reduction in motor control automaticity and an increase in downward stylus pressure.

Consistent with Duda (2012), the present study found no difference in the medicated and un-medicated ADHD on Mean Power Frequency as a measure of handwriting automaticity. While the previous study analyzed the number acceleration changes in time (Mean Jerk) to assess writing fluency, the present study utilized temporal-spatial characteristics to measure automaticity. By using the full spectrum of temporal-spatial characteristics, automaticity in the stylus can be inferred. Using this measure, the ADHD groups MPF was almost significantly lower when compared to the control group, and may have been reached significance with additional power. It was hypothesized that both the medicated and the un-medicated ADHD groups would have a lower MPF than the control group, although the trend only appeared in the un-medicated ADHD group. This trend indicates that individuals with un-medicated ADHD may have decreased automaticity during handwriting tasks. One of the key symptoms associated with ADHD is decreased-inhibition at a macro level (American Psychiatric Association, 2013), and because this group was un-medicated, a lack of inhibition would still be prominent. These symptoms may have manifested themselves at a micro level in fine motor control, in which they effectively decreased automaticity. Un-medicated individuals with ADHD may have increased their constraints to account for poor motor control in the hand. Further, this finding could account for the irregular letter shapes cited in previous literature (Frings et al., 2010). An additional consistency between the present and previous study can be observed in the analysis of trials. In Duda's (2012) study, during the "Hello" writing trials, the participants had more fluency than when performing the "Novel symbol" task. Similar results were seen in the present study while using a novel measure in assessing automaticity; writing was more automatic across all participant groups when performing the "Hello" task. This was to be expected, as the "Novel symbol" task was created for the purpose of being a non-automatized task. This finding assists in validating MPF as a measure of automaticity in handwriting. To our knowledge, this is the first time a FFT has been used to analyze handwriting automaticity. These were also similar to the results observed by Wulf, McNevin, & Shea (2001) when comparing an automatized and un-automatized group during a stabilometer task. Thus, this study has potentially set a precedent for future research utilizing this method to measure handwriting automaticity.

Consistent with the increased mean pen pressure exerted by children with ADHD observed by Adi-Japha et al. (2007), the present study found increased MSP in un-medicated, and additionally, medicated adults with ADHD when compared to a control group. This is important to note, as the present study indicates that these issues manifested in childhood persist into adulthood.

4.1 Indications of the Present Study

The results of the present study indicate that there is no difference in MPF of writing between medicated and un-medicated adults with ADHD, and adults without ADHD, although there may be a difference when comparing un-medicated adults with ADHD to neurotypical adults. However, medicated and un-medicated adults with ADHD used a significantly greater amount of pen pressure when writing. The increase in MSP could potentially account for the lack of a statistical significance in the MPF results.

The MPF was measured using a vector sum of x and y coordinates of the writing on the tablet. The MPF provided and indication of muscle stiffness while writing using tremor. Due to the task being two dimensional, unlike the previous task conducted by McNevin and Wulf (2002), friction could have impacted tremor. By increasing pen pressure in the z plane, participants could have effectively constrained their movements in the x and y planes, thus eliminating tremor. While this is not the first time elevated pen pressure has been documented in ADHD (Adi-Japha et al., 2007; Schoemaker et al., 2005), to our knowledge this is the first time it has been observed in adults with ADHD. This is a significant finding, as elevated pen pressure is indicative of writer's cramp. If the writer's cramp occurring in individuals with ADHD is dystonic writer's cramp, it can have a significant impact throughout all fine motor control activities.

A significantly higher MSP was observed in the “Novel symbol” task when compared to the “Hello” task across all groups; this was not expected to occur in the two ADHD groups. This indicates that the “Novel symbol” task was not automatic for any of the groups. Thus, the increase in MSP observed in ADHD participants during the “Hello” task may not have been due to issues with automaticity. The overall increase in MSP in the ADHD participants is possibly due to other motor control impairments such as muscle hyperactivity, which may be caused by the lack of inhibition associated with ADHD (American Psychiatric Association, 2013). A significantly higher MSP pressure being observed across both tasks, in both medicated and un-medicated ADHD has implications for both future studies and rehabilitative programs. It should be determined if the manifested disorder is simple, or dystonic writer's cramp; if increased pressure is exerted by individuals with ADHD is occurring just in handwriting, or across other fine motor control tasks. This will help determine what kind of rehabilitative measures should be taken to assist this population.

A statistical difference was expected when comparing medicated and un-medicated trials on measures of MPF and MSP, but was not observed. The use of adults in this study may have impacted this observation. Prior research conducted on children with ADHD has indicated that medication increases their focus on the task of handwriting. Adults who have lived with ADHD for a significantly longer time than children may have developed stronger coping strategies, such as using greater cognitive resources to focus on handwriting while off of their medications. Another possible explanation is that the adults in this study may have developed a tolerance to their medication after years of use. Thus, the medications may not have impacted the participants' results as significantly as they would have in a study conducted on children. If this study is replicated on children with ADHD, there may be an impact of medication observed.

4.2 Limitations

A limitation of this study was that, due to a sample of convenience, it included a vast difference in ADHD symptoms. A Majority of the ADHD group participants were classified as “ADHD-combined type”, which exhibits the most severe diagnostic symptoms of ADHD. Due to the variable degree of ADHD symptoms in this small sample group, it is possible that within subject variance (see error bars in figures 1 and 2) may have negated any statistical differences.

Due to a limited number of participants, DCD was not screened for. With the inclusion of ADHD participants with DCD, there is a potential that DCD could have impacted the results. It is important to note that it is still uncertain which impairments of motor control are associated with DCD, and which impairments are associated with ADHD. Thus, with a co-morbidity rate estimated at 50% (Watemberg et al., 2007) the results in this study should still be considered relevant to the diagnostic and rehabilitative knowledge base of ADHD.

4.3 Future Research

This study is the first to explore the use of FFT to measure automaticity in handwriting. While the present study’s results were possibly inhibited due to the ADHD participants’ elevated stylus pressure, the study did yield a main effect when comparing an automatized and non-automatized task. Future studies could utilize this platform to evaluate automaticity of handwriting in other special populations. In addition, the use of adults may have impacted the MPF measures of the present study. A replication of the current study using child participants may exhibit different results, as they may not have developed the coping strategy of increasing stylus pressure to increase writing legibility.

To our knowledge, this is the first study to observe significantly elevated MSP in an adult ADHD population. The present study observed similar MSP results in both un-medicated and medicated ADHD participants. As stated previously, these results may be indicative of writer's cramp. Future studies should be conducted to determine if simple or dystonic writer's cramp is occurring, and if so development treatment methods should be developed.

5. CONCLUSION

The purpose of this study was to determine if automaticity during a handwriting task is impaired in adults with ADHD using MPF and MSP as measures. The expectation was that adults with medicated ADHD would yield significantly a significantly lower MPF and higher MSP than un-medicated adults with ADHD, and un-medicated adults with ADHD would yield significantly lower MPF and higher MSP than neurotypical control participants. The MPF yielded no significant results, however, the MPF of un-medicated ADHD and control participants trended towards significance. The lack of significance seen in MPF may have been due to the results seen in MSP. The MSP between un-medicated and medicated adults with ADHD were significantly higher than neurotypical control participants. These results have indicated that MSP issues associated with childhood ADHD continue through adulthood, and fine motor control may be significantly impaired due to dysfunctional inhibition when adults with ADHD do not take their medications.

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Appendix A

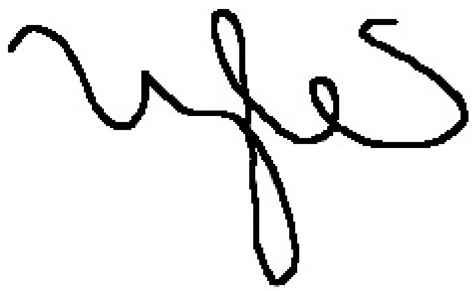

Figure A. Example of the Novel symbol provide to participants.

Appendix B

Provide instructions: “Write the word hello in cursive and lower case as it is written on the card. Just write how you typically write.”

If asked further for instructions on how to write: “Simply write how you typically write in cursive.”

Instructions pertaining to the novel symbol were: “Here is another symbol for the word ‘hello.’ Please write the symbol as demonstrated on the card.”

If asked for further instructions pertaining to neatness, the researcher replied: “Just write it how you would write any other word, but make it look like the symbol as demonstrated on the card.”

Appendix C

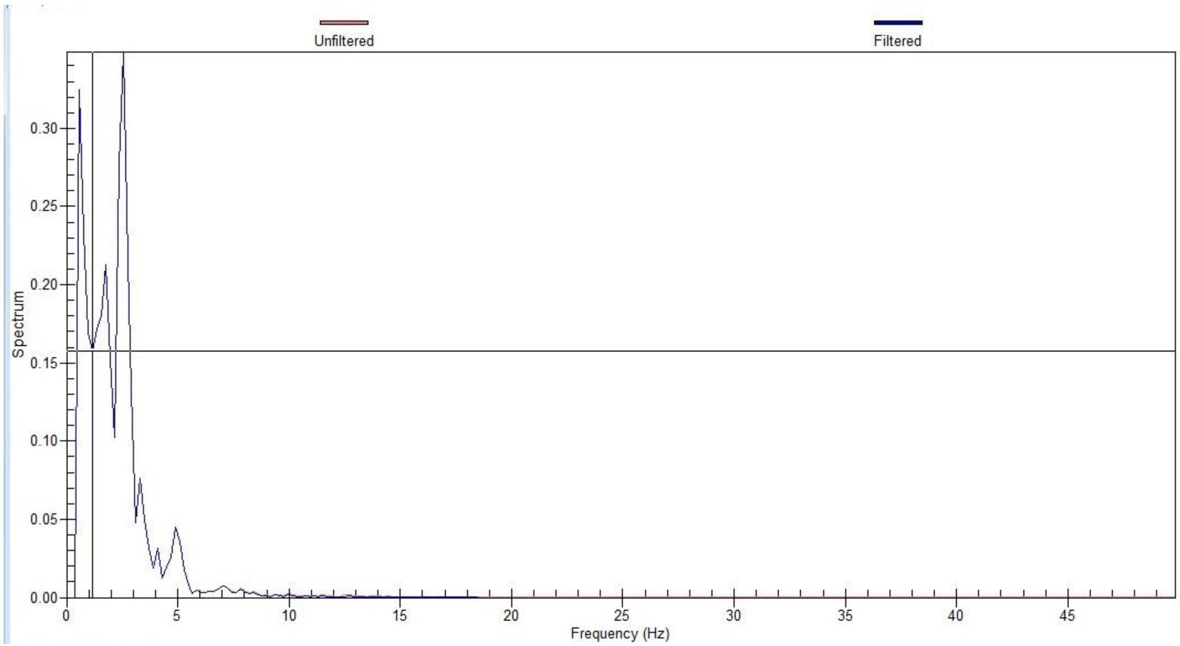

Figure A. Example of control participant FFT

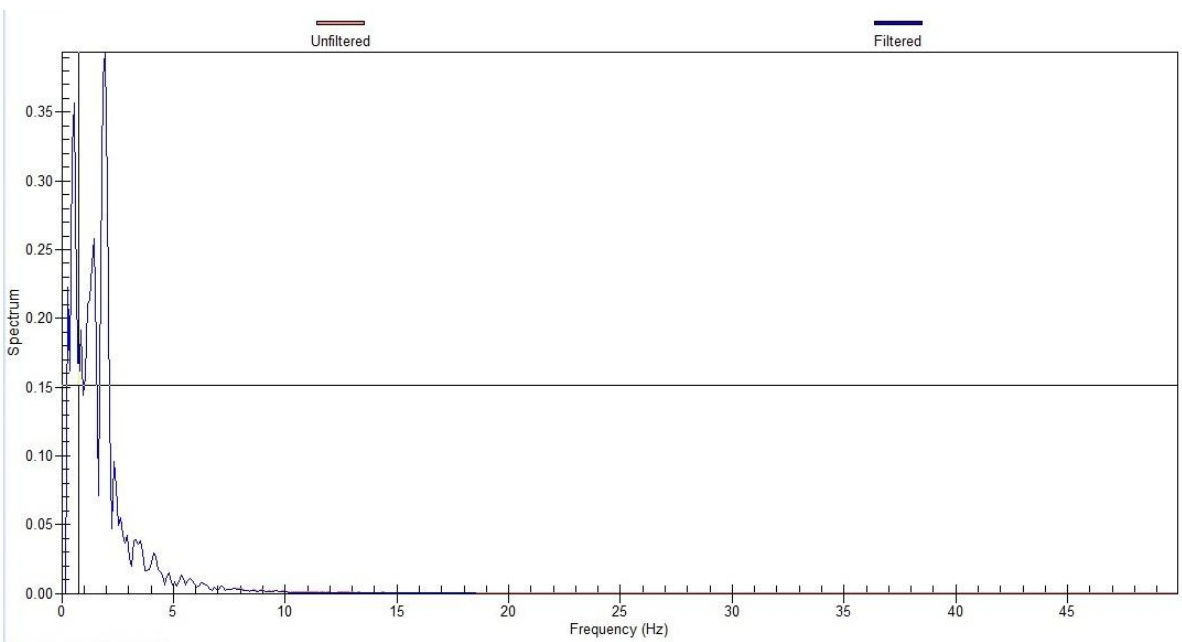

Figure B. Example of ADHD-ON participant FFT

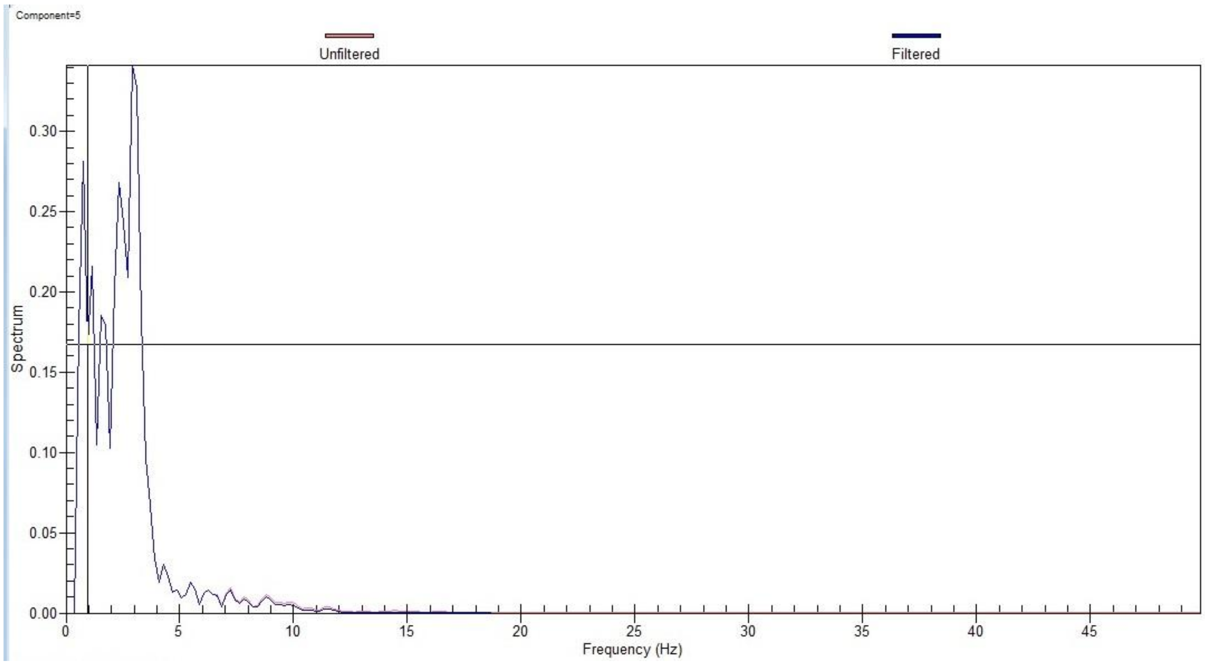

Figure C. Example of ADHD-OFF participant FFT

GLOSSARY

Automaticity - the ability to complete a task without devoting significant cognitive resources to complete it

FFT - Fast Fourier Transform

Fluency - The amount of changes in direction of acceleration or velocity recorded by digitizing technology and analyzed by appropriate software (Duda, 2012)

MPF - Mean Power Frequency

MSP - Mean Stylus Pressure

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