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Online control of handwriting in children with Developmental Coordination Disorder

by

Helga Miguel

A thesis submitted to the graduate faculty $\\ \text{in partial fulfillment of the requirements for the degree of } \\ \text{MASTER OF SCIENCE}$

Major: Kinesiology

Program of Study Committee: Ann Smiley-Oyen, Major Professor James Bloedel Panteleimon Ekkekakis Spyridoula Vazou

Iowa State University
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Abstract

Background: Previous research indicates that children with Developmental Coordination

Disorder (DCD) present difficulties in forward modeling and online control. Most of these studies emphasize speeded discrete movements, but controlling movements online is imperative for movement sequences of longer duration such as control necessary in handwriting.

Aim: To examine online planning in children with DCD during a handwriting task. It was hypothesized that children with DCD would present more difficulty adjusting to a change in an ongoing handwriting task, as evidenced by decreased fluency, longer duration of strokes, and greater percentage of time before peak velocity in the stroke immediately after a perturbation. Additionally, it was hypothesized that children with DCD would exhibit greater difficulty when more complex control is required, as shown by decreased fluency, longer stroke duration, and greater percentage of time after peak velocity when performing simple and complex sequences of loops and peaks.

Method: Eleven children with DCD (10 ± 1.34 years) and 11 typically developing children (10 ± 1.34 years) performed continuous (loops) and discontinuous (peaks) movement sequences in which complexity was varied (a series of shapes of the same height or of a combination of heights). On some trials children had to increase the size of the loops on cue. Kinematic analysis of movement sequences was performed using NeuroScript and a digitizing tablet.

Results: Children with DCD were more dysfluent and spent more time to peak velocity than the TD but adjusting to the tone by changing their plan online was not different. Discontinuous tasks (peaks) required a greater control from DCD and the TD group, with the simple sequence being the only that captured differences in strategies used to control the movement. Children with DCD

spent equal time in the upstroke and downstroke, compared with TD who spent more time in the downstroke. Additionally, children with DCD spent a greater percent of time into peak velocity in contrast with the TD group, who spent a greater percentage after peak velocity.

Conclusion: Children with DCD present different strategies to control their movements that may interfere with their ability to plan online. Further research is needed that include tasks with greater level of complexity.

Chapter 1 – Introduction

Developmental coordination disorder (DCD) is a neurodevelopmental condition that is characterized by a lack of motor coordination that impacts children's performance in daily activities and academic achievement. DCD does not result from a medical condition and children do not meet the criteria for diagnostics for conditions such as cerebral palsy or pervasive developmental disorder. The motor impairment is substantially below the child's chronologic age and intelligence, and it is manifested as a delay in achieving gross and fine motor skills such as performing sports or buttoning, scissors and handwriting. Children may also present delays in achieving motor milestones, such as walking, crawling or sitting. It is estimated that 5 to 6% of school-age children are affected by DCD (DSM-IV-TR, 2000).

Deficits presented by children with DCD impact their performance in everyday tasks, including school and home setting. Parents report that areas such as gross motor skills, fine motor skills, dressing, self-care, or academic performance are delayed in their children (Missiuna, Moll, King, King, & Law, 2007). Children experience difficulties in skills required in school, such as the use and manipulation of materials, but also in recreational activities resulting in less time spent in playing compared to peers (Wang, Tseng, Wilson, & Hu, 2009).

Although DCD seems well characterized, researchers and clinicians working with this population agree that its heterogeneity leads to the conclusion that it is not a uniform disorder. Studies have been done as an attempt to characterize the disorder, understanding its nature, subtypes and comorbidities, and ultimately applying the results to improve the diagnosis and treatment (Dewey & Kaplan, 1994; Hoare, 1994; Visser, 2003; Wright & Sugden, 1996). Based on children's performance in different sensorimotor tasks, the studies identified different subtypes of DCD. Even if the findings have to be carefully extrapolated because of different

samples and assessments between studies, a consistent finding is that many of these children have problems with writing, drawing, and other manual skills (Wright & Sugden, 1996), poor visual-perceptual-motor skills that impair performance of motor behaviors (Dewey & Kaplan, 1994), and motor execution problems that affect fine motor control (Hoare, 1994).

One type of fine motor control important to children is handwriting. It is well recognized that handwriting performance of children with DCD is impaired, constituting one of the diagnostic criteria (DSM-IV-TR, 2000). These children present less legible letters, and erase and overwrite more frequently. They take more time to write and have trouble with space arrangement compared with typically developed children (Rosenblum & Livneh-Zirinski, 2008; Smits-Engelsman, Niemeijer, & van Galen, 2001). Additionally, children with DCD spend more time on-paper and in-air time per stroke and apply less pressure than controls when writing (Rosenblum & Livneh-Zirinski, 2008), take longer to get writing automated, and have a lower performance in writing complex characters than typically developed children showed by a lower stroke velocity and pen pressure (Chang & Yu, 2010).

Several factors can contribute to the poor handwriting, including perceptual and motor components. These components include but are not limited to visual motor integration, visual perception, kinesthesia, sensory modalities, sustained attention, and motor planning (Cornhill & Case-Smith, 1996; Tseng & Murray, 1994; Volman, Van Schendel, & Jongmans, 2006).

Children with DCD have difficulties with motor planning, or in the ability to pre-plan a strategy before the movement starts (Van Swieten et al., 2010). They also have difficulties in planning during the movement, known as online control, for movements that require rapid adjustments such as rapid aiming or double-step reaching (Hyde & Wilson, 2010; Smits-

Engelsman, Wilson, Westenberg, & Duysens, 2003). Examination of this type of difficulty for movements of longer duration, such as handwriting, has not been done in children with DCD.

Handwriting is a task that is continuous in nature (Van Galen & Weber, 1998), constituting an appropriate paradigm to examine online control in children with DCD.

Handwriting follows a developmental trend, with children progressing from slower, less legible movements, to a faster and less variable handwriting (Blöte & Hamstra-Beltz, 1991; Karlsdottir & Stefansson, 2002; Ziviani & Watson-Will, 1998). More complex tasks mature after less complex ones (Rueckriegel et al., 2008; Van Mier & Hulstijn, 1993), and continuous movements appear to be linked to more skilled movement planning and programming (Van Mier, 2006).

The purpose of the present study was to examine online planning in children with DCD during a handwriting task. It was hypothesized that children with DCD will present more difficulty adjusting to a change in an ongoing handwriting task, as evidenced by decreased fluency, greater percentage of time after peak velocity, and longer duration of strokes.

Additionally, children with DCD will exhibit greater difficulty when more complex control is required, as showed by decreased fluency, greater percentage of time after peak velocity, and longer stroke duration.

Chapter 2 - Review of Literature

Children with DCD experience difficulties in activities of daily living, handwriting in particular. A contributing factor may be motor planning, i.e. planning as the movement is occurring. This is known as online control. This literature review will focus on online control and how it can be examined through a handwriting task.

The Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR, 2000) defines Developmental Coordination Disorder (DCD) as a neurodevelopmental condition characterized by a lack of motor coordination that impacts children's performance in daily activities and academic achievement. A child has to meet three specific criteria in order to be diagnosed as DCD: (1) motor performance that is substantially below the child's chronologic age and intelligence, and it is manifested in a delay in daily activities performance, including performing sports or handwriting; children may also present delays in achieving motor milestones such as walking, crawling or sitting; (2) the poor motor performance interferes significantly with academic achievement or activities of daily living; and (3) does not result from a medical condition and children do not meet the criteria for diagnostic such as cerebral palsy or pervasive developmental disorder. It is estimated that approximately 6% of school age children (DSM-IV-TR, 2000) have this disorder, but different studies report percentages that range from 1.4 to 9%, including those children having moderate problems (Kadesjo & Gillberg, 1999; Lingam, Hunt, Golding, Jongmans, & Emond, 2009; Wright & Sugden, 1996).

Research has shown that children with DCD present problems across motor and sensory areas, as well as the integration of both (Visser, 2003). Some motor-based problems include poor postural control (Johnston, Burns, Brauer, & Richardson, 2002), difficulties with motor execution (Raynor, 2001) and poor fine motor skills (Smits-Engelsman, et al., 2001). Timing and

force of muscle contractions in both rhythmic and discrete tasks also appear to be impaired (Volman & Geuze, 1998). Sensory problems, including visual-spatial, kinesthetic, and cross-modal processing deficits were also reported in children with DCD (P. H. Wilson & McKenzie, 1998). Furthermore, their performance is lower than typically developing children in measures of visual-motor integration and visual perception (Van Waelvelde, De Weerdt, De Cock, & Smits-Engelsman, 2004). The heterogeneity of problems presented by children with DCD suggests that is it not a uniform disorder.

Handwriting is a complex perceptual-motor skill that results from the integration of cognitive, perceptual, and motor skills. Handwriting constitutes the most immediate form of graphic communication (Feder & Majnemer, 2007). It is a demanding skill in the school setting, with children spending 31% to 65% of an academic day in fine-motor activities (McHale & Cermak, 1992); 85% of this time is spent in paper-and-pencil tasks and 15% spent in manipulative tasks. Therefore, impairment in this skill highly interferes with the school performance in children with DCD.

It is well recognized that handwriting performance of children with DCD is impaired, being part of the diagnostic (DSM-IV-TR, 2000). Children present less legible letters, erase and overwrite more frequently, take more time to write, and have trouble with spatial arrangement compared with controls (Rosenblum & Livneh-Zirinski, 2008; Smits-Engelsman, et al., 2001).

Children with handwriting problems differ from controls in tests of fine motor coordination, visual motor integration, visual perception, and cognitive planning, although visual motor integration is the best and only significant predictor in children with handwriting problems (Volman, et al., 2006). Unimanual dexterity was found to be a significant predictor of handwriting quality, but similar results were found in controls. Differences regarding speed of

handwriting were found between groups, and also within the group with handwriting problems, suggesting that there can be different underlying mechanisms in both situations.

Cornhill and Case-Smith (1996) examined the factors that contribute to good and poor handwriting and concluded that eye-hand coordination, visuo-motor integration, and in-hand manipulation all differentiated subjects with handwriting problems. In contrast, Tseng and Murray (1994) considered that motor planning was the only and best predictor of handwriting legibility in children with poor handwriting from third to fifth grade.

Van Swieten et al. (2010) investigated motor planning in children with DCD, children with autism, and adults. Participants were asked to reach-and-grasp a cylinder then turning it clockwise or counterclockwise with their dominant or non-dominant hand. Possibilities of performing the task included a more skilled grasp that would result in a confortable final posture or selecting a more simple initial movement that would result in an awkward end position.

Adults selected grips that resulted in end state comfort, while typically developing younger children selected simple grips that resulted in awkward end positions. Children with autism performed similarly to age matched controls. Therefore, differences between adults, typically developing children, and children with autism were based on developmental trends. The absence of differences between age-matched controls and children with autism is evidence of the low executive demand of the task. In contrast, the majority of children with DCD selected a simple grip and this behavior was independent of age. The authors suggested, therefore, that grip selection difficulties in children with DCD are due to a motor planning deficit.

While the above study addresses planning prior to movement onset, a continuous task such as handwriting requires planning during movement. This will be referred to as online

control. Online correction of movements is the ability to adjust the action plan online after the movement is initiated. Equivocal results have been obtained in children with DCD.

Using a reciprocal aiming task, Smits-Engelsman et al. (2003) examined differences between children with DCD and typically developing children when manipulating the size of the target, two control regimes, discrete aiming, and cyclic aiming. Discrete movements consisted of moving a pen after an acoustic signal and reversing on the next acoustic signal. In the cyclic movement children were asked to draw back and forth, starting and ending with an acoustic signal. Children with DCD made twice the number of errors than typically developing children in the cyclic task, presenting larger endpoint areas. Differences were not significant between groups in the discrete task. This indicates that when children with DCD must continuously monitor their movements as well as anticipate the upcoming movement, thereby relying more on a feedforward mode of control, they present significantly more difficulties than when the action is brief. Such continuous actions rely on internal representations to pre-plan and to anticipate the motor action.

Consistent with previous results, Hyde and Wilson (2010) found that children with DCD have difficulty in making online adjustments. They examined children with DCD and controls using a double-step reaching paradigm that involved reaching for targets that were presented in a screen. Targets could either stay in same position or move to another location on the screen. Children with DCD took more time to initiate the movement, but were not significantly different from controls. Differences between groups were relative to the movement time in trials where the location of the target changed. This condition required that children integrate visual and proprioceptive information and change a previously established motor plan online in order to

reach to a new position. For the condition where the target did not change, movement time was similar to typically developed children.

In contrast with the previous studies, Plumb et al. (2008) did not find that children with DCD have difficulties with online control. They used a step-perturbation task to examine online control in children with DCD and typically developing children. Children moved a stylus from a starting location to a target. In one condition the target remained in same position and remained in the same color. In another condition, the position changed, but the color remained the same. In the third condition, the target remained in the same position, but a distractor with a different color stimulus was placed on the screen. The DCD group exhibited a longer movement time in the condition when the target remained the same color but changed position, but the difference was not significant. Results on peak speed, time to peak speed, and deceleration time suggested that the difference found in their movement time was related specifically with the feedback component of the grasp (deceleration time). The authors suggested that the poorer performance by the DCD group may be explained by a general deficit in movement production, not specifically the online correction. However, the differences between groups may have been deemphasized because of procedural differences between groups. Because children with DCD had difficulties performing the experimental tasks, they performed the task sitting instead of standing, and held a thicker stylus to perform all the conditions. These adaptations gave children with DCD fewer degrees of freedom to control, thereby simplifying the task.

Children with DCD present difficulties in making adjustments online. Rather than rely on anticipatory feedforward control, they appear to rely heavily on feedback, a mode that is not efficient when the action requires rapid changes. Thus far, the only tasks that have examined online control involve rapid aiming, double-step reaching, or step-perturbation. What is not

known is if this difficulty also occurs when they have to perform tasks that require online control in movements of longer and continuous duration, such as handwriting.

The view that handwriting is a task continuous in nature is supported by van Galen and Weber (1998). By manipulating the length of a writing line, they observed the ability of adults adapting their writing size to the line space in the vertical and horizontal dimensions. The task consisted of non-sense words composed of the letters l, h, e, n and m. The sequences were nine characters longer. Data were recorded using a digitizing tablet and the variables of interest were trajectory length, horizontal displacement, vertical displacement, and stroke duration. The authors found that participants were able to continuously adjust to changes in line lengths. Adaptation was more evident and occurred earlier in upstrokes (acceleration phase) than downstrokes (deceleration phase). The changes in the ongoing word were also more evident in the horizontal than in the vertical direction, but eventually they were attracted again to the original ratio. Moreover, movement time did not increase when constraints changed.

Due to its continuous nature, handwriting is an appropriate paradigm for the study of online control of movement. Moreover, children with DCD present difficulties in this functional task. To fully understand the difficulties presented by these children in handwriting, it is important to examine developmental trends of handwriting, including age and gender differences. Moreover, aspects related to complexity and modality of the movements will also be addressed.

Handwriting generally develops from scribbling to intentional and meaningful movements that follow a typical trend. The ability of performing vertical strokes develops at about age two, horizontal strokes at two years and six months, and circles at age three. Children

are able to imitate geometric shapes, such as the triangle at five years and six months, and begin to present the skills needed to start writing (Beery & Beery, 2010).

Between ages 7 to 12 years the mean writing speed increases twice in girls and three-fold in boys, and girls tend to present higher rates of legibility (Ziviani & Watson-Will, 1998). In a large sample of primary schools, children completed a test where they were asked to copy a sentence as many times as they could in a certain amount of time. Speed and legibility were measured. Younger children write more slowly, whereas greater speeds were reached by older children. A positive but not significant relation was found for speed and legibility, meaning that children tend to loose quality when asked to write faster.

In a five year longitudinal study starting at grade two, children's script moved from irregular and unsteady, to an even and smooth handwriting (Blöte & Hamstra-Beltz, 1991). There was a large improvement in the quality or legibility of writing from grades two to four, with slight improvement after that. This plateau in performance is consistent with the end of formal instruction of handwriting at grade four in Netherlands. An increase in speed was especially noted in third grade, with children who wrote faster being smoother than slow writers. In higher grades however, writing more quickly was related with poor handwriting. Although there is a progress in both quality and speed of handwriting across grades, this relation is not linear, with children presenting variations.

Karlsdottir and Stefanson (2002) found that children in grade one experience the largest growth of handwriting quality, with a slight decrease in performance at grade two. Between third and fifth grades there is no significant improvement. This contrasts with previous findings, which is probably due to the measures used to assess handwriting, and the handwriting instruction difference across countries. The correlation found for quality and speed is in

agreement with Blöte and Hamstra-Bletz, and Ziviani & Watson-Will who also found weak positive correlations between these two variables.

Rueckriegel et al. (2008) used a kinematic analysis to examine handwritings parameters in a group of children and adolescents from 6 to 18 years-of-age. Speed, automation, and pressure increased with age, and variability decreased. In speed and automation domains, handwriting movements matured after circle drawing. Furthermore, the complexity level (drawing circles versus writing a sentence) resulted in changes in parameters such as automation, variability and pressure. As complexity increased, automation took longer to occur and the movements were more variable.

In addition to increased experience, complexity of a task affects handwriting performance. Van Mier & Hulstijn (1993) looked at initiation time as a measure of preprogramming or the ability to plan movements in advance. Movements consisted of letters, figures, and patterns, and the number of strokes varied from four to ten. Initiation time increased with the number of strokes and the complexity of the sequence, and initiation time decreased with repeated trials.

Handwriting development is also influenced by the nature of the task. Van Mier (2006) found differences in the performance of younger and older children when performing a continuous (drawing around obstacles in a slalom-like pattern) and a discontinuous (zigzag pattern) task. Younger children tended to perform the continuous task in a discrete manner. He looked at performance of children between 4 and 12 years-of-age when connecting targets using lines making zig-zag (discrete) or slalom (continuous) movement. Using a digitizer drawing time, percentage of stop time, drawing distance, velocity, and errors were measured. All children performed the zig-zag discretely. This was shown by the stop time percentage at each target. In

the slalom task, only children older than six were able to perform it in a more continuous way.

Moreover, age was related to a decrease in the percentage of stop time, which was interpreted as more proficient planning in older children.

Handwriting follows a developmental trend characterized by maturation of specific parameters, including speed and legibility. Children progress from slower, less legible movements, to a faster and less variable handwriting. Handwriting is affected by complexity, with more complex tasks maturing after less complex ones, and possibly with the number of strokes determining the ability to correct a movement online. The ability to use discrete to continuous modes does not occur before six years old and appears to be linked to a more skilled movement planning and programming, appearing that the modality of the movement influences the ability to make corrections online.

The developmental trends of handwriting in children with DCD are different from typically developing children. They execute fewer number of letters per minute, have lower legibility, erase more letters and have difficulties when arranging a written text in space (vertical alignment of letters, spacing, and letter size) (Rosenblum & Livneh-Zirinski, 2008). Additional kinematics analyses showed they spend more time on-paper and in-air time per stroke and that apply less pressure than controls when writing a paragraph. These variables were analyzed by performing three tasks: writing their name, writing an alphabet sequence from memory, and copying a paragraph.

Even in writing their name, which is a task that they perform repeatedly and should be automated, children with DCD presented a longer movement time. In-air time is considered a temporal variable and consists of the time during writing performance in which the pen is not in contact with the writing surface. Authors suggest that longer in-air time might be related with

difficulties in the perceptual aspect of the motor act, difficulty with motor memory for letter formation, or difficulty in visualizing the letters while they are performing it rapidly. These results can also be interpreted as a difficulty that these children present in planning their movements while they are writing, resulting in more time in-air.

The in-air phenomenon was examined in more depth, comparing a sample of poor writers and good-writers (Rosenblum, Parush, & Weiss, 2003). Children ages 8 and 9 years were asked to perform a variety of handwriting tasks in Hebrew recorded on a digitizing tablet: continuous and discontinuous writing patterns, single letters, words, sentences and paragraph. Poor writers presented longer duration of word, sentence and paragraph task. Moreover, as the task increased in duration, in air-length increased in both groups, with poor writers increasing the most. Both proficient and poor writers had a shorter path length when the letters were continuous in nature, which is consistent with raising the pen when progressing from unit to unit. In both continuous and discontinuous writing pattern task poor writers took longer to perform them and presented longer in-air path length for the discontinuous task compared with the continuous.

In this experiment the discontinuous condition required that the child lifted the pen from the tablet because the characters were separated in between, which results necessarily in a greater in air-time. If the characters were together in the discontinuous condition, it could be argued that the greater in air-time was due to difficulties in planning the next stroke of the character during the movement. However these results should be extrapolated carefully for DCD population, because being a poor writer does not mean having movement difficulties. Also, no movement assessment was done in the sample.

Chang and Yu (2010) looked at the motor control aspect of handwriting in children with DCD using computerized movement analysis. Simple and complex Chinese characters were

reproduced in a digitizing tablet to examine automation of handwriting and control of handwriting movements. Automation of handwriting was measured by having children copying simple Chinese characters 40 times, while in control of handwriting condition, children were asked to copy six complex characters.

Children with DCD took longer to automate their writing, showing more changes in velocity even during the simple characters. Furthermore, children with DCD used faster stroke velocity to write simple characters, but the stroke velocity was slower in the complex characters. This difficulty in reproducing complex characters might be due to more anticipatory control or the ability to plan how to write the characters during the movement.

Using a grapho-motor task other than handwriting, Smits-Engelsman et al. (2001) found similar results. A sample of 12 poor writers, from which three were considered DCD, performed the flower-trail-drawing item of Movement ABC-I. This task requires that the child draws a line between the two solid lines of the flower trail as accurately as possible.

Poor writers committed more errors, crossing of the outlines more frequently than proficient writers. Additionally, they performed the task faster and used higher movement velocity. No differences were found for pen pressure. The trail-drawing item can be compared to a simple movement, where children do not need to anticipate or update their movements online as much as in a complex task. In these situations their movement's time seems to be shorter than typically developing children.

There is evidence that children with DCD perform handwriting tasks differently than typically developing children. Although there might be several factors that contribute to these differences, one seems to be related to their ability to plan during the movement, i.e., online control. Through manipulation of complexity of the movement, it is expected to determine the

degree to which online control is difficult for children with DCD compared with typically developing children.

Chapter 3: Online control of handwriting in children with Developmental Coordination Disorder

A paper to be submitted to *Human Movement Science*Helga Miguel and Ann L. Smiley-Oyen

1. Introduction

Children with the diagnosis of Developmental Coordination Disorder (DCD) are characterized by a lack of motor coordination that interferes with the child's ability to perform activities of daily living and with academic achievement (DSM-IV-TR, 2000). The manifestation of the disorder can vary with age and development. Younger children are likely to present clumsiness or delay in achieving motor milestones such as walking, crawling or sitting; older children often present difficulties in gross and fine motor tasks as playing ball, building models or handwriting (DSM-IV-TR, 2000).

Poor motor planning has been implicated as a contributing factor to poor handwriting performance in children with DCD (Tseng & Murray, 1994). Using a reach-to-grasp paradigm van Swieten et al. (2010) found that children with DCD selected a less skilled grasp, resulting in an awkward end position, indicating a poor ability to plan ahead. However, this study addressed planning prior to movement onset. Other aspect important to performance of motor tasks, particularly a continuous task as handwriting, is the planning during movement. This is referred to as online control.

Online control of movements is the ability to adjust the action plan online after the movement is initiated. The results obtained in children with DCD are equivocal (Smits-Engelsman et al. 2003; Plumb et al. 2008; Hyde & Wilson, 2010). Smits-Engelsman et al. (2003) used a reciprocal aiming task and found that when children were required to monitor their

movements as well as anticipate the upcoming movement, thereby relying more on a feedforward mode of control, children with DCD showed more difficulties than controls. This suggests that children with DCD do not present the internal representations needed to pre-plan and anticipate actions that are continuous in nature. Hyde and Wilson (2010) used a double-step reaching paradigm that involved reaching for targets in that could either stay in the same position or move to other locations on the screen. Children with DCD presented differences from controls only in the condition where the target changed, indicating that children with DCD have trouble integrating new sensory information and changing a previously established motor plan online, in order to reach a new position. In contrast, Plumb et al. (2008) did not find that children with DCD had difficulties with online control. Using a step-perturbation task children moved a stylus to a target that changed in color, location, or did not change but a distractor was introduced. The authors suggested that differences found in the movement time were related specifically with the feedback portion of the movement, but the results were not significant. However, the differences between groups may have been deemphasized because the task was simplified for children with DCD.

Children with DCD present difficulties in making adjustments online. Rather than rely on anticipatory feedforward control, they appear to rely heavily on feedback, a mode that is not efficient when the action requires rapid changes. What is not known is if this difficulty also occurs when they have to perform tasks that require online control in movements of longer and continuous duration, such as handwriting. Due to its continuous nature (van Galen & Weber, 1998) handwriting is an appropriate paradigm for the study of online control of movement. Moreover, children with DCD present difficulties in this functional task.

Rosenblum and Livneh-Zirinski (2008) found that children with DCD spend more time on-paper and in-air time per stroke than controls when writing a paragraph. Even in writing their name, which is a task that they perform repeatedly and should be automated, children with DCD presented a longer movement time. In-air time is considered a temporal variable and consists of the time during writing performance in which the pen is not in contact with the writing surface. These results can be interpreted as a difficulty that these children present in planning their movements while they are writing, resulting in more time in-air.

In another study, children with DCD took longer to automate their writing, showing more changes in velocity even during the simple characters. Furthermore, children with DCD used faster stroke velocity to write simple characters, but the stroke velocity was slower in the complex characters (Chang & Yu, 2010). This difficulty in reproducing complex characters might be due to the fact that it requires more anticipatory control or the ability to plan how to write the characters during the movement.

Using the flower-trail-drawing item of Movement ABC-I, Smits-Engelsman et al. (2001) found similar results. Poor writers, including children with DCD, committed more errors, crossing of the outlines more frequently than proficient writers. Additionally, they performed the task faster and used higher movement velocity. The trail-drawing item can be compared to a simple movement, where children do not need to anticipate or update their movements online as much as in a complex task. In these situations their movement's time seems to be shorter than typically developing children.

There is evidence that children with DCD perform handwriting tasks differently than typically developing children. Although there might be several factors that contribute to these differences, one might be related to their ability to plan during the movement, i.e., online control.

The purpose of the present study was to examine online planning in children with DCD during a handwriting task. It is hypothesized that children with DCD will present more difficulty adjusting to a change in an ongoing handwriting task, as evidenced by decreased fluency, greater percentage of time after peak velocity and longer duration of strokes. Additionally, children with DCD will exhibit greater difficulty when more complex control is required, as showed by decreased fluency, greater percentage of time after peak velocity and longer stroke duration.

2. Methods

2.1 Participants

Participants were recruited from the community, including ChildServe Outpatient Rehabilitation Services, daycares, and the general public through posted flyers. The experimental group consisted of eleven children with DCD (7 male, 4 female, age range 7 to 12 years old, with three children also diagnosed with ADHD). The inclusion criteria were: (1) does not have a neurological disability or physical impairment; (2) does not have autism; (3) has an IQ above 90. A comparison group matched for age and gender was a convenience sample from a community advertisement (n = 11; range 7 to 12 years old, with one child diagnosed with ADHD). Children in the comparison group did not have history of psychiatric and neurological disabilities. Procedures abided by the code of ethics established by Iowa State University. Monetary compensation was given for each session children participated.

2.2 Instruments

Experimental and control groups performed several tests in order to assess their motor development, visual-motor integration, handwriting and intelligence. In addition, children completed all conditions of the experimental graphic task.

2.2.1 Movement Assessment Battery for Children, 2nd Edition (M-ABC2)

The M-ABC2 assesses motor impairment in children from 3 to 16 years old. It is divided into three age bands: 3 to 6, 7 to 10, and 11 to 16 years old. Eight items are evaluated, with the tasks divided in three major areas: manual dexterity, ball skills and static/ dynamic balance. The overall score is translated into a percentile, with the lowest 5th percentile representing definitive motor coordination problems and lowest 10th percentile representing a risk of impaired motor coordination. It takes approximately 20-30 minutes to administer. The test has an overall reliability of .80, and a good criterion related and discriminative validity, as supported by different studies included in the Test Manual (Henderson, Sugden, & Barnett, 2007).

2.2.2 M-ABC Check-List (M-ABCC)

The M-ACBC is a parent questionnaire that gives additional information about the child's competence in the movement domain. It includes three sections: movement in a static and/or predictable environment, movement in a dynamic and/or unpredictable environment and, non-motor factors that might affect movement (Henderson, et al., 2007). It has been shown be internally consistent (α = .94) and sensitive (85%) (B. N. Wilson et al., 2009).

2.2.3 Beery-Buktenica Developmental Test of Visual-Motor Integration, 6th Edition (VMI)

The Beery-VMI was used to measure visual motor integration. It consists of a sequence of geometric forms to be copied with paper and pencil, and the ability to copy the first eight designs is related to readiness for handwriting instruction. VMI takes approximately 20 minutes to administer. It has an overall reliability of .92 based on an average of inter-scorer, internal consistency, and test-retest reliabilities. The test presents content, concurrent, construct, and predictive validity (Beery & Beery, 2010).

2.2.4 Evaluation Tool for Children's Handwriting – Manuscript

ECTH evaluates manuscript and cursive handwriting in children between grades 1 to 6. This standardized test includes tasks such as alphabet and numerical writing, near point and farpoint copying, dictation, and sentence generation (Amudson, 1995). It takes approximately 20-25 minutes to administer. Scoring consists of legibility of individual tasks and total tasks, and speed. Legibility of letters, words and numerals have a specific score criterion. The ECTH- manuscript has an interrater reliability of .90 to .92, intraclass reliability of .84 and test-retest reliability of .77 (Amudson, 1995).

2.2.5 Kaufman Brief Intelligence Test-2 (KBIT-2)

KBIT-2 is a measure of intelligence used in people 4-90 years old. It provides three scores: verbal, nonverbal and an IQ composite. The verbal scale contains items of verbal knowledge and riddles that measure the knowledge of words and their meaning (crystallized intelligence); the nonverbal scale includes matrices which measure fluid thinking, or the ability to solve new problems by perceiving relationships and analogies. It takes approximately 20-30 minutes to administer. Concurrent validity was established by analysis with WISC-R, WAIS-R and K-ABC (Canivez, Neitzel, & Martin, 2005).

Table 1 presents DCD group characteristics. Differences in performance in the tests are presented in Table 2. There were no differences between the DCD and TD group for age, gender and handedness. Furthermore, no differences were found for intelligence, CARS-Impulsivity and handwriting legibility for words, letter and numeral. Groups were different for scores of M-ABC, with the DCD presenting a lower percentile than TD $(5.2\pm2.9, 64.5\pm21.6, p < 0.01)$. Differences were also found for Beery $(14.5\pm14.7, 45.3\pm25.1, p = 0.022)$ and in the inattentive portion of CARS $(63.9\pm14, 48.8\pm7.5, p < 0.05)$. Additionally, the distribution of children classified as

having motor problems in the M-ABC checklist was significantly different between groups ($X^2 = 12.17$, p = 0.023), with more children from DCD group in the Red Zone (identified as having definitely motor problems) compared to one child in the TD group.

Table 1: DCD group characteristics.

	ETCHN	88	92	94	82	94	82	82	100	100	100	82
	ETCHL	91	83	92	87	94	95	93	81	95	26	87
	ETCHW	83	68	95	94	95	95	9/	99	100	94	9/
Connors	Hy	45	06	71	14	72	47	83	78	53	75	75
Connors	ln	49	06	09	62	92	41	82	61	58	64	09
	Beery	9	1	13	1	42	7	23	9	37	23	0.4
	Kaufman	86	06	93	116	66	123	104	110	116	107	06
	MABCC	Green	Red	Amber	Red	Red	Amber	Red	Red	Red	Red	Red
M-	ABC	6	2	5	2	5	6	5	6	5	5	1
	Handedness	Right	Right	Right	Right	Right	Right	Left	Right	Left	Right	Right
	Gender	Female	Female	Male	Male	Male	Female	Male	Male	Male	Female	Male
	Age	7	6	6	10	10	10	10	Ξ	=======================================	==	12
	Subject Age Gender	1	2	3	4	5	9	7	∞	6	10	11

M-ABC C. Movement Assessment Battery for Children, score expressed in percentile.

MABCC.- Movement Assessment Battery for Children Check List, Green – children at no risk of movement difficulties; Amber – children at risk of movement difficulties; Rad – children with definitely movement difficulties.

MABCC.- Movement Assessment Battery for Children Check List, Green – children at no risk of movement difficulties.

MABCC.- Movement Assessment Battery for Children – children at no risk of movement difficulties; Amber – children as risk of movement difficulties.

Beery – Beery-Bukterica Developmental Test of Visual-Motor Integration, score expressed in percentile.

Connortal – Common Rating Scale – Instruction, score expressed in percentile.

CONNORTAL – Counces Rating Scale – Instruction, score expressed in percentile.

ETCHN – Evaluation too for children is handwriting – Letter legibility, score expressed in percent legibility.

ETCHN – Evaluation tool for children is handwriting – Numeral legibility, score expressed in percent legibility.

Table 2: Descriptive statistics comparing children with DCD and typically developing children

	DCD	TD	
	(n=11)	(n=11)	p
Age (years)	10 ± 1.34	10 ± 1.34	
	(7-12)	(7-12)	
Gender (M/F)	7 M/4F	7M/4F	
Handedness (R/L)	9R/2L	9R/2L	
M-ABC	5.2±2.9	64.5±21.6	< 0.001
	(1-9)	(25-95)	
M-ABCC	Red-8	Red-1	0.023
(zone)	Amber-2	Amber-1	
	Green-1	Green-9	
Kaufman	104.4±11.02	109.7±7.58	0.198
	(90-123)	(99-122)	
Beery VMI	14.5±14.7	45.3±25.1	0.0022
	(.4-32)	(4-86)	
ConnorsIn	63.9±14	48.8±7.5	0.002
	(41-90)	(40-58)	
ConnorsHy	63.9 ± 22	49.7 ± 8.2	0.059
	(14-90)	(40-92)	
ECTH-W	87.4±10.9	88.09 ± 14.6	0.9
	(65-100)	(53-100)	
ECTH-L	90.5±5.2	90±14	0.92
	(81-97)	(51-100)	
ECTH-N	89±9	93±13.4	0.42
	(81-97)	(51-100)	

M-ABC- Movement Assessment Battery for Children, score expressed in percentile.

Beery – Beery-Buktenica Developmental Test of Visual-Motor Integration, score expressed in percentile.

ConnorsIn – Connors Rating Scale – Inattention, score expressed in percentile.

ConnorsHy- Connors Rating Scale – Hyperactive, score expressed in percentile.

ETCHW – Evaluation tool for children's handwriting – Word legibility, score expressed in percent legibility.

ETCHL – Evaluation tool for children's handwriting – Letter legibility, score expressed in percent legibility. ETCHN – Evaluation tool for children's handwriting – Numeral legibility, score expressed in percent legibility.

M-ABCC- Movement Assessment Battery for Children Check List, Green - children at no risk of movement difficulties; Amber - children at risk of movement difficulties; Red - children with definitely movement difficulties.

Kaufman – Brief Intelligence Test, score expressed in percentile.

2.3 Graphic Task

The handwriting tasks were performed on A4 paper in landscape orientation and were taped on a digitizing graphics tablet (Wacom, UD-12-18-R), which was connected to a Dell computer. Drawing trajectories were recorded and analyzed using Movalyzer 6.10. The *x*, *y* and *z* position of a digitizer wireless ink pen was sampled at a frequency of 100Hz. The pen left an ink trace on the paper, visible to the children. The screen was out of sight of children, making sure that they did not see their performance. This made the task similar to a typical drawing task. There were several patterns as described below. Each pattern was written on a separate sheet on a line approximately 10-cm wide. Children were instructed to look at the pattern and make the same pattern in the space between the lines. During the tasks, patterns were referred to as waves (loops) and mountains (peaks) to make the task more attractive and familiar to children.

2.3.1 Continuous task. In this task, children were asked to write sequences of cursive loops with two different levels of complexity on the digitizer surface (Big Loops and Combined Loops, see Figure 1: A and B). The number of loops they had to write was not specified.

Additionally, children performed a condition in which they had to change the ongoing simple cursive loops after they heard a tone (see Figure 1:C). The tone occurred in different parts of the pattern, so that children did not anticipate the movement. The tone was produced after the second, third, fourth, fifth or sixth loops.

2.3.2 Discontinuous task. In this task, children copied discontinuous sequences presented to them as they did in the previous task (Big Peaks, Combined Peaks, see Figure 1:D and E).

Levels of complexity were the same and the number of peaks they had to write was not specified.

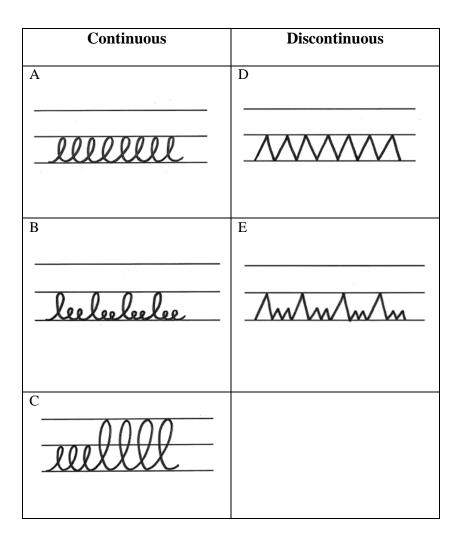


Figure 1:Writing sequences grouped according to continuity (continuous in left column, discontinuous in right column) and level of complexity (simple: **A** and **D**, and high: **B** and **E**). Figure **C** represents the product of a trial where the tone occurred after the third loop. Big Loops (A), Combined Loops (B), Big Peaks (D) and Combined Peaks (E).

2.4 Procedures

Each child visited the Motor Control and Learning Research Laboratory twice at Iowa State University. Testing was individual and was conducted either in the Lab or in a quiet room. In the first session, the child and parent read and signed the consent and assent forms, and exclusionary criteria were confirmed. Movement-ABC and the other tests were administered, and parents completed the Developmental Coordination Disorder Questionnaire and the Connors

Rating Scale. The first session took approximately 90 minutes. A break between tests was provided.

The second session took place the following week. Children were seated at a table with feet supported to assure a confortable drawing position. Before the experiment started, they were invited to write their names on the tablet to become familiarized with the setup.

Patterns to copy were printed individually on A4 paper in landscape orientation. Patterns were placed in a binder, positioned 1 inch from the top of the digitizer. The examiner demonstrated a first trial of 8 loops, drawing half of the line, and asked the child to complete the rest of the line as a practice. After the child confirmed that the task was understood, the examiner administered the first pattern to copy, and began collecting practice trials.

Children performed 14 practice trials, consisting of two of each movement mode (continuous/discontinuous/), complexity level (simple and complex) and tone, and one additional trial of simple loops to assure that children did not anticipate the tone trial. The practice trials were followed by 21 formal trials. Two of the same conditions were never presented consecutively. The examiner flipped the page after the child finished copying the pattern.

Conditions were counterbalanced across trials. Children were instructed to perform the tasks as accurately as possible, reinforcing that they were not being timed ("Copy the loops, going up and down the lines, without going outside them. You have to always touch the lines but you cannot go outside them). The second session took approximately 40 minutes. Breaks were permitted after every 14 trials.

2.5 Statistical Analyses

The following variables were analyzed: movement fluency (number of zero crossings within the acceleration signal made during drawing of individual strokes/ duration), movement

duration (time interval in seconds, between the first and last samples in a stroke), percent time to peak vertical velocity (ratio of time duration at which the maximum peak velocity occurs to total time x 100) and accuracy (mean number of under or overshoots of more than 2 mm of a stroke intended to the end on a line. Performance across three trials was averaged. If a trial was not successfully completed it was not included in the analysis, resulting in 90% of the trials for the DCD group and 95% in the TD group.

A group (2) by stroke (4) analysis of variance (ANOVA) was conducted to test the hypotheses 1. In addition, a T-test was used to examine differences in physical errors and a chi square analysis was conducted to examine differences in completion of trials. A group (2) by condition (4) by stroke (2) ANOVA was conducted to test hypothesis 2, and a T-test was used to examine differences in physical errors. Statistical analyses were performed using SAS (Statistics Analysis System – Version 9.2) and the significance level was set at $p \le 0.005$. Effect size was calculated for primary analyses using ω^2 (omega squared) with .01 being a small effect, .09 being a moderate effect and .25 being a large effect (Tabachnick, 2007). The Tukey test was used for posthoc comparisons.

3. Results

3.1 Hypothesis 1

The first hypotheses was that children with DCD would present more difficulty adjusting to a change in an ongoing handwriting task, as evidenced by decreased fluency, longer duration, and greater percentage of time to peak velocity in the stroke immediately after the tone. A 2 (group) by 4 (stroke: -1, tone, +1, +2) repeated measures ANOVA was performed on each dependent variable.

3.1.1 Fluency. The distribution of this variable was positively skewed, so a logarithmic transformation was conducted. In Figure 2 fluency is presented for a total of eight strokes, three

before the tone occurred (-3, -2, -1 respectively) and 4 after (+1, +2, +3, +4). Note that high values represent less fluent movements.

A group main effect was found (F(1,256) = 40.44, p < 0.001, ω^2 = .13), with the DCD group being less fluent than typically developing children (DCD = 6.37 ±0.67; TD = 5.93 ±0.42). There was no main effect for stroke and no interactions.

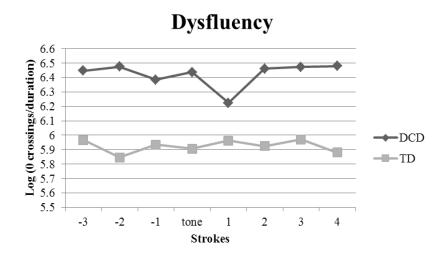


Fig 2: Mean values for dysfluency for children with DCD and typically developing children. Note that higher values represent less fluent movements.

3.1.2 Duration. Duration of strokes is presented in Figure 3 for a total of eight strokes. Note that duration increases after tone and is longer for the bigger loops.

A group main effect was found (F(1,256) = 40.44, p < 0.001, ω^2 = .11), with the TD group taking longer (M=1.297 ±0.45) to write the strokes compared with the DCD group (M=0.963 ±0.46). There was no main effect for stroke and no significant interaction.

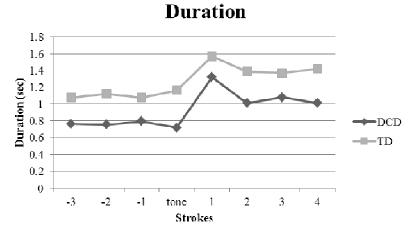


Fig 3: Mean values for duration for children with DCD and TD children. Note that TD children took longer to write each stroke.

3.1.3 Percent time to peak vertical velocity. Percent time to peak vertical velocity is presented in Figure 4 for eight strokes. A group main effect was found (F(1,256) = 7.37, p = 0.0071, ω^2 = .02), with the DCD group presenting greater percentage time to peak vertical velocity (M = 45% ±16%) compared to TD children who devoted 39% (±15%). Additionally, a main effect of stroke was found (F(3,256) = 14.42, p < 0.001, ω^2 = .13), with stroke +1 (M = 52.6% ±19%) differing from strokes -1 (M=42.2% ±13%), tone (M=38.3% ±13%) and +2 (M = 36.8% ±14%). There was no interaction.

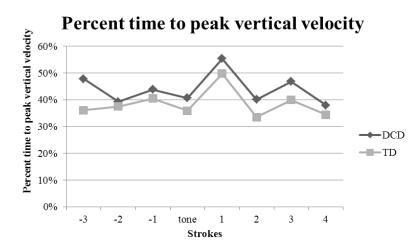


Fig 4: Mean values for percent time to peak vertical velocity for children with DCD and TD children. Overall children with DCD spent more percent time to peak vertical velocity than TD.

To better understand the strategies children with DCD were using to perform the task, a follow up ANOVA was done looking at peak vertical acceleration. Peak vertical acceleration is presented in Figure 5 for eight strokes. No main effect for group was found. However, there was a significant effect for stroke (F (3,256) = 234, p < 0.001, ω ²= .709). Additionally, there was an interaction between group and stroke (F (3,256) =7.94, p < 0.001, ω ²= .02). Differences were statistically different in Stroke +2, where children with DCD presented a mean peak vertical acceleration of -71.467 (±55) compared with -44 (±24) presented by TD children.

Peak vertical acceleration

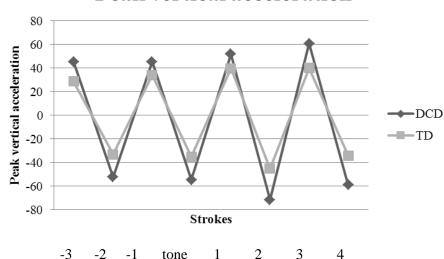


Fig 5: Men values for peak vertical acceleration for children with DCD and typically developing children. Children with DCD show greater peak acceleration values for all strokes, with stroke +2 being the highest. Note that positive values represent upstrokes and negative values downstokes.

3.1.4 Errors. A t-test was performed to examine physical errors. A maximum of two physical errors could be committed (downstroke and upstroke immediately after the beep). DCD children made more errors than controls $(0.60\pm0.70,\,0.15\pm0.28,\,p=0.066)$.

3.1.5 Task Completion. A chi square analysis was performed to analyze the differences in task completion. Eight trials were included in the analysis. Table 3 shows that group with DCD completed fewer trials than TD, stopping or executing extra small loop after tone (Chi Square p = .0288).

Table 3: Chi square for task completion

	Not completed	Completed	р
DCD	14	74	0.0288
TD	5	83	

3.2 Hypothesis 2

The second hypothesis was that children with DCD would exhibit greater difficulty when more complex control was required. Loops were considered more complex due to the continuous nature and peaks were considered less complex. Additionally, doing a sequence of loops (Big

Loops) and peaks (Big Peaks) of the same size was considered less complex, than doing a sequence of loops and peaks of two different sizes (Combined Loops and Combined Peaks, respectively). Fluency, movement duration and percentage time to peak vertical velocity were examined. A group (2) by condition (4) by stroke (2) repeated measures ANOVA was conducted for each dependent variable.

3.2.1 Fluency. There was a main effect of group (F(1,3563) = 779.76, p < 0.0001, ω^2 = .15), with children with DCD being less fluent than TD children (6.79 ±0.73,6.20 ±0.60). There was also a main effect for condition (F(3,3563) = 176.34, p < 0.000, ω^2 = .1) with Big Loops (M=6.26±0.71) and Big Peaks (M=6.50 ±0.68) more fluent that Combined Loops (M=6.35 ±0.6) and Combined Peaks (M=6.88±0.75). A main effect for stroke (F(1,3563) = 8.85, p = 0.003, ω^2 = .001), demonstrates that across all conditions stroke 1 (upstroke) (M=6.53 ±0.71) was less fluent than stroke 2 (downstroke) (M=6.47 ±0.74).

A significant interaction was found for group and condition (F(3,3563) = 5.32, p = 0.0012, ω^2 = 0) (see Figure 6). Follow up analysis indicated that Big Loops (M= 6.59±.03, M=5.93±.03) and Combined Loops (M=6.58±.02, M=6.11±.02) were more fluent than Big Peaks (M=6.83±.03, M=6.16±.03) and Combined Peaks (M=7.16±.02, M=6.6±.02) for the DCD and TD group, respectively.

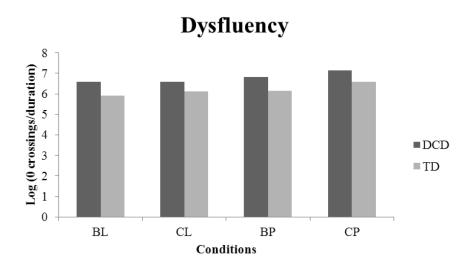


Fig. 6 – Mean values of dysfluency for DCD and TD children in each of the 4 conditions. DCD were always less fluent than TD children, with discontinuous tasks presenting greater values than continuous (BL-big loops; CL-combined loops; BP- big peaks; CP-combined peaks).

There was also an interaction between condition and stroke $(F(3,3563) = 6.04, p = 0.0004, \omega^2 = .002)$. Follow up comparisons showed that stroke 1 and 2 differed significantly in Big Peaks with stroke 1 being more dysfluent, but stroke 1 did not differ from 2 in any other condition. 3.2.2 Duration. Children with DCD were faster than TD children $(F(1,3563) = 519.32, p < 0.0001, \omega^2 = .1$; DCD = 0.59 ±0.30, TD = 0.83 ±0.40). A main effect was also found for condition $(F(3, 3563) = 269.85, p < 0.0001, \omega^2 = .16)$, with Big Loops taking the longest (0.89 ± 0.41) , followed by Big Peaks (0.83 ± 0.39) , Combined Loops (0.61 ± 0.61) , and Combined Peaks (0.51 ± 0.28) . There was also a main effect for stroke $(F(1,3563) = 7.23, p = 0.0072, \omega^2 = .001)$, with stroke 2 taking longer (0.72 ± 0.40) than stroke 1 (0.69 ± 0.34) .

An interaction was found for group and stroke (F(1, 3563) = 4.97, p = 0.0258, $\omega^2 = 0$), with children with DCD taking approximately the same time in both strokes and TD taking longer in stroke 2 than stroke 1 (see Figure 7).

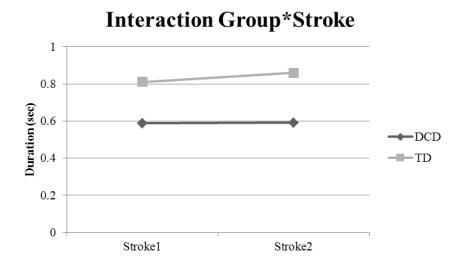


Fig.7 – Mean values of DCD and TD children for duration for Stroke 1 and Stroke 2. Children with DCD were performing the movement faster but the duration did not differ between strokes. TD children took longer in stroke 2. (BL- big loops; CL-combined loops; BP- big peaks; CP- combined peaks).

There was also an interaction for group and condition (F(3,3563) = 22.82, p < 0.001, $\omega^2 = .01$). In the DCD group Big Loops (0.73 ± 0.36) was significantly different from Combined Loops (0.53 ± 0.26 , p< 0.0001) and Combined Peaks (0.44 ± 0.22 , p<0.0001) but not for Big Peaks (0.667 ± 0.27 , p=0.253). In TD group Big Loops differed significantly from all the others (see Figure 8).

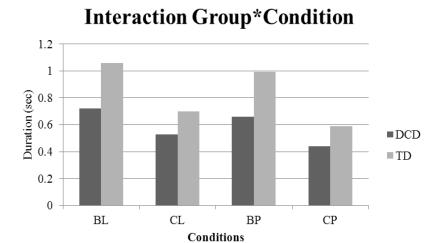


Fig.8- Mean duration that DCD and TD children took for the different conditions. Conditions BL and BP took longer than CL and CP for both groups, with TD children taking longer to perform them

(BL big loops: CL combined)

(BL- big loops; CL-combined loops; BP- big peaks; CP-combined peaks).

An interaction was also found between condition and stroke (F(3,3563) = 3.34, p = 0.0186, ω^2 = 0). With the exception of Combined Loops stroke 2 was longer for all conditions, and was significant only in Big Peaks (0.78 ±0.25, 0.87 ±0.29, p = 0.0070) (see Figure 9).

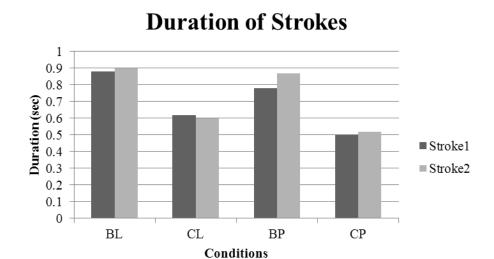


Fig.9- Mean duration of strokes 1 and 2, for the different conditions.

Stroke 3 is always longer with the exception of Condition 2. In Condition 3 the duration between strokes is significant.

(BL- big loops; CL-combined loops; BP- big peaks; CP- combined peaks).

3.2.3Percent time to peak velocity. Children with DCD allotted a greater percentage of time to peak velocity compared with TD children (F(1,3563) = 83.41, p < 0.001, $\omega^2 = .02$; 39.5% $\pm 14\%$, 35.2% $\pm 15\%$). There was also a condition main effect (F(3,3563) = 130.83, p < 0.001, $\omega^2 = .09$), with all conditions significantly different from each other. The greatest percentage allotted to peak velocity was Combined Loops (43% $\pm 13.6\%$), followed by Big Loops (40% $\pm 13\%$), Combined Peaks (34% $\pm 14.7\%$) and finally BP (31% $\pm 14.8\%$). Main effect of Stroke (F(1,3563) = 10.65, p = 0.0011, $\omega^2 = 0$) showed that the percent time to peak velocity was greater in stroke 1 than in stroke 2 (38% $\pm 15\%$, 36% $\pm 14\%$).

An interaction was found for condition and stroke (F(3,3563) = 3.92, p = 0.0084, ω^2 = 0). Big Peaks was the only condition where stroke 2 was longer than stroke 1. The only significant difference between strokes was in Combined Loops (44% ±14%, 41±12%, p = 0.0012) (See Figure 10).

Percent time to peak vertical velocity

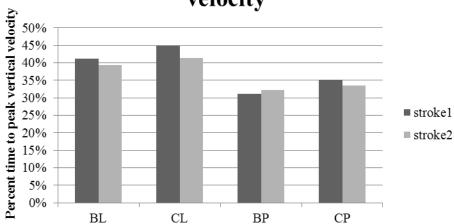


Fig. 10- Mean percent time allotted to peak velocity by stroke, in the different conditions. (BL- big loops; CL-combined loops; BP-big peaks; CP-combined peaks).

The interaction group and stroke $(F(1,3563) = 6.35, p = 0.0118, \omega^2 = 0)$, revealed that DCD children allotted a similar percentage of time in stroke 1 and stroke 2 (39.6% $\pm 14\%$, 39.3% $\pm 13\%$), compared with TD children who spent a greater percentage in stroke 1 than in stroke 2 (36.6% $\pm 15\%$, 33.3% ± 14) (see Figure 11).

Percent time to peak vertical velocity

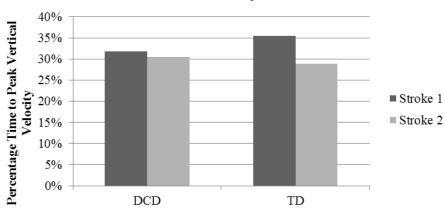


Fig.11- Mean percentage time allotted to peak velocity in children with DCD and TD children. DCD children allot approximately same percentage of time in the upstroke (stroke1), than the downstroke (stroke 2), whereas TD children use a significantly less amount of time, specifically in the downstroke.

To better understand the differences in the percentage time to peak velocity in the two groups, four follow up ANOVAs (group by stroke) were performed for each Condition to examine percent time spent in strokes 1 and 2 (see Figure 11). An interaction was only found for peaks, specifically for BP (F (1, 763) = 6.77, p=0.0094). Children with DCD allotted more time in Stroke 2 compared with Stroke 1 (31.8% \pm SD, 35.5% \pm SD), whereas TD children used greater percentage of time in Stroke 1 compared with Stroke 2 (30.5% \pm SD, 28.8% \pm SD).

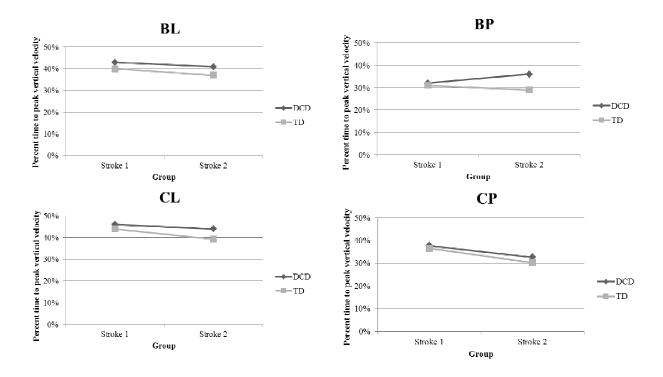


Figure 11 – Percent time to peak velocity in each of the four conditions BL, LC, BP and PC. Only condition 3 showed a significant interaction for group and stroke. (BL- big loops; CL-combined loops; BP- big peaks; CP-combined peaks).

3.2.4 Errors. A t-test was performed to examine physical errors. For all conditions a maximum of 12 errors could be committed (2 for each big loop or peak and 1 for each small loop or peak). Children with DCD committed more errors than TD in Big Loops (2.30 \pm 2.94, 0.74 \pm 1.15, p=

0.1175) and Combined Loops (1.72 \pm 2.21, 0.54 \pm 0.89, p = 0.1160), but differences were only significant in the Big Peaks (1.60 \pm 1.46, p = 0.0047) and Combined Peaks (1.63 \pm 2.04, 0.06 \pm 0.20, p = 0.0191).

4. Discussion

The purpose of this study was to determine if children with DCD exhibit difficulties planning movements online compared with typically developing children. This was examined through a handwriting task in which the children had to adjust the ongoing movement after a tone occurred, and when writing in a continuous and discontinuous mode as well as writing simple and complex patterns.

The first hypothesis, that children with DCD would present more difficulty adjusting to a change in an ongoing handwriting task, was partially supported. Children with DCD had greater difficulty integrating the adjustment into their motor plan as evidenced by fewer successfully completed trials (i.e., stopping after the tone or doing one extra loop after the tone). Hyde and Wilson (2010) found similar results in their double-step reaching task in which children with DCD committed more errors than TD, but because the results were not sufficiently strong to drawn inferences, they explain the differences between groups with an inhibition problem instead of an online control problem. However, for the trials completed correctly, children with DCD integrated the change into their ongoing plan in a manner similar to the TD group.

Overall, however, the handwriting of children with DCD was more dysfluent, was faster, and a lesser percent of total time was spent in the second submovement (i.e.,time after peak velocity). This is consistent with previous findings in which children with DCD were not able to scale their movements by slowing down (Smits-Engelsman et al., 2003). Instead, they seem to

perform the movements in a more ballistic mode. In addition, they exhibited greater acceleration two strokes after the tone, suggesting a disruption or change in the control of the movement, but adjustments in the stroke immediately after the tone were similar between the groups.

Studies addressing online planning in DCD are contradictory, with one study finding that children with DCD had problems changing a plan online (Hyde & Wilson, 2010) and another showing no difference (Plumb et al., 2008), although the mean differences were consistent with Hyde and Wilson. Both of these studies used a double-step paradigm that involved a single rapid aiming movement to a target, whereas the task in the current study was continuous, thus providing a longer window in which the children could integrate a change in the plan. Therefore, this additional time may have allowed children with DCD to adjust. A change in the direction of the movement (thus a more abrupt adjustment) may have been more sensitive to differences in their ability to change the plan online.

The second hypothesis was that children with DCD would exhibit greater difficulty when more complex control was required. It was thought that loops would be more difficult than peaks and combined sizes of strokes would be more difficult than similarly sized strokes. These expectations were based on previous work in which van Mier (2006) found greater developmental differences in TD children when they executed a slalom pattern (continuous) compared to a zig-zag (discontinuous). And based on our pilot testing with young children (age 5), the loop letterforms were more difficult to form. But in the study sample (age range 7 to 12 years), both groups were more fluent in loops than peaks, thus indicating the loops were easier to form. However, they also committed more errors in loops compared (i.e. were not forming the letterforms as carefully) compared to peaks, thus possibly increasing fluency. Regarding increasing complexity of control by changing letterform size, we found no difference. Possibly

because there was no middle line to indicate a specific height for the small letterform, so a lack of accuracy constraints may have confounded results.

Given that group differences were evident especially in the Big Peaks condition, the focus of discussion will be on formation of those letterforms. As expected, the children with DCD exhibited less fluency than the TD group. In addition the DCD group moved more quickly and committed more errors. These latter results are similar to other studies. Chang and Yu (2010) also found that simple letter forms were executed more quickly by the DCD group, but more complex letterforms were not. Smits-Engelsman et al. (2001) found that children with DCD drew a flower-form faster than TD children, but they also committed more errors.

When examining how each peak letterform was written it is clear the children with DCD were using a different strategy. The DCD group spent approximately the same time in the upstroke and downstroke, while TD children took longer in the downstroke. In addition, the TD children spent a greater percent of the total time in the second submovement in the downstroke (time after peak velocity). This indicates either a greater use of feedback for accuracy in the downstroke or indicating the tendency to plan ahead for the next letterform. Together, these results indicate the children with DCD executed the peaks as a series of individual lines whereas the TD group was executing the letterform in a more integrated fashion.

The current study presents several limitations. The sample size was small and the DCD group was heterogeneous. This could have contributed to more variability and a lack of significance in the results. In addition, the tone was delivered by the examiner rather than computer generated tone based on kinematics of the downstroke, which would have provided more precise timing. The task might not have been sufficiently challenging to capture differences in the online planning between the DCD and TD groups. In addition to this, children were

allowed to practice each condition before formal trials, thereby possibly decreasing group differences.

The ability to plan the movements while performing them is important for monitoring and adjusting to changes. Children with DCD seem to differ from TD children in this process in tasks that require a rapid change. To our knowledge this study was the first that examined online planning in tasks of longer duration, such as handwriting. We did not find differences between DCD children and TD but further research is needed. It is of extreme importance that this process be studied thoroughly to better understand the difficulties presented by these children, thereby developing better and more efficient strategies in treatment.

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