INFLUENCE OF ATTENTION ON STATIC BALANCE CONTROL AND POSTURAL ADAPTATIONS IN TYPICALLY DEVELOPING CHILDREN AND CHILDREN WHO MET THE CRITERIA FOR DCD

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Abstract

Attentional issues may be a contributing factor to poor static and dynamic postural control for many children with DCD, particularly since many of them may have a dual diagnosis with ADHD. To date, only a few investigations have examined the impact of attention on static balance, with the majority of them involving only traditional measures of balance. However, there has been no research attempting to examine such issues in the context of dynamic postural adaptations. As a result, the purpose of this study was to investigate the impact of attentional loading on static balance control and postural adaptations in children with and without DCD, using traditional and non-traditional descriptors of the center of pressure (COP).

Ten children who met the criteria for DCD (8 males and 2 females) and ten typically developing children (5 males and 5 females), between 8 and 10 years of age, participated. To investigate the issues in attention, a dual-task methodology involving a motor and an attentional task was incorporated (e.g., Laufer et al., 2007). Two balance tasks, static balance and postural adaptation (leaning task), were performed with and without attentional loading. The dependent measures (mean and variability) included three traditional (Ao, AP sway, L), as well as three non-traditional measures (f_{dis}, f_{mode}, Pp). In static balance, the results revealed a main effect for group (mean) area of sway, as children with DCD demonstrated larger area of sway, regardless of attentional loading. The results also revealed a significant interaction effect and a main effect for attention (mean and variability) for frequency mode. The addition of an attentional load resulted in an increase of frequency mode. No other significant between or within group differences were found. In terms of postural adaptations, the results also revealed main effects for attention in terms of (mean and variability) frequency mode. The addition of an attentional load resulted in an increase in frequency measures. No other between or within group differences were found. The overall lack of differences indicated that an issue in attention, as shown by this protocol, for the children who met the criteria for DCD, does not impact balance performance as measured by this protocol.

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Definitions

Area of Sway: An ellipse that encloses 95% of the center of pressure data.

Attention: A multidimensional factor in which the performance of task(s) largely depends on the performer's ability to successfully divide and allocate his/her focus to the performance of important task(s) while ignoring all other distractions (Shumway-Cook & Woollacott, 2001).

Automaticity: Implies minimal attentional requirement in the performance of a skill or movement task (Schmidt & Lee, 2005).

Balance Control: The ability to maintain the COP within the stability boundary in a near static position.

Center of Pressure (COP): Point of application of the resultant of vertical forces acting on the surface of support. It represents the collective outcome of the activity of the postural control system and the force of gravity. It is represented as a central point located between the feet (Winters, 1995).

Dual Tasking: Methodology that involves performing two tasks simultaneously. Generally, it involves the performance of a motor task in concurrence with an attention task (Abernethy, 1988).

Dual Task Interference: In balance, it can be an observable hindrance on motor performance, on the attentional task, or the combination of both as a result of dual task performance. It is inferred from a substantial change in sway measures, as a result of one of the tasks requiring more attention than what is available and the inability to divide attention (Kahneman, 1973).

Fast Fourier Transform (FFT): A method used to transform data from time domain to a frequency domain.

Frequency Spectrum: Frequency wave generated from the FFT. The resulting values are measured in amplitude and frequency.

Path Length: The total distance traveled by the COP (cm).

Mean Frequency (f_{mean}): Weighted average of the sum of the spectral signal (McClenaghan et al., 1996).

Median Frequency (f_{median}): Fifty percent (50%) of the cumulative power frequency (McClenaghan et al., 1996).

Mode Frequency (f_{mode}): Largest peak in amplitude of the spectral signal (McClenaghan et al., 1996).

Postural Adaptation: The ability to voluntarily control the movement of the COP as close to the stability boundaries without initiating any balance recovery strategy, i.e. hip or step strategy (Riach & Starkes, 1993).

Posture Control: Perceptual-motor process that requires sensory information from visual, somatosensory, and vestibular systems, to be coupled with the appropriate motor response for the dual purposes of stability and orientation (Shumway-Cook & Woollacott, 2001).

Power Density: Measure of the amplitude of the displacement in frequency domain (McClenaghan et al., 1996).

Spectral Analysis: Descriptive technique that uses time-frequency measures to allow for a visual comparison of time-varying spectral changes in COP sway measures.

Stability Boundary: The boundary within which the body can maintain stability without changing the base of support or initiating a balance recovery strategy (Shumway-Cook & Woollacott, 2001).

Introduction

Children with DCD demonstrate difficulties on a wide range of motor tasks, with postural control being one of the more pronounced issues. Much of the DCD literature in the postural control domain has focused on issues in action (Williams, Fisher, & Tritschler, 1983) and perception (Wilson & McKenzie, 1998) in relation to motor control. However, many children with DCD demonstrate issues in attention (Dewey, Kaplan, Crawford, & Wilson, 2002). As a result, an understanding of the influences attention has on postural control mechanisms may provide more insight into motor control issues common to many children with DCD.

Two studies were carried out in order to investigate such issues. A pilot study was completed to address the suitability of dependent measures and varying degrees of attention loading on static balance control and postural adaptations in typically developing children and young adults. The results led to the selection of dependent variables, as well as the attention task that was incorporated in the major study. The main study investigated the impact of attention on static balance control and postural adaptations of typically developing children and children who met the criteria for DCD.

This document comprises three sections. The review of literature focuses on developmental coordination disorder, postural control, attention and dual-tasking, as well as traditional and non-traditional measures. Subsequently, the results of the pilot work are addressed. The last section of the thesis involves the main study methodology, results and discussion, followed by general conclusions and recommendations drawn from this research.

Review of Literature

Developmental Coordination Disorder

Many children acquire adequate proficiency in the performance of motor tasks. However, there are also some children who exhibit pronounced difficulties in the coordination of activities of daily living (e.g., shoe lace tying) and/or fundamental movement skills (e.g., catching balls or maintaining balance). These children are often described as being ‘clumsy’, ‘awkward’ or ‘poorly coordinated’, and may have experienced a delay in the acquisition of motor milestones (Van Waelvelde, De Weerdt, & De Cock, 2005). The inability to perform certain movement tasks usually results in a withdrawal from physical activity, which may have negative consequences on skill development and social interactions (Cermak & Larkin, 2002). Many of these children are diagnosed with developmental coordination disorder (DCD).

The most widely accepted diagnostic criteria for DCD comes from the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM- IV). The DSM-IV defines DCD as a condition that is characterized by motor coordination performance which is substantially below what is expected given the child’s chronological age and measured intelligence (American Psychological Association (APA), 2000). The motor difficulties must negatively impact activities of daily living (ADL) or academic performance, and the motor difficulties cannot be explained by any medical or neurological disorders (APA, 2000). If the IQ measure is below that expected for the chronological age of the child, the movement difficulties must be in excess of issues associated with low IQ (APA, 2000).

Developmental coordination disorder impacts approximately 6 % of school aged children (Cermak & Larkin, 2002), and the issues associated with the disorder persist well into adulthood (Losse, Henderson, Elliman, Hall, Knight, & Jongmans, 1991). The population of DCD is quite heterogeneous as it is associated with varying degrees and types of movement impairments. DCD occurs concomitantly with other disorders including attention deficit hyperactivity disorder (ADHD) and learning disorders (LD) (Cermak & Larkin, 2002). The nature and variety of movement issues that children with DCD experience complicate the understanding of the disorder. Not all children with DCD experience the same movement difficulties. Only about half of the children diagnosed with DCD experience movement difficulties in one specific area (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001). The remaining half experience difficulties in multiple areas, with balance control being one of the most pronounced (Hoare, 1994; Macnab, Miller, & Polatajko, 2001).

Recent research efforts have looked into identifying information processing deficits that might underlie the disorder. Movement difficulties are postulated to be a result of issues within the sensory systems (Wilson & McKenzie, 1998), or in the use of feedforward/feedback mechanisms of control (Przysucha, Taylor, & Weber, 2008). A new approach to understanding issues in static balance control, as well as postural adaptation's in children with DCD, is the impact of attention on balance performance. Children with DCD experience issues in attention (Dewey, Kaplan, Crawford, Wilson, 2002; Wilmut, Brown, & Wann, 2007), which may be an influential factor in their poor motor coordination. An explanation for issues in attention may be rooted in the potential inability to process the appropriate information for both tasks in parallel. As a result, deterioration in balance or attentional task occurs. To date, research investigating the impact of attention on balance control and postural adaptations in children with DCD is limited. An understanding of the influence of attention on balance control and postural adaptations may provide more insight into the balance issues common in children with DCD.

Postural Control

Postural control is fundamental to all aspects of movement performance (Shumway-Cook & Woollacott, 2001). Musculoskeletal and neural components have equally important roles in the achievement of the functional goals associated with postural control. The functional goals include maintaining an appropriate biomechanical relationship amongst the body segments, maintaining an appropriate relationship between the orientations of the whole body with respect to the environment, and the use of sensorimotor strategies in order to provide stability during self-initiated or externally induced perturbations (Horak, 2006; Shumway-Cook & Woollacott, 2001). These goals are achieved through the direct involvement of the central nervous system (CNS). The CNS is responsible for the integration and interpretation of sensory information and for mapping sensation to action. Through this process, appropriate motor responses, including adaptive and anticipatory aspects of postural control, are selected and programmed (Redfern, Jennings, Martin, & Furman, 2001).

Postural control is achieved through an open-loop closed-loop integrative system, which begins to emerge around 6 years of age. It continues to develop until adult like level of performance is achieved around 11 years of age (Kirshenbaum et al., 2001). The use of either control mechanism depends largely on the individual’s skill level and task constraints (Hatzitaki, Zisi, Kollias, & Kioymourtzoglou, 2002). The open-loop control mechanism alters the location of the body in space through anticipatory adjustments (Gahery & Maisson, 1981), whereas online-sensory corrections fine tune the position of the COP to remain within the stability limits through closed-loop feedback control (Kirshenbaum et al., 2001).

The status of postural control can be analyzed through static balance and postural adaptation tasks. Research has used quiet standing tasks in order to assess static balance control.

On the other hand, tasks such as leaning without losing balance have been used to make inferences regarding the nature of voluntary postural adaptations (Przysucha, Taylor, & Weber, 2008).

Postural control in typically developing children. Static balance control is a basic fundamental movement skill that improves over the first 10 years of life. It is directed by short-term open-loop mechanisms, but it is largely maintained through closed-loop control (Collins & De Luca, 1995). Improvement in balance control is characterized by the refinement of a feedback-based type of control which results in a decrease in sway measures during static balance control performance (Kirshenbaum, Riach, & Starkes, 2001; Rival, Ceyte, & Olivier, 2005). Until approximately 6 years of age, visual information appears to be the dominant source of feedback for maintaining standing balance (Woollacott, Shumway-Cook, & Williams, 1989). Although vision is an optimal source of sensory information, especially for providing information about the orientation of the body with respect to the environment, predominant reliance on vision can result in delayed movement responses (Wann, Mon-Williams, & Rushton, 1998). It takes much longer to process visual feedback, causing the COP to move much closer to the stability region before the necessary corrective adjustments are made. As a result, young children tend to sway more and make more corrective adjustments in order to maintain vertical alignment (Riach & Starkes, 1994). After 6 years of age, an integration of multiple sensory systems begins to occur, and the result is an improvement in dealing with conflicting sensory information. A switch from visual dominance to a more proprioceptive dominance in combination with other sensory information begins to occur (Shumway-Cook & Woollacott, 1985). These online modifications create more smooth and controlled adjustments, which is typical of adult-like performance (McClenaghan, Williams, Dickerson, Dowda, Thombs, &

Eleazer, 1996). Balance performance is thus characterized by a decrease in sway measures during static balance control. A decrease in sway is also paralleled with changes in electromyographic (EMG) data. The improvement of balance control is characterized by the decrease in amplitude of muscular activity and refinement of muscular onset and co-contraction (Williams, Fisher, & Tritschler, 1983). Static balance control fully develops in typically developing children at around 10 to 12 years of age (Hatzitaki, Zisi, Kollias, & Kioymourtzoglou, 2002).

Literature investigating postural adaptations in typically developing children is limited. Postural adaptations require the integrative use of open and closed-loop control mechanisms. Postural adaptation, through the analysis of a leaning task, is a goal directed movement task of altering the body's position in space while maintaining a stationary base of support. The open-loop control initiates the movement of the COP during the lean, where as online-corrections effectively maintain balance. The limited research does indicate that the ability to lean as close to the stability boundary without losing balance begins to emerge around 7 to 8 years of age (Riach & Starkes, 1993) and reaches an adult like level around 11 years of age (Schmid, Conforto, Lopez, Renzi, & D'Alessio, 2005).

It is evident from the review of literature that both static balance control and postural adaptations improve over the first ten years of life. The improvement in the use of feedback control as well as optimal integration of control mechanisms results in adult levels of performance seen in children 10 to 12 years of age.

Postural control in children with DCD. A general consensus is that a large majority of children with DCD do experience difficulties in postural control (Cermak & Larkin, 2002; Macnab, Miller, & Polatajko, 2001). Static balance seems to be least impaired in children with

DCD (Geuze, 2003; Przysucha & Taylor, 2004). Recent research has indicated that children with DCD do not over rely on vision, as previously perceived, and they perform similarly to typically developing children of the same age. For example, Geuze (2003) found that children with DCD demonstrated a larger area of sway, but were not different in terms of AP sway or lateral sway when compared to typically developing children. In addition, Przysucha and Taylor (2004) also found that children with DCD demonstrated higher values in terms of area of sway in comparison to typically developing children. Higher sway values were also evident for AP sway for children with DCD. In terms of path length and lateral sway, children with and without DCD did not differ (Przysucha & Taylor, 2004). Although some differences in performance were found in previous research (Geuze, 2003; Przysucha & Taylor, 2004), the overall performance between the two groups was not different. Children with DCD were just as effective in controlling balance as compared to the typically developing children.

Subtle differences in performance between children with and without DCD were noted at the kinematic level (Geuze, 2003; Przysucha et al., 2008), and the results are further supported by EMG analysis. Children with DCD exhibited higher EMG activation levels (Williams, Fisher, & Tritschler, 1983) and they experienced more co-contraction and activation levels in controlling the ankle joint when compared to age matched peers (Geuze, 2003). The pattern of muscle activation can result in a more unsophisticated and less refined level of control and can result in more erratic movements when compared to typically developing children.

The investigation of postural adaptations in children with and without DCD is a novel methodology emerging in DCD literature. To date, only one research study has been published (Przysucha et al., 2008). It was concluded that children with DCD were not able to lean as far from the vertical when compared to typically developing children. The results were consistent with previous literature assessing postural adaptation performance between younger and older children, with the younger children demonstrating the most difficulties (Riach & Starkes, 1993). In addition, children with DCD exhibited little control over their movements while leaning (Przysucha et al., 2008). The inability to lean as close to the stability limits with little control and orientation of movement can become problematic when the child is faced with self-initiated or environmentally induced perturbations. These results imply that the ability to generate postural adaptations may be problematic for children with DCD. The difficulties experienced during voluntary postural adaptations can be a result of an immature integrated type of control (Przysucha et al., 2008). Children with DCD spent about half of the movement time in an open–loop type of control, coinciding with more ballistic responses. The dominance of open-loop type of control, when feedback corrections are desired, in children with DCD has also been evident in reaching and aiming tasks. They exhibited difficulties using online corrections to hit the target when compared to typically developing children (Smyth, Anderson, & Churchill, 2001). This result shows that children with DCD may also rely more heavily on a ballistic type of control when leaning.

From the review of literature it becomes apparent that children with DCD do not have major issues in static balance control, however, issues arise with postural adaptations. The integration of control mechanisms seems problematic as children with DCD rely less on feedback based control and more heavily on ballistic type of corrections.

Attention, Dual Tasking, and Postural Control

Posture control was traditionally viewed as a task of automaticity, implying that it can be performed in the absence of attention. However, research utilizing a dual task methodology has shown that the regulation of posture is, to some degree, attentionally demanding (Kerr, Condon,

& McDonald, 1985). Attention refers to the information processing capacity of an individual (Shumway-Cook & Woollacott, 2001). Kahneman (1973) suggests that the major limitation on information processing lies within the human processing system as it possesses a limit in attention capacity. Information from multiple tasks can be carried out in parallel, assuming that the limited capacity of attention has not been reached (Kahneman, 1973).

The concept of attention is divided into two processing systems, controlled and automatic (Schneider & Shiffrin, 1977). Controlled processing is highly demanding on attentional capacity, in that it cannot take place unless a sufficient amount of attention is directed to the information processing system. This type of processing is also slow and serial in nature. Controlled processing is easily established, altered, and can even be reversed since it is under conscious control (Schneider & Shiffrin, 1977). It is also strongly dependent on task demands. Novel, or not well learned tasks for example, depend on controlled information processing for a successful outcome. Automatic processing, on the other hand, occurs much more rapidly and it involves parallel processing of information (Schneider & Shiffrin, 1977). It is not attentionally demanding thus multiple operations can occur simultaneously without interference. This type of processing is difficult to alter, ignore or suppress as it is not performed in a conscious manner (Schneider & Shiffrin, 1977). A well learned task, for example, uses automatic processing. Automatic processing, or the ability to attend to many different tasks and/or environmental constraints, without interference, represents one of the most important characteristics of a skilled movement repertoire (Schmidt & Wrisberg, 2008).

The construct of attention is multidimensional and encompasses factors such as focused, sustained, selective, alternating, and divided attention (Shumway-Cook & Woollacott, 2001). In the context of static balance control and postural adaptations, divided attention, or the ability to respond simultaneously to multiple tasks, is of crucial importance (Shumway-Cook & Woollacott, 2001). It entails the ability of the performer to process the required information for two tasks, such as a balance task and an attentional task, in parallel. The performer must then successfully divide and allocate the required amount of attention to each process. A methodological approach which allows for the investigation of attentional demands on postural control is known as the dual-task paradigm (Shumway-Cook & Woollacott, 2001). The assumption that individuals possess a limited amount of attention is imbedded in the conceptual framework for investigating dual-task performance (Wickens, 1991). Dual-tasking is a method which uses postural control as the primary task and a cognitive (attention) activity as a secondary task (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). The impact of an attentional task is inferred from differences in COP measures between conditions where the participant performs the balance task alone, and where both the motor and the attention demanding tasks are performed together (Kahneman, 1973). Such differences may emerge due to limited attentional capacity to meet the demands of the task or because attention is being placed on another task. It can also result from insufficient availability of the relevant (sensory) input, hence, the performer does not attend to the appropriate stimuli (Kahneman, 1973). If no significant differences are observed in COP measures, in this methodology, then it can be concluded that both tasks require similar degrees of attention without exceeding the individual's attentional capacity. Also, such a pattern may imply that balance control involves automatic (parallel) processing, as opposed to a more controlled (serial) processing (Kahneman, 1973).

Dual-tasking in typically developing individuals. The application of the dual-task methodology has allowed for the investigation of attentional demands of postural control tasks. The current literature involving typically developing individuals indicates that when a secondary attention task is added, changes in balance control occur (Kerr, Condon, & McDonald, 1985). As mentioned earlier, the amount of attention required to perform postural control tasks is largely dependent on the complexity of the balance task (Dault, Geurts, Mulder, & Duysens, 2001), the type of attention task (Pellecchia, 2003) and skill level of the performer. Unperturbed bipedal stance with the addition of a small degree of attentional loading does not present a significant threat to balance performance of typically developing young adults (Anderssons, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Huxhold, Li, Schmiedek, & Lindenberger, 2006; Redfern, Jennings, Martin, & Furman, 2001). However, an increase in task difficulty, such as introducing a difficult attention task in combination with a balance task, results in deterioration of balance performance (Pellecchia, 2003). A more difficult task requires more attention and thus leads to more pronounced performance decrements as the attention has to be shared between two tasks (Guttentag, 1989). Developmentally, younger children may require more attention for the performance of movement tasks than older children until the skill becomes more automated. The ability to divide attention between the two tasks while ignoring all other forms of distraction for optimal performance reaches adult like levels around 11 years of age (Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004).

A number of different motor tasks have been used in dual-task methodologies implemented to examine attentional issues in children. Some studies incorporated rhythmical, continuous tasks such as finger tapping (Guttentag, 1984; Hiscock, Kinsbourne, Samuels, & Krause, 1985; White & Kinsbourne, 1980), running, or walking (Whitall, 1991). Also, fundamental movement skills such as balance have been incorporated (Blanchard, Carey, Coffey, Cohen, Harris, Michlik, & Pellecchia, 2005; Reilly, van Donkelaar, Saavedra, & Woollacott, 2008; Schmid, Conforto, Lopez, & D'Alessio, 2007).

Research utilizing finger-tapping tasks was not solely concerned with the overall performance of movement. Much of the emphasis was placed on the development of cognitive strategies and attention sharing (Guttentag, 1984). The research has shown that older children (> 8 years) tended to demonstrate more optimal performance compared to younger children by demonstrating less interference when faced with the second task (Guttentag, 1984; Hiscock et al., 1985; White & Kinsbourne, 1980). On the other hand, older children demonstrated a more optimal performance as a result of a decrease in attentional demands for finger tapping and parallel processing of information.

In terms of more complex rhythmical actions, Whitall (1991) investigated the impact of cognitive tasks on running and galloping in children and adults. Two different cognitive tasks, singing and letter memorization, were implemented. The degree of interference associated with dual-tasking was age-related. With the imposition of the cognitive tasks, both groups demonstrated changes in the control variables (e.g., velocity), however, the youngest children demonstrated a more pronounced effect as a result of implementation of both attentional conditions.

The impact of attention on balance performance in children and adults was investigated in a number of studies, but the results are conflicting. Schaefer and colleagues (2008) introduced two types of attention tasks during a balance task. Both children and young adults were affected by the addition of the attention tasks, but they demonstrated different postural sway patterns. Young adults exhibited an increase in sway area measures under dual-task conditions, indicating that they had difficulty coping with the demands of dual-performance. Generally, an increase in sway measures indicates performance deterioration in a quiet standing task as the COP moves closer to the stability boundaries (Hill & Vandervoort, 1996). The analysis of sway profiles of children revealed the tendency to decrease the amount of sway, with the addition of an attention task (Schaefer et al., 2008). This result was attributed to less than optimal ability to divide attention between the two tasks. The tendency to reduce the amount of sway was coined as a "stiffening" strategy (Shumway-Cook & Woollacott, 2001) to cope with attention demands of two tasks. In elderly populations, this is viewed as a mechanism of defence to reduce the amount of movement that the older adults exhibit to prevent falling (Melzer, Benjuya, & Kaplanski, 2001).

The remaining developmental studies confirm that typically developing children are impacted by attention loading while balancing, but once again no uniform pattern of behaviour emerges (Blanchard et al., 2005; Schmid et al., 2007). The research shows that children between 8 and 10 years of age cannot maintain the same level of control while performing a secondary attention task. Blanchard and colleagues (2005) found that path length values increased with the addition of an attention load, while there was an overall decrease in terms of sway range and sway velocity measures while dual tasking. Thus, children increased the total distance travelled by the COP, but did so in a smaller range, restricting the movement closer to the vertical. This pattern of results is consistent with the "stiffening" hypothesis put forward by Schaefer and colleagues (2008). Schmid and colleagues (2007) also noted changes in sway parameters from no attentional loading to attentional loading conditions. However, the authors used different dependent variables, including COP excursion descriptors (e.g., mean velocity, sway area, and mean amplitude) as well as frequency measures (e.g., mean power frequency, centroidal frequency, and frequency at 95% radial displacement). In line with previously discussed data, children were unable to maintain the same level of balance performance with the addition of a secondary task. The data showed that children increased their excursion as well as frequency measures. In terms of the latter finding, this indicates that as a result of attentional loading, an increase in COP activity is evident. The increase in frequency characteristics indicates that the children made more corrective adjustments while performing an attentional load (Schmid et al., 2007).

Taken together, the literature clearly indicates that typically developing children are impacted by dual performance of balance and attention. However, in some instances children demonstrated a decrease in COP measures as a result of attentional loading (Schaefer et al., 2008), while in other studies an increase in COP measures was noted (Blanchard et al., 2005; Schmid et al., 2007). At this point it remains unclear why such discrepancies emerge thus further justifying the replication of previous studies and/or incorporation of novel measures and tasks.

Dual-tasking in children with DCD. The literature clearly indicates that children with DCD demonstrate issues in motor coordination, in a wide range of motor activities (Cermak & Larkin, 2002). Although much investigation into motor performance of children with DCD has been completed, the cause(s) of the disorder is still not fully understood. It is plausible that the movement difficulties experienced by children with DCD may be largely rooted in attention issues. The available literature indicates that children with DCD are affected by the addition of attentional tasks (Laufer, Ashkenazi, & Josman, 2007; Tsai, Pan, Cherng, & Wu, 2009). There is also related literature which shows that this group of children have difficulties performing two motor tasks simultaneously (Cherng, Liang, Chen, & Chen, 2008; Mackenzie, Getchell, Deutsch, Wilms-Floet, Clark, & Whitall, 2008; Whitall, Getchell, McMenamin, Horn, Wilms-Floet, & Clarke, 2006) which may also have something to do with issues in attention.

Whitall and colleagues (2006) investigated the impact of a dual-motor task of clapping while marching coupled with an auditory beat presented at different frequencies, in children with and without DCD (6 to 8 years of age) and healthy adults. The results showed that the children with DCD were not able to adopt absolute coupling of claps and footfalls as frequently as typically developing children, and the number of successful couplings decreased as the frequency of the beat increased. In addition, Mackenzie and colleagues (2008) examined the same motor task of marching in place coupled with visual clapping and audible footfalls in children with and without DCD (6 to 8 years old) and healthy adults. The visual input was manipulated by using a blindfold and auditory input by using of headphones. Children with DCD demonstrated more variability in the phasing of their claps and footfalls in comparison to the two other groups, but did not differ significantly than typically developing children on overall gross-motor coordination. Although these two studies are not assessing attentional demands of dual-task performance, the results show that performance of two complex coordinative tasks at the same time is difficult for children with DCD. As task difficulty increases (for example, increase in frequency of beat or altering sensory information), motor-performance suffers to a larger degree. Although the two studies did not make inferences regarding attentional requirements, they clearly show the difficulties children with DCD experience when multi-tasking.

The dual-task methodology has also been applied to gait analysis. Cherng and colleagues (2009), for example, incorporated walking with a simple motor task (carrying an empty tray) and difficult motor task (carrying a tray with marbles) in children 4 to 6 years of age with and without DCD. Children with DCD experienced greater interference during the dual-motor task, more specifically with the addition of the difficult motor task, when compared to typically developing children. Cherng and colleagues also investigated the addition of an easy cognitive task (reciting a forward series of digits), and a difficult cognitive task (repeating a backward series of digits) on walking performance in the young children with and without DCD. Both groups were impacted to the same degree, regardless of task difficulty. Thus the results imply that gait is attentionally demanding for both groups. However, the results of dual motor tasks indicate that children with DCD may require more attention to its performance thus experiencing greater dual-task interference.

In terms of balance control and attention, children with DCD tend to demonstrate more interference when compared to typically developing children (Laufer et al., 2007; Tsai et al., 2009). A few factors have surfaced that appear to induce higher demands on attention during postural control performance for children with DCD. An increase in the balance task difficulty, such as static balance control on a compliant surface (Laufer et al., 2007), results in an increase in the attentional demands necessary for balance performance. Laufer and colleagues investigated the impact of a secondary attentional task (object identification) while standing on a firm and a compliant surface, in children with and without DCD. The results indicated that children with DCD demonstrated greater COP velocity and amplitude variability in the AP and ML directions as compared to the typically developing children. The differences were accentuated on a more difficult (compliant surface) task with the addition of attention. These results implied that children with DCD required more attention to perform a more difficult balance task. They also prioritized the performance of the attention task, sacrificing optimal balance performance (Laufer et al., 2007). Similar results were observed in an older group of children with DCD (Tsai et al., 2009). Five different cognitive tasks were administered during quiet standing in children with and without DCD between 9 and 10 years of age. Without attentional loading, the two groups did not differ, which is consistent with other literature examining quiet standing in children with and without DCD (Geuze, 2003; Przysucha & Taylor, 2004). However, children with DCD were more impaired by the addition of three (oral counting, auditory-verbal reaction, and auditory-memory tasks) out of the five secondary attention tasks when compared to the typically developing children. Changes in performance were demonstrated by an increase in the variation index from no attention loading to attention loading (Tsai et al., 2009). Sway area for the no attentional loading condition over the sway area for the attentional loading condition was used to calculate the variation index. A variation index less than one reflected degradation in performance, and a variation index greater than one indicated improvement in balance performance (Jamet, Deviterne, Gauchard, Vancon, & Perrin, 2007). The authors attributed the higher variation indexes to a more controlled type of processing. This result indicates that the children with DCD maintained balance under a more conscious type of control, demonstrating difficulties with dividing attention (Tsai et al., 2009).

Currently, no investigations have been completed on the attentional demands of postural adaptations. Interpretations from previous literature on postural adaptations without attention loading (Przysucha et al., 2008) as well as the performance of more complex tasks such as gait, with the addition of an attention load (Cherng et al., 2009) were used. As previously mentioned, typically developing children are able to achieve adult like levels of postural adaptation through the integration of control mechanisms. Children with DCD, on the other hand, demonstrate less than optimal performance derived from a less than optimal integration of control mechanisms (Przysucha et al., 2008). In addition, children with DCD also demonstrate significant difficulties on the dual performance of a motor task and attention (Cherng et al., 2009). If the issues in performance of the leaning task are also attentionally related the addition of a cognitive load will further impair performance in children with DCD.

Traditional and Non-Traditional Measures of Postural Sway

Center of pressure (COP) measures are used most often in the literature to make inferences regarding postural control. The COP is the point of application of the resultant of all vertical forces acting on the surface of support into a central point under the feet (Winter, 1995). The COP is used to infer several parameters of sway in the anterior-posterior, medial-lateral and vertical directions. Path length (PL), anterior-posterior sway (AP), lateral sway (L), and area of sway (Ao), are examples of traditional descriptive measures that provide information regarding the amount, direction and range of COP excursions, respectively (Duarte, Freitas, & Zatsiorsky, 2011).

It is assumed that an increase in sway measures from one task condition to another, for example balance without attentional loading to balance with attentional loading, represents a decrease in stability (Blanchard, Carey, Coffey, Cohen, Harris, Michlik, & Pellecchia, 2005; Pellecchia, 2003). On the other hand, it is traditionally understood that a decrease in sway measures implies an improvement in sway, especially for developmental studies (Rival et al., 2005). However, a decrease in sway measures while dual-tasking is more indicative of deterioration in balance performance rather than an improvement. In addition, changes in sway observed from COP excursion measures may also be a result of functional adaptations made by the postural control system to maintain balance, rather than an increase or decrease in stability (Newell, van Emmerik, & Sprague, 1993).

A non-traditional method known as spectral analysis allows for investigation of underlying control processes involved in balance, rather than just describing sway patterns (Schumann, Redfern, Furman, El-Jaroudi, & Chaparro, 1994). Spectral analysis provides a measure of frequency (Hz) and amplitude of COP oscillations. Frequency represents the number of cycles per unit of time of periodic data and it provides a measure of COP adjustments during quiet standing and postural adaptations. Low frequency sway (< 1 Hz) is representative of a more optimal control of balance as it coincides with subtle COP adjustments (Oppenheim, Kohen-Raz, Alex, Kohen-Raz, & Azarya, 1999). In addition, low frequency sway is in tune with the optimal use of sensory information (Oppenheim et al., 1999). High frequency sway (> 1 Hz) is representative of many chaotic and abrupt movements of the COP, and generally it implies less than optimal balance control (Przysucha, Taylor, & Weber, 2008). Power is a measure of the magnitude of change of COP displacement in the frequency domain (Riach & Hayes, 1987). Low power sway indicates smooth and controlled corrective adjustments, which is representative of a more closed-loop control. On the other hand, high power is representative of more ballistic corrective adjustments. The combination of these two measures may collectively provide information regarding the use of control mechanism(s) during balance task performance (Schmid, Conforto, Lopez, & D’Alessio, 2007).

Spectral analysis has revealed that typically developing children under 6 years of age display a more ballistic type of control during quiet standing making large, rapid adjustments of the COP (Riach & Hayes, 1987). Children under that age lack maturity of the sensory system, which would account for the high frequency measures (Riach & Hayes, 1987). Maturation of the sensory system and the implementation of feedback based control in older children produce more smooth and controlled adjustments to the COP position, as inferred from the decrease in frequency characteristics (Kirshenbaum, Riach, & Starkes, 2001). These patterns are in line with adult performance (McClenaghan, Williams, Dickerson, Dowda, Thombs, & Eleazer, 1996). In terms of postural adaptations, typically developing children between 7 and 11 years of age demonstrate sway frequencies of approximately 1.0 Hz, which is within the optimal performance range (Przysucha et al., 2008).

Literature incorporating spectral characteristics to infer postural control of children with DCD is limited. To date, only one study has investigated spectral characteristics of postural adaptations in boys with and without DCD (Przysucha et al., 2008). Results showed that children with DCD displayed higher peak frequency values when compared to the age matched controls. In turn, this was considered as an indication that children with DCD may exhibit a less than optimal use of the proprioceptive input, thus limiting the effective performance of the postural task. It was postulated that optimal use of sensory input may force children with DCD to use open-loop control to a greater extent as compared to their typically developing peers who relied more on feedback, as evident from the COP velocity profiles (Przysucha et al., 2008).

In terms of dual task performance, spectral analysis has revealed that attention loading influences balance performance in child (Schmid et al., 2007) and adult populations (Dault, Geurts, Mulder, & Duysens, 2001). An increase in the frequency measures was evident in both populations under dual tasking conditions. In children, an increase in frequency measures coincided with an increase in variability of sway (Schmid et al., 2007). The change in frequency indicates that both children and adults could not maintain the same level of postural activity, and changed the control of balance in order to achieve dual performance. In both situations, the increase in frequency characteristics is interpreted as an increase in instability under dual task conditions.

Purpose and Hypotheses

Static balance control of children with and without DCD has been well reviewed in the literature. On the other hand, research investigating postural adaptations of both groups is limited. The literature clearly indicates that children with DCD demonstrate issues in balance, especially under more difficult balance tasks. It is quite possible that issues in attention may account for the balance difficulties experienced by children with DCD. In order to investigate how attention influences balance performance, descriptive COP measures (e.g., path length, area of sway, and AP sway) have been used. Spectral analysis is a relatively newer method in the analysis of postural control. The combination of the two analyses may provide a better understanding of the underlying issues experienced by children with DCD during postural control in conditions with and without attention. Thus, the purpose of this study was to investigate the impact of an attention task on balance control and postural adaptations in children with and without developmental coordination disorder using different measures of balance control.

This study examined two issues. First, performance of children with and without DCD was compared on two balance tasks, using traditional and non-traditional measures. Second, the study examined if attentional load influenced balance performance of either group, across balance tasks. In terms of static balance control, it is hypothesized that no differences are expected to emerge for traditional and non-traditional measures between the two groups (Geuze, 2003; Przysucha & Taylor, 2004). However, differences in COP measures, traditional and non-traditional, are expected to emerge with the implementation of attentional loading. Thus, both groups of children are expected to demonstrate interference (Blanchard et al., 2005; Laufer et al., 2007). However, children with DCD will demonstrate larger differences in COP measures, in comparison to the typically developing group, with the addition of the attentional task (Laufer et al., 2007).

With regard to postural adaptation, differences are expected to emerge between the groups without attentional loading. These differences will be seen in both traditional and non-traditional measures. Currently, no investigations have been completed on postural adaptations with the addition of an attentional load. Based on previous literature on postural adaptations without attentional loading (Przysucha et al., 2008), and other dual-tasking literature (Laufer et al., 2007; Tsai et al., 2009), it is anticipated that both groups of children will demonstrate performance interference with the addition of an attentional load. However, children with DCD will demonstrate larger differences in COP measures (traditional and non-traditional) from no attentional to attentional conditions.

Pilot Study

Introduction

Dual-tasking under quiet standing conditions has been previously investigated. The majority of the research pertains to the adult population (Woollacott & Shumway-Cook, 2002). Research investigating the effects of a secondary attentional task on postural adaptation is currently lacking in the literature. In the existing studies, traditional measures of postural sway (e.g., Ao, L, and AP sway) have been primarily used to make inferences regarding the impact of a secondary task on postural control. A few studies are available which incorporate spectral analysis as a dependent measure, but they are limited to static balance control of children (Schmid, Conforto, Lopez, & D’Alessio, 2007) and adults (Dault, Geurts, Mulder, & Duysens, 2001), not postural adaptations. In order to address the current gaps in the literature, a pilot study was completed. The purpose was to examine the suitability of the testing protocol and dependent variables chosen to examine the effect of varying degrees of attentional loading on balance control and postural adaptation of children and young adults.

In terms of static balance control, differences between groups were expected to occur with attentional loading (Hatzitaki, Zisi, Kollias, & Kioymourtzoglou, 2002), but not in the baseline condition without a secondary task. It was hypothesized that children would demonstrate significantly different scores when compared to adults for traditional (Schaefer, Krampe, Lindenberger, & Baltes, 2008) and non-traditional measures (Dault et al. 2001; Schmid et al., 2007).

In terms of postural adaptation, differences between groups were expected to emerge with and without attentional load (Riach & Starkes, 1993; Przysucha et al., 2008). The differences between groups were expected to be greater with the addition of the attentional loads. Children were expected to demonstrate significantly different measures when compared to adults for both traditional and non-traditional measures.

Participants

Five children (*M* = 9.4 yrs, 1 male and 4 females) and five adults (*M* = 23.5 yrs, 2 males and 3 females) volunteered to take part in the study. Participants were recruited from The School of Kinesiology at Lakehead University, as well as the local community in Thunder Bay, Ontario. All participants were free of balance and attention related disorders, and free of injuries that may have affected their ability to balance. This information was acquired from the consent form. The adult participants also completed a Par-Q for additional screening.

Testing Protocol

Participants carried out static balance control and postural adaptation tasks, with and without attentional loading. The static balance control task required the participants to stand as still as possible. The postural adaptation task required the participants to lean as far from the vertical in the anterior and posterior directions, without losing balance (e.g. bending at the hips, not maintaining full foot contact with the floor, or taking a step). Both postural tasks required the participant to stand on a force platform with feet approximately shoulder width apart, with arms resting comfortably at their sides, while avoiding extraneous movements such as bobbing of the head or twitching of the arms or fingers. During the performance of the two balance tasks, participants were instructed to fix their vision on a target that was presented on screen in front of them. Two different attention tasks were incorporated to induce differing degrees of attentional loading. The two attention tasks included an object (easier task), and a numeric identification (more difficult task). The object identification was classified as the easier task as it required the participants to identify simple objects projected on a screen such as a ball, an umbrella and a cat. The projection screen was located approximately 15 feet in front of the participants. The numeric classification task was the more difficult task as it required the participant to identify the correct number recited from an audio recording, and classify the number as higher or lower than fifty. For example, the numbers 1 and 6 would be recited, the participant was to identify the number as 16 and then indicate that it was lower than 50.

Six conditions were assessed which included static balance without attention, static balance with object identification, static balance with numeric classification, dynamic balance without attention, dynamic balance with object identification, and dynamic balance with numeric classification. The participants were required to complete three trials for each condition and all trials lasted 10 seconds. The participants completed three trials of each condition with quiet standing, progressing to the addition of the simple attention task, and then the more difficult attention task. The same progression occurred for the conditions involving the postural adaptation task. All participants were tested individually.

Measures

All testing was completed on an AMTI force plate. The gain was set at 4000, with a low pass filter of 10.5 Hz. The force platform data were collected at a sampling rate of 100 Hz. The traditional dependent measures of the COP included area of sway (A_o; cm^2), path length (L; cm), and anterior-posterior sway (AP; cm). The area of sway was used to make inferences regarding the range of excursion of the COP during the performance of each balance condition. Path length was used to infer the total distance travelled by the COP, and anterior-posterior sway was used to make inferences about displacement of the COP in the sagittal plane of motion.

Spectral analysis was used to transform the data from a time domain to frequency domain and compute power spectrum for COP data. The non-traditional dependent measures included the fundamental frequency (Ff; Hz), which was identified as the first frequency pocket of the signal, and the corresponding power density (Pd; Hz/cm^2), which is the power measure at the fundamental frequency. These measures were used to infer the rate of change of the COP during the performance of the different testing conditions. AMTI BioDaq Analysis was used to analyse the COP. The program provided the displacement measures as well as the frequency characteristics of the COP.

Design and Analysis

A 2 (children vs adults) x 2 (static balance control vs postural adaptation) x 3 (attention task 1 vs attention task 2 vs no attention) mixed factorial design with repeated measures on the last two factors was used. Given the small sample size, a series of Mann-Whitney U statistics were used to examine mean differences between the groups, across both balance tasks with the varying degrees of attentional loading.

Results

Static balance control with and without attentional loading.

The mean scores on performance were calculated across three trials for all conditions, for children and adults. These mean scores, and all statistical results can be viewed in Appendix A.

Traditional measures. In terms of no attentional loading, the results partially supported the hypothesis. A group difference was found for path length ($z = -2.61$, $p \geq .05$), as children demonstrated larger values when compared to adults. However, no differences were found for Ao or AP sway (see *Figure 1*).

For attentional loading, Mann-Whitney U statistics also partially supported the hypotheses. The addition of the object identification task yielded differences for Ao ($z = -2.61$, $p \leq .05$), and L ($z = -2.61$, $p \leq .05$). Children demonstrated higher excursion values on both measures when compared to adults. In terms of the addition of the numeric classification task, differences between children and adults were also found for area of sway ($z = -1.98$, $p \leq .05$) and path length ($z = -2.61$, $p \leq .05$). Once again, children demonstrated larger values on both measures (see *Figure 1*). No differences were found for AP sway, for both attentional tasks.

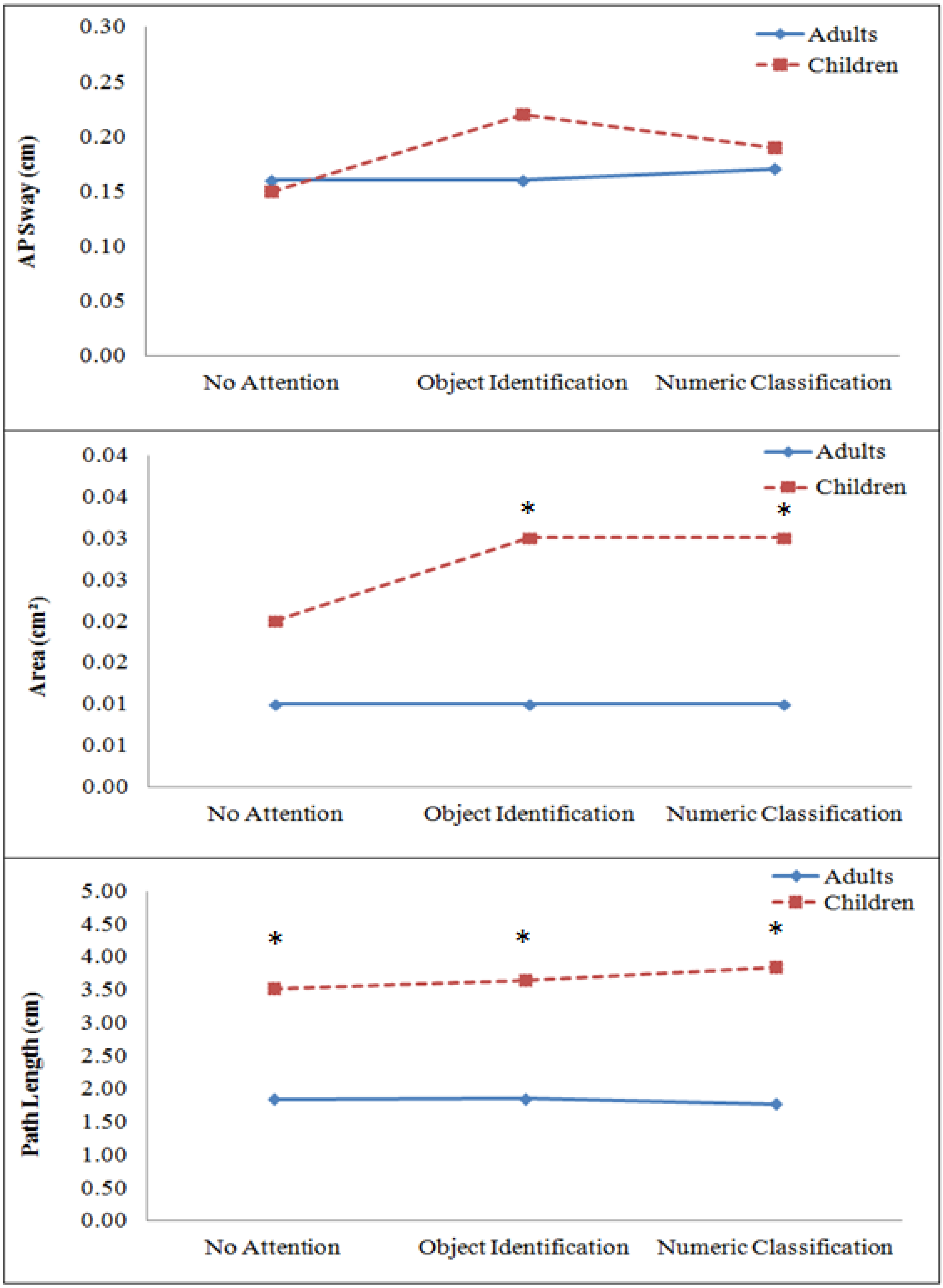

Figure 1. Means observed for traditional COP excursion measures for both groups in static balance conditions.

Note: * denotes significance at $p \leq .05$

Non-traditional measures. In terms of no attentional loading, the results supported the hypothesis as Mann-Whitney U statistics revealed that children and adults did not differ (see *Figure 2*). No differences were found for any of the non-traditional measures as demonstrated by the mean values (see Appendix A).

In terms of attentional loading, the results did not support the hypotheses. The addition of the object identification condition as well as the numeric classification condition yielded no differences in performance between the groups on fundamental frequency and power density (see Appendix A).

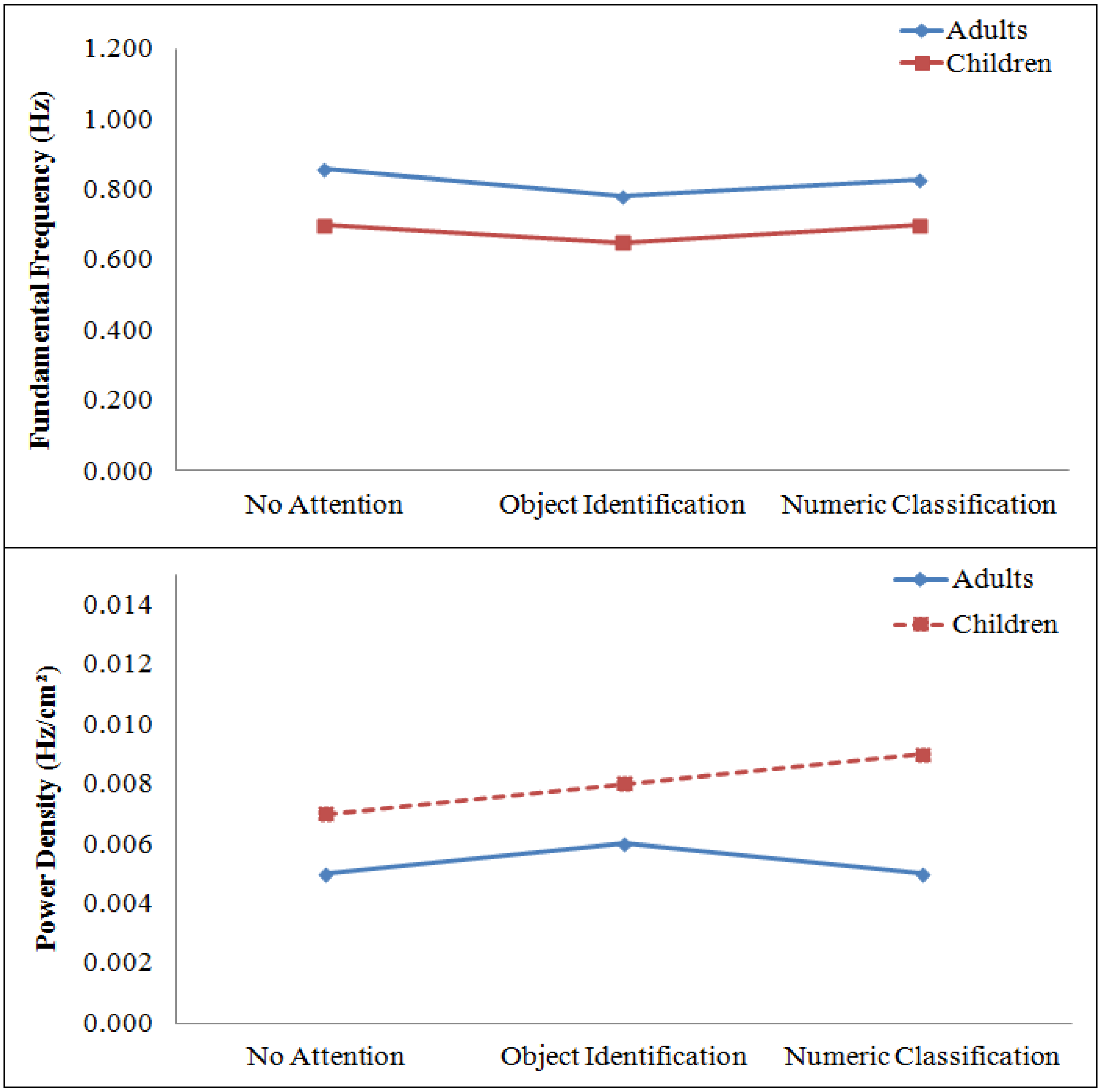

Figure 2. Mean scores observed for measures of frequency and power density for both groups in static balance conditions.

Postural adaptations with and without attentional loading.

The mean scores and variability on performance for three trials between children and adults on all conditions, and all statistical results can be viewed in Appendix A.

Traditional measures. In terms of no attentional loading, Mann-Whitney U statistics partially supported the hypothesis. The results revealed that children and adults performed differently in terms of the traditional measures (see Appendix A). Significance was found for AP sway ($z = - 2.19, p \leq .05$) and PL ($z = - 1.98, p \leq .05$). The children were not able to lean as far from the vertical in comparison to the adults, but they demonstrated more overall COP movement in terms of the mean values for path length (see *Figure 3*). However, no between group differences were found for area of sway.

In terms of attentional loading, the results partially supported the hypotheses. Group differences were found for path length on the object identification condition ($z = -1.98, p \leq .05$), as well the numeric classification condition ($z = -1.98, p \leq .05$). However, in terms of AP sway and Ao, no differences between the groups were found (see *Figure 3*).

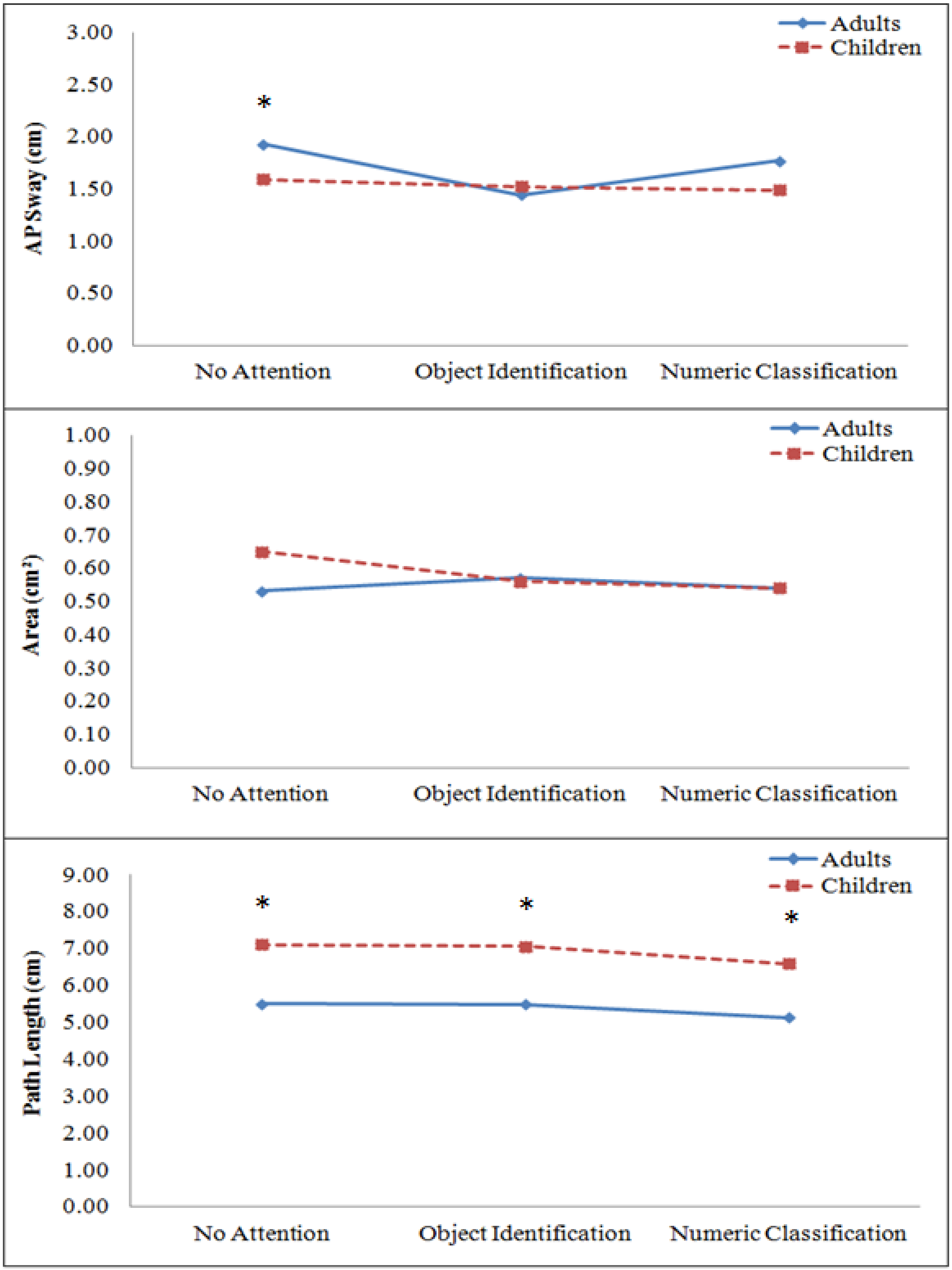

Figure 3. Means observed for traditional COP excursion measures for both groups in postural adaptation conditions.
Note: * denotes significance at $p \leq .05$

Non-traditional measures. In terms of no attentional loading, the results did not support the hypothesis. Children and adults did not differ in terms of fundamental frequency or power density (see *Figure 4*). The results for the attention loading conditions partially supported the hypotheses. Mann-Whitney U revealed no differences between the groups with the implementation of the object identification task. However, significance was found for power density on the numeric classification task ($z = -2.41$, $p \leq .05$), but not for fundamental frequency.

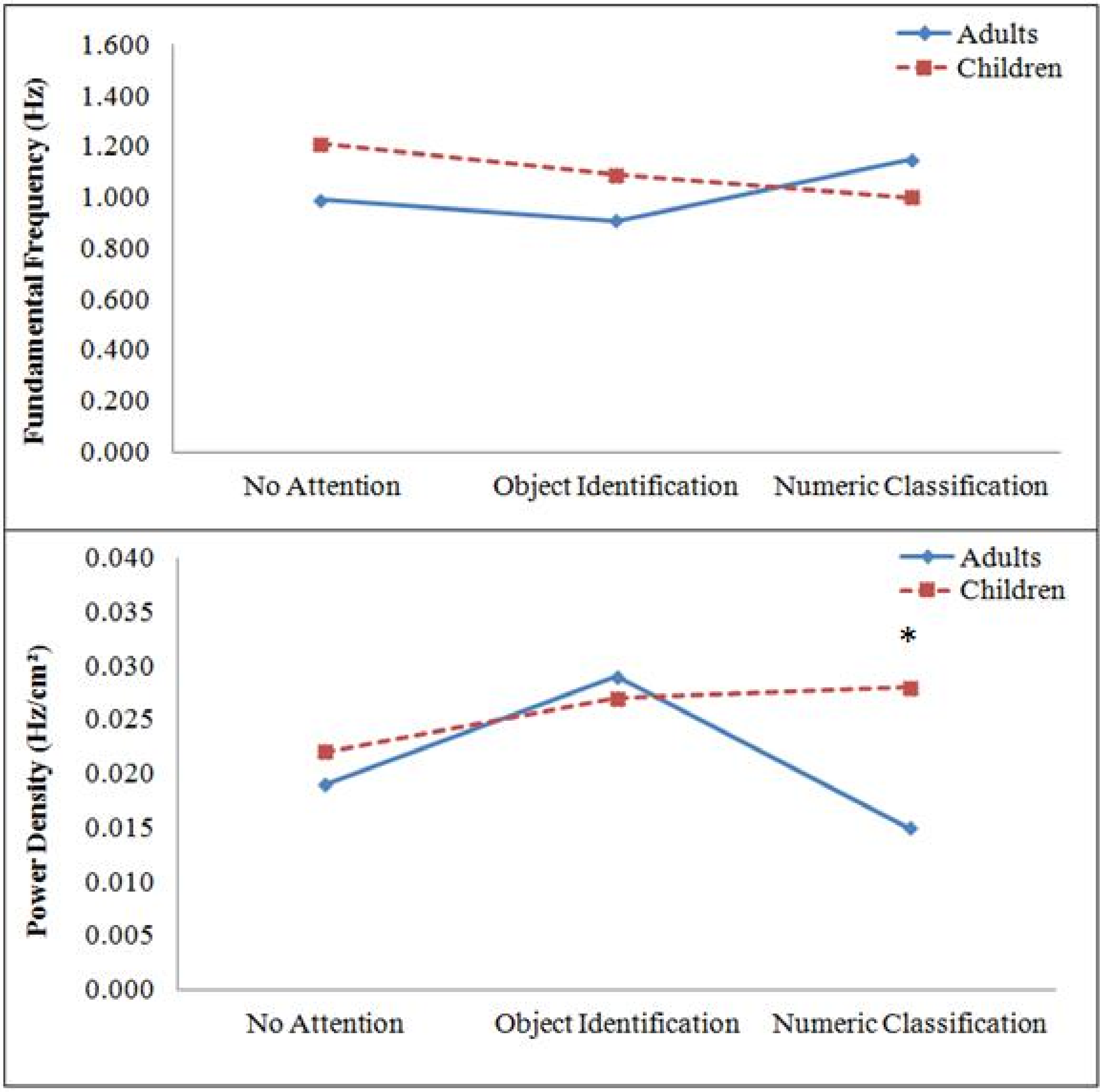

Figure 4. Mean scores observed for fundamental frequency and power density for both groups in postural adaptation conditions.
Note: * denotes significance at $p \leq .05$

Discussion

The pilot study sought to explore the suitability of the testing protocol and dependent variables in examining differences in balance control and postural adaptations between children and adults. Specific traditional (AP sway, Ao and L) and non-traditional measures (Ff and Pd) were selected to determine if they could demonstrate performance characteristics of the two samples on two postural control tasks, with and without attentional loading. The following discussion elaborates on the suitability of the selected traditional and non-traditional measures in demonstrating performance differences between the two samples with and without differing degrees of attentional loading.

Static balance control with and without attentional loading.

The literature shows that children between 7 and 10 years of age begin to demonstrate adult like ability in the context of postural control (Forsberg & Nashner, 1983). Thus, it was hypothesized that children between 8 and 10 years of age would not differ on performance of static balance control without attentional loading as demonstrated by the traditional and non-traditional measures when compared to adults.

The results partially supported the hypothesis as some differences in sway patterns were evident. Children demonstrated larger path length values when compared to adults, indicating more movement of the COP. The data did not reveal any differences in terms of AP sway or area of sway. The overall lack of significance of the measures indicated that children did not differ in terms of sway patterns on static balance control when compared to the adults.

The analysis of the fundamental frequency and corresponding power density measures also indicated that children and adults did not differ on the performance of static balance, further supporting the hypothesis. Both groups demonstrated frequency values below 1 Hz, indicating subtle adjustments made by the COP (Riach & Hayes, 1987).

It is difficult to make accurate comparisons to previous literature, as fundamental frequency and corresponding power density measures have not been previously used. Riach and Hayes (1987) used Root Mean Square (RMS) amplitude to determine frequency and power characteristics, and found that adult like level of performance began to appear as early as 7 years of age in typically developing individuals. It was characterized by low frequency (< 1 Hz) and low power sway (Riach & Hayes, 1987). The results of the pilot study are in line with these findings suggesting that by 8 to 10 years of age, children demonstrated adult like performance.

Differences between the two groups were expected to emerge with the addition of attentional loading. The literature indicated that the degree of attentional loading impacts postural control for both children (Blanchard et al., 2005) and adults (Pellecchia, 2003). The degree of attentional loading was expected to impact children to a much larger degree, which would be demonstrated by a significant difference in sway measures when compared to adults. The differences would have been due to less than optimal information processing ability (Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004) as a result of dual-tasking and difficulties with dividing attention.

The result partially supported the hypotheses. The addition of the object identification task resulted in an increase in area of sway and path length for children when compared to the adults. At the descriptive level, it becomes evident that differences in path length between the two groups were not attributed to the degree of attention loading (see *Figure 1*). The mean values did not change from the no attentional loading to attention loading conditions, for children or adults (Appendix A). In contrast, the differences in area of sway between the two groups were attributed to attentional loading, as evident from changes at the descriptive level. Children increased sway area with the addition of the attentional tasks in Appendix A. However, the degree of difficulty of the two attentional tasks was not a factor, as little change in sway measures were evident (see *Figure 1*).

No differences on AP sway, fundamental frequency, or power density occurred between children and adults. The addition of the numeric classification task resulted in the same findings. As evident from *Figure 1*, path length values did not change across conditions, which indicated that attentional loading, was not a factor contributing to the difference between children and adults. The lack of between group differences for frequency characteristics on the attentional loading conditions indicated that children and adults were able to successfully maintain the same level of control. Both groups demonstrated subtle adjustments of the COP, which ensured optimal performance while dual-tasking (Kahneman, 1973).

Overall, the results did not fully support previous findings. Blanchard and colleagues (2005), for example, also demonstrated an increase in path length values when a secondary task was added. However, a decrease in velocity and sway range of the COP in the AP and ML directions was also evident. The overall distance travelled by the COP increased, but the postural control system restricted the COP movement within smaller range. A decrease in sway is typically a characteristic of improved balance (Kirshenbaum et al., 2001), however, in this particular situation, it was considered as less than optimal. In terms of the pilot study, the differences for area of sway do not support Blanchard and colleagues, as the children in the pilot research demonstrated an increase in sway area. Unlike Blanchard and colleagues, the children in the pilot study allowed the COP to travel closer to the stability boundaries.

Schmid and colleagues (2007) also investigated the impact of an attentional load on postural control in children. The analysis of several COP excursion and frequency variables, among others, showed that there was an increase in the majority of the measures when attention was added. In line with the pilot study, Schmid and colleagues also demonstrated an increase in sway area with the addition of an attentional load. The increase in sway area also coincided with an increase in COP velocity and amplitude measures. The children's COP traveled closer to the stability boundaries at higher velocities. As the COP moved closer to the stability boundaries, especially at higher velocities, there was an increased risk of losing balance (Shumway-Cook & Woollacott, 2001). Schmid and colleagues also demonstrated a tendency towards an increase in frequency measures (e.g., mean power frequency, centroidal frequency, and frequency at 95% of radial displacement) from no attentional load to attentional load conditions in children. This further demonstrates an increased instability during dual-task conditions. The children in the pilot study did not demonstrate changes in frequency characteristics, thus opposing the frequency findings of Schmid and colleagues. The overall findings of Schmid and colleagues imply that the children could not maintain the same level of control while dual tasking. The addition of the secondary task compromised optimal balance performance. The lack of changes at the frequency level in the pilot study implied that children were able to maintain the same level of control while dual-tasking.

Overall, children and adults did not differ in terms of performance, with and without attentional loading. The children demonstrated relatively similar sway patterns as adults, differing only in terms of path length without attentional loading. Children were influenced by attentional loading, as demonstrated by changes in area of sway but overall displayed similar patterns of sway and frequency characteristics under attentional conditions. Thus, both groups were able to maintain effective control of static balance while dual-tasking and the selected measures were not able to demonstrate the expected performance differences between children and adults.

Postural adaptation with and without attention loading.

Optimal performance of postural adaptation does not reach adult like level of performance until approximately 11 years of age (Schmid, Conforto, Lopez, & D'Alessio, 2007). It is around this age that the appropriate use of either mode of control matures in children (Hatzitaki, Zisi, Kollias, & Kioymourtzoglou, 2002). Thus it was expected that the selected traditional measures would show performance differences between children and adults without attention loading. In terms of non-traditional measures, it was also anticipated that children would show different frequency characteristics when compared to adults (Przysucha, Taylor, & Weber, 2008).

In terms of traditional measures, the results partially supported the hypotheses as AP sway and path length were able to demonstrate performance differences between children and adults. Children were not able to lean as far in the AP direction, but demonstrated larger path length values when compared to the adults. The results showed that children were demonstrating more movement of the COP, but it was not due to leaning as far as possible in the AP direction. In terms of the non-traditional measures, the results did not support any of the hypotheses. No differences were found between the two groups, as children and adults demonstrated similar fundamental frequency and power density measures.

The results of this pilot study are, to some degree, in contrast to the developmental literature comparing younger and older children (Riach & Starkes, 1993), as well as younger and older adults (Blaszczyk, Hansen, & Lowe, 1993). The results of the pilot study, in terms of traditional measures, are in support of the research findings of Riach & Starkes, who demonstrated differences in sway patterns for younger and older children. The younger children could not lean as far from the vertical when compared to older children as demonstrated by smaller ranges in the AP directions. Similar findings have been reported in studies when comparing younger to older adult populations (Blaszczyk et al., 1993). Older adults were unable to lean as far from the vertical in the AP direction when compared to younger adults. The combination of the above mentioned studies demonstrate differences in performance between populations.

The dual task paradigm is novel to the postural adaptation literature. With no prior investigations, some interpretations were derived from the previous literature examining postural adaptation without attentional loading, as well as dual-tasking during static balance control. It was expected, given the nature of the task, that children would be most influenced by the addition of an attentional load and demonstrate significantly different measures when compared to adults.

The results did not support the hypotheses as there was only one variable (path length), which revealed significant between group differences on both attentional load conditions. At the descriptive level, it became evident that differences in path length between the two groups were not attributed to the degree of attention loading (see *Figure 3*). The mean values did not change across conditions, for children or adults (see Appendix A). No differences were reported for fundamental frequency and power density measures. Children and adults were able to maintain the same level of performance with the varying degrees of attention loading. This result indicated that the attentional tasks generally had no impact on the ability to perform postural adaptations for either group. Both children and adults were able to successfully divide attention and optimally perform the two tasks simultaneously.

The results showed that both groups demonstrated equivalent sway patterns and frequency characteristics for postural adaptations with and without attention loading (see *Figure* 3). Both groups also demonstrated successful division and allocation of attention to the performance of both tasks without compromising performance (Kahneman, 1973). The results of the study indicate that the addition of an attentional load did not significantly interfere with performance (Schneider & Shiffrin, 1977).

General Discussion and Conclusion

The pilot study sought to investigate the suitability of the balance tasks in combination with secondary attention tasks, as well as the capability of the selected dependent measures in demonstrating performance differences between the two samples. The implications of the pilot study were used to make final decisions about the main study in terms of appropriate use of balance and attention tasks, and suitable measures for determining group differences.

The results of the study indicated that neither group differed on the performance of either balance task (static balance control or postural adaptations), with or without attentional loading. Minor performance differences were observed, more specifically on area of sway and path length. However, overall, the children and adults demonstrated similar sway patterns and control of balance across the varying degrees of attentional loading. The lack of interference observed for both groups indicates that children and adults did not exceed their capacity of attention (Kahneman, 1973). Children demonstrated near adult-like performance across the attentional loading conditions.

There are a few other possible reasons for the overall lack of differences between the two groups. The samples that were selected may not have been different, regardless of initial expectations. The children were able to demonstrate near adult-like performance without attentional loading for static balance control and postural adaptations. A ceiling effect may also account for a lack of differences. Although it was expected that the two tasks differed in their difficulty, it is plausible that they did not. In fact, the two attentional tasks may have been too easy to elicit any differences in performance between children and adults. As a result, successful division of attention between the two tasks occurred for both groups, and no hindrance in postural control resulted (Kahneman, 1973).

Lastly, the selected traditional measures were able to demonstrate some between group differences, which is supported in previous research (Blanchard et al., 2005; Pellecchia, 2003). Fundamental frequency and power density, on the other hand, have not been investigated in previous literature. Other investigations have used different frequency measures, such as frequency mean, frequency mode, or spectral dispersion to distinguish performance differences between populations (McClenaghan, Williams, Dickerson, Dowda, Thombs, & Eleazer, 1996; Schmid et al., 2007). Fundamental frequency and corresponding power measures were selected for convenience. It could be quite possible that without analyzing a greater portion of the frequency wave, inferences regarding stability or control processes may be underestimated or insufficient.

Although there was a lack of observable differences between the performances for both groups, the testing protocol still has positive implications for future use in the proceeding project involving children with Developmental Coordination Disorder (DCD). The major study seeks to determine how and to what extent postural control performances would be impacted by attentional loading in children with movement and balance difficulties. Although the attentional tasks (object identification or numeric classification) were not able to elicit performance differences here, the decision to use the numeric classification task was made. It was anticipated that children with DCD would demonstrate issues in attention (Dewey, Kaplan, Crawford, & Wilson, 2002), which would result in difficulty completing two tasks simultaneously (Laufer et al., 2007). The selected attention task would clearly highlight the expected performance differences between children with and without DCD.

The traditional measures used in this pilot study will be utilized to demonstrate the expected differences in performance between children with and without DCD in the proceeding research project. Although the simplicity of the fundamental frequency and corresponding power density measures was attractive for analyzing performance, more in depth frequency analysis may be required. The selected non-traditional (fundamental frequency and corresponding power density) measures will not be utilized in the proceeding project. An exploration of other spectral characteristics for analyzing balance behaviour will be completed in order to determine more suitable variables. Variables such as frequency mode, spectral dispersion, and peak power have been used to successfully analyze postural control performances (McClenaghan et al., 1996), and may be more sensitive to postural control processes. These measures look at larger bandwidths of the frequency wave and incorporate more detailed information regarding COP activity. The more in depth frequency analysis combined with the traditional measures will provide a clearer understanding of postural control of children with and without DCD, and the implications of dual-tasking for the two groups.

Main Study

Participants and Recruitment

Ten children who met the criteria for DCD (8 males and 2 females) and ten typically developing children (5 males and 5 females), between 8 and 10 years of age were recruited from the local elementary schools in Thunder Bay, Ontario. Purposive sampling was used. In order to recruit participants, the director of education of the school boards was contacted and gave permission to approach individual schools. The researcher discussed the project and recruitment process with the principals. Once the principals agreed to be involved, grade 3 and 4 classrooms (children 8 to 10 years of age) were given recruitment letters (see Appendix B), along with consent forms (see Appendix C), a Developmental Coordination Disorder Questionnaire (see Appendix D), and a Child Information Sheet (see Appendix E). Children were asked to bring all forms home for review by the parents. If the parent and child were willing to participate, the child was required to return the completed forms to his/her teacher, with signed consent sealed in the envelopes provided. The teachers were requested to store the envelopes in a secure place until they were picked up by the researcher or the faculty advisor.

Three children were also recruited through the Motor Development Clinic with the assistance of the clinic director, Dr. Eryk Przysucha. Parents of children involved in the clinic were approached by the program director and asked if they would like their child to be a participant in the study. If so, the parents received a recruitment letter (see Appendix F), along with a consent form, DCDQ, and child information sheet. The parents were required to complete the forms, seal them in the envelope provided, and return it to Dr. Przysucha during one of the following clinical sessions.

Screening

In order to be assigned to the DCD group, four criteria outlined by the DSM-IV (APA, 2000) had to be met. The motor coordination had to be substantially below what is expected for the child's chronological age and measured intelligence level. This criterion was inferred from the Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1982). The test took approximately 35 minutes to complete and it was administered in the Motor Development Clinic located in room 1028 in the Sanders Building at Lakehead University. The MABC scores were used to provide information about the overall motor skill level (Total Impairment Score; TIS) and balance abilities as inferred from the Total Balance Score (TBS). Children met the first criterion to be included in the DCD group if their performance was at or below the 15th percentile for the TIS and below the 5th percentile for the TBS. On the other hand, if the TIS and TBS scores were above the 20th percentiles, the child was classified as typically developing. The 20th percentile was selected to avoid the possibility of being 'at risk' for movement impairments. The second criterion that had to be met was whether motor coordination issues impacted activities of daily living (ADL) or academic achievement. This information was gathered from the Developmental Coordination Disorder Questionnaire (DCDQ; Wilson, Kaplan, Crawford, & Roberts, 2007). The DCDQ is a parent-based report that asks them to compare their child's motor performance to that of his/her peers using a 5 point Likert scale, ranging from 'not at all like your child' to 'extremely like your child'. The questionnaire was attached to the recruitment letter and consent form. The third criterion, as stated in the DSM-IV, indicates that the motor coordination issues cannot be due to any known medical conditions. The fourth criterion in the DSM-IV states that if low IQ is present, motor difficulties must not be in excess of those usually associated with it. The third and fourth criteria were determined through the administration of the checklist and the consent form. The checklist asked parents to provide information about the child in terms of the presence of any attention or balance related disorder, as well as known IQ level. In the chance that IQ was not measured, a question regarding enrollment in a special education class as a result of an intellectual disability was incorporated. Children who were identified as meeting all four criteria were assigned to the DCD group. The children who did not present any movement difficulties, who were not identified with movement issues as outlined in the DCDQ, who were not diagnosed with a known medical condition, and who had an IQ level consistent with that of a typically developing child (> 80, or not enrolled in a special education class as a result of an intellectual disability) were assigned to the group of typically developing individuals.

Balance Tasks Procedure

The balance task procedures were consistent with those used in the pilot study. Both balance tasks, as well as the numeric classification task were utilized. All children had their height, weight, foot width and foot length recorded just prior to testing (see Table 1). They were asked to complete the static balance control and postural adaptation tasks, with and without attention loading. A large projection screen was located in front of the participants, approximately 5 meters away. The projection screen displayed a large star located approximately at eye level, in order to provide a visual reference for the children. Each participant completed 3 trials per condition, for a total of twelve trials. Each trial lasted 10 seconds and all testing took approximately 15 minutes. All participants were tested individually.

Apparatus

An AMTI strain gauge force platform connected to a standard amplifier was used to record the changes in displacement of the center of pressure (COP). The force platform measures three ground reaction forces along three axes: medio-lateral, anterior-posterior, and vertical directions. The maximal gain was set to 4000 with a low pass filter of 10.5 Hz. The force platform data was collected at a sampling rate of 100 Hz. BioDaq Analysis was used to analyze the COP data. The analysis program provides displacement measures as well as frequency characteristics of the COP.

Dependent Measures

The traditional dependent measures of the COP included area of sway (A_o), path length (L), anterior-posterior sway (AP). The A_o was used to make inferences regarding the area of COP excursions during the performance of each balance condition. Path length was used to infer the total distance travelled by the COP, whereas, anterior-posterior sway was used to make inferences about displacement of the COP in the sagittal plane of motion.

The Fast Fourier Transform (FFT) was used to estimate frequency components of the COP data. Dependent variables were extracted from each participant's frequency wave that ranged from 0 to 5Hz. The variables extracted from the COP data included frequency dispersion (f_{sd}; Hz), and mode ($f_{\mathrm{mode};}$ Hz), as well as peak power ($\mathrm{cm}^2/\mathrm{Hz}$). Frequency dispersion captures the distribution of energy at different frequencies, and how it is dispersed around the mean frequency (McClenaghan et al., 1996). It provided an indication of the variability within the frequency signal. Small dispersion values indicate that the frequency distribution is centered close around the mean frequency (low variability). Whereas, larger values indicate a larger dispersion around the frequency mean (high variability). Low variability indicates consistency of postural control behavior. On the other hand, high variability indicates inconsistency of postural control behavior. Frequency mode is the frequency value characterized by the dominating peak in amplitude of the signal (McClenaghan et al., 1996). For quiet standing, larger frequency values (> 1 Hz) imply greater rates of change of the COP, which are indicative of a less than optimal performance (Riach & Hayes, 1987; Przysucha et al., 2008). For postural adaptations, the literature is quite limited and the knowledge of frequency characteristics is still unknown. However, it is assumed that performance values greater than 1 Hz could be indicative of a less then optimal performance (Przysucha et al., 2008). Peak power is representative of the largest peak in amplitude of the signal. Quiet standing should be characterized by power measures located at lower frequencies (Riach & Hayes, 1987). Currently, no aspects of power measures have been analyzed during the performance of postural adaptations. Since a feedforward type of control initiates the movement of the COP during postural adaptation, and the remainder of the movement is governed by feedback based control, it is anticipated that postural adaptation would be represented by low power measures.

Design and Analyses

A 2 (group) x 2 (balance task) x 2 (level of attention) mixed factorial design with repeated measures on the last two factors was used. Static balance control and postural adaptations are different in terms of postural control processes and task requirements; therefore, the two tasks were analyzed separately. As a result, a series of 2 x 2 mixed factorial ANOVAs was carried out for both balance tasks, for the traditional and non-traditional measures. The alpha value was set at $p \leq .05$. The mean (*M*) and standard deviation (*SD*) of three trials per condition were calculated. Eta squared was calculated for each ANOVA to determine effect size (η^2). A small effect is represented by a value below 0.03, a medium effect is a value between 0.06 and 0.09, and a large effect is any value above 0.15 (Cohen, 1977). If a significant interaction effect was found for the dependent variables, planned comparisons were calculated. Independent samples *t*-tests determined between group differences and dependent samples *t*-tests determined within group differences. Cohen's *d* was used to determine the effect size. A value below 0.2 indicates a small effect size, a value around 0.5 indicates a medium effect size, and a value above 0.8 indicates a large effect size (Cohen, 1977). Independent samples *t*-tests were also used for the comparison of morphological characteristics between the groups.

Results

Morphological Characteristics and MABC Scores

The between group differences regarding morphological characteristics and MABC scores met the assumptions of variance (Levene's Test). As Table 1 shows, significant differences between the groups emerged for total impairment and total balance scores. Children who met the criteria for DCD scored higher (more poorly) on both aspects of MABC compared to the typically developing children. No differences were found for morphological characteristics.

Table 1.

Descriptive Statistics and Independent Samples t-test Results For Morphological Characteristics and MABC Scores.

	Typically Developing Children		Children with DCD			
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Height (cm)	136.40	6.29	140.60	9.03	1.20	.24
Weight (kg)	33.70	5.49	39.50	8.44	1.82	.08
Foot Width (cm)	7.91	1.49	8.65	.44	1.50	.15
Foot Length (cm)	21.45	1.07	22.06	1.47	1.06	.30
TIS	2.90	2.31	16.95	3.46	10.69	.00*
TBS	.35	.53	4.66	2.46	5.41	.00*

Note: TIS = total impairment score; TBS = total balance score.
* $p \leq .05$.

Static Balance Control With and Without Attention

Mean scores and intra-individual variability as well as statistical outcomes for traditional and non traditional measures are reported in Appendix G.

Traditional measures. No interaction effects were found for any of the COP excursion measures. However, (mean) area of sway (Ao) did reveal significant main effects for both group ($F(1,18) = 5.33$, $p \leq .05$, $\eta^2 = 0.23$), and attentional conditions ($F(1,18) = 11.95$, $p \leq .05$, $\eta^2 = .40$). Children who met the criteria for DCD demonstrated overall larger sway values when compared to the typically developing children (see *Figure 5*). Also, overall sway area increased with the addition of an attentional load (see *Figure 5*). No other significant differences were reported.

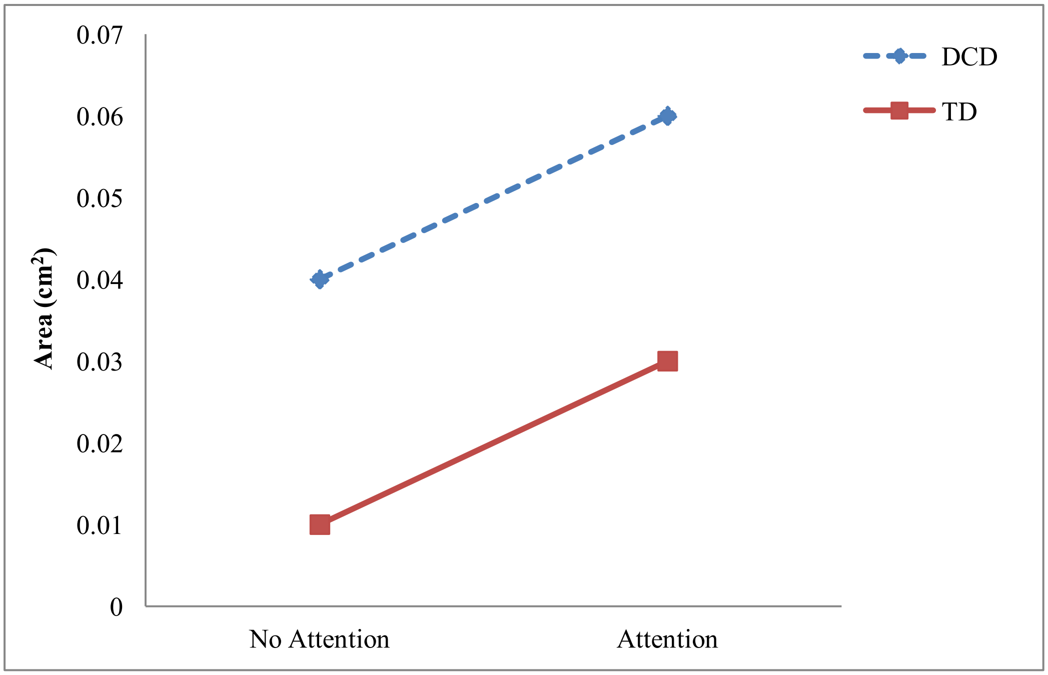

Figure 5. Performance of both groups (DCD & TD) with and without attentional loading in a static balance control task.

Non-traditional measures. The analyses of COP frequency derivatives revealed a significant interaction effect for variability of frequency mode (f_{mode}) ($F(1,18) = 6.00$, $p \leq 0.05$, $\eta^2 = .25$). To determine potential between group differences, an independent samples *t*-test was used. The *t*-test showed that there were significant differences between the groups for the attentional loading condition ($t(18) = 2.032$, $p \leq 0.05$, $d = 1.00$). The analysis of variance also revealed a main effect for attention for (mean) frequency mode (f_{mode}) ($F(1,18) = 23.87$, $p \leq .05$, $\eta^2 = .57$). Data showed an increase in frequency mode between no attention ($M = .10$) and attention conditions ($M = .15$). A significant main effect for attention was also found for variability of frequency dispersion (f_{sd}) ($F(1,18) = 5.86$, $p \leq .05$, $\eta^2 = .25$). The intra-individual variability increased from no attention ($M = .09$) to attention ($M = .17$). The analysis of variance did not reveal any other significant effects.

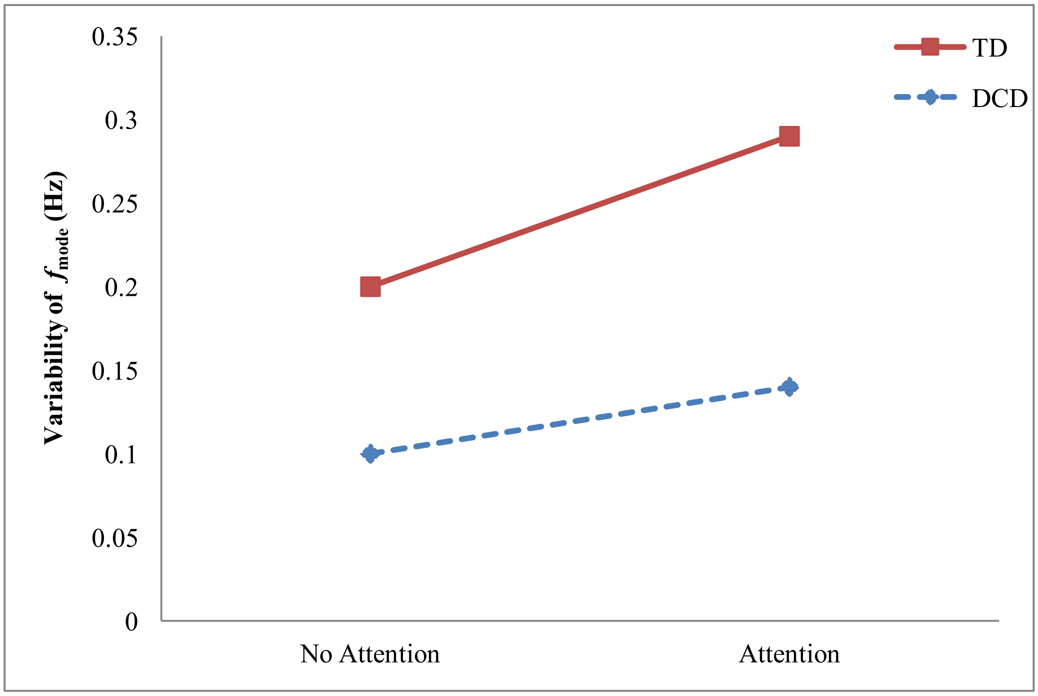

Figure 6. The influence of attention on variability in the performance of static balance of children with and without DCD.

Postural Adaptations with and without Attention

The mean and variability of three trials were analyzed and statistical outcomes for traditional and non traditional measures are reported in Appendix H.

Traditional measures. The analysis of variance on the traditional measures, between children with and without DCD, did not reveal any significant interaction or main effects.

Non-traditional measures. The analysis of the COP frequency derivatives also failed to reveal any significant interaction effects. However, a main effect for attention was found on (mean) frequency mode (f_{mode}) ($F(1, 18) = 25.46, p \leq .05, \eta^2 = .57$), and intra-individual variability on the same measure (f_{mode}) ($F(1, 18) = 16.09, p \leq .05, \eta^2 = .47$). The analysis of variance did not reveal any other significant differences.

Discussion

The influence of attentional loading on static balance control and postural adaptations of children who met the criteria for DCD and typically developing children was investigated. The following discussion is divided into two sections. The first section focuses on static balance control, whereas the subsequent section examines performance in postural adaptation task, with and without attentional loading. Within each section, traditional measures are discussed first. When necessary, individual profiles are discussed in addition to the group (mean) comparisons.

Static Balance Control without and with attentional loading

No attentional loading condition. In the literature, it has been well documented that children with DCD do no exhibit accentuated difficulties in static balance control (Geuze, 2003; Przysucha & Taylor, 2004). In fact, it is the least impaired aspect of the balance repertoire of children with DCD. As a result, it was hypothesized that the two groups would not differ, demonstrating similar COP sway profiles and frequency characteristics.

The results of the study partially support the hypothesis. Significant differences between the groups were found for area of sway, but not in AP and path length variables. These results indicate that children who met the criteria for DCD in this study demonstrated larger area of COP excursions moving further away from the vertical, before the corrective responses emerged. In other words, their COP was closer to the stability limits, which is generally an indicator of jeopardized balance. However, since none of the participants actually fell or stepped off the platform, it can be assumed that these differences had no functional impact on the effectiveness of the emerging balance control. In terms of other characteristics of COP sway profiles, the lack of differences found for AP indicate that children who met the criteria for DCD demonstrated equivalent sway patterns in the sagittal plane of motion. Also, in relation to path length, a lack of differences showed that the distance travelled by the COP for both groups was equivalent. Overall, the data showed that children who met the criteria for DCD did not demonstrate difficulties in static balance control without attention as they performed similarly to the typically developing group of children.

The results for the traditional measures are largely supported in previous DCD literature. Geuze (2003), through the analysis of AP, lateral, and area of sway, demonstrated that under normal two foot standing conditions, children with DCD did not significantly differ from the control group. Much like the results of the current study, Geuze noted differences in terms of area of sway, but no differences were found for the other measures. Przysucha and Taylor (2004) also found that children with DCD demonstrated higher values in terms area of sway. However, unlike the results of the present study, the researchers also found differences for AP sway. Children with DCD demonstrated higher sway measures in comparison to the typically developing group. Although some sway measures showed significance in the studies of

Przysucha and Taylor and Geuze, the overall lack of significance for all measures, and no reports of falls or loss of balance, indicate that children with DCD were just as effective in maintaining balance as compared to the typically developing children.

The similarities in sway patterns between children who met the criteria for DCD and typically developing children were paralleled with effective balance control, as inferred from the frequency data. The dominating frequency of the signal was located at the lower end of the spectrum indicating minimal corrective adjustments made by the COP for both groups (McClenaghan et al., 1996). The low magnitude in power measures demonstrated by both groups also indicated that the adjustments made by the COP were smooth and controlled (Riach & Hayes, 1987). Lastly, the low variability in the dispersion measure for both groups indicated consistent and relatively stable performance. The concentration of power was located close to the frequency mean, which was also located in the very low end of the frequency spectrum. This result further indicated consistency of performance.

Although much research has used traditional measures to make inferences regarding balance control, the use of frequency characteristics as a form of measurement is limited in the DCD literature. Previous work involving typically developing individuals showed that low frequency (> 1 Hz) and low power measures indicate optimal balance performance (Riach & Hayes, 1987). This pattern of behaviour is evident around 7 years of age, when typically developing children start to display more mature levels of performance. These inferences were determined from root mean square (RMS) of amplitude values. These results were in line with the adult literature. McClenaghan and colleagues (1996), analyzed balance performance in younger and older adults through the use of frequency characteristics including frequency mode, frequency dispersion, and peak power, among many other variables. In terms of frequency, the researchers indicated that adult performance was characterized by low frequency low power sway. The adults also demonstrated a relatively consistent pattern of postural control during quiet standing inferred from the dispersion measures (McClenaghan et al., 1996). As the findings of the present study are in line with previous research findings involving typically developing children as well as adults, it can be inferred that both groups of children demonstrated a more adult like performance in terms of frequency characteristics.

Attentional loading condition. Static balance requires the least amount of attention (Chen, Schultz, Ashton-Miller, Giordani, Alexander, & Guire, 1996). In order to investigate attentional demands of static balance control, a dual task paradigm is implemented. The dual-task literature for children with and without DCD is somewhat equivocal. The majority of the dual-task literature indicates that typically developing children experience interference (Blanchard, Carey, Coffey, Cohen, Harris, Michlik, & Pellecchia, 2005; Schaefer, Lindenberger, Krampe, & Baltes, 2008; Schmid, Conforto, Lopez, & D'Alessio, 2007). However, there is also some literature indicating that balance control can become a task of automaticity as early as 8 to 10 years of age. Tsai and colleagues (2009), for example, demonstrated that typically developing children remained relatively unaffected by dual tasking.

DCD is highly concomitant with issues in attention (Cermak & Larkin, 2002). This can lead to difficulties in the automaticity of balance control leading to compromised performance under dual-tasking situations (Laufer et al., 2007; Tsai et al., 2009). Balance performance of children with DCD has shown to be impacted by the addition of a secondary attentional load (Laufer et al.; 2007; Tsai et al., 2009). With the addition of attentional loading, children with DCD demonstrated deterioration in balance performance (Laufer et al., 2007; Tsai et al., 2009). In view of previous findings, it was hypothesized that both groups of children would demonstrate dual-task interference, which would be evident through changes in COP sway measures and frequency characteristics. However, children who met the criteria for DCD were expected to demonstrate greater interference in comparison to the typically developing children.

The results of the study did not fully support the hypotheses. First, no between group differences were evident, which does not support the hypothesis that children who met the criteria for DCD would perform substantially worse than the typically developing children. The data showed that both groups of children demonstrated similarities in sway patterns in terms of (mean and variability) AP sway, area, and path length. In addition, no significant differences were found on any of the frequency characteristics. Thus, the results indicated that both groups of children demonstrate similar patterns of control under dual-tasking conditions.

Although no between group differences were evident, the addition of the attentional load did influence performance to some degree. This finding partially supported the hypothesis that both groups of children would be affected by dual tasking. A main effect was found for area of sway with the addition of the attentional load. The increase in area of sway indicated that the COP for both groups of children travelled closer to the stability boundaries while dual-tasking. Changes also occurred at the behavioral level, as demonstrated by the frequency characteristics. There was an overall increase in (mean and variability) frequency mode with the addition of the attentional load. Both groups of children demonstrated an increase in the number of COP adjustments. However, the frequency values did remain in the very low end of the frequency spectrum (> 1 Hz). A high amount of intra-individual variability on attentional loading was also evident for frequency mode and frequency dispersion with attentional loading. This indicates that there was a higher amount of inconsistency in performance with the addition of an attentional load for both groups. The overall changes in frequency and variability of frequency characteristics implied that some changes are occurring in the postural control system with the implementation of a secondary task (Schmid et al., 2007). However, the lack of overall differences between groups, and across conditions indicated that attention did not significantly interfere with performance.

Children who met the criteria for DCD and typically developing children showed subtle changes in balance performance with the addition of a secondary task. Both groups of children demonstrated high variability in performance as a result of attention loading. The increase in variability led to a decrease in stability of movement patterns. However, minimal changes to all other measures indicated that attention did not significantly interfere with balance performance. Both groups of children were successful at maintaining balance in the attentional condition. The changes in variability of frequency characteristics implied that attention influenced the underlying processes of balance for both groups, but overall, attention did not significantly interfere with performance. This conclusion was demonstrated by an overall lack of change to sway patterns and the production of smooth controlled adjustments of the COP while dual tasking. The lack of major differences with the addition of attention indicated that both groups of children may have achieved automaticity of balance control, and therefore could perform two tasks in parallel.

The results for the typically developing group are in accordance with some dual-tasking literature and not in accordance with others. The results of the study are in support of literature which indicated that typically developing children between 8 and 10 years of age demonstrate automaticity of balance control. This result was inferred through the use of variation index measures on area of sway (Tsai et al., 2009). The values of the variation indexes did not change under attentional conditions implying that typically developing children remained relatively unaffected during dual-task conditions. The similarity in performance outcomes could indicate that the children in the present study demonstrated a more automatic (parallel) processing of information.

Most other literature is not in support of automatic processing of balance under dual-task conditions. The majority of literature on dual-tasking involving typically developing children indicated that they are impacted by the addition of an attentional load. This effect has been demonstrated through changes in traditional COP sway measures and frequency characteristics. Blanchard and colleagues (2005), through the analysis of path length, sway range, and sway variability in the AP and ML directions, demonstrated a decrease in COP movement. These results are in line with a "stiffening" of postural control (Shumway-Cook & Woollacott, 2001), reducing overall movement in order to meet demands of dual-tasking. Although a decrease in sway measures can imply an improvement in balance seen in developmental studies (Kirshenbaum et al., 2001), the notion of "stiffening" can infer a decrease in performance as it is also associated with destabilization. On the other hand, Schmid and colleagues (2007) used measures including area of sway, several frequency characteristics, in addition to other measures, and demonstrated an increase in COP sway and frequency measures. The authors suggested that dual-tasking exceeded the attentional capacity in children resulting in an increase of sway, and broadening of the frequency spectrum. The combination of the different measures indicates more corrective adjustments of the COP and movement closer to the stability boundaries thus increasing instability. Although Schmid and colleagues and Blanchard and colleagues demonstrated different postural control strategies to compensate for dual tasking, both researchers attributed the changes of COP measures to the inability of the system to maintain the same level of control. As a result, it appears that the children employ one of two different strategies to cope with the high attentional demands of dual-tasking.

The results of the present study are not in support of previous DCD literature. The results of the present study indicated that balance performance of children who met the criteria for DCD was relatively unaffected by attentional loading. Tsai and colleagues (2009), on the other hand, found that the majority of the attentional loading conditions resulted in significant increases in measures. The authors suggested that for children with DCD, balance control may not be a task of automaticity as they demonstrated dual task interference and typically developing children did not. Tsai and colleagues' findings are also in accordance with the findings of Laufer and colleagues (2007). The authors used path length velocity (total distance traveled by the COP divided by stance time), as well as amplitude variability in the AP and ML directions, to make inferences about balance control in children with and without DCD under dual-task conditions. The results indicated that children with DCD demonstrated greater path length velocity and amplitude variability in the ML direction, on both compliant and non-compliant surfaces, in comparison to the typically developing children (Laufer et al., 2007). The increase in velocity measures indicated that children with DCD were using more of a ballistic type of strategy to control balance when dual tasking. Laufer and colleagues also noted that children with DCD had difficulty in the performance of the attention task (object identification) while in a seated position. The authors suggested that during the dual-tasking conditions, children with DCD placed more focus on the performance of the attention task, and less focus on the balance task, since attention could not be divided equally between the two. Prioritizing the attention task over balance performance resulted in an increase in sway measures and a compromised balance performance (Laufer et al., 2007). The children in the two previously mentioned studies could not perform the two tasks in parallel. Issues in automatic processing of information resulted in a more controlled type of information processing, resulting in prioritization of one task over the other. In the case of Laufer and colleagues, the results indicated that the children prioritized the attention task over balance. The children who met the criteria for DCD in the present study did not demonstrate a more controlled type of processing as previously seen in the DCD literature. Since the results of the present study were not in line with previous research, individual profiles were analyzed.

At the individual level of analysis, minimal changes occurred in both the traditional and non-traditional measures with the implementation of attentional loading. The children who met the criteria for DCD, with and without balance difficulties, demonstrated quite consistent COP sway measures across the two attentional conditions as viewed in Appendix I. Non-traditional measures on the other hand were variable, especially peak power measures. Participant 9, not identified with balance issues, demonstrated significantly higher peak power measures in comparison to all other children who met the criteria for DCD. The participant's results can be viewed in Appendix I. The high power measures would indicate extreme ballistic adjustments of the COP during quiet standing. However, this child did not lose balance. Since the measure is substantially different in comparison to all other children who met the criteria for DCD, a separate analysis that exempted the child with the very high peak power measures was completed. The separate analysis was conducted to examine if group means were being affected by the outlier. No significant differences in results were found. All children who met the criteria for DCD, balance problems or not, demonstrated successful performance under dual-tasking conditions.

Postural Adaptations with and without Attentional Loading

No attentional loading condition. The concept of postural adaptation is not new to the literature, but it has not gained a sufficient amount of focus. Conceptually speaking, the analysis of postural adaptation can provide an insight into the performance of goal directed actions of the postural control system in order to explore the effective use of open-loop closed-loop integrative systems (Przysucha, Taylor, & Weber, 2008). A dynamic balance task, such as a lean task, allows for the investigations into the implementation of integrative systems involved in postural adaptation. According to Riach and Starkes (1993), the ability to lean as far as possible from the vertical, in the anterior and posterior directions, begins to reach adult like levels of performance around 7 years of age. These adult like abilities are a result of the effective use of the open loop and closed loop integrative control systems (Hatzitaki, Zisi, Kollias, & Kioymourtzoglou, 2002).

In the DCD literature, it has been suggested that less than optimal integration of control mechanisms is a possible limiter to the poor performance in reaching and aiming tasks (Smyth, Anderson, & Churchill, 2001), and recently in postural adaptations (Przysucha et al., 2008). It was hypothesized that children who met the criteria for DCD would show differences in the performance of postural adaptation without attentional loading, demonstrated by the traditional and non-traditional measures, when compared to the typically developing group on traditional and non-traditional measures (Przysucha et al., 2008).

The results of the study did not support the hypothesis. Children who met the criteria for DCD and typically developing children did not demonstrate significant differences in the performance of postural adaptations without attentional loading. Children who met the criteria for DCD were able to effectively lean as far in the anterior posterior directions as the typically developing children. In addition, the children who met the criteria for DCD also demonstrated similar area of sway and overall distance travelled by the COP. The frequency characteristics also showed that children who met the criteria for DCD were as successful on the performance of the lean task when compared to the typically developing children. The results for both groups indicated that the majority of COP activity was concentrated at the lower end of the frequency spectrum (< 1 Hz), as evident from (mean) frequency mode and frequency dispersion. Regardless of the group, the power measures were also concentrated at the lower end of the frequency spectrum. The combination of the low frequency and low power measures indicated that both groups demonstrated subtle, smooth and controlled adjustments of the COP during the performance of the leaning task. In addition, the small frequency dispersion measures indicated consistent performance for both groups.

The results of the study are not in line with literature examining DCD, as well as developmental studies comparing younger and older children. Children who met the criteria for DCD in the present study were able to effectively lean as far from the vertical in the AP directions as the typically developing children. This result implied that children who met the criteria for DCD were as effective in performing the leaning task as the typically developing group of children. However, this finding is in contrast to previous work by Przysucha and colleagues (2008), who examined postural adaptations in boys with and without DCD who were 7 to 10 years of age. The group of children with DCD were identified with definitive balance problems (TBS < 5th percentile). The researchers investigated the nature of postural adaptations based on AP and lateral sway measures, path length, and area of sway, in order to make inferences regarding sway pattern. The researchers also incorporated spectral analysis using peak frequency to make inferences about the nature of corrective adjustments of the COP during self-initiated adaptations, and measures used to infer control tendencies (time spent in the acceleration phase). The present study also utilized the majority of the same measures excluding lateral sway and velocity measures used to infer control tendencies. Przysucha and colleagues found that boys with DCD were not able to lean as far in the AP direction in comparison to the typically developing children resulting in smaller path length values when compared to boys without DCD. In terms of frequency characteristics, the boys with DCD demonstrated significantly larger peak frequency values (> 1 Hz) when compared to the typically developing group of children. The researchers attributed the findings to a less than optimal use of integrative systems. The boys with DCD relied more on ballistic control than feedback-based control as demonstrated by the typically developing boys.

Although the results of this study are not in support of Przysucha and colleagues (2008), their interpretations can be applied to the present study in order to make inferences regarding the optimal use of integrative systems and control mechanisms. The researchers attributed their findings to the less than optimal integration of control mechanisms, derived from higher velocity measures and more time spent in the acceleration phase for children with DCD. In combination with the high peak frequency measures, indicating more ballistic corrections, the results indicated that children spent more time in an open-loop type of control before switching to a more feedback based type of control, demonstrating a less than optimal performance. Since the children with DCD in the present study demonstrated similar movement patterns and frequency characteristics as did the typically developing children, it implies that both groups would have demonstrated optimal integration of both control mechanisms for effective performance of this task.

Attentional loading condition. The dual-task paradigm is novel to the postural adaptation literature, which made it difficult to derive a hypothesis in regards to expected outcomes. Results from dual tasking on more complex processes of dynamic actions such as gait (Cherng, Liang, Chen, & Chen, 2009) were used to make comparisons. The research indicated that walking performance was impacted by attentional loading in children with and without DCD. Also, it was found that an increase in difficulty of the attentional task (e.g. repeating a backwards series of digits) increased the level of interference, especially for children with DCD. It has been concluded that the more complex actions require more attention (Cherng et al., 2009). Therefore, in the context of present research, it was hypothesized that children who met the criteria for DCD and typically developing children would experience interference with the addition of attentional loading. However, children who met the criteria for DCD were expected to demonstrate greater impact on their performance.

The results of the study partially supported the hypotheses. No between group differences were evident, which did not support the hypothesis that children who met the criteria for DCD would be much more impacted by dual tasking compared to typically developing children. Both groups presented with similar AP sway measures, demonstrating equal capabilities of projecting the COP in the anterior and posterior directions, even under the influence of attentional loading. The overall lack of differences between the two groups in terms of path length indicated that the COP travelled equivalent distances. The lack of differences for area of sway indicated COP movement, for both groups, was obtained within the same area around the vertical. Collectively, the similarities in traditional measures indicated that both groups displayed similar sway patterns, even under the influence of an attentional load. A lack of between group differences was also evident in the analysis of frequency measures, as both groups demonstrated equivalent characteristics for controlling sway.

The addition of the attentional load did not influence performance, aside from an increase in (mean and variability) frequency mode. This finding indicates that the participants made more corrective adjustments when attentional load was added. Although an increase in frequency mode resulted under the influence of attention loading, the frequency measures remained in the very low end of the frequency spectrum, thus still indicating optimal performance. The data also indicated that intra-individual variability increased with the addition of attentional loading. However, this pattern is not uniform as the rest of the variables did not show such differences. Thus, the results showed that attention did not degrade balance performance.

To date, no literature has investigated the impact of a secondary task on postural adaptations. In turn, investigations into other dynamic movement actions such as gait were incorporated for comparison (Cherng et al., 2009). In terms of gait analysis, the literature indicated that children with and without DCD were impacted by the addition of a secondary task, whether it was a cognitive secondary task or a motor secondary task. In terms of the secondary cognitive task, both groups experienced similar degrees of interference (Cherng et al., 2009). However, children with DCD were more impacted by the addition of a secondary motor task, in comparison to the typically developing children. These data clearly indicated that the actions of children with and without DCD are impacted by the addition of an attentional load.

In summary, the results of the children who met the criteria for DCD were not in support of previous literature investigating dual-tasking in other dynamic tasks. In order to investigate if attention influenced postural adaptations in children with DCD, individual profiles were analyzed. At the individual level of analysis, no major changes occurred in performance of children identified with DCD. The COP profiles were relatively consistent in terms of COP displacement in the AP direction, path length and area of sway. However, a large amount of inter-individual variability was observed for peak power. Some children who met the criteria for DCD demonstrated higher values, especially participant 9 (Appendix I). Frequency mode and dispersion measures were quite consistent across the two attentional conditions for all children who met the criteria for DCD. Overall, these results indicate that even at the individual level, the children who met the criteria for DCD did not demonstrate issues during dual-task performance, regardless of the scores obtained on the MABC.

Overall, the results of the present study reflect the ability of the postural control system and capacity of attention to maintain an optimal level of parallel performance (Kahneman, 1973). The addition of the numeric classification task did not interfere with relevant mechanisms to compromise performance. The resulting frequency measures indicated that children who met the criteria for DCD and typically developing children were incorporating the same types of control predominantly utilizing feedback based corrections. This is consistent with previous research on reaching and aiming (Smyth et al., 2001), thus indicating that the nature of motor control mechanisms used are task specific.

General Discussion and Conclusions

From the review of literature it was apparent that issues pertaining to dual-tasking in children who met the criteria for DCD and typically developing children required further investigations. Underlying issues in attention may be a contributing factor to the poor motor performance of many children with DCD. Attentional issues of children with DCD have been proposed in the limited literature incorporating the dual-task paradigm (Laufer, Ashkenazi, & Josman, 2007; Tsai, Pan, Cherng, & Wu, 2009). To further investigate the potential issues and add to the literature, the dual-task paradigm was incorporated with static balance control and postural adaptations.

In terms of static balance control without attention, the findings of the present study further support previous literature (Geuze, 2003; Przysucha & Taylor, 2004). Children who met the criteria for DCD demonstrated relatively similar COP sway profiles as the typically developing group. These results indicate, from the motor control standpoint, that static balance control without attentional loading is not problematic for the children who met the criteria for DCD. In order to further infer the nature of COP adjustments, frequency characteristics were used. The low frequency, low power sway demonstrated by typically developing children is consistent with previous literature (Riach & Hayes, 1987). The patterns observed in children who met the criteria for DCD are novel in the postural control domain. Previous literature has used COP sway measures such as velocity to infer underlying processes to control (e.g., Laufer et al., 2007; Przysucha et al., 2008). The use of frequency characteristics provided a more sophisticated way of analysis for making inferences regarding underlying processes. The findings indicated that children with DCD demonstrated smoother and more controlled adjustments of the COP, as opposed to more erratic type of corrections as previously reported (Laufer et al., 2007; Przysucha et al., 2008).

The addition of attentional loading somewhat influenced static balance performance, but it did not hinder it. The findings of the present study added to previous literature (Tsai et al., 2009) supporting the notion that automaticity of balance control can occur as early as 8 to10 years of age. The findings of those children who met the criteria for DCD contradicted previous literature (Laufer et al, 2007; Tsai et al., 2009). In terms of frequency characteristics, the results indicated that there were no differences in performance in terms of (mean) frequency dispersion and peak power, indicating that both groups exhibited subtle and smooth and corrective adjustments. This type of behavior is generally associated with dominance of feedback based control (Przysucha et al., 2008). From the standpoint of attentional interference, the present research showed that in both groups, balance control tasks were carried out automatically, or without controlled processing.

In terms of postural adaptations, the results for typically developing children are in support of previous literature (Blaszczyk, Hansen, & Lowe, 1993; Riach & Starkes, 1993). However, the findings are inconsistent with literature investigating children with DCD (Przysucha et al., 2008). The COP sway profiles for both groups were similar. Both groups leaned equally as far in the AP direction, and demonstrated equivalent excursions in terms of area of sway and path length. The COP adjustments inferred from frequency characteristics also implied that children who met the criteria for DCD were able to demonstrate smooth and controlled corrective adjustments of the COP. This finding, paralleled with the interpretations derived from measures inferring underlying mechanisms from Przysucha and colleagues (2008), indicated that children who met the criteria for DCD were able to effectively use an integrative type of control in order to optimally perform the leaning task, rather than implementing a more ballistic type of control.

The present study was the first to incorporate the dual-task paradigm with dynamic postural adaptations. The results indicated that children who met the criteria for DCD and typically developing children were successful in leaning as far in the AP direction in a controlled fashion while dual tasking. Both groups of children also demonstrated consistent movement patterns characterized by smooth and controlled corrective adjustments of the COP, regardless of attentional requirements. Thus, children who met the criteria for DCD were just as capable of dividing attention between the performances of the two tasks when compared to the typically developing children.

In contrast to the significant differences found on TIS and TBS, children who met the criteria for DCD did not differ on balance performance when compared to typically developing children. A major limitation to the study, which possibly contributed to the lack of differences between the two groups, is related to sampling. This issue pertained more specifically to the group of children identified in the DCD group. None of the children in that group had an official diagnosis of DCD. As a result, the children were 'identified' as meeting the criteria based on performance scores on the MABC, scores on the DCD-Q, and information collected from the child information sheet. Also, these children, as a group, did not exhibit balance problems as indicated by TBS score ($M = 4.5$). This places them at no risk of balance issues (> 15th percentile). In terms of individual analysis, only two children were identified by the MABC as demonstrating definitive balance issues (TBS < 5th percentile or a score higher than 7). Three other children were at risk of balance issues (TBS 5th to 15th percentile, or scoring between 5 to 6.5), and the remaining five children identified as meeting the criteria for DCD did not demonstrate issues in balance control. Past work has used more rigorous selection criteria for children with DCD to include individuals with definitive balance problems (Laufer et al., 2007; Tsai et al., 2009). The previous literature included children who scored less than the fifth percentile in terms of the total impairment score and total balance score as outlined by the MABC. Secondly, none of the children in the group identified with DCD had a dual-diagnosis of ADHD. As a result, it is plausible that they did not exhibit attentional issues. A ceiling effect may also account for the lack of performance differences. The numeric classification task used may not have been challenging enough to elicit interference in children who met the criteria for DCD. A more novel or a more difficult attention task, such as counting backwards by three or memorizing a list of objects as used in previous literature (Tsai et al., 2009), may have created the expected interference.

The overall results of the study indicated that both groups of children did not differ in terms of performance. Both groups were able to demonstrate mature performance in terms of COP sway patterns and frequency measures. Regardless of balance task and attentional demands, both groups of children demonstrated similar sway patterns, which are consistent with adult data as reported in other studies (Blaszczyk et al., 1993; McClenaghan et al., 1996). In order to make inferences regarding the corrective adjustments of the COP during performance, spectral analysis was incorporated. Both groups of children demonstrated subtle, smooth, and controlled adjustments of the COP during the performance of both balance tasks. Optimal performance was elicited through the effective use of the integrated control system, as inferred from inferences of previous studies (Przysucha et al., 2008). In terms of the dual-task paradigm, both groups of children were able to perform both tasks in parallel, hence they were able to demonstrate a more automatic type of information processing (Schneider & Shiffrin, 1977). This finding is contrary to the majority of dual-tasking literature (Blanchard et al., 2005; Laufer et al., 2007; Schmid et al., 2007; Tsai et al., 2009), involving children who met the criteria for DCD.

Future Recommendations

The following recommendations are made for future research in the area of dual-tasking in children with DCD:

1. The relationship between attention and balance performance should be examined using a more stringent screening process to include only children with a diagnosis of DCD and definitive balance issues.
2. A combination of differing degrees of difficulty of attentional tasks should be incorporated. This gradation will allow for investigations of a wider range of levels and limits of attentional loading which affect balance.
3. A standard method for determining level of attentional task difficulty should be established for future dual-task studies.
4. The postural adaptation task of the present study should be replicated to continue to explore motor control performances on more complex balance tasks in children with DCD. In addition, more complex balance tasks (e.g. Romberg or stork stance) can also be incorporated to identify issues with more difficult balance positions.
5. The continual use of spectral analysis, as well as variables to examine the nature of control tendencies (velocity based measures) to explore the mechanisms impacted by attention loading, should be incorporated.

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Appendices

Appendix A

Pilot Study Results

Table A1

Mann-Whitney U Descriptive Statistics for Quiet Standing and Attentional Conditions

	No Interference		Interference NC		Interference OI	
DV	*M*	*SD*	*M*	*SD*	*M*	*SD*
AP Sway	.15	.04	.18	.05	.19	.06
Ao	.01	.02	.02	.01	.02	.01
PL	2.68	.99	2.81	1.17	2.74	1.06
Ff	.78	.22	.77	.29	.72	.14
Pd	.00	.00	.00	.00	.01	.00

Note: AP sway = anterior posterior sway; Ao = area of sway; L = path length; Ff = fundamental frequency; Pd = power density.

Table A2

Mann-Whitney U Results for Quiet Standing and Attentional Conditions

	No Interference			Object Identification			Numeric Classification		
DV	U	*Z*	*p*	U	*Z*	*p*	U	*Z*	*p*
AP	12.00	-.10	.971	4.00	-1.78	.076	7.00	-1.15	.251
Ao	11.00	-.31	.754	0.00	-2.61	.009*	3.00	-1.98	.047*
L	0.00	-2.61	.009*	0.00	-2.61	.009*	0.00	-2.61	.009*
Ff	7.50	-1.05	.293	5.00	-1.57	.117	10.00	-.52	.599
Pd	7.50	-1.05	.293	8.00	-.94	.346	5.00	-1.57	.116

Note: AP sway = anterior posterior sway; Ao = area of sway; L = path length; Ff = fundamental frequency; Pd = power density.
* $p \leq .05$

Table A3

Mann-Whitney U Descriptive Statistics for Postural Adaptations and Attentional Conditions

	No Interference		Interference NC		Interference OI	
DV	*M*	*SD*	*M*	*SD*	*M*	*SD*
AP Sway	1.69	.33	1.62	.26	1.48	.50
Ao	.59	.17	.54	.23	.57	.20
PL	6.30	1.29	5.86	1.15	6.26	1.27
Ff	1.10	.25	1.07	.25	1.00	.18
Pd	.02	.01	.02	.01	.03	.01

Note: AP sway = anterior posterior sway; Ao = area of sway; L = path length; Ff = fundamental frequency; Pd = power density.

Table A4

Mann-Whitney U results For Postural Adaptation and Attentional Conditions

	No Interference			Object Identification			Numeric Classification		
DV	U	*z*	*p*	U	*z*	*p*	U	*z*	*p*
AP	2.00	-2.19	.028*	9.00	-.73	.465	5.00	-1.57	.117
Ao	8.00	-.94	.347	11.00	-.31	.754	11.00	-.31	.754
PL	3.00	-1.98	.047*	3.00	-1.98	.047*	0.00	-2.61	.009*
FF	8.00	-.94	.347	6.00	-1.36	.175	8.50	-.84	.402
PD	12.00	-.10	.917	10.00	-.52	.602	1.00	-2.41	.016*

Note: AP sway = anterior posterior sway; Ao = area of sway; L = path length; Ff = fundamental frequency; Pd = power density.

* $p \leq .05$

Appendix B

Recruitment Letter for School Children Participants

Recruitment Letter

Dear Parents,

I would appreciate your child's participation in a research study titled "Impact of attention on postural control in children with and without movement and balance difficulties". This study will be undertaken by me, Jodi Trapp, a graduate student at Lakehead University, School of Kinesiology.

The purpose of this research is to look into how attention impacts balance control and postural adaptations in children with and without movement and balance difficulties. In order to participate, your child must be between 8-10 years of age, have an intelligence level consistent with children of the same age, and be free of any injury that could affect his/her balance. In order to get this information, you will be asked to sign a consent form, and complete a child information sheet and a Developmental Coordination Disorder Questionnaire (DCDQ), which are attached to this letter. The information sheet will ask you to answer some questions about your child, as well as gather some contact information. The information from the DCDQ will be used to gain some information about how your child performs specific movements when compared to children of the same age. I kindly ask you to fill out the information sheet and the DCDQ to the best of your knowledge. The filled out forms should be put in the envelope provided and brought back to the teacher as soon as possible. The information given is confidential and it will not be seen by the teacher or school officials. All returned envelopes will be kept in a secure place by the teacher until they are picked up by the researcher. The returned forms will be reviewed to find out if your child meets the inclusion criteria. If selected, your child will be asked to come to a 45 minute session for the assessment of balance and movement using the Movement Assessment Battery for Children (MABC). The MABC will be used to provide information about the child's performance of age-appropriate tasks within 3 subsections: Manual Dexterity, Ball Skills, and Static and Dynamic Balance. Two scores will be calculated, a total impairment score (TIS) and a total balance score (TBS). The TIS is a combined score of all three subsections, and the TBS is a score for the balance only. The child's performance is then compared to normative data. If child's TIS is at or above the 20th percentile, and the TBS is above the 15th percentile, then the child will be included in a group consisting of typically developing children. If the TIS and TBS are at or below the 5th percentile, then the child will be included in the group consisting of children with movement and balance difficulties.

Once the MABC test has been completed, you and your child will be asked to come to a balance testing session. At the beginning of the balance testing session, I will measure your child's foot length, foot width, and height. Your child will then be asked to complete 4 testing conditions. Three trials will be completed for each condition, with each trial lasting 10 seconds. A total of 12 trials will be completed. All testing will take about 20-30 minutes. Your child will be asked to perform two balance tasks with and without the addition of the attention task. The two balance tasks are quiet standing, which your child will be asked to stand as still as possible, and a postural adaptation, in which your child will need to lean as far as possible forwards and backwards from the upright standing position, without losing balance (e.g. bending at the hips, not maintaining full foot contact with the floor, or taking a step). The attention task is a number task that will ask your child to identify a number herd off of a recording, and then indicate whether it is higher or lower than 50. Each child will be tested individually. The balance tests will be completed while standing on a force platform which is located in the floor. A practice trial for each task will be given prior to data collection so the child will know what to do for each testing condition.

As the child will be a volunteer, he/she may refuse to complete any part of the tests and withdraw from the study at any time. All tasks are safe and do not pose any physical or psychological risk to those participating in the study. The benefits of the study include receiving results on your child's MABC scores, balance abilities, as well as group results once the study is completed. You will also have the chance to set up a private meeting time to discuss your child's results, and any questions or concerns you may have. In the case your child is selected to be in the group with movement and balance difficulties, you will be an opportunity to enrol your child in the Motor Development Clinic, if you wish. It is a one-on-one intervention program which runs twice a week, and it takes place at Lakehead University. It is free of charge. The main focus of the program is skill development and improvement of coordination and balance. If you would like to find out more information, you can contact Dr. Eryk Przysucha (343-8189 or e-mail eprzysuc@lakeheadu.ca) or Dr. Jane Taylor, clinic director, at 343-8572 or email jane.taylor@lakeheadu.ca.

If you agree to have your child participate, all signed and filled forms must be put into the envelope and returned to the teacher as soon as possible. You are also asked to provide contact information so the researcher can get into contact with you once the forms have been reviewed. In addition, a phone number and email address is provided at the end of this letter if you have any questions, or concerns. Dates and times will be made available to you for the MABC assessment and balance testing sessions. You can choose the times that best fit your schedule. If the dates and times are not suitable for you, changes can be made.

All information that you provide will be strictly confidential and stored for 5 years with Dr. Eryk Przysucha, faculty advisor. Numbers will be given to each child to ensure that the child's results remain confidential. Only the researcher and the faculty advisor will have access to data. If you would like to access your child's results please contact Jodi Trapp at Lakehead University, School of Kinesiology.

This research is a partial fulfillment for my master's thesis. The data and concluding results will be formally presented during the thesis defense. This research has been approved by the Lakehead University Research Ethics Board. If you have any questions/concerns regarding the ethics of the project please contact the Board at 807-343-8283 or research@lakeheadu.ca

Thank you for your time.
Jodi Trapp

Contact information:
Jodi Trapp –Phone: 343-8649
Email: jtrapp1@lakeheadu.ca

Dr. Eryk Przysucha –Phone: 343-8189
Email: eprzysuc@lakeheadu.ca

Appendix C

Consent Form

Consent Form

Child Participant Consent Form

I ____ agree to have my child ____ participate in the study titled, "Impact of attention on postural control in children with and without movement and balance difficulties", by Jodi Trapp.

- I recognize that Jodi is a graduate student at Lakehead University, School of Kinesiology doing research for her master's thesis under the supervision of Dr. Eryk Przysucha, faculty advisor.

- My child is between 8-10 years of age, has an intelligence level consistent with children of the same chronological age, and is free of injury that may affect his/her balance.

- I understand that I need to complete the child information sheet and DCDQ to the best of my knowledge, and return the completed forms sealed in the envelope to my child's teacher.

- I understand that my child will be asked to complete the Movement Assessment Battery for Children to assess his/her movement and balance. The test will take about 45 minutes to complete.

- I understand that my child is asked to complete two balance tasks, with and without an attention task, while standing on a force platform. There are a total of 12 trials, each 10 seconds, and that all testing will take about 20-30 minutes to complete.

- I understand that all information that I provide will stay confidential, my child's identity will not be revealed, and that my child may withdraw his/her participation from the study at any time.

- I am also aware that this study poses no physical or psychological risk to my child. The benefits of the study include receiving my child's individual scores, information on my child's balance abilities, and group results once the study is completed.

- I understand that I will be able to set up a personal meeting with the researcher once the study is completed to discuss my child's results as well as address any questions or concerns.

- I explained the research study to my child and he/she agrees to be a participant.

- If you would like to enrol your child into the Motor Development Clinic please indicate below
  YES NO

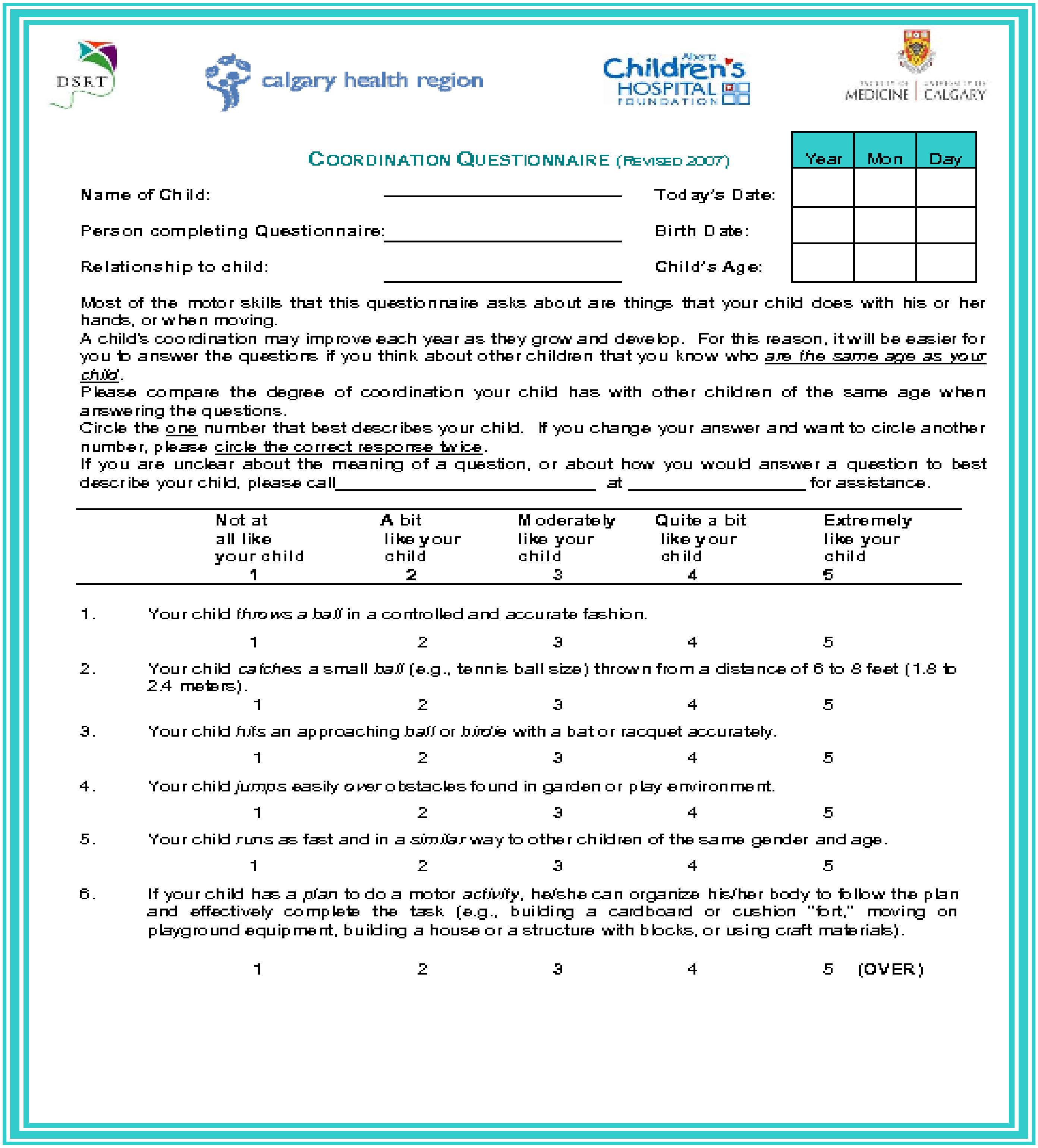
Signature of Parent/Guardian: ____

Signature of Child: ____

Date: ____

Appendix D

Developmental Coordination Disorder Questionnaire (DCDQ ’07)



DSRT

calgary health region

Alberta Children's HOSPITAL FOUNDATION

INSTITUTE OF MEDICINE | UNIVERSITY OF CALGARY

COORDINATION QUESTIONNAIRE (REVISED 2007)

			Year	Mon	Day
Name of Child:	______________	Today's Date:			
Person completing Questionnaire:	______________	Birth Date:			
Relationship to child:	______________	Child's Age:			

Most of the motor skills that this questionnaire asks about are things that your child does with his or her hands, or when moving.

A child's coordination may improve each year as they grow and develop. For this reason, it will be easier for you to answer the questions if you think about other children that you know who *are the same age as your child*.

Please compare the degree of coordination your child has with other children of the same age when answering the questions.

Circle the one number that best describes your child. If you change your answer and want to circle another number, please circle the correct response twice.

If you are unclear about the meaning of a question, or about how you would answer a question to best describe your child, please call______________ at ______________ for assistance.

Not at all like your child	A bit like your child	Moderately like your child	Quite a bit like your child	Extremely like your child
1	2	3	4	5

1. Your child *throws a ball* in a controlled and accurate fashion.

   1 2 3 4 5

2. Your child *catches* a small *ball* (e.g., tennis ball size) thrown from a distance of 6 to 8 feet (1.8 to 2.4 meters).

   1 2 3 4 5

3. Your child *hits* an approaching *ball* or *birdie* with a bat or racquet accurately.

   1 2 3 4 5

4. Your child *jumps* easily *over* obstacles found in garden or play environment.

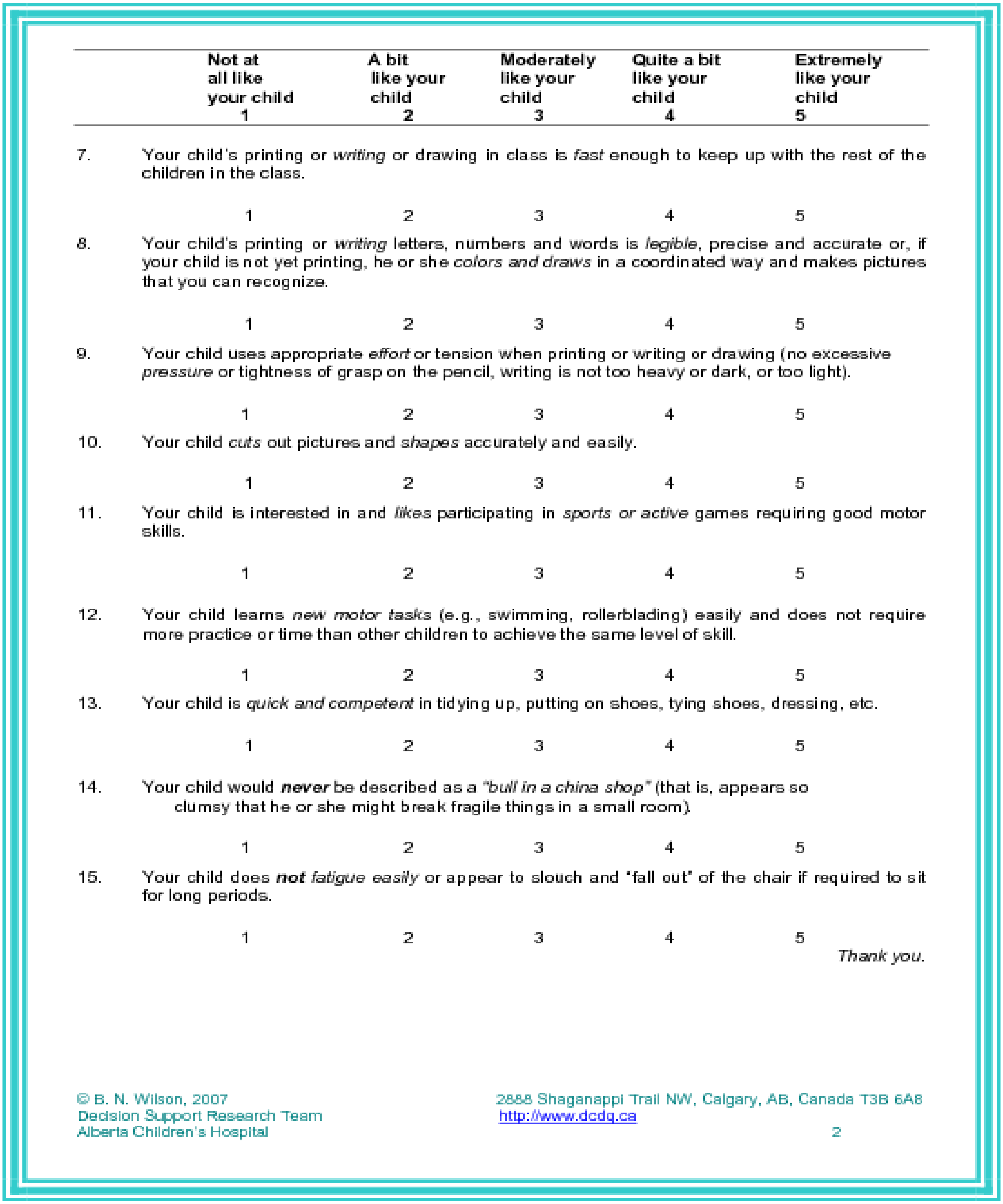
   1 2 3 4 5

5. Your child *runs* as fast and in a *similar* way to other children of the same gender and age.

   1 2 3 4 5

6. If your child has a *plan* to do a motor *activity*, he/she can organize his/her body to follow the plan and effectively complete the task (e.g., building a cardboard or cushion "fort," moving on playground equipment, building a house or a structure with blocks, or using craft materials).

   1 2 3 4 5 (OVER)



	Not at all like your child 1	A bit like your child 2	Moderately like your child 3	Quite a bit like your child 4	Extremely like your child 5

7. Your child's printing or *writing* or drawing in class is *fast* enough to keep up with the rest of the children in the class.

1 2 3 4 5

8. Your child's printing or *writing* letters, numbers and words is *legible*, precise and accurate or, if your child is not yet printing, he or she *colors and draws* in a coordinated way and makes pictures that you can recognize.

1 2 3 4 5

9. Your child uses appropriate *effort* or tension when printing or writing or drawing (no excessive *pressure* or tightness of grasp on the pencil, writing is not too heavy or dark, or too light).

1 2 3 4 5

10. Your child *cuts* out pictures and *shapes* accurately and easily.

1 2 3 4 5

11. Your child is interested in and *likes* participating in *sports or active* games requiring good motor skills.

1 2 3 4 5

12. Your child learns *new motor tasks* (e.g., swimming, rollerblading) easily and does not require more practice or time than other children to achieve the same level of skill.

1 2 3 4 5

13. Your child is *quick and competent* in tidying up, putting on shoes, tying shoes, dressing, etc.

1 2 3 4 5

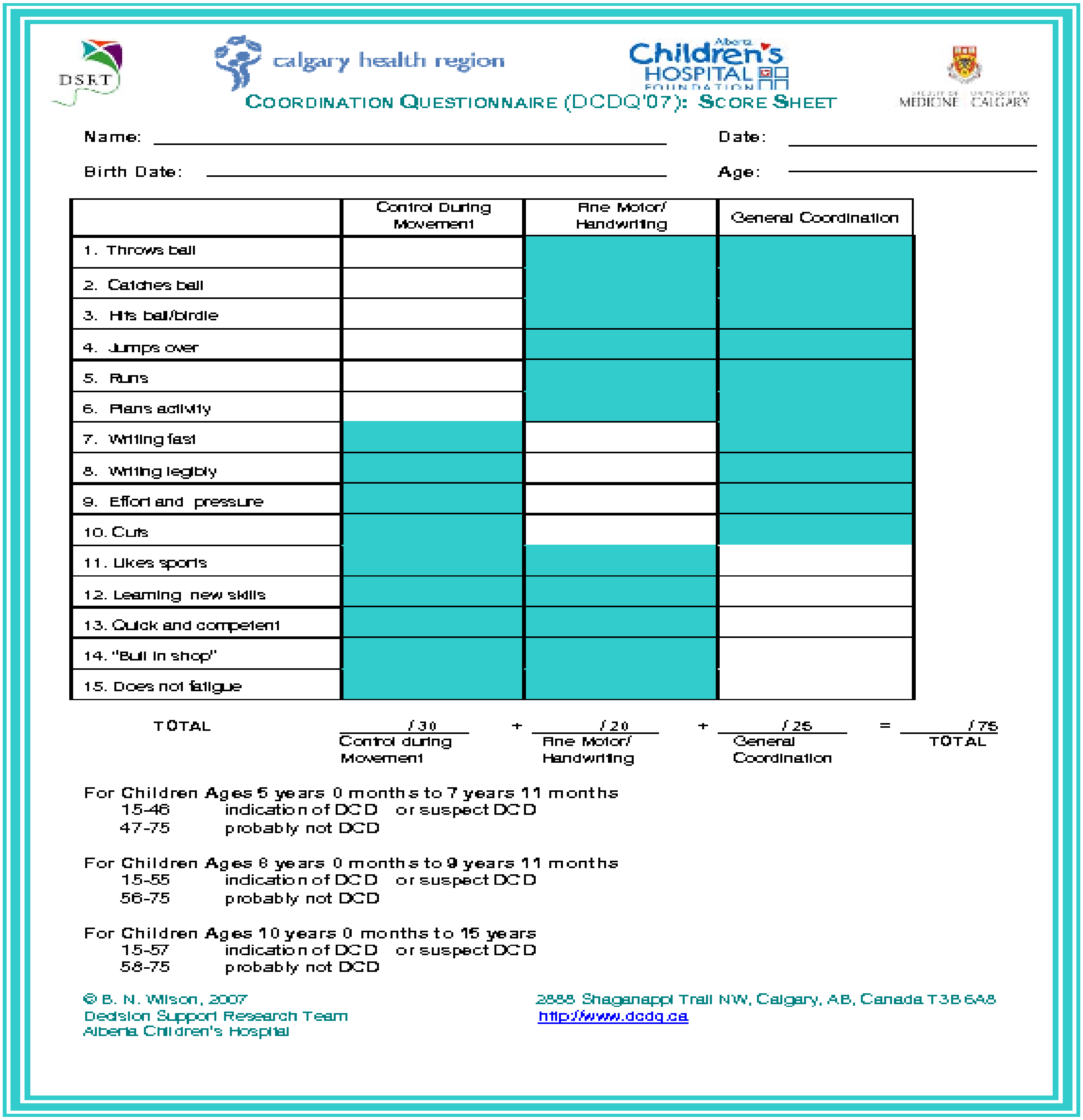
14. Your child would ***never*** be described as a *"bull in a china shop"* (that is, appears so clumsy that he or she might break fragile things in a small room).

1 2 3 4 5

15. Your child does ***not*** *fatigue easily* or appear to slouch and "fall out" of the chair if required to sit for long periods.

1 2 3 4 5

Thank you.



calgary health region

Alberta Children's Hospital Foundation

DSRT

Faculty of Medicine, University of Calgary

COORDINATION QUESTIONNAIRE (DCDQ'07): SCORE SHEET

Name: ____________________ Date: ____________

Birth Date: ____________________ Age: ____________

	Control During Movement	Fine Motor/ Handwriting	General Coordination
1. Throws ball		▨	▨
2. Catches ball		▨	▨
3. Hits ball/birdie		▨	▨
4. Jumps over		▨	▨
5. Runs		▨	▨
6. Plans activity		▨	▨
7. Writing fast	▨		▨
8. Writing legibly	▨		▨
9. Effort and pressure	▨		▨
10. Cuts	▨		▨
11. Likes sports	▨	▨	
12. Learning new skills	▨	▨	
13. Quick and competent	▨	▨	
14. "Bull in shop"	▨	▨	
15. Does not fatigue	▨	▨	

TOTAL ______ /30 Control during Movement + ______ /20 Fine Motor/ Handwriting + ______ /25 General Coordination = ______ /75 TOTAL

For Children Ages 5 years 0 months to 7 years 11 months

15-46	indication of DCD or suspect DCD
47-75	probably not DCD

For Children Ages 8 years 0 months to 9 years 11 months

15-55	indication of DCD or suspect DCD
56-75	probably not DCD

For Children Ages 10 years 0 months to 15 years

15-57	indication of DCD or suspect DCD
58-75	probably not DCD

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Decision Support Research Team
Alberta Children's Hospital

2888 Shaganappi Trail NW, Calgary, AB, Canada T3B 6A8
http://www.dcdq.ca

Note. From "The developmental coordination questionnaire, revised 2007 (DCDQ'07)," by Wilson, 2010, Administrative manual for the DCDQ'07 with psychometric properties. Copyright 2010 by Alberta Health Services. Reprinted with permission.

Appendix E

Child Information Sheet

Child Information Sheet

Child's Name: ______________________________________ Age __________

Please answer the following questions to the best of your knowledge and judgement.

1. Does your child experience movement difficulties during the performance of every-day tasks including self-care, tying shoes, or writing?

   Yes No

2. Does your child experience movement or balance issues, serious enough to concern you, during regular play activities including bike riding, playing on playground equipment, running, throwing or catching?

   Yes No

3. Does your child have difficulties concentrating or paying attention either at home or in the classroom?

   Yes No

If you answer "Yes" to the above questions, please answer the following questions below.

1. Has your child been diagnosed in the past as having:

   a. Developmental Coordination Disorder (DCD)
   b. Reading Disability (RD)
   c. Learning Disability (LD)
   d. Attention Deficit-Hyperactivity Disorder (ADHD)
      i. Predominantly Inattentive
      ii. Predominantly Hyperactive-Impulsive
      iii. Combination of Inattentive, Hyperactive and Impulsive
   e. Other:____

   If "Yes", please circle the appropriate answer(s)

2. Is your child currently enrolled in a special education program?
   Yes No

   If you circled "Yes", is your child enrolled in the program as a result of:
   a. An intellectual disability
   b. A neurological disorder (e.g. Cerebral Palsy, Muscular Dystrophy)
   c. Pervasive Developmental Disorder
   d. Other:____

   Please circle the most appropriate answer(s)

3. Have you ever had your child's IQ evaluated?
   Yes No
   If "yes", can you please indicate the IQ measure below:

   ____

Please provide your contact information below.

Contact Information:

Name of Parent/Gaurdian: ____

Home Phone Number: ____

Parent Email Address: ____

Appendix F

Recruitment Letter for Motor Development Clinic

Clinic Recruitment Letter

Dear Parents,

I would appreciate your child's participation in a research study titled "Impact of attention on postural control in children with and without movement and balance difficulties". This study will be undertaken by me, Jodi Trapp, a graduate student at Lakehead University, School of Kinesiology.

The purpose of this research is to examine how attention impacts balance control and postural adaptations in children with and without movement and balance difficulties. In order to participate, your boy/girl must be between 8-10 years of age, have an intelligence level consistent with typically developing children of the same age, and be free of any injury that could affect his/her balance and coordination on activities of daily living. You will be asked to sign a consent form, and complete a child information sheet and a Developmental Coordination Disorder Questionnaire (DCDQ), which will be provided to you should you agree to have your child participate. The information sheet will ask you to answer some questions about your child, as well as gather some contact information. The information from the DCDQ will be used to gain some information about how your child performs specific movements when compared to children of the same age. You will have the opportunity to fill the forms out in the initial meeting with the researcher, or take the forms home and fill them at a later time. I will ask you to return the filled forms in a concealed envelope provided to one of the clinic sessions your child attends, or mail the information at the address that will be provided on the envelope. The forms will be reviewed to find out if your child meets the inclusion criteria. If selected, your child will be asked to come to a 45 minute session for the assessment of balance and movement using the Movement Assessment Battery for Children (MABC).The MABC will be used to provide information about the child's performance on age-appropriate tasks within 3 subsections: Manual Dexterity, Ball Skills, and Static and Dynamic Balance. Two scores will be calculated, a total impairment score (TIS) and a total balance score (TBS). The TIS is a combined score of all three subsections, and the TBS is a score for the balance only. The child's performance will then be compared to normative data. If your child's TIS and TBS are at or below the 5th percentile, your child will be included in the group consisting of children with movement and balance difficulties.

Once the MABC test has been completed, you and your child will be asked to come to a balance testing session. At the beginning of the balance testing session, I will measure your child's foot length, foot width, and height. Your child will then be asked to complete 4 testing conditions. Three trials will be completed for each condition, with each trial lasting 10 seconds. A total of 12 trials will be completed. All testing will take about 20-30 minutes. Your child will be asked to perform two balance tasks, with and without the addition of the attention task. The first balance task will be quiet standing, where your child will be asked to stand as still as possible. Second, a postural adaptation task will be incorporated, which your child will be asked to lean as far as possible forwards and backwards from the upright standing position, without losing balance (e.g. bending at the hips, not maintaining full foot contact with the floor, or taking a step). The attention task is a number task that will ask your child to identify a number recited from a recording, and then indicate whether it is higher or lower than 50. Each child will be tested individually. The balance tests will be completed while standing on a force platform which is located in the floor. A practice trial for each task will be given prior to data collection so the child will know what to do for each testing condition.

As the child will be a volunteer, he/she may refuse to complete any part of the tests and withdraw from the study at any time. All tasks are safe and do not pose any physical or psychological risk to those participating in the study. The benefits of the study include receiving results on your child's MABC scores, balance abilities, as well as group results once the study is completed. You will also have the chance to set up a private meeting time to discuss your child's results, and any questions or concerns you may have. In addition, you will have the opportunity to enroll your child in the Motor Development Clinic, if you wish. The main focus of the program is skill development and improvement of coordination and balance. If you would like to find out more information, you can contact Dr. Eryk Przysucha at 343-8189, or email eprzysuch@lakeheadu.ca.

A phone number and email address is provided at the end of this letter if you have any questions, or concerns. Dates and times will be made available to you for the MABC assessment and balance testing sessions. You can choose the times that best fit your schedule. If the dates and times are not suitable for you, other arrangements can be made.

All the information provided will be strictly confidential and stored for 5 years with Dr. Eryk Przysucha, faculty advisor. Numbers will be assigned to each child to ensure that the child's results remain confidential. Only the researcher and the faculty advisor will have access to data.

This research is a partial fulfillment for a master's thesis. The data and concluding results will be formally presented during the thesis defense. This research has been approved by the Lakehead University Research Ethics Board. If you have any questions/concerns regarding the ethics of the project please contact the Board at 807-343-8283 or research@lakeheadu.ca

Thank you for your time.

Jodi Trapp

Contact information:

Jodi Trapp –Phone: 343-8182	Dr. Eryk Przysucha –Phone: 343-8189
Email: jtrapp1@lakeheadu.ca	Email: eprzysuc@lakeheadu.ca

Appendix G

Main Study Descriptive Statistics and ANOVA Results for Static Balance Control

Table G1.

Mean Score (M) and Variability Measures (SD) on Quiet Standing Conditions For Children with and without DCD and Group Total.

Variable	Group	No Attention		Attention	
		M	SD	M	SD
AP sway	DCD	.26	.09	.30	.11
	TD	.22	.11	.26	.14
	Total	.24	.10	.28	.13
A_o	DCD	.04	.03	.06	.05
	TD	.01	.01	.04	.03
	Total	.03	.03	.05	.04
L	DCD	4.01	1.77	4.22	1.05
	TD	4.07	.89	4.35	.89
	Total	4.04	1.37	4.28	1.37
Pp	DCD	34.26	67.55	11.79	7.72
	TD	9.56	13.11	16.26	11.48
	Total	21.91	49.02	14.03	9.79
f_{mode}	DCD	.10	.01	.14	.04
	TD	.10	.01	.16	.05
	Total	.10	.01	.15	.04
f_{sd}	DCD	.70	.14	.71	.22
	TD	.70	.17	.65	.20
	Total	.70	.15	.68	.21

Note: AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table G2.

Statistical Results For The Mean Performances and Variability (SD) For The Group x Attention Mixed ANOVA Analyses on Quiet Standing.

Variable	Group			Attention			Group x Attention		
	F	*p*	η^2	*F*	*p*	η^2	*F*	*p*	η^2
AP	.76	.395	.04	1.68	.212	.09	.00	1.000	.00
SD	.09	.766	.01	.85	.369	.05	.20	.659	.01
Ao	5.33	.033*	.23	11.95	.003*	.40	.33	.574	.02
SD	3.58	.075	.17	.59	.452	.03	1.50	.237	.08
L	.04	.836	.00	1.53	.232	.08	.03	.867	.00
SD	3.05	.098	.15	.27	.613	.02	.06	.808	.00
Pp	.73	.405	.04	.59	.453	.03	2.02	.173	.10
SD	1.04	.320	.06	.72	.407	.04	1.26	.277	.07
f_{mode}	1.02	.326	.05	23.87	.000*	.57	.71	.411	.04
SD	2.32	.145	.11	2.67	.120	.13	6.00	.025*	.25
f_{sd}	.40	.535	.02	.04	.846	.00	.16	.691	.01
SD	.43	.518	.02	5.86	.026*	.25	.13	.726	.01

Note: AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.
* $p \leq .05$.

Appendix H

Main Study Descriptive Statistics and ANOVA Results for Postural Adaptations

Table H1.

Mean Score (M) and Variability Measures (SD) on Postural Adaptation Conditions For Children with and without DCD and Group Total.

Variable	Group	No Attention		Attention	
		M	*SD*	*M*	*SD*
AP sway	DCD	1.39	.36	1.39	.28
	TD	1.57	.20	1.48	.23
	Total	1.48	.30	1.44	.25
A_o	DCD	.62	.29	.56	.30
	TD	.74	.31	.65	.31
	Total	.68	.30	.60	.30
L	DCD	7.53	2.49	7.74	2.33
	TD	7.81	1.78	7.60	1.32
	Total	7.67	2.11	7.67	1.85
Pp	DCD	29.40	63.48	54.83	125.61
	TD	13.99	8.68	12.01	15.73
	Total	21.69	44.80	33.42	89.86
f_{mode}	DCD	.13	.04	.09	.00
	TD	.17	.06	.09	.00
	Total	.15	.05	.09	.00
f_{sd}	DCD	.76	.43	.70	.16
	TD	.72	.11	.64	.07
	Total	.74	.31	.67	.12

Note: AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table H2.

Statistical Results For The Mean Performances and Variability (SD) For The Group x Attention Mixed ANOVA Analyses on Postural Adaptations.

Variable	Group			Attention			Group x Attention		
	F	*p*	η^2	*F*	*p*	η^2	*F*	*p*	η^2
AP	1.65	.216	.08	.63	.438	.03	.59	.452	.03
SD	.30	.592	.02	.28	.606	.02	.41	.528	.02
Ao	.77	.391	.04	1.39	.253	.07	.04	.846	.00
SD	.02	.887	.00	.09	.767	.01	.16	.693	.01
L	.01	.931	.00	.00	.999	.01	.20	.657	.01
SD	2.19	.156	.11	1.09	.311	.06	.25	.626	.01
Pp	1.35	.260	.07	1.35	.260	.07	1.85	.191	.09
SD	.99	.334	.05	2.24	.152	.11	.73	.406	.04
*f*mode	3.51	.077	.16	25.46	.000*	.57	3.51	.077	.16
SD	1.71	.208	.09	16.09	.001*	.47	1.71	.208	.09
f_{sd}	.53	.476	.03	.73	.404	.04	.02	.894	.00
SD	.60	.449	.03	3.67	.071	.17	.15	.700	.01

Note: AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.
* $p \leq .05$.

Appendix I

Individual Profiles

Table I1

Participant 1's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
18.5	6 *	AP sway	.31	.13	.19	.03	1.26	.08	1.00	.05
		Ao	.05	.00	.04	.02	.42	.16	.34	.09
		L	3.15	.24	3.09	.02	6.62	1.58	5.21	.62
		Pp	6.99	1.72	3.88	1.75	5.56	2.28	12.55	4.66
		Fmode	.10	.00	.13	.06	.16	.06	.10	.00
		Fdis	.63	.08	1.00	.18	.63	.22	.67	.14

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

* denotes at risk of balance difficulties as identified by the TBS in the MABC (5th – 15th %ile).

Table I2

Participant 2's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
19	5.5 *	AP sway	.22	.07	.31	.09	1.53	.07	1.36	.10
		Ao	.02	.02	.05	.03	.44	.11	.44	.12
		L	3.67	.23	4.35	.63	8.01	.65	7.07	.38
		Pp	16.73	2 .95	8.51	5.33	13.57	2.63	19.54	3.44
		Fmode	.10	.00	.13	.06	.10	.00	.10	.00
		Fdis	.61	.02	.67	.20	.77	.27	.61	.07

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

* denotes at risk of balance difficulties as identified by the TBS in the MABC (5th – 15th %ile).

Table I3

Participant 3's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
22.5	7.5**	AP sway	.17	.03	.24	.07	1.46	.11	1.51	.21
		Ao	.01	.01	.02	.01	.46	.14	.52	.34
		L	2.82	.34	2.92	.05	5.60	.39	5.38	.49
		Pp	.64	.52	6.32	3.45	8.72	2.23	.49	.34
		Fmode	.10	.00	.23	.06	.20	.00	.10	.00
		Fdis	.75	.25	.31	.09	.21	.07	.85	.47

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

** denotes definite balance difficulties as identified by the TBS in the MABC (< 5th % ile).

Table I4

Participant 4's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
19.5	7.5**	AP sway	.27	.06	.31	.06	1.63	.05	1.41	.08
		Ao	.05	.01	.06	.02	.64	.15	.35	.10
		L	8.64	.23	6.09	3.41	13.00	1.34	8.11	1.62
		Pp	6.11	4.85	15.98	10.06	8.89	9.16	2.53	1.16
		Fmode	.10	.00	.10	.00	.10	.00	.10	.00
		Fdis	.75	.06	.65	.23	.72	.03	1.08	.11

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

** denotes definite balance difficulties as identified by the TBS in the MABC (< 5th % ile).

Table I5

Participant 5's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
16	6*	AP sway	.37	.09	.30	.05	1.58	.09	1.45	.07
		Ao	.09	.05	.19	.03	1.02	.26	.78	.12
		L	4.22	.41	5.00	.55	7.95	.60	7.97	.50
		Pp	38.45	5.54	26.37	3.07	18.24	7.97	29.23	4.87
		Fmode	.10	.00	.10	.00	.10	.00	.10	.00
		Fdis	.61	.08	.50	.09	.70	.34	.64	.10

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

* denotes at risk of balance difficulties as identified by the TBS in the MABC (5th – 15th %ile).

Table I6

Participant 6's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

Participant 6-DCD			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
14.5	4.5	AP sway	.33	.13	.33	.14	1.58	.01	1.63	.14
		Ao	.05	.04	.05	.01	1.06	.27	1.01	.63
		L	4.30	.34	4.64	.14	10.06	.68	11.81	.73
		Pp	31.94	9.47	11.92	3.69	15.32	4.24	51.21	2.21
		Fmode	.10	.00	.13	.06	.10	.00	.10	.00
		Fdis	.62	.06	.71	.30	1.88	2.08	.56	.04

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I7

Participant 7's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

Participant 7-DCD			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
19.5	1.5	AP sway	.19	.02	.22	.03	.83	.14	.78	.11
		Ao	.03	.02	.04	.01	.34	.07	.23	.11
		L	4.41	.43	4.78	.33	6.24	.53	6.00	.34
		Pp	2.41	1.16	2.02	.44	1.64	.96	3.85	1.96
		Fmode	.10	.00	.20	.00	.20	.00	.10	.00
		Fdis	.76	.06	.73	.34	.78	.26	.70	.06

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I8

Participant 8's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
16	5	AP sway	.36	.04	.33	.02	1.70	.04	1.57	.12
		Ao	.05	.03	.07	.02	.73	.30	.48	.10
		L	2.85	.32	3.05	.18	6.26	.55	7.29	1.17
		Pp	1.15	.98	11.02	4.46	5.00	1.95	4.33	4.74
		Fmode	.13	.06	.16	.06	.13	.06	.10	.00
		Fdis	1.05	.37	.66	.35	.44	.08	.58	.02

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I9

Participant 9's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
12.5	0.5	AP sway	.08	.06	.19	.03	.68	.71	1.59	.11
		Ao	.01	.01	.02	.01	.22	.34	.88	.22
		L	2.31	1.42	4.38	.09	4.20	3.50	9.61	1.45
		Pp	222.95	312.67	21.97	1.46	209.50	329.56	409.64	314.45
		Fmode	.10	.00	.10	.00	.10	.00	.10	.00
		Fdis	.58	.01	.83	.06	.68	.12	.58	.02

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I10

Participant 10's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
11.5	3	AP sway	.33	.16	.58	.17	1.67	.24	1.59	.16
		Ao	.07	.05	.12	.04	.91	.22	.95	.14
		L	3.70	.40	3.87	.37	7.39	1.06	6.00	1.21
		Pp	15.21	2.97	9.96	1.38	7.49	2.74	15.00	1.97
		Fmode	.10	.00	.13	.06	.16	.06	.10	.00
		Fdis	.64	.03	1.06	.07	.78	.17	.60	.05

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I11

Participant 11's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
2.5	1	AP sway	.11	.01	.15	.05	1.28	.09	1.37	.06
		Ao	.01	.00	.01	.01	.23	.08	.40	.15
		L	3.17	.03	3.22	.11	5.22	.42	6.49	.52
		Pp	.16	.05	5.17	2.55	5.10	.94	2.23	.77
		Fmode	.13	.06	.20	.00	.23	.06	.10	.00
		Fdis	1.14	.30	.63	.06	.66	.41	.69	.04

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I12

Participant 12's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
6	0	AP sway	.14	.03	.12	.03	1.35	.14	1.35	.10
		Ao	.01	.01	.01	.00	.45	.00	.72	.20
		L	3.07	.18	3.11	.07	5.64	.69	5.83	.53
		Pp	3.71	.36	13.50	3.02	20.25	8.25	1.96	.57
		Fmode	.10	.00	.10	.00	.10	.00	.10	.00
		Fdis	.66	.03	.47	.07	.65	.09	.57	.02

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I13

Participant 13's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
0	0	AP sway	.21	.07	.22	.01	1.56	.12	1.30	.20
		Ao	.03	.01	.02	.01	.50	.10	.28	.11
		L	4.68	.11	4.44	.05	7.89	.62	7.80	.91
		Pp	9.08	.17	9.83	1.93	8.08	5.39	11.86	2.03
		Fmode	.10	.00	.20	.00	.23	.06	.10	.00
		Fdis	.59	.04	.71	.20	.94	.13	.59	.03

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I14

Participant 14's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1.5	1.5	AP sway	.21	.05	.54	.20	1.94	.05	1.83	.07
		Ao	.03	.01	.09	.03	1.08	.09	.61	.20
		L	6.10	.17	6.21	.58	9.22	1.55	9.01	.09
		Pp	2.38	1.68	15.17	7.30	13.16	.85	10.29	5.71
		Fmode	.13	.06	.20	.00	.23	.06	.10	.00
		Fdis	.74	.07	.91	.13	.91	.12	.59	.09

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I15

Participant 15's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
3	0	AP sway	.36	.27	.29	.12	1.72	.12	1.54	.08
		Ao	.05	.03	.03	.02	1.00	.36	.54	.29
		L	3.72	.32	3.36	.21	7.02	.78	6.34	.69
		Pp	3.00	.36	12.05	4.38	5.90	1.35	2.10	1.62
		Fmode	.10	.00	.20	.00	.23	.06	.10	.00
		Fdis	.51	.12	.43	.28	.66	.40	.81	.24

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I16

Participant 16's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	0	AP sway	.31	.04	.50	.09	1.58	.09	1.40	.08
		Ao	.04	.01	.09	.02	.88	.24	.84	.22
		L	4.06	.51	5.25	.50	7.51	.49	8.54	.97
		Pp	7.14	1.74	44.55	23.84	25.67	9.92	9.05	7.88
		Fmode	.10	.00	.10	.00	.10	.05	.10	.00
		Fdis	.68	.10	.52	.14	.60	.48	.66	.17

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I17

Participant 17's Means Score (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
5.5	0.5	AP sway	.20	.03	.20	.04	1.46	.22	1.62	.12
		Ao	.02	.01	.04	.01	.70	.38	.79	.28
		L	3.74	.21	4.10	.09	6.94	1.24	7.71	.63
		Pp	44.86	.25	27.47	1.16	29.82	6.44	54.93	4.08
		Fmode	.10	.00	.10	.00	.10	.05	.10	.00
		Fdis	.64	.03	.49	.00	.67	.16	.58	.02

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I18

Participant 18's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
2	0	AP sway	.12	.01	.16	.03	1.79	.05	1.84	.02
		Ao	.00	.00	.01	.00	.99	.29	.99	.18
		L	4.47	.34	4.51	.09	8.66	.80	9.03	.56
		Pp	6.45	.76	13.23	3.83	15.72	1.45	7.88	3.67
		Fmode	.10	.00	.20	.00	.20	.00	.10	.00
		Fdis	.70	.12	.57	.17	.71	.34	.63	.02

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I19

Participant 19's Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
6.5	0.5	AP sway	.15	.04	.22	.05	1.60	.13	1.50	.12
		Ao	.01	.01	.05	.03	1.11	.21	.51	.19
		L	3.95	.07	4.68	.43	9.92	.24	6.84	.21
		Pp	15.21	2.97	9.96	1.38	7.49	2.74	8.71	.92
		Fmode	.10	.00	.13	.06	.16	.06	.20	.00
		Fdis	.57	.03	1.06	.07	.78	.17	.66	.16

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.

Table I20

Participant 20's Individual Profile for Mean Scores (M) and Variability (SD) For Two Balance Tasks and Attentional Conditions.

			Static Balance Control				Postural Adaptations			
TIS	TBS	Variable	No Attention		Attention		No Attention		Attention	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	0	AP sway	.45	.46	.21	.06	1.48	.18	1.10	.25
		Ao	.01	.00	.03	.01	1.07	.52	.24	.04
		L	4.25	.03	4.70	.34	9.19	1.00	6.08	.30
		Pp	3.63	1.94	11.73	3.36	15.00	1.97	4.79	2.64
		Fmode	.10	.00	.20	.00	.10	.00	.10	.00
		Fdis	.65	.05	.73	.43	.60	.05	.67	.14

Note: TIS = total impairment score; TBS = total balance score; AP sway = anterior posterior sway; A_o = area of sway; L = path length; Pp = peak power; f_{mode} = frequency mode; f_{sd} = frequency dispersion.