THE COMPARISON OF BALANCE PERFORMANCE BETWEEN BOYS WITH AND WITHOUT DEVELOPMENTAL COORDINATION DISORDER

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ABSTRACT

The purpose of the present study was to investigate the performance of 6 to 13 year old boys with and without Developmental Coordination Disorder (DCD) on two balance tasks: balance space and quiet standing. The participants were 40 boys, assigned to either a control or an experimental group, based on initial screening by teachers with the Motor Behavior Checklist, and subsequent testing conducted at Lakehead University School of Kinesiology Motor Development Clinic using the Movement ABC (MABC). Final group assignment was based on the MABC Total Impairment Score and Total Balance Score. Boys were tested in a subsequent session in 20 second trials using an AMTI force plate with the sampling frequency set at 100 Hz, gain at 4000x, 5x, and electronic filter at 10.5 Hz using the CAS stability Program to measure the following dependent measures: anterior-posterior sway, lateral sway, path length and area of sway. The study incorporated a 2 (age) x 2 (condition) completely randomized factorial design. The data analysis incorporated MANOVA, factorial ANOVA, planned comparisons and Pearson correlations, with the significance level at alpha level $p < .05$. The results of the study indicated that boys without DCD and balance difficulties were more effective in the balance space task than boys with DCD and balance difficulties. There was no difference between the groups in the quiet standing tasks. Developmentally, older boys performed much better than the younger boys. A significant interaction effect based on balance space indicated that the older boys from the control group perceived their tolerance region significantly better than any other group ($F(4,32) = 3.27$, $p < .05$). It was postulated that: older boys with DCD exhibited anticipatory postural behavior similar to those of boys with no DCD who were 2 to 3 years younger, and that this gap

in balance performance between boys with and without DCD increased with age. Further study of a longitudinal nature is required to confirm this hypothesis. Although the balance space task proved to be more sensitive to differences in balance performance, participants exhibited a similar pattern of behavior in both tasks. More skilled balancers scored high on balance space tasks and low on quiet standing tasks, while the reverse behavior was evident in the performance of less skilled balancers. It appears that the quality of feedforward balance responses relates to the quality of feedback based mechanisms as control children who experienced balance difficulties related to voluntary balance mechanisms also experienced difficulties with involuntary balance control. In terms of balance control and vision, children with DCD performed significantly poorer than the control group with eyes open but not with eyes closed. It was postulated that the absence of visual input may be a facilitating factor for boys who cannot effectively respond to a multisensory environment. Although further study is needed, it was concluded that the balance space task is most effective at showing condition, developmental and interaction effects, whereas the quiet standing task is more sensitive to balance control differences due to age. It was recommended that for future studies both tasks be incorporated, so that the relationship between the postural mechanisms they represent can be studied further.

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INTRODUCTION

The ability to maintain a balanced, upright posture is a fundamental part of the development of both the basic and complex skills that are acquired throughout the life span. Traditionally, the term "balance" defines a state of equilibrium maintained between opposing forces such as friction, gravity, external perturbations and body orientation (Winter, 1993). A concept closely related to balance is "postural control". According to Horak (1987), it is "the ability to maintain equilibrium in a gravitational field by keeping or returning the center of the body mass over its base of support" (p.1881).

Although, balance had been perceived for years as discrete skill which prevented the body from falling, in recent decades, balance has been viewed as a continuously developing state. This state is a complex process that is task specific and alters according to the conditions of the environment and the characteristics of the "self" (Burton & Davis, 1992).

The development of postural stability is affected by various reflex mechanisms, as well as, complex central psychomotor processes. These processes include the development of somatosensory, visual and vestibular systems, neuromuscular responses, muscle strength and adaptive mechanisms that an individual would use to coordinate the information received from the environment and within the body system (Woollacott & Shumway-Cook, 1996). According to various models of development, balance control is acquired as an individual is maturing, starting from birth and lasting to or through adulthood. From this perspective, a person goes through developmental stages during which various motor milestones are achieved. Any delays or early impairment present during these stages may postpone or even prevent the development of adequate postural control mechanisms (Assaiante & Amblard, 1995). The rate and the quality of balance control development is related to age, gender, physical characteristics (height, weight, size of base of support), and ability to process sensory-perceptual information (Odenric & Sandsted, 1984; Usai, Maekawa & Hirasawa, 1995; Woollacott & Shumway-Cook, 1996).

The ability to control balance may become an issue when irregular development of major neuromuscular, physiological, cognitive and perceptual processes occurs. Numerous investigations have confirmed that there is a relationship between certain motor deficiencies and lack of postural stability in children. Children with Developmental Coordination Disorder (DCD), constitute one of the groups who are characterized by delays in various segments of their fine and gross motor repertoire (Geuze & Borger, 1987; Geuze, 1995; Willoughby & Polatajko, 1994). Children with DCD, also known as children with "clumsiness", exhibit movement coordination problems without any major neurological dysfunction and with normal intelligence (American Psychiatric Association, 1994). The balance control problems they experience are associated with slow information processing, and subsequent problems in timing, accuracy and response selection, as well as problems related to proprioception and kinaesthetic awareness (Geuze & Borger, 1993; Geuze & Kalverboer, 1994; Piek & Coleman-Carman, 1995).

Children with DCD have been the target of many investigations and reviews related to their motor problems (Geuze & Kalverboer, 1987; Geuze & Borger, 1993; Piek & Coleman-Carman, 1995; Taylor, 1984; Van Dallen & Geuze, 1988; Wall & Taylor, 1984 ;Wilson & McKenzie, 1998; Willoughby & Polatajko, 1995). However, there is a limited number of investigations which relate to balance control and this specific population (Mon-Williams, Wann & Pascal, 1994). Also, the studies that have investigated balance performance have usually been constrained to very static tasks and subsequently the results describe the outcomes of the performance, rather than the process (Blaszczyk, Hansen & Lowe, 1993; Slobounov, Slobounov & Newell, 1997).

Statement of the Problem

The primary purpose of this study was to investigate the differences in balance performance between children with Developmental Coordination Disorder (DCD) and balance difficulties and children with no DCD or balance difficulties. Developmental differences between groups were also analyzed.

The study also investigated the performance of skilled and unskilled balancers within the balance space and quiet standing tasks and the ability of each task to successfully distinguish between the different skill levels.

Lastly, performances with eyes open and closed, and in the sagittal and lateral planes were compared.

Definitions

Balance control: a controlled and flexible process related to the use of all of the forces acting on the body to achieve the intended outcome of a particular functional task to maintain balance (Winter, 1993, p.135).

Developmental Coordination Disorder: delay in motor development (a lack of adequate motor skills), in the absence of clear neurological impairment, in people with normal intelligence (DSM 4-R) (American Psychiatric Association, 1994).

Center of Mass (COM): a point equivalent of the total body mass in the global reference system. It is the weighted average of the COM of each body segment in three dimensional space. The vertical projection of the COM onto the ground is called Center of Gravity (Winter, 1993, p. 135).

Center of Pressure (COP): a point location of the vertical ground reaction force vector. COP represents a weighted average of all of the pressures over the surface of the area in contact with the ground. It is totally independent of COM (Winter, 1993, p.135).

Quiet Standing: an orientation of the body in which the body attempts to maintain maximum, possible equilibrium in reaction to internally generated forces (Usai et al., 1995, p. 987).

Balance space: perceptually created space reflecting awareness of the amount of sway a person can generate without falling (Slobounov et al., 1997, p.264).

Stability boundary: space area restricted by the contour based on the size of the base of support. The boundary which defines the maximum, possible displacement of COM and COP, without the system losing balance (Slobounov et al., 1997, p.265).

Sway: a constant, small corrective deviation from the vertical orientation, when standing upright (Odenric & Sandsted, 1984, p.244).

Anterior - posterior sway (AP): a motion of the body in which the COM and COP are displaced forward and backwards. This displacement is dependent on the forces generated by the plantar and dorsi flexor of the ankle joint (Winter, 1993, p.137).

Lateral sway (LAT): a motion of the body in which the COM and COP are displaced laterally from the vertical projection of the body. This displacement is dependent on the forces generated by the "load-unload" mechanisms (Winter, 1993, p.137).

COP path length (L) : total amount of COP displacement caused by body sway, expressed in centimeters (cm) (Jeong, 1994, p.1276a).

COP area of sway (Ao) : measurement of sway which defines the shape and size of the area created by the displacement of COP during sway in different directions, expressed in centimeters squared (cm^2) (Usai et al., 1995, p.987).

Movement ABC: an assessment tool used for screening and assessment of the motor performance of children who are perceived and diagnosed as exhibiting delays in fine and gross motor skills (Wright & Sugden, 1996, p.3).

Delimitations

The participants were divided into experimental and control group based on initial screening by teachers with the Motor Behavior Checklist (Lefebvre & Reid, 1998; Weir, 1992), and subsequent motor skill assessment using the Movement ABC Assessment Tool (Henderson & Sugden, 1992). Final group assignment was based on scores obtained from two sections of the Movement ABC, Total Impairment Score (TIS), which measures overall motor skill abilities, and Total Balance Score (TBS), which quantifies balance control.

The MABC has been used successfully in a number of investigations for screening children with DCD (Ng & Tan, 1995; Smyth & Mason, 1997; Sugden & Sugden, 1990; Wright & Sugden, 1993; Wright & Sugden, 1996). The MABC was particularly useful in the present study, because it contained static and dynamic balance tasks, the two types of tasks that were used in this study (Burton & Miller, 1998; Henderson & Sugden, 1992).

Limitations

One limitation to this study may be that younger children or those with DCD, may have difficulties completing some of the more demanding tasks (i.e. one leg standing, eyes open and closed). In addition to age and motor problems, the study may be limited by the participants' lack of experience or fear of falling in the balance space task.

Hypotheses

1. There will be a significant difference in balance performance between the control group and children with DCD. The "better balancers" will have a higher score on the balance space task and a lower score in the quiet standing task.
2. There will be significant developmental differences on each task, within each group.
3. There will be a significant interaction effect based on age and condition between the groups, as children with DCD will execute task-appropriate balance responses less effectively than their

age matched peers with no DCD. Also, the pattern of postural behavior of older children with DCD will be similar to that exhibited by younger controls.

4. There will be a negative relationship between the balance space scores and quiet standing scores.

5. Swaying in the AP direction will be greater than Lat sway, especially in the balance space task.

6. Performing with eyes open will result in better controlled balance performance than performing with eyes closed.

REVIEW OF LITERATURE

Models of Development

The development of postural control has been associated with gradual maturational changes occurring within the human body. The sequence of developmental events leading to the acquisition of independent stance follows a general pattern that starts at the moment when the infant sits independently (5 months), pulls itself to stand (12 months), stands with help (8 months), and at last stands alone at 14 months. This general and very simplified sequence of events is underlined by a number of neural, biomechanical and psychomotor transitions, which could be described in terms of two approaches: the reflex-hierarchical model, and the systems model (Shumway-Cook & Woollacott, 1995).

The Reflex - Hierarchical Model

One of the first models attempting to organize and depict the patterns of development was the reflex-hierarchical model. This approach viewed motor development as a series of transitions from simple and basic reflexes to voluntary control as the system matured. In balance development, the emergence of independent stance is seen as dependent on the maturation of sequentially higher levels of the Central Nervous System (CNS), where the higher levels of behavior modify and take the place of the lower controlling factors of developmental behavior within the CNS (Woollacott & Shumway-Cook, 1990). Equilibrium reactions, which are hypothesized to be controlled by the highest level of CNS, the cortex, develop through the inhibition of more primitive reflexes by the cerebral cortical pathways, or through reflexes that become the substrate for voluntary actions. The model predicts that prior to attaining the next developmental milestone, equilibrium reactions must mature in the previous milestone. Thus, before children learn to stand, they need to learn how to sit (Shumway-Cook & Woollacott, 1995). The model predicts that the crucial time line for balance control mechanisms to develop is around 7 or 8 months of age when tilting fixations of the body through independent sitting to independent standing occurs (Woollacott et al., 1987).

This model has been considered for many years as an important guide to the process of motor development. However, it fails to show the flexibility and adaptability of balance control systems in different environmental constraints, and as a result its application in the process of investigating balance control mechanisms is limited.

Dynamic System Theory of Development.

The systems approach, on the other hand, emphasizes a goal-directed neural organization of multiple, interacting systems, and it stresses the importance of retroactive and proactive mechanisms of balance control (Hoare, Henry & Shumway-Cook, 1997). Furthermore, this theory does not deny the importance of postural reflexes, but considers them as only one of the many contributing elements to the development and control of posture and movement. As a result, and in view of above considerations, postural control is not a skill or a state of the body, but rather an aspect of a particular action involving a variety of processes that allow the body to stay in equilibrium when faced with a functional task, which may vary as does the surrounding environment (Burton & Davis, 1992)

This approach depicts the process of balance development with respect to the following factors: a) biomechanical; b) motor coordination (strategies and synergies); and c) sensory systems (vestibular, visual and somatosensory) (Westcott, Pax Lowes & Richardson, 1997).

Although the present model describes development sequentially from the emerging head control period, to independent sitting to independent stance, for the purpose of this study only the last developmental stage will be considered, independent standing (Shumway-Cook & Woollacott, 1995).

A successful transition from sitting to standing is a crucial developmental milestone in the evolution of balance control mechanisms. This transition is an enormous task for the body system, and requires a number of effective adjustments. As the child explores the surrounding environment, he/she is faced with different balance tasks that require coordination and integration of various sensory and biomechanical factors. At this point in development, balance mechanisms have to compensate for physical constraints such as a decreasing base of support (from crawling to standing), higher COM location, and changing body morphology (longer limbs) (Assaiante & Amblard, 1995; Burton & Davis, 1992), all of which influence the quality of balance control.

Biomechanical factors

Biomechanical constraints affect selection and quality of movement strategies used for balance. From the developmental stand point, an effective control of force output, muscular strength, and range of motion (ROM) are all required for quality of balance control development (Hoare et al., 1997; Shumway-Cook & Woollacott, 1995; Westcott et al., 1997).

Maintaining stability based on these basic biomechanical relationships often requires controlled, subtle and sustained adjustments rather than maximal outbursts of muscular activity. Modifying forces appropriate to the speed and amplitude of body sway is a critical aspect of effective automatic postural control and it is called scaling (Horak et al., 1997). Assuming, that the body's equilibrium system attempts to maximize the efficiency of postural control, by using the minimum energy expenditure necessary to activate a control strategy, scaling is a strategy that matches the system's actions to the goals of perception and action (Riccio & Stoffregen, 1988). Although, the exact timing for the development of this important neurological function in children is unknown, it could be postulated that its effectiveness would be reached around the age of 8- 10, when adult-like postural control emerges (Shumway-Cook & Woollacott, 1995).

Another biomechanical factor that affects balance control as a child grows is range of motion (ROM) (Sherrill, 1998). Although the theoretically adequate ROM for certain movements is unknown, nevertheless it is crucial to investigate it since adequate ROM is necessary to optimize the pull of gravity, which affects balance (Prat, 1991). Decreased ROM changes the line of the pull of gravity, which usually lies behind the hip joint and in front of the knee and ankle joints. This alignment allows the body to use ligamentous and bony structures to provide stability, rather than by using excessive muscle activity (Van der Linden, 1992). It has been found that limited ROM at the ankles, due to the shortening of the gastrocnemius and soleus muscles, often limits the ability to generate forces against the surface to control COM displacement while standing (Horak et al., 1997).

Motor Coordination.

The age-dependent development of biomechanical factors discussed in the previous section relates to the ability of the muscular system to counteract postural perturbations. Research has shown that postural stability is insured through the coordination of multiple muscles organized into schematic units called sway synergies (Ganchev & Draganova, 1986; Kuo & Zajac, 1993; Shumway-Cook & Woollacott, 1985; Williams, Fisher & Tritschler, 1985).

These synergies are characterized by specific amplitude, timing and ordering of muscle activity, factors that may be further organized in terms of two main balance control strategies: a) ankle strategy, and b) hip strategy (Allum & Honegger, 1993; Burton & Davis, 1992; Horak & Nashner, 1986; Kuo & Zajac, 1993; McCollum & Leen, 1989; Riccio & Stoffregen, 1988; Winter, 1995).

The organized muscular responses have been already found in infants as early as at 7 to 9 months, as they attempt to coordinate legs and trunk in order to obtain and retain bipedal stance. By this time, these responses are organized in an ascending direction, with synergies involving ankle muscles appearing first, and followed by thigh and trunk muscles (Keshner, 1990; Shumway-Cook & Woollacott, 1995). Even though, these muscular responses may be consistently organized by 15 months of age, they are characterized by slower response time, longer latencies and durations than the responses of adults. Although children between age 1.5 and 3 are already able to produce well organized muscular responses, it is not till the age of 8 to 10 that adult-like levels are reached (Shumway-Cook & Woollacott, 1985; Woollacott, Debu & Mowatt, 1987).

As the muscular synergies develop, they are coordinated into balance control strategies as units such as the hip or ankle strategy. The type of strategy and synergy used in a specific balance control task depends on the initial body position, initial support condition, type of perturbation and characteristics and location of sensory stimuli triggering the response (Woollacott & Shumway-Cook, 1990). When incorporated, these synergies and strategies are chosen as to minimize the number of muscles activated in order to maximize the force input used in a response (Kuo & Zajac, 1993).

Developmentally, the ankle strategy appears earlier in life than the hip strategy, and it is the main tool for maintaining equilibrium till the age of 3 or 4. This strategy is mainly used in response to small perturbations, which are mostly encountered as the child becomes more ambulatory. The hip strategy, which is believed to be chosen to respond to quick, large perturbations, becomes a part of the balance control repertoire around the age of 4. However, the maturation of both strategies does not occur until later in childhood, when both strategies may be combined in order to respond to one, specific perturbation (Hass et al., 1986; Horak et al, 1990; McCollum & Leen, 1989; Kuo & Zajac, 1993; Woollacott et al., 1998). It has been hypothesized that the reason young children (1 years of age) are unable to activate hip strategies is because of the short time constant for the release of the response (about 114 milliseconds). On the other hand, the ankle strategy allows more time for the child to elicit the response (about 333 milliseconds), as a result it has been suggested that hip strategies become efficient only by the age of 3 or 4 (McCollum & Leen 1989).

Sensory Contribution.

From the dynamic view point, balance control is based on the sensory-motor mechanism that operates as a closed loop system. In this view, the biomechanical system is adjusted and accordingly activated based on information that is processed and released from the sensory system (Collins & De Luca, 1995). This information may come from single or multiple sources depending on a persons' age and developmental stage (Lee & Aronson, 1974). The information conveyed from these sources is the basis for the sensory organization which describes the processes that determine timing, direction and amplitude of corrective postural responses (Ribadi, Rider & Toole, 1987).

Information for controlling balance is provided primarily through the visual, tactile and vestibular systems, and through Golgi tendon organs, muscle spindles, and joint receptors. Whereas, the latter three types of receptors provide only proprioceptive information and the vestibular system provides only information from the outside, the visual and tactile receptors can provide both (Burton & Davis, 1992).

Visual system.

As the child goes through the initial stages of transition from sitting to bipedal stance, balance control mechanisms are based primarily on visual input (Butterwoth & Hicks, 1977; Forssberg & Nashner, 1982; Lee & Aronson, 1974). Studies on babies and children have indicated that visual, particularly peripheral cues, play a prominent role in the elaboration and control of static postural stability (Amblard & Carblanc, 1980; Ashmead & McCarty, 1992; Butterworth & Hicks, 1997; Jouen, 1984). The dominance of visual input for balance control lasts until about the age of 4-5. Consequently, there is a linear negative relationship between the role of peripheral and central visual input and age, as with time children start to incorporate other sensory sources for balance control purposes (Stoffregen et al., 1987). Nevertheless, it has been suggested that during this period children are able to absorb information from all three systems, but vision plays a major role in the calibration of proprioception and more sophisticated sensory mechanisms (Wann, Mon-Williams & Rushton, 1998).

In terms of research concerning balance control and visual input it has been established that detection of optical flow (the changing optic array on the retina) is an integral component of the postural control system for both, children and adults (Lee & Lishman, 1975). Since children between 18 months and 3-4 years of age predominantly depend on visual information to maintain balance, they are much more vulnerable to its disruption than older children or adults (Burton & Davis, 1992). Children who were faced with incomplete, inaccurate or missing visual information performed much poorer on balance tasks than when vision was available (Butterworth & Hicks, 1977; Butterworth & Cicchetti, 1978; Clark & Watkins, 1984; Forssberg & Nashner, 1982; Lee & Aronson, 1974; Odenric & Sandstedt, 1984; Riach & Hayes, 1987; Wann et al., 1988; Wolff, Rose, Jones, Bloch, Oehlert & Gamble et, 1998). Also, adults have been found to evoke compensatory postural responses when vision was limited or disturbed (Lee & Lishman, 1975, 1977; Lestienne, Soechting & Berthoz, 1977; Ring, Nayak & Isaacs, 1989). However, the effect of lack of visual input was not as pronounced in adults than in children, at least not till late adulthood (Hytonen, Pyykko, Aalto & Starck, 1993; Hu, Hung, Huang, Peng & Shen, 1996; Ring et al., 1989).

Vestibular system.

The predominance of visual control of balance gives way to vestibular-somatosensory dependence by the age of 3-4. Although the transition to adult-like balance responses is not complete even by the age of 6, during this period of development children are already able to effectively use all the sensory inputs available (Foudriat, Di Fabio & Anderson, 1993). As the responses to balance perturbations become more sophisticated, there is a significant improvement in the child's ability to control head stabilization. Assaiante and Amblard (1995), suggested that the information specifying the head position relative to the supporting surface becomes progressively more available to the equilibrium control centers due to the transient predominance of the dynamic vestibular contribution to balance control at 7 years of age. In addition, the vestibular system provides the orientational reference against which conflicts in somatosensory and visual information are quickly identified (Nashner, Black & Wall, 1982). Furthermore, the vestibular system is considered to have a direct relation to the development of appropriate balance control, as it serves to control the awareness of body position and movement in space, postural control and head stabilization (Fisher, Murray & Bundy, 1991). It has also been reported that enrichment of the vestibular contribution may be the prelude to the future alternating responses in relation to the environmental conditions presented to the balance system (Woollacott & Shumway-Cook, 1996)

Somatosensory system.

The somatosensory system is considered to include tactile, muscle, joint and tendon receptors and provides information about the movements and position of body parts incorporated in a given movement. This system is believed to be most useful when body position is well practiced, and the surface is stable (Burton & Davis, 1992). The importance of this system increases with age, starting at about the age of 7 or 8. Somatosensory receptors are especially important when balance control strategies are generated at the ankles in anterior-posterior and lateral sway, and these proprioreceptors have been found to be more sensitive to higher sway frequencies than other perceptual systems (Burton & Davis, 1992). The somatosensory system is considered to be more sophisticated than the two others, and is acquired later in the childhood. The removal of this type of information may be detrimental to balance performance as balance control mechanisms are not flexible enough to be able to execute postural responses on only visual or vestibular sensory inputs (Shumway-Cook & Woollacott, 1995; Willoughby & Polatajko, 1994).

Conclusion

It is widely assumed that there is a steady age-related improvement in balance control. However, as a child's balancing repertoire becomes more and more sophisticated and complex, at the age of 5-6, there is a noticeable regression in terms of the ability to respond effectively to balance perturbations (Shumway-Cook & Woollacott, 1985; Woollacott & Shumway-Cook, 1990).

The developmental pattern is characterized by a consistent improvement till the age of 3, during which time the responses become progressively more effective. However, between the ages of 4 and 6, there is an abrupt decline in balance system efficiency. As responses become more variable and slower, the amplitudes are bigger and latencies are longer. This regression in development is due to the fact that children go through a number of physiological, sensory and morphological developments that affect the input and output processes involved in balance control mechanisms (Shumway-Cook & Woollacott, 1990). At this point in development, till about the age of 7 to 9, when adult-like responses are consistently generated, balance ability is inferior to both younger and older children (Riach & Hayes, 1987).

Developmental Coordination Disorder and its characteristics

Many children who are considered able bodied individuals have movement difficulties severe enough to affect perception, social interaction, and development of adequate, age appropriate skill and consequent involvement in physical activities. The nature of their behaviors has been expressed by different terms over the years. Motor awkwardness, dyspraxia, perceptuomotor dysfunction, and movement difficulties are some of the synonyms describing this population (Missiuna & Polatajko, 1994; Wright & Sugden, 1995). Recently this group of children has been classified by the Diagnostic and Statistical Manual (DSM-4) as having Developmental Coordination Disorder (American Psychiatric Association, 1994).

Children with DCD may be described as children without known neuromuscular problems, who fail to perform culturally-normative motor skills with acceptable proficiency (Wall & Taylor, 1984), and in the absence of general sensory and intellectual impairment, without showing signs of overt neurological damage (Missiuna & Polatajko, 1994). They are also characterized by delayed or abnormal development of muscular, nervous or skeletal systems; genetically imposed body size and motor coordination limitations; problems related to proper use of space, equipment and surface; and inability to follow rules and instructions (Piek & Coleman-Carman, 1995).

Children with DCD and motor problems.

Children with DCD constitute about 10 to 15% of the total school population in North America (Wright & Sugden, 1996). From the physical activity stand point, they exhibit problems in learning and performing various motor activities that incorporate balance, bilateral coordination, agility, and ball handling. It has been postulated that children with DCD may experience a variety of fine or gross motor problems that prevent them from performing tasks at an age-appropriate level (Piek & Coleman-Carman, 1995). The heterogeneity of this population has been addressed in studies that attempted to map their performance patterns in a variety of situations (Hoare, 1994; Wright & Sugden, 1996). In regard to balance, Wann and colleagues (1998), studied balance performance of children with and without DCD. They underlined the fact that the DCD population is very heterogenous, as not all the children with DCD experience the same degree of balance problems. In their study, children who were identified as having

DCD, but scored borderline on the balance tasks, did not differ significantly from matched controls in terms of balance performance. As a result, it was concluded that having DCD may not indicate automatically that balance problems are present in one's motor repertoire. However, other studies emphasized the connection between the DCD condition and resulting balance difficulties.

Wright and Sugden (1996), using the Movement ABC assessment tool, described four performance profiles of children with DCD. These clusters were described in terms of their responses to changing environments, by hand coordination, catching, control of self, and dynamic balance, which was considered as one of the most important skills. The inclusion of changing environment and control of self relates to the child's inability to perform open, unpredictable skills. The "control of self" task refers to a similar ecological approach, which is based on the assumption that each task requires different adjustments of the child's motor repertoire segments (Sherrill, 1998). The four profiles were described in terms of how many children exhibited similar patterns of behavior. Overall, the results of cluster analysis showed that three out of four groups performed poorly on balance tasks, making balance a most frequent reoccurring factor among all children. A similar attempt to map performance characteristics was proposed by Hoare (1994). Her analysis of DCD subtypes was based on six skills: kinesthetic acuity (ability of a child to detect and appropriately use the information about static posture and superimposed movements of the body (Piek & Coleman-Carman, 1995); visual-perceptual ability; visual-motor integration; dexterity; fitness and static balance. Among five clusters established by analysis, balance was found once again to be at or below average in four of them.

Overall, two facts should be concluded: a) for research purposes and the sample selection process, children with DCD should be carefully assessed based on their overall skill level, as well as on the specific motor subdivisions of their motor behavior; and b) the fact remains that a large number of children with DCD do experience balance problems no matter what other motor behaviors are exhibited in their motor repertoire.

Children with DCD and cognitive and behavioral problems.

The inability to perform culturally-normative skills, ultimately affects behavior, social skills and school performance. It has also been postulated that these motor deficiencies negatively affect the learning process, causing school failure and psychological problems as the child is distancing him/herself from his peers (Missiuna, 1994). As Taylor (1984), noted, the performance inadequacies of awkward children are noticed by peers, and humiliation and rejection is often the result. Subsequently, these children have problems making friends, and they may lose self confidence to the extent that they will not participate in activities, which they are capable of doing. Ultimately, minimal enjoyment of physical activity and related social difficulties may combine to create a disinterest in physical activity causing the fitness and skill level to further diminish (Causgrove- Dunn & Watkinson, 1994). As children with DCD grow older, the lack of skill, limited opportunity and interest form a "vicious circle", where complete withdrawal from physical activity may result (Wall & Taylor, 1984)

Children with DCD and sources of difficulties.

The disorder has often been associated with a number or combination of deficits related to perceptual, motor control, and cognitive processes. The term perceptual is used to describe the processes by which sensory information is registered, integrated and interpreted so as to be rendered meaningful, in the early stages of information processing (Wilson & McKenzie, 1998). With respect to perceptual processing the deficits include visuospatial perception and perceptual motor function (Hulme, Biggerstaff, Moran & Hufschmidt, 1982 a; Hulme, Smart & Moran, 1982 b; Lord & Hulme,1988); kinaesthetic function (the perception of limb movement and position) (Bairstow & Laszlo, 1981, 1989; Laszlo et al., 1988); and cross modal perception (inability to integrate vestibular, proprioceptive and tactile information resulting in poor movement planning (Newnham & McKenzie, 1993; Wilson & McKenzie, 1998). Motor control deficits, on the other hand, include response selection (van Dallen & Geuze, 1988; 1990) and motor programming (Smyth, 1991), which are part of the general information processing schema. Lastly, cognitive difficulties which cause faulty "knowledge interpretation" may pertain to apraxia, agnosia and ataxia, terms which respectively refer to faulty movement planning, inability to make sense of sensory input, and no understanding of what needs to be done or planned to counteract a movement that jeopardizes stability (Wall & Taylor, 1982).

In addition, children with DCD may experience lack of accuracy of goal directed movements, inability to incorporate visual and vestibular feedback and feedforward mechanisms, slow processing speed (Smyth & Glencross, 1986; van Dallen & Geuze, 1988, 1990) as well as inability to perform everyday tasks like tying laces, buttoning or drawing (Geuze & Borger, 1993).

In terms of physical, neurophysiological and sensory development, some researchers have postulated that the delays are related to the pathological nature of the development of reflexes (Sherrill, 1998). Whereas others, insist that the source of the problems originates within the sensory system in relation to the conditions known as apraxia, agnosia and ataxia (Sugden &

Sugden, 1991). These problems have been further divided into uni- and multi- sensory deficiencies (Willoughby & Polatajko, 1994).

One approach taken by researchers to explain the source of mentioned motor deficiencies is based on the argument that the integration of reflexes, does not function appropriately. Reflexes that are not integrated at the developmentally appropriate time become pathological, in that voluntary shifts of muscle tone interfere with smooth, coordinated movement. In other words these neurological dysfunctions within the CNS may occur when reflexes are preserved beyond the age at which they should be terminated, are completely absent, are developed unilaterally, or are too strong or too weak (Westcott et al., 1997). The resulting less than optimal neurological status often leads to larger response inconsistency from one balance task to the next. Inconsistency implies that reproducibility and precise timing of movements is poor (Geuze & Kalverboer, 1987). There is also a lack of appropriate adaptation to environmental task demands which become more complex and challenging with age.

The other postulated explanation for the existence of motor difficulties within the children with DCD is related to sensory disorders. These disorders are grouped into multi-sensory and unisensory deficits (Willoughby & Polatajko, 1995). The multi-sensory theory insists that the problems are the result of ineffective sensory integration and movement coordination. The application of appropriate balance strategies is based on information from sensory sources, and in the case of children with DCD this information inflow is conflicting instead of being complimentary (Riccio & Stoffregen, 1988). The possible redundancy of information from various sensory systems has detrimental effects on interpretation and decision making processes. This condition is called a "sensory organization deficit" and is most likely present in children with learning disabilities, DCD, ataxic cerebral palsy and Down Syndrome (Burton & Davis, 1992; Shumway-Cook, 1985). A similar condition that children with DCD often experience is related to the phenomenon called scaling. This process is based on the ability to adjust the magnitude of automatic motor responses in relation to the demands that the body encounters in different environments and in performing different tasks (Riccio & Stoffregen, 1988). The source of this condition is associated with the inadequate effectiveness of the frontal lobe of the cerebellum in the use of sensory systems to adjust the balance response (Dichgans & Diener, 1986; Horak & Diener, 1994).

Overall, the general conclusion that can be drawn from the studies quoted above, is that developmental motor coordination disorder refers to a heterogenous population with a collection of specific motor difficulties that are present in different degrees of severity (Geuze & Borger, 1993). However, balance control difficulties seem to be a reoccurring phenomenon that have a negative influence on the overall motor repertoire of children. In summary, although there are many possible sources and explanations for the existence of these problems, without a doubt, they persists till later childhood and adulthood, and they should be addressed as early as possible in development.

Developmental Coordination Disorder and balance control

Biomechanical system.

Inability of children to proficiently perform various motor tasks, balance included, may stem from biomechanical, physiological or sensory sources. Although the amount of available research is limited, children with DCD have been found to be exposed to the consequences of inappropriately functioning mechanisms that affect force output, muscular strength and ROM (Sherrill, 1998).

In this intercorrelated schema of biomechanical factors, children with neurological abnormalities have been found to exhibit limitations in the alignment and range of motion of body joints. These limitations are due to contraction of connective or muscle tissue or other related musculoskeletal deformities, which restrict the repertoire of balance control strategies (Horak et al., 1997; Shumway-Cook, 1989). Inadequate ROM, in turn, affects muscular strength which plays an important role in the process of maintaining equilibrium with respect to the demands of the environment, task and body. Lack of sufficient strength, specifically in the hamstrings, rectus femoris and gastrocnemius muscles (Kuo & Zajac,1993), may not allow children to generate responses to postural perturbations fast enough, or with sufficient torque to regain equilibrium (McCollum & Leen, 1989).

As a result of minimal strength and limited ROM, children with DCD are required to readjust their responses in order to accomplish any balancing task. The generation of these appropriately intensified contractions may not be difficult for some children, however children with neurological dysfunctions often will exhibit disproportionally small (hypometric) or large (hypermetric) responses to postural perturbations causing them to fall, take a step or lose confidence in accomplishing a given balance-related task (Horak et al., 1997).

Motor coordination.

There is a very close connection between biomechanical constraints and motor coordination, since synergies and strategies involved in balance control depend on the function of joints, muscles and tendons.

There is a limited amount of research pertaining specifically to the muscular responses of children with motor difficulties when facing various equilibrium problems. However, there are a number of studies which have investigated postural muscular responses among individuals whose balance performance is similar to performance of children with motor difficulties. Individuals with cerebral dysfunction, which affects timing and scaling of postural responses (Diener et al., 1993), and vestibular problems, which are also identified as the possible causes of sensory integration deficit in children with the DCD (Willoughby & Polatajko, 1994; Wilson & McKenzie,1998), experience postural responses that are similar to the pattern of responses exhibited by the DCD population, in terms of higher velocities, amplitude and frequency of sway (Allum & Honegger, 1993; Baloh et al., 1998; Gatev, Thomas, Lou, Lim & Hallett, 1996).

Williams et al., (1983), investigated muscular responses of children with and without motor awkwardness and concluded that both groups have different response patterns, where children who were awkward experienced greater amounts of muscular activity (hypermetric) than their able peers performing the same balance task. A similar investigation of children who were awkward and those who were not was carried out in order to explore the motor response characteristics of the two groups in quiet standing. The activity of the gastrocnemius, tibialis anterior and erector spinae indicated that children who were awkward generated longer responses in the trunk than in the leg muscles. Also, the responses in the leg muscles themselves were of longer latencies in the awkward group, indicating more instability (Williams et al., 1985). Also, in a study of children with spastic diplegia it was concluded that problems related to muscular response were related to the defective recruitment of motor units, abnormal velocity-dependent recruitment during muscle stretch, non-selective activation of antagonist muscles, and changes in passive mechanical properties of the muscle (Woollacott et al., 1998). This group of children was also found to show a reversal of the normal distal to proximal muscle response patterns and excessive co-activation of antagonist muscles in response to support surface perturbation while standing (Nashner, Shumway-Cook & Marin, 1983).

Sensory systems.

The visual system.

During stance the reduction of visual information may decrease postural control and increase body sway by 50 % (Bai, Bertenhal & Sussman, 1987). Also, the same detrimental effect on balance control may be observed when vision is blurred (Paulus et al, 1984), stroboscopic illumination is used (Amblard & Carblanc, 1980), or when there is visual impairment related to depth and figure-ground perception (Ribadi et al., 1987; Zernicke, Gregor & Cratty, 1982). All of these conditions may cause a person to lose balance, become dizzy, take a step, or fall.

It has been reported that removal of visual input may cause similar problems in children with developmentally acquired motor difficulties. The studies that have addressed the importance of visual feedback, spatial orientation and awareness, and perceptual judgments, have shown that children with DCD performed much poorer on non visual tasks when compared to children with no motor difficulties (Lord & Hulme, 1987; Smyth & Mason, 1998; Wann et al., 1998; Wilson & Maruff, 1999). The pronounced differences in the ability of children with and without DCD to accomplish the same balancing tasks without visual input, have been presumed to be related to many different physical, physiological and information processing factors.

For the longest time children with DCD had been considered to experience poor quality of visual image (retinal image), problems related to binocular coordination and depth perception, in problem solving situations concerning objects and distance (Sherrill, 1998). However, this point of view has been challenged by recent research which has suggested that low-level sensory and motor factors that support the visual system, such as visual acuity, vengeance control and accommodation do not appear to be responsible for these problems (Wilson & McKenzie, 1998). Mon-Williams, Wann and Pascal (1994), explored the relationship between visual impairment and motor abilities of children with and without motor difficulties. The data showed that motor problems experienced by children with DCD may occur even when perfect vision is reported, and conversely, poor binocular vision is not always related to poor motor performance. The study concluded that the quality of retinal image does not affect balance control, as children with DCD who did not experience visual problems still were not able to balance as effectively as children with no DCD. Willoughby and Polatajko (1995), also underlined the significance of visual information processing sequence as the possible source of balance problems among children with motor difficulties. The results showed that children with DCD may experience motor problems in relation to visual-based sensory input or lack of it, due to faulty visual memory and rehearsal strategies. A similar conclusion was reached by other researchers who linked visual based deficits of children with DCD to low-level perceptual processing functions (Hulme et al., 1982a, b, 1983, 1984; Lord & Hulme, 1987, 1988); visual-spatial processing (Wilson & McKenzie, 1998); short term visual memory (Dwyer & McKenzie, 1994; Skorji & McKenzie, 1997) and visual feedback and visual rehearsal mechanisms (Geuze & Kalverboer, 1987; Lord & Hulme, 1988; van der Muelen, Denier van der Gon, Gielen, Gooskens & Willemse, 1991).

Vestibular System.

Although, the contribution of the vestibular system to motor performance is assumed to be essential, it is not well understood. It has been hypothesized that the relationship may be based on the fact that balance control mechanisms depend extensively on the stabilization of the head, as the reference frame, and therefore on the functioning of the vestibular apparatus (Assaiante & Amblard, 1995; Crowe & Hoare, 1988).

Although, disorders of the vestibular system have been implicated to exist in children with learning disabilities and poor motor coordination (Burton & Davis, 1992), the role of this system in balance control and motor learning remains controversial. The majority of children with DCD and learning disability (LD) have been found to have a normally developed vestibular apparatus, but still experience problems when vestibular information is needed. It has been suggested that these difficulties result from the faulty integration of visual, vestibular, and somatosensory information for postural orientation, a condition known as sensory organization deficit (Shumway-Cook & Horak, 1987; Willoughby & Polatajko, 1994).

In terms of the symptoms that children with DCD experience when faced with balancing tasks, they are similar to the pattern of behavior that individuals with vestibular problems exhibit. A faulty selection of movement strategies (Shumway-Cook & Horak, 1990), development of weaker synergies, or relying on an ankle strategy when the task requires the use of a hip strategy (Allum & Honegger, 1993; Horak et al., 1990; Runge et al., 1998; Shumway-Cook & Horak, 1990), increased body sway velocities and amplitudes (Baloh et al., 1998; Enbom, Magnusson & Pyykko, 1991), exaggerated "chaotic sway" or "sway noise", (Blaszczyk et al., 1993; Yamada, 1995), and excessive amount of sway in quiet, relaxed standing (Wolley, Rubin, Kantner & Armstrong, 1993), are some of the characteristics that both groups share.

Somatosensory System.

As a child matures, balance control tasks become more complex and required more sophisticated response mechanisms that may incorporate a combination of sensory inputs. Somatosensory inputs are believed to emerge in the balance control repertoire as the child's balancing responses become more adult-like. It has been suggested that proprioceptive responses, which are based on the somatosensory system, may be more important than other perceptual information (Burton & Davis, 1992). They provide information about the position, movement and environmental characteristics related to balance control. These functions are often referred to as kinaesthesis or kinaesthetic perception (Laszlo & Bairstow, 1983). A number of investigations have indicated that children with DCD are significantly worse on the tasks involving kinaesthetic perception than their same age peers with no DCD (Bairstow & Laszlo, 1981; Laszlo & Bairstow, 1983; Laszlo, Bairstow, Bartrip & Rolfe, 1989). However, other researchers have challenged this apparent causal relationship between kinaesthetic and motor difficulties of children with DCD (Hoare & Larkin, 1991; Mon-Williams et al., 1999; Piek & Coleman-Carman, 1995), taking note of particular flaws in the measurement and sampling techniques used (Hoare & Larkin, 1991; Wilson & McKenzie, 1998).

Overall, it can not be denied that children with DCD experience problems with this particular sensory information in relation not only to balance control but also to other motor tasks, but the causal relationship has not been reliably established, and more research is required.

Balance control mechanisms

Any action performed by a standing person is accompanied by various compensatory postural activities, which reduce or abolish the postural disturbance generated by the movements and keep the person's center of gravity within the supporting base. These postural activities are triggered by either anticipatory or feedback-based control processes, depending on the sensory information available, and the behavioral and environmental context (Hay & Redon, 1999).

Based on the dynamic-theory of balance control, the evaluation of postural control may be investigated in relation to two different, but correlated tasks. The first task requires maintenance of steadiness which is " the ability to keep the body as motionless as possible" (Goldie et al., 1989, p. 510). This task involves the participation of involuntary, feedback mechanisms in order to maintain equilibrium (Blaszczyk et al., 1993). The other task involves exploring one's stability boundary by " transfer of vertical projection of the COG around the supporting base" (Goldie, Timothy, Owen & Evans, 1989, p. 510). This voluntary action is controlled by sensory information that is involved in anticipatory, feedforward strategies (Riach & Hayes, 1990).

One of the most frequent methods of investigating balance control is force-plate posturography. It is based on measures which display performance based on registration of COP displacement during various movements. This type of balance control quantification has been found to successfully show differences in balance control based on age, skill level (Wolff et al., 1998), altered sensory involvement (i.e. eyes open vs eyes closed) (FitzGerald, Murray, Elliot & Birchall, 1993), and different size of base of support (Holbein & Chaffin, 1997). For a number of years investigations regarding balance control mechanisms incorporated quiet standing tasks where a "good balancer" was associated with as a small amount of sway, which decreased with increasing age or skill level (Clark & Watkins, 1984; Diener, Dichgans, Bachner & Gompf, 1984; Ekdahl & Jarnlo, 1989; Foudriat et al., 1993; Lehman et al., 1990; Nakagawa, Ohashi & Watanabe, 1993; Odenric & Sandstedt, 1984; Parker, Larkin & Ackland, 1993; Riach & Hayes, 1987; Wann et al., 1998; Wolff et al., 1998).

However, more recent research has begun to incorporate more complex, feedforward based tasks, in order to fully appreciate the complexity of balance control performance. Stribley and colleagues (1974), investigated balance control of healthy young and older adults in a quiet standing task on two feet and one foot. The lack of differences between the groups was attributed to task simplicity rather than true balance abilities. A similar conclusion was reached by Osinski and colleagues (1994), who investigated the reliability and validity of balance control parameters based on healthy young adults. They suggested that quiet standing balance only provokes voluntary balance adjustments and a more rigorous task may be needed to explore other aspects of balance control behavior. Also, when balance performance of older and younger adults was investigated, the lack of significant differences was associated with the type of the task, and the use of both dynamic and static tasks was suggested (Baloh et al., 1994; Perrin, Jeandel, Perrin & Bene, 1997). The need for inclusion of more complex tasks was also underlined in other investigations, which stress the importance of a) addressing both, voluntary and involuntary adjustments in balance control behaviors, and b) the inclusion of more complex tasks for the discriminatory purposes (Blaszczyk et al., 1993 & 1994; Figura et al., 1991; Hay & Redon, 1999; Holbein & Chaffin, 1997; Panzer et al., 1995).

Feedback mechanisms.

One of the most common tasks used to investigate balance control is quiet standing, where the participant attempts to prevent body sway, under different conditions depending on the scope of the study (standing on one leg vs two legs, with eyes open or closed) (Clark & Watkins, 1984; Foudriat et al., 1993; Nakagawa, et al., 1993; Odenric & Sandstedt, 1984: Parker et al., 1993; Riach & Hayes, 1987; Usai et al., 1995).

Feedback based strategies, which are incorporated in these particular balance mechanisms, are the primary defense system of the body against unexpected, external perturbations, such as those experienced in quiet standing (Frank & Earl, 1990). Although feedback mechanisms develop earlier in life than feedforward systems, control is not completely matured until feedforward schema appear (Westcott et al., 1997). Postural sway, induced by externally imposed disturbances, produces consistent, directionally specific voluntary muscular responses (synergies) in children as young as 15-31 months. These synergies are fully developed by the age of 6-7 years, after the balance control mechanisms have switched from visual control to more adult- like multisensory responses (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985).

In balance control research, the effects of various sensory feedback on balance control have been studied. The results indicated that performance on balance tasks improved when feedback, especially visual, is provided or practiced, than when it is withheld or disturbed (Barona, Zapater, Montalt & Armengot, 1994; Riach & Hayes, 1990). Also, it has been found that when feedback based postural control is required: a) younger children take longer to respond to perturbations than adults, b) children with vestibular impairment take longer to respond than the children with no vestibular impairment, and c) children with Cerebral Palsy and Down syndrome take longer to respond than their able bodied peers (Forssberg & Nashner, 1982; Hass et al., 1986; Nashner et al., 1983; Shumway-Cook & Woollacott, 1985).

Also children with DCD have been found to experience problems related to faulty use of feedback mechanisms (Wilson & Maruff, 1999). These problems have been attributed to inappropriate patterns of muscle contractions, contractions that were not developed, or took too long to produce. These problems may be related to both, poor timing and reproducibility of these movements, as well as poor visual perception and processing (Barona et al., 1994; Henderson & Barnett, 1998; Lord & Hulme, 1987).

Feedforward mechanisms.

Balance space tasks, also known as the measure of a performer's perceptual-motor work space, demand the participant to sway as far as he perceives to be safe in relation to his true and hypothetical balance limits (Slobounov et al., 1997). In contrast to the quiet standing task, "balance space" reflects the ability to conceptualize how far the COP may be displaced in different directions, without movement of the feet or falling. In this task, sway measures are expected to increase with age, as better balancers should have a better perception of their "stability limits", as the CNS matures (Slobounov et al, 1997; Riccio & Stoffregen, 1988). This type of balance performance is based on the quality and reliability of feedforward mechanisms which are the result of a persons's ability to predict perturbations of equilibrium and generate appropriate postural adjustments in advance of a disturbance (Riach & Hayes, 1990).

Attributing developmental priority to the feedback mode is logical, as feedforward adjustments are acquired through transformation of feedback-based postural corrections into anticipatory postural corrections. However, this developmental pattern seems to be interchangeable and contemporaneous as the maturation of one system corresponds to the maturation of the other (Hay & Redon, 1999).

Riach and Hayes, (1990), investigated the timing and characteristics of feedforward mechanisms in balance behaviors of children. They found that feedforward postural adjustments were present as early as at 4 years of age, however the frequency and timing of responses was inconsistent. The highest consistency was found in 11-14 year old children. Hay and Redon (1999), also investigated this developmental pattern and confirmed that feedforward mechanisms may appear at age 4. They also confirmed that evolution of anticipatory responses is not monotonous, and its consistency decreases between the age of 6 and 8, when the timing and coordination of response generation is not optimal.

In terms of motor difficulties and use of feedforward mechanisms, it has been found that children with DCD also experience problems when required to produce an anticipatory response (Hay & Redon, 1999). Wright & Sugden, (1996) speculated in regards to children with DCD, that they seem to use feedback based postural responses when voluntary, feedforward responses are required by the constraints of the task. Shumway-Cook (1985), suggested a similar conclusion, finding that children with Down syndrome also used feedback based responses when feedforward responses should have been incorporated. Also children with spastic diplegia showed a similar pattern of behavior (Nashner et al., 1983).

It has been suggested that the inability to consistently utilize feedforward and feedback mechanisms by young children with motor problems may be due to the large amount of background (Riach & Hayes, 1990), chaotic sway that they experience (Yamada, 1995). An increase of the noise level at the input of any control system causes a decline in information detection and perception which affects their ability to process sensory inputs. Therefore, the increased sway level might result in additional delays in the sensory systems and, as a consequence, in the increase of postural instability (Blaszczyk et al., 1993). Furthermore, besides the information processing problems that children with DCD experience, the inconsistency in timing and precision of movement, may be attributed to neuromuscular "scaling" problems, as the muscular responses tend to be either too large or too weak (Williams et al., 1983). Overall, the physiological, biomechanical or sensory problems that children with DCD experience, have detrimental effects on their confidence as they avoid situations which may cause them problems (Causgrove-Dunn & Watkinson, 1994; Taylor, 1994).

Balance control measures

Quiet Standing

Age and balance control.

The amount of sway experienced in the standing position decreases with age up to late adulthood (Shumway-Cook & Woollacott, 1985). Wolff et al., (1998) studied postural balance measurements for children and adolescents ages 5 to 18. The results indicated that 5 and 6 year old children had the greatest postural sway, whereas those of 15-18 years old, had the least. On average the decrease in amount of sway was expressed by the following: 33% in radial displacement, 27% in medio-lateral amplitude, 61% in area of sway, and 5% in the anterio-posterior sway. The most abrupt decrease was noted in sway area values corresponding to performance of 5-6 and 7-8 year old children. A similar pattern of results was also obtained in other investigations confirming that balance control does improve with age in quiet standing tasks (Figura et al., 1991; Foudriat et al.,1993; Odenric & Sandsted, 1984; Osinski et al., 1994; Riach & Hayes, 1987; Usai et al., 1995).

Nevertheless, from the developmental perspective, the improvement of balance control among children in feedback based responses does not occur linearly. Usai et al., (1995), studied balance control abilities of 1200 healthy children aged 3 to 11 years of age. They found a non linear development of balance control, where a significant decrease of sway was registered between the ages of 3 and 8, and after that period the improvement was less pronounced. Riach and Hayes (1987), obtained similar results, concluding that although balance control did improve with age, as scores got smaller, there was a large amount of between subjects variability present, especially in children ages 2-6. Foudriat et al., (1993), studied balance control among children between ages 3 and 6. They also found that balance control improved with age, yet again the improvement was not linear, but stage-like with significant differences occurring between ages 4 and 5. Based on these investigations it may be postulated that the developmental pattern of balance control in children may be symbolized by the "U' curve, where young children and older adults experienced the most variability in balance responses and children between ages 8 and 12 through adulthood exhibit the most stable balance response patterns (Hytonen et al., 1993).

Sensory integration and balance control.

Numerous studies have also investigated balance performance of children in different sensory conditions like balancing with eyes open and eyes closed in order to determine the role of vision in maintaining balance (Romberg's quotient) (Riach & Hayes, 1987). According to the dynamic system model, vision is a predominant factor in balance control among infants (Ashmead & McCarty, 1992), and young children until the age of 4-6, at which time balance control mechanisms start to rely on other, more sophisticated sensory inputs (Shumway-Cook & Woollacott, 1995).

Wolff et al., (1998), investigated the effect of visual input on balance performance of children ages 5 to 11. The participants were asked to maintain their equilibrium with eyes open and closed. The study concluded that children balanced more effectively with eyes open than closed, and the effect of visual input was more pronounced in younger than older participants. Similar results were also obtained in other investigations, confirming the enhancing role of vision on balance control (Butterworth & Hicks, 1977; Butterworth & Cicchetti, 1978; Clark & Watkinson, 1984; Forssberg & Nashner, 1982; Hu et al., 1996; Lee & Aronson, 1974; Wann et al., 1998). However, as was stated previously, the importance of vision decreases with age as other sensory inputs play a more predominant role. This pattern of behavior was confirmed in some investigations, which speculated that as children reach 8-10 years of age, there is no significant difference in their balance control with or without visual input (Foudriat et al., 1993; Hytonen et al., 1993; Odenric & Sandstedt,1984; Riach & Hayes, 1987). Moreover, it was noticed that some older children consistently swayed less with eyes closed than with eyes open (Riach & Hayes, 1987)

Body morphology and balance control.

One of the most important physical affordances in relation to maintaining stability is base of support, also known as area of contact, stability limits (Riccio & Stoffregen, 1988) or region of tolerance (Slobounov et al., 1997). The bigger the region, the more displacement of COG and COP can be tolerated without resulting in a fall or step (Winter, 1985). The research shows that there is a positive relationship between the size of the base of support and balance control as a person ages (Foudriate et al., 1993; Odenric & Sandstedt, 1984; Woollacott & Shumway-Cook, 1995). Moreover, it has been suggested that there is a strong, age-dependent relationship between the initial location of the COG and the amount of sway available before reaching the stability borders (Riccio & Stoffregen, 1988). Usai et al., (1995), investigated the changes in COG location within the foot and amount of sway experienced by children. The results showed that COG location tended to shift away from the heel in older children. Its position varied from about 37 % of the foot length from the heel, between 3 and 5 years of age , to 43% between the ages of 8 and 11. In a similar study, Odenric and Sandstedt (1984), found that the distance from the heel to the COP was about 36% of the foot length for 3 to 5 year olds, 38 % for 6 to 7 year olds, and 41 to 42% for 10 and 11 year olds. Hirasawa (1979), also investigated the same phenomenon, concluding that the location of COP fluctuated between 46% (± 6.2) between the ages of 12 and 14, and 48% (± 4.9) between the ages of 20 and 50, and this fluctuation was again accompanied by more stable postural control. Overall, the further the COP is displaced, the better the balance performance.

The other important factor related to balance performance and surface of contact is its size. Numerous studies have investigated balance performance while the participants were tested on one or two feet. Generally participants were found to sway more on one foot than two feet (Berger, Discher & Tripple, 1992; Clark & Watkins, 1984; Slobounov & Newell, 1992). Osinski et al., (1994), found that standing on one foot elicited a larger number of deflections from the vertical. The length of the deflection was also larger resulting in a bigger area of sway, path length and radius displacement. Stribley et al., (1974) also investigated the role that size and shape of the support area inflicts on balance control. The study found that in healthy young adults there was a significant increase in sway when one foot was used as support area than when two feet were used. However, there was no significant difference in the amount of sway registered when narrow stance (one foot after the other) and one foot standing were compared. Also, there was no significant difference between the measures when the one leg stand was performed on the preferred and non preferred foot.

Irregular balance control

It has been well documented that children with DCD or with general motor control problems do experience problems with tasks and skills involving balance control adjustments (Henderson & Barnett, 1998; Hoare et al., 1997; Kaplan et al., 1998; Sugden & Sugden, 1990; Willoughby & Polatajko, 1994; Wilson & McKenzie, 1998). Nevertheless, there is a limited amount of quantitative data regarding balance performance of children with DCD compared to children with no balance problems. Williams et al., (1983) and Williams et al., (1985), investigated EMG activity of normal children and children who were "slowly developing". The results indicated a different pattern of muscle responses between the two groups, with awkward children responding with longer latency and amplitude and overall more muscular activity than the other group. Wann et al., (1998), used the posturographic method to investigate the differences in balance performance between children with DCD and children with no DCD. The results showed that children with DCD swayed more than their age matched controls, and younger controls in both, eyes open and closed conditions. The eyes open condition, however, produced a much more within group variability, than the eyes closed task. In this study however, the experimental group was represented by only six children, two of whom passed the balance component of the Movement ABC assessment test. Wolff et al., (1998), compared balance performance of children with spastic diplegia (who were ambulatory) and healthy children. The study concluded that balance performance of children with motor difficulties is on average 2 to 3 standard deviations greater than that of control children in the eyes open and closed conditions.

Quiet standing measures

There are a number of dependent measures incorporated in quantification of postural sway in quiet stance tasks. Some of them tend to be more sensitive than others in their ability to distinguish differences in balance performance due to age, postural difficulties, visual feedback (input), and base of support (one vs two feet).

The dependent variables most often used are: a) AP and LAT sway (Ekdahl et al., 1989; Diener et al., 1984; Odenrick & Sandstedt, 1984; Riach & Hayes, 1987; Wolff et al., 1998), b) path length and sway area (Diener et al., 1984; Ekdahl et al., 1989; Hu et al., 1996; Hufschmidt, Dichgans, Mauritz & Hufschmidt, 1980; Lehman et al., 1990; Nakagawa et al., 1993; Osinski et al., 1994; Usai et al., 1995; Wann et al., 1998; Wolff et al., 1998) and c) radius and velocity of displacement (Figura et al., 1991; Hytonen et al., 1993; Lehman et al., 1990; Osinski et al., 1994; Prieto, Myklebust, Hoffman, Lovett, & Myklebust, 1996; Wolff et al., 1998).

Validity and reliability of measures.

Evaluation of reliability, validity and sensitivity of these measures for postural control varies. Goldie et al., (1989) investigated the reliability and validity of AP and Lat sway, total path length, and average deviation, compared to force measures in quiet stance with eyes open and closed, and on one and two feet among young healthy adults. The study concluded that; a) there was no significant relation between the two types of measures for various tasks, and b) the correlations for force measures were much higher than the correlations for center of pressure measures. Nevertheless, the center of pressure variables were found to be useful in balance control investigations, although it was advised that force measures should be taken into consideration. These variables were also investigated using an intra-participant variability method (Guerts, Nienhuis, Eng & Mulder, 1993; Osinski et al., 1994). The studies concentrated mostly on the dependent measures most effective in the description of sagittal and lateral directions. The results indicated that velocity and displacement were the most effective descriptors of sway in the sagittal plane. In lateral directions, on the other hand, frequency of sway was the most reliable measure. Joeng (1994), also examined measures such as AP and LAT sway, area of sway, perimeter (described as the radius length), and total sway (expressed in path length), in the sagittal excursions. The results of between-measure comparisons revealed that total amount of sway occurring during the COP excursions was best correlated with AP sway ($r = .95$; $p < .05$), LAT sway ($r = .94$; $p < .05$) and sway area ($r = .87$; $p < .05$). Lateral sway and AP sway were also strongly related to each other ($r = .79$; $p < .05$). He concluded that these four parameters were the most consistent descriptors of balance adjustments occurring during the stability sequence.

Dependent measures and balance control

Hu et al., (1996), also investigated the validity of force platform measures, with young healthy children of various ages under different sensory conditions. He concluded that area of sway was the most sensitive measure to exhibit differences due to age and sensory input (eyes closed vs eyes open). These results were also confirmed by other researchers who used area of sway, path length, AP and LAT sway, radius of displacement and velocity, to describe balance performance of healthy children (Figura et al., 1991; Odenric & Sandstedt, 1984; Riach & Hayes, 1987; Usai et al., 1995; Wolff et al., 1998). Among the variables mentioned, area of sway and velocity were the two most sensitive indicators of age difference, whereas AP and LAT sway were the most stable variables across the age groups (Figura et al., 1991; Odenric & Sandstedt, 1984; Usai et al., 1995; Riach & Hayes, 1987; Wolff et al., 1998).

The measures that have been found to be useful in investigations regarding balance performance of young children, have also been used in studies that explored balance control differences between young and older adults. In the quiet stance tasks, velocity of sway was found to be a reliable measure of age difference, as it increased significantly with age (Baloh et al., 1994; Hytonen et al., 1993; Prieto et al., 1996). Similarly, Ekdahl et al., (1989), concluded that area of sway, path length and velocity showed both, age and gender differences under different sensory conditions. Nakagawa et al., (1993), explored the contribution of proprioception to posture control in healthy young adults in eyes open and closed conditions. Path length, AP and LAT sway as well as area of sway significantly increased as vibration was applied in both visual and non visual trials. Moreover, area of sway was a more sensitive measure in the eyes open and eyes closed conditions.

As was mentioned earlier the amount of research devoted to balance performance of children with motor delays is rather scarce. Nevertheless, there are a number of studies which have attempted to explore differences in balance control of individuals with sensory organization problems, similar to those experienced by children with DCD.

Enbon et al., (1991), investigated the balance performance of children with congenital and bilateral vestibular loss and healthy children in tasks involving standing on flat surfaces and foam rubber with eyes closed and open. In all of the task variations, velocity of sway was significantly smaller in the control group. Baloh et al., (1998), also investigated the effect of vestibular and cerebellar lesions on balance control of adults, using a similar testing protocol. The results indicated, however, that velocity and amplitude of sway, did not show between group differences. The lack of dependent measure sensitivity was however attributed to the simplicity of a task such as quiet standing. In yet another study balance performance of healthy children and ambulatory children with spastic diplegia was investigated (Wolff et al., 1998). The study incorporated path length, area of sway, AP and Lat sway and radius of displacement as dependent measures. Area of sway and path length indicated significant differences between the groups, as well as age differences within groups. These results were similar to the earlier studies which compared balance performance of healthy adults and adults with cerebral diseases causing poor balance control (Diener et al., 1984; Hufschmidt et al., 1980). The results showed that the most effective parameters to detect postural instability were sway path, sway area and AP sway, and least effective were Lat sway and the quotient of AP and Lat sway.

Balance Space

Age and balance control.

Traditionally, balance performance has been studied in quiet stance positions where feedback control mechanisms are incorporated. However, in more recent investigations the complexity of balance control has been addressed by studying the range of sway from the vertical. This task recognizes that the balance control repertoire consists of feedback and voluntary feedforward mechanisms (McCollum & Leen, 1989). Therefore, "the evaluation of stability limits of human posture should include not only the study of the control of the center of gravity reference position during normal stance but also the control at the border of postural stability" (Blaszczyk et al., (1993), p. 1334).

The perception of one's balance space, increases until the beginning of late adulthood when the ability to perceive stability limits without falling or taking a step decreases (Blaszczyk et al., 1993, & 1994; Holbein & Chaffin, 1997; Schieppati, Hugon, Grasso, Nardone & Galante, 1994; Vamos & Riach, 1992). It was found that the maximal distance of excursion decreases in late adulthood, by about 35 to 40% in AP sway, and by 10-15% in Lat sway (with both groups swaying further in AP than in Lat sway)(Blaszczyk et al, 1993, & 1994). In a similar investigation, healthy younger and older adults as well as older adults with Parkinson's were examined. It was noted that the distance between maximal forward and backward displacement of COP was significantly reduced in the elderly, as young participants were able to displace their COP up to 60% of their stability limits, compared to 30 - 40% for the older group. Further comparison of healthy older adults and those with Parkinson disease, revealed that the second group was able to displace their COP only about 25 to 30% of their foot length in the sagittal plane, and the amount of displacement was inversely correlated with the severity of the disease (Blaszczyk et al., 1993 & 1994; Schieppati et al., 1994).

There are still a limited number of investigations regarding balance space measurement and age related development of this balance control mechanism. Riach and Hayes (1990) compared the ability of young (4-7) and older children (8-11) to generate anticipatory postural responses in the sagittal and lateral planes. The study concluded that mechanisms which regulate the responses in these directions are independent of each other and develop individually, as also noted by Winter (1995). It appears that mechanisms controlling sway in the lateral direction develop first, as the ability of younger children to explore AP sway is ineffective in terms of amplitude, frequency and timing of responses. However, as children age and the balance control repertoire becomes more sophisticated, the ability to generate responses to the left and right remains constant, but the ability to generate AP responses increases and exceeds Lat sway.

These developmental changes involved body morphology and strategy implementation. Younger children, who have a small base of support, are unable to use the ankle strategy in order to generate sway in different directions, and as a result they experience a higher velocity of movement and smaller time constants when leaning in AP or Lat directions (about 1.19 s). With age, the base of support expands significantly, especially in length, allowing the child to explore his sagittal stability region more effectively. Also, as children become more efficient at using the ankle strategy their swaying time becomes longer (1.33 s) and the velocity of sway decreases resulting in larger excursions into the stability region in any direction (McCollum & Leen, 1989).

Sensory integration and balance control.

There is a limited amount of information concerning the relationship between the perception of the stability region and visual input. Blaszczyk et al., (1993) investigated healthy young and elderly adults and found that there was no significant difference between and within the groups in eyes open and closed conditions in both AP and LAT directions. Moreover, there was no pattern of consistent increase in sway with eyes open. Schieppati et al, (1994), obtained similar results as there was no significant difference in performance with eyes closed or open within each group (young, elderly, Parkinsonians) in AP and LAT sways. However, the pattern of results revealed that participants from all three groups swayed further with eyes open as the postural security range became smaller in both directions. Between group comparisons revealed that young subjects were able to sway further than the two other groups in both AP and LAT directions but once again the differences were not significant.

Body morphology and balance control.

It was found that extending the BOS in a particular direction (i.e., twice the shoulder width) extended the amount of excursion of COP in that direction. Lengthening the stance by placing the feet asymmetrically extended the anterior stability, but reduced LAT stability. There was a significant main effect between the size and shape of the base of support and the amount of sway achieved in a particular direction (Holbein & Redfern, 1997; Holbein & Chaffin, 1997). More research is needed in this area.

Balance space measures.

Exploring one's balance space, which requires voluntary excursion from the vertical in different directions, may be expressed by a variety of measures. One of the measures that has been used is the angle of lean from the vertical, which is calculated based on the height of the participant, foot length and the initial location of COP within the foot (McCollum & Leen, 1989). It has been reported that for healthy adults, excursions may reach about 12° anteriorly, and 5° posteriorly. However, these figures represent the maximum possible vertical excursion and therefore are seldom achieved (Black & Nashner, 1984; Peterka & Black, 1987). The reliability of limits of stability measures were also investigated in AP and Lat sway (Brouwer, Culham, Liston & Grant, 1998). The results indicated that measurement of the angle of excursion was a reliable measure among 70 healthy participants. There was a greater angle of lean in the anterior direction (7.46°) than posterior direction (1.12°). However, participants were able to lean to their left and right to a similar extent (7.46° and 7.08° respectively). Kauffman et al., (1997), had similar results as their sample of healthy adults yielded scores of 6.25° in anterior direction, 4.45° posteriorly, and 8° to each side (Lat sway). Holbein et al., (1997) also incorporated this dependent variable in the description of balance performance of healthy adults. The results showed that anterior sway ($\bar{x}$ = 21°) was significantly greater than posterior ($\bar{x}$ = 7°), and lateral sways ($\bar{x}$ = 19°) were not significantly different from the frontal lean but significantly larger than posterior sway.

Another dependent variable incorporated in the studies investigating balance perception within the tolerance region, is the percentage of functional stability limit (%FSL) (Holbein et al., 1997), also described as percentage of maximum voluntary excursion (Blaszczyk et al., 1993 & 1994). It has been postulated that the %FSL is a valid measure to dissociate balance performance of young and elderly adults, as the ability to lean was found to be strongly correlated with age (Lee & Deming, 1987). The amount of COP displacement within the foot has been found overall to be greater for younger than older adults (Blaszczyk et al., 1993 &1994; Schieppati et al., 1994). Younger adults are able, on average to reach, 40-45% of their available foot space in anterior sway, 45-50% in the posterior direction, and 35-40% in the lateral directions. Older adults, on the other hand, are able to reach approximately 30% of foot length in the anterior direction, 18% in the posterior direction and 30-35% in the lateral directions. As a result, the most pronounced difference in the ability to sway in different planes was attributed to sagittal sway.

In relation to the dependent measures used in the quiet standing task, velocity and area of sway have also been incorporated in balance space investigations. Schieppati et al., (1994), found that area of sway was significantly larger for younger than older subjects, and also there was a significant difference between healthy older persons and those with Parkinson's disease. Slobounov et al., (1997), proposed that time and velocity are the two crucial parameters in executing postural responses when faced with balance perturbances requiring anticipatory adjustments. They postulated that as velocity of sway increases, the amount of time available to construct an appropriate balance adjustment declines. Therefore, the postural response may be released too late, pushing the COP too close to the stability boundary and resulting in a fall or step. McCollum and Leen, (1989), confirmed this hypothesis concluding that children sway faster than adults, and the time cycle that allows a person to respond to balance perturbations increases with age.

When considering the balance space measures used in the past, and the measures incorporated in the present investigation, it should be mentioned that although they are different, they still describe the same postural behaviors generated under various conditions (i.e., eyes open and closed), and in different planes (i.e., sagittal and lateral planes). In consequence all measures described, originate from the same biomechanical as well a technical (i.e., instrumentation) view point, and based on the pilot study preceding this investigation and the knowledge acquired, they are considered comparable.

Summary

In summary, it is apparent that children with DCD, in addition to their many other motor difficulties, experience problems in balance control, in both feedback and feedforward tasks. The source of their balance control ineffectiveness has been attributed to various sensory, biomechanical and coordination systems, however these mechanisms are still not well understood. Although, there is a general awareness of existing problems within the discussed population, the present study is the first exploratory step towards better understanding and identifying components of the postural behavior of children with DCD, when they are faced with static and dynamic tasks, tasks which they would be exposed to in every day activities.

METHOD

Pilot Study

The major purpose for undertaking a pilot study was to investigate the suitability of the tasks for determining between group differences, and to investigate which dependent measures were most appropriate. The sample comprised 20 healthy boys aged 6 to 15. The children were exposed to two balance tasks; a) in the balance space task they were asked to sway as far as possible in AP and Lat directions and b) in the quiet standing task they were required to remain as steady as possible. The second task was carried out on one and two feet, as well as with eyes open and closed. Each trial lasted 20 seconds.

It was found that the protocol used was suitable as all of the children were able to complete it. As a consequence the same protocol was incorporated in the main investigation. Between-group developmental differences were best illustrated by path length, sway area, AP and Lat sway. There was also a negative relationship between the scores from the two tasks. Therefore, it was stipulated that better balancers, in this case older children, were able to score higher in the balance space task and score lower in the quiet standing task when compared to younger, less effective balancers. The efficient balancers were able to generate both feedback and feedforward balance control responses more effectively than the younger, less skilled group (see Appendix A).

Participants

Subsequent to approval by the Lakehead University Research Ethics Committee, the Thunder Bay District Catholic School Board was contacted and agreed to provide volunteers for the study (see Appendix B). A " parents package" containing a parents cover letter (see Appendix C) and a consent form (see Appendix D) was distributed by teachers to all male students in the class. As a result forty boys were selected for the study.

Procedure

Group assignment.

The participants for the study were all males, ages 6-8 and 9-13, selected and assigned to two groups based on three separate, but interrelated tools. First, the classroom teachers used the Motor Behavior Checklist in order to identify boys with and without motor skill difficulties (see Appendix E). The checklist consisted of 10 questions related to motor abilities, simple day-to day activities and behavioral patterns of the child. This screening tool had been viewed by teachers and researchers as a reliable and effective means of screening children with motor difficulties (Lefebvre & Reid, 1998; Weir, 1992; Taylor, 1992).

The next stage in the screening process involved the use of a formal assessment tool, the Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1982). The MABC was incorporated in this study in order to obtain information about the overall motor skill level of the child based on Total Impairment Score (TIS) (combined score for manual dexterity, ball skills and balance), as well as Total Balance Score (TBS) (combined score for static and dynamic balance). At first, the TIS and TBS raw scores were transformed into percentile scores, which indicated more precisely the skill level of the child (Henderson & Sugden, 1992). A TIS score above 13, placed the child in the lowest 5th percentile of scale scores, indicating severe motor problems. A score below 11.5 indicated that the child had an average or above average skill level and would be assigned to the control group. If the child scored between 11.5 and 13, he was considered at risk, and his group assignment would depend on the two remaining measures. In terms of balance abilities, a score at or above 7.5 indicated severe balance difficulties and would be equal to the 5th percentile. Children who obtained those scores were assigned to the experimental group. A score below 5 placed the child at or above 15th percentile, as he would be perceived to have average or above average balance skills and subsequently he would be assigned to the control group. A score between 5 and 7.5 indicated that the child was at risk of having balance difficulties and his group assignment depended on the status of the other two criteria (see Appendix F).

Instruments

The program used for the balance measurement was the CAS Stability Computer Program (A.M.T.I., 1997). CAS output displays the balance measurements, path of the center of pressure, direction of the sway, sway area, maximum anterior-posterior and lateral sway, and amplitude distribution. The program also illustrates the shape and direction of the sway based on changes in COP displacement.

The force platform was an AMTI force plate, with standard (x,y,z) coordinates. The force platform and the AMTI computer system were connected to the standard amplifier to record changes of COP displacement. The displacement of COP was measured at .01 s frequency (100 Hz), with the gain set at 4000 x, 5 x, and the electronic filter set at 10.5 Hz.

Balance Testing Procedure.

Before the participants performed the actual task, their weight, height and size of feet were measured. At this point the participant stood on the platform barefooted, and the contour of their feet was recorded with chalk to insure that they stood in the same position during each trial. Each child was exposed to one testing session, of 45 minutes, which included three practice trials and sixteen formal trials, of 20 seconds duration. A practice trial was performed at the beginning of testing to make sure that the participants understood the procedure.

Balance Space.

The first task involved measurement of balance space while the participant stood on the platform with both feet together, arms placed on the chest and looked at a point on the wall, approximately 5 meters away from the force plate. In three trials, the child moved from vertical position by leaning as far as possible in the forward, backward, right and left directions consecutively, without losing balance. The key to a valid measurement was that the child did not move his feet, and stayed on the "plate" for 20 seconds. If balance was lost and the child stepped off the platform the trial was repeated, unless the trial lasted 15 seconds. This procedure (direction and time of the sway) was the same for each trial.

Quiet Standing.

The second task required the participant to stand on the platform without swaying. This task was called "quiet standing", and was performed in the "eyes closed" and "eyes open" condition. Only one trial was performed for each condition.

Quiet Standing (preferred and non preferred with eyes open and closed)

The third task involved standing on one leg (preferred, and non preferred), with eyes open for three consecutive trials. The same procedure was repeated with eyes closed. However the scores obtained on this task were excluded from the analysis as 17 out of 20 children in the experimental group were unable to successfully complete the task.

Design

The dependent variables in this study were path length (cm), area of sway (cm^2), and AP (cm) and LAT sway (cm) in the tasks balance space, quiet standing with eyes open and quiet standing with eyes closed. The independent variables were age (6-8 vs 9-13) and group condition (DCD and balance difficulties vs no DCD, and no balance difficulties). The design for the study was a 2 (age) x 2 (condition) factorial design.

Data Analysis

The statistical analyses incorporated were MANOVA, Factorial ANOVA, planned comparisons and Pearson correlation. The significance level was set at alpha level (α) .05.

Prior to analysis of balance performance data, factorial ANOVA was used to examine the scores from the MABC (TIS and TBS), and the morphological characteristics of the participants. Also Pearson correlation was used to establish the relationship between the MABC scores as well as between MABC scores and dependent measures incorporated in the study.

In order to investigate the influence of the treatment effect on four dependent variables, a 2 x 2 MANOVA was carried out on the scores for each of the three tasks When the multivariate test showed significant main or interaction effects, factorial ANOVA was performed on each dependent variable in order to establish which measure best described the between groups differences existing within a given task (Thomas & Nelson, 1996). Results of these ANOVAs were also used to examine the group performance pattern in the eyes open and eyes closed task, and the group differences in sagittal and lateral sway. Significant interaction effects were further examined by planned comparisons to establish which group comparison contributed the most to the overall between group variance. Multiple correlation analyses were used to explore the strength of the relationship between the dependent variables within and between tasks (Diekhoff, 1992).

RESULTS AND DISCUSSION

The main purpose of the investigation was to explore the differences in balance performance between children who do not exhibit age-adequate postural control and those who are considered to exhibit at least average postural control abilities. The hypothesized differences due to age, skill level or a combination of the two components, were investigated in different tasks (balance space and quiet standing) as well as different sensory inputs (eyes open and closed). However, prior to the analysis of the balance performance on different tasks, the characteristics of the participants are presented and discussed.

Results

Sample characteristics

Selection criteria.

The control group, Group 1 (6-8 years old) and Group 2 (9-13 years old) consisted of children who were identified by teachers as not having motor difficulties and those who scored above average on the two categories from the Movement ABC. In this group, all 20 children passed the three criteria. On the other hand, the experimental group, Group 3 (6-8) and Group 4 (9-13), consisted of boys who fulfilled at least two of the three criteria: a) were identified as having motor difficulties by the teachers; as well as scored below average on: b) Total Impairment Score; and c) Total Balance Score. Among 20 boys, 12 of them fulfilled all three criteria. Three boys were perceived by teachers not to have any visible motor problems, but did poorly on the two sections of Movement ABC. Furthermore, three other boys were referred directly by an occupational therapist (see Appendix F). In terms of MABC Total Balance Score, two boys scored at the 15^th^ percentile, and two others were perceived to be at risk Their group assignment was based on the two other criteria which they fulfilled.

Analysis of the MABC scores, by factorial ANOVA, showed that children in the experimental group obtained significantly higher scores than the control group, at alpha level $p < .05$, on TIS ($F(1,35) = 127.16$, $p < .001$), and TBS ($F(1,35) = 95.03$, $p < .001$) (see Table 1). There was no significant main effect for age and no significant interaction effect. Furthermore, when an additional Pearson correlation procedure was carried out, TIS and TBS were found to be significantly related to each other at alpha level $p < .05$ ($r = .459$, $p < .05$). Based on these two analyses, it was concluded that children who were assigned to the experimental group, experienced overall motor skill difficulties as well as specific balance problems. The participants in the control group, on the other hand, exhibited significantly better overall motor and balance abilities when compared to children from the experimental group (see Table 1).

Table 1 Sample selection criteria for control and experimental groups on Movement ABC (MABC) Total Impairment Score (TIS), and MABC Total Balance Score (TBS).

Variables	Groups	n	DCD $\bar{x}$ (SD)	no DCD $\bar{x}$ (SD)
Age (years)	6-8	10	7.1 (.8)	6.9 (.7)
	9-13	10	10.3 (1.4)	10.6 (1.1)
	Total	20	8.7 (2.1)	8.6 (2.0)
MABC TIS (scale score, 0-40)	6-8	10	18.3 (4.8)	5.25 (2.9)
	9-13	10	18.9 (5.6)	3.5 (2.2)
	Total	20	18.6 (5.1)	4.3 (2.7)
MABC TBS (scale score, 0-15)	6-8	10	8.7 (2.7)	1.5 (2.0)
	9-13	10	8.6 (2.6)	1.9 (1.8)
	Total	20	8.6 (2.6)	1.7 (1.8)

Morphological characteristics

When considering morphological factors crucial to balance control, a number of factorial ANOVAs was carried out in order to investigate the differences between the groups based on height, foot size, and the amount of space available for anterior and posterior displacement. In the present investigation the location of COG was established based on a constant, age-appropriate percentage of the foot length obtained from the literature (Hirasawa, 1979; Usai et al., 1995). In relation to that value, the space available for the anterior and posterior sways was calculated. The anterior space was the area of the foot from the COG location towards the end of the toes. The posterior space, on the other hand, was the area of the foot from the COG location towards the end of the heel. The significant main effects for age, indicated that older children were taller (height ($F_{(1,35)} = 47.11$, $p < .001$)), had a larger base of support (foot size ($F_{(1,35)} = 36.14$, $p < .001$)), and subsequently more space available for anterior ($F_{(1,35)} = 18.39$, $p < .001$) and posterior ($F_{(1,35)} = 56.19$, $p < .001$) displacement. However, there was no significant main effect for condition or significant interaction effect (see Table 2).

Table 2 Comparison of group morphology and maximum available sway (mean and standard deviation).

Variable	Groups	n	DCD x̄ (SD)	no DCD x̄ (SD)
Height (cm)	6-8	10	128.8 (7.7)	125.7 (9.1)
	9-13	10	147.0 (10.5)	146.10 (8.1)
	Total	20	137.42 (12.8)	135.93 (13.42)
Foot length (cm)	6-8	10	20.01 (1.7)	19.36 (1.1)
	9-13	10	22.97 (1.8)	22.3 (1.4)
	Total	20	21.41 (2.2)	20.84 (1.96)
COG location(cm)	6-8	10	7.5 (.69)	7.44 (.56)
	9-13	10	9.33 (1.0)	9.26 (.67)
	Total	20	8.41 (1.23)	8.35 (1.1)
Anterior sway (cm)	6-8	10	12.34 (.97)	11.93 (.63)
	9-13	10	13.64 (.98)	13.06 (.79)
	Total	20	12.96 (1.1)	12.49 (.91)
Posterior sway (cm)	6-8	10	7.59 (.30)	7.44 (.57)
	9-13	10	9.33 (1.0)	9.26 (.67)
	Total	20	8.41 (1.2)	8.35 (1.1)

Discussion

The process of selecting participants and group assignment was a crucial part of this study, as children with DCD exhibit various clusters of conditions which do not necessarily include balance control problems (Henderson & Barnett, 1998; Hoare, 1994; Kaplan et al., 1998; Wright & Sugden, 1996).

When considering the selection criteria, a Motor Behavior Checklist (MBC) was implemented for preliminary screening of children for visible motor difficulties. The MBC, which was found to be an effective screening tool in the past (Lefebvre & Reid, 1998; Weir, 1992), was also found to be a reliable tool in this investigation. Among 40 participants, only 3 boys were not identified correctly by teachers as having movement difficulties when compared to the actual assessment results. The MABC was also found to be effective in identifying children with both motor delays and balance difficulties. The TIS and TBS scores were able to group children successfully, as boys from the experimental group had significantly higher scores when compared to the boys assigned to the control group. Moreover, the two scores were also found to be positively correlated ($r = .459$, $p < .05$), further strengthening the hypothesis regarding their efficiency to differentiate between children who exhibit developmental motor delays and those who do not. The efficiency of the screening protocol used in the present investigation is supported by past research that used similar screening procedures (Hoare, 1994; Mon-Williams et al., 1994; Wann et al., 1998; Wilson & Maruff, 1999; Wright & Sugden, 1996).

Once the two groups were established based on skill level, they were further divided into two age groups per population. Since this study did not incorporate a matching procedure for participants' selection, it was important to investigate the morphological difference between both age groups. If the same-age children with and without DCD performed differently on balance tasks, and their morphological characteristics were significantly different, it would be very difficult to establish the source of the between group variance (i.e., skill level or size of base of support). However, since none of the morphological factors investigated provided a significant main effect for condition, it is reasonable to assume that the differences obtained from the two balance tasks incorporated in this study could be attributed to varying skill levels and not to morphological characteristics.

Results

Balance performance on balance space.

The results will be reported in the following way: a) a descriptive analysis of group performance; b) group differences (main effects) due to condition and developmental level; c) interaction effects; and d) differences in sagittal and lateral sway. The discussion of the results will immediately follow each section. Following the analysis of balance performance, a separate section is included discussing task effectiveness.

The ability of children to perceive their tolerance region by leaning as far as they could without falling, was evaluated based on area of sway (Ao), path length (L), anterior-posterior (AP) and lateral sway (Lat). Examination of the mean scores on each variable measured in balance space indicated that a better performance was associated with a higher score (see Table 3). This pattern was evident for both ages in the control group on all four variables and for both ages in the experimental group in all variables but path length (see Figure 3).

The 2 x 2 (age x condition) MANOVA indicated a significant main effect for condition (F (4,32) = 5.20, p <.05), and age (F (4,32) = 7.57, p <.001), as well as a significant interaction effect (F (4,32) = 3.27, p <.05).

Table 3 Performance of participants in the balance space task based on area of sway (Ao), path length (L), anterior-posterior (AP) and lateral sway (L) (means and standard deviations).

Variables	Groups	n	DCD $\bar{x}$ (SD)	no DCD $\bar{x}$ (SD)
Ao (cm2)	6-8	10	6.85 (3.6)	9.18 (2.4)
	9-13	10	10.45 (3.8)	18.09 (3.8)
	Total	20	8.56 (4.0)	13.64 (5.5)
L (cm)	6-8	10	77.06 (17.5)	72.86 (5.4)
	9-13	10	76.13 (18.2)	96.70 (15.0)
	Total	20	76.62 (17.3)	84.78 (16.45)
AP (cm)	6-8	10	7.3 (1.7)	7.93 (.9)
	9-13	10	8.16 (1.6)	10.66 (.89)
	Total	20	7.74 (1.7)	9.29 (1.64)
Lat (cm)	6-8	10	7.74 (1.9)	8.10 (1.0)
	9-13	10	9.10 (.8)	10.21 (1.0)
	Total	20	8.38 (1.6)	9.15 (1.4)

DCD vs no DCD

A 2 (age) x 2 (condition) factorial ANOVA computed for each dependent variable revealed two significant main effects for condition: area of sway (F (1,35) = 20.157, p <.001), and AP sway (F (1,35) = 13.303, p <.001). Boys in the control group were found to have significantly larger area of sway and AP sway than boys in the experimental group.

In addition, boys without DCD were able to explore their tolerance region significantly further in AP direction (F (1,35) = 13.303, p < .001), as swaying in the lateral direction was not found to be significantly different between the groups (F (1,35) = 3.11, p = .086).

Developmental differences.

Examination of main effects for age, through factorial ANOVA showed that older children scored significantly higher than the younger ones in area of sway (F (1,35) = 31.767, p <.001), path length (F (1,35) = 5.791, p <.01), and both AP (F (1,35) = 17.599, p <.001) and Lat sway (F (1,35) = 17.556, p < .001).

Condition and developmental differences.

Application of factorial ANOVA, also identified significant interaction effects for age and condition in AP sway (F (1,35) = 4.80, p <.05) (see Figure 1), area of sway (F (1,35) = 5.71, p <.05) (see Figure 2), and path length (F (1,35) = 6.76, p <.05) (see Figure 3).

Planned comparisons revealed that the older, control children (Group 2) scored significantly higher than both, their age peers with DCD (Group 4), and younger children with DCD (Group 3). The differences were obtained on all of the measures except Lat sway when Group 2 was compared to Group 4 (t (39) = -1.861, p < .071). Also, Group 2 performed significantly better than Group 1 (young, no DCD) on all measures. These developmental differences were also visible when the two experimental groups were compared, as Group 4 outperformed Group 3 in area of sway (t (39) = 2.264, p < .05), and Lat sway (t (39) = 2.294, p <.05) (see Appendix H1).

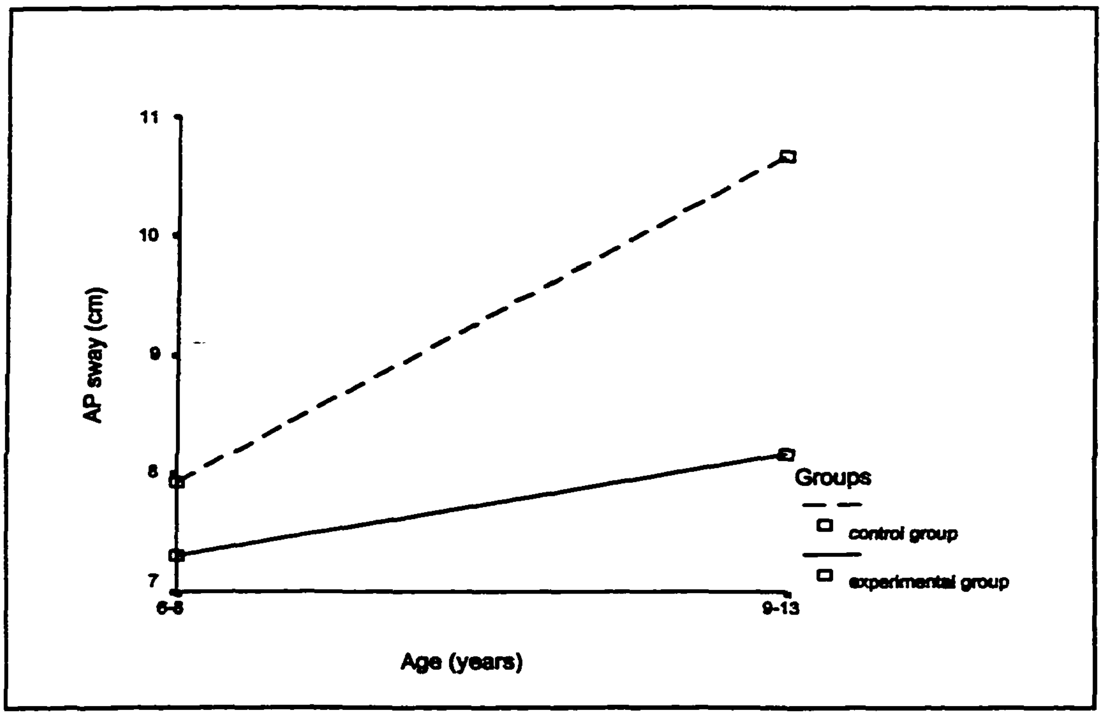


Figure 1. Interaction effect for Age x Condition in balance space task, based on AP sway.

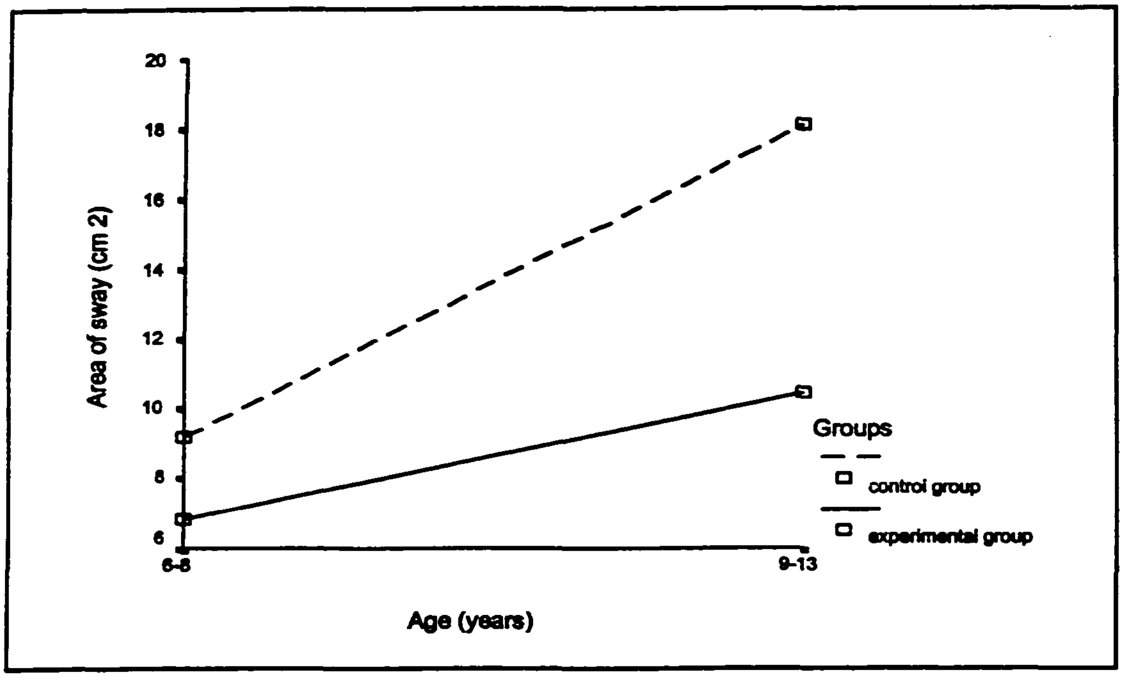


Figure 2 Interaction effect for Age x Condition in balance space task based on area of sway.

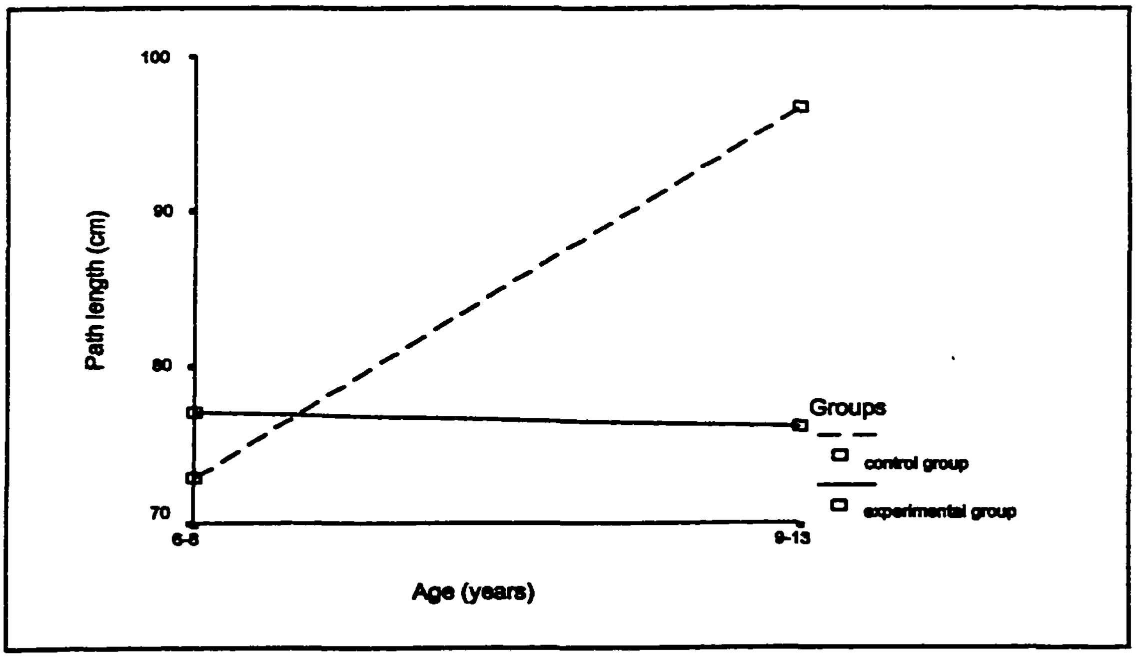


Figure 3 Interaction effect for Age x Condition in balance space task based on path length.

Discussion

The balance space task requires voluntary, feedforward postural responses (Goldie et al., 1989; Riach & Hayes, 1990), that are generated in the form of maximum excursions of COP from the initial position towards the stability borders (Blaszczyk et al., 1994; Slobounov et al., 1997). In order to effectively complete this task a number of biomechanical, perceptual and motor coordination requirements are necessary. The movements have to be: a) generated effectively at the ankles (ankle strategy) (McCollum & Leen, 1989), b) controlled in terms of torques implemented (Riccio & Stoffregen, 1988) and generated velocities (McCollum & Leen, 1989); and c) effectively scaled, according to the demands of the task as well as the affordances and constraints of the individual (Bouffard et al., 1998; Riccio & Stoffregen, 1988).

DCD vs no DCD

The results support the first hypothesis that the control group would significantly outperform the experimental group. In other words, not having DCD and balance difficulties was associated with a greater capacity to perceive the tolerance region.

Although there are no previous investigations examining the anticipatory balance control of children with DCD, the present discussion will address two critical mechanisms related to coordinated movement: a) perceptual input of information, and b) muscular responses (Wilson & McKenzie, 1998). The question of interest is therefore twofold: is the lack of ability to generate anticipatory postural movements related to a) ineffective or faulty interpretation and processing of sensory inputs; or b) a faulty motor output process.

In terms of the first consideration, children with DCD have been found to experience perceptual processing problems resulting in faulty timing and accuracy of muscular responses, as well as inconsistent reproducibility of movements (Geuze & Kalverboer, 1987; Van Dellen & Geuze, 1988; Wilson & McKenzie, 1998). Also, they are believed to experience kinaesthetic difficulties which relate to the ability of perceiving limb location and position during active movements (Bairstow & Laszlo, 1981, 1989; Laszlo et al., 1989). In direct relation to voluntary balance responses, ataxic children were found to experience difficulties with sensory evaluation of verticality of body position (Massion, 1994). Although the literature provides quite an extensive description of information processing difficulties of children with DCD, it could be only speculated that these problems do have a direct relation to the behavior reported in this study.

When the performance based on the center of pressure (COP) excursions was evaluated, two different patterns of behavior were apparent (see Appendix J). Children with DCD explored their tolerance region by exhibiting frequent, short excursions that often were directionally inconsistent with the demands of the task and protocol. They behaved as if they were trying to stay as close to a vertical, safe position as possible, instead of venturing into an exploration of their stability region as they were asked to do. It appeared they were using feedback based strategies to carry out a feedforward based task. It is unclear which sensory system may have affected their behavior, however it could be concluded that they were not able to generate an anticipatory schema of responses based on the visual, vestibular and somatosensory information available to them. Although the population and evolving issues investigated in the present study have been seldom addressed in the past, similar problems within other special populations have been explored. It was found that: a) children with DCD replace anticipatory monitoring of movements with feedback based monitoring (Wright & Sugden, 1996); b) ataxic children experience problems with voluntary movements (Massion, 1994); c) children with Down Syndrome (Shumway-Cook, 1985) and spastic diplegia (Nashner et al., 1983) replace feedforward mechanisms with feedback based responses; d) and adults with balance problems are not able to use feedforward based balance mechanisms effectively (Schieppati et al., 1994).

The inability to incorporate the appropriate information processing schema in order to impose most effective feedforward mechanisms may also be related to biomechanical and motor coordination constraints of children with DCD. In order to be able to fully explore one's stability region, an efficient movement has to take place. Its efficiency relies on: a) use of the appropriate, most effective, least energy consuming strategy; and b) a muscular output that is generated with the precise amount of force, specific to goals of the task (Riccio & Stoffregen, 1988).

The balance space task requires the system to incorporate an ankle strategy in order to generate an appropriate balance response. The efficiency of such a response depends on three biomechanical factors: a) range of motion (ROM), which determines the distance a joint is able to be displaced; b) strength; and c) force output, which allows the body to carry out movements through properly scaled contractions. In terms of balance difficulties and the above mentioned parameters, children with DCD have often been found to experience limited ROM and weakness at the ankles where the torque is generated (Horak et al., 1997; Kou & Zajac, 1993; Sherrill., 1998). As a result, these children were found to either avoid tasks requiring these components of movement output production, or tended to alternate their balance strategies. Therefore, they were still able to address the demands of the tasks at hand, however the resulting movement was not nearly as efficient as the strategy that should have been incorporated (Allum & Honegger, 1993; Horak et al., 1990; Shumway-Cook & Horak, 1990; Runge et al, 1998). A similar pattern of behavior was noticed when older adults with balance problems were asked to lean in different directions. They tended to alternate their balance strategies when the demands, similar to those of the present study, were imposed on them. They would bend their body at the hips when attempting to sway in different directions about the ankle joint. This alternative choice of movement, known as the hip strategy, resulted in a decreased COP displacement, the same phenomena which was observed in the present investigation (Shumway-Cook & Woollacott,1995; Winter, 1995).

In addition, it was also proposed that an incorrect choice of balance strategy may cause excessive sway velocities and amplitudes resulting in loss of balance (Baloh et al., 1998; Enbon et al., 1991). Although the velocity of displacement was not discussed in this investigation, it was hypothesized that children who are less skilled generate balance responses with higher frequency and velocity, but smaller amplitude. From the biomechanical stand point, such ineffective execution may be caused by the lack of strength, limited ROM, or an ineffective scaling of force. Each balancing task is based on a specific amount of torque generated to counter the effects of gravitational forces acting on the body due to perturbation, and children with DCD have been found to experience difficulties with generation of such forces. They tend to generate hypometric responses which are too strong for the demands of the task, and result either in a fall, a step or the constrained balance response witnessed in the present study (Horak & Diener, 1994; Williams et al., 1983; Williams et al., 1985).

Overall, there are many possible causes of balance difficulties experienced by children with DCD in tasks requiring anticipatory postural responses. However, it is proposed in this study that the primary factors responsible for such delays are related to the children's inability to generate appropriately scaled responses due to lack of strength, inadequate range of motion or ineffective processing of perceptual information. As a result they tend to alternate their balance strategies and fail to meet the age-appropriate demands of voluntary-based balance tasks.

Developmental differences.

The results obtained support the second hypothesis, that older boys would obtain significantly higher scores than the younger boys on all four variables incorporated. Older children were able to generate more effective voluntary, feedforward balance responses than younger children, as they were able to displace their COP closer to their stability boundary. In terms of age related balance control, these results correspond to the pattern of behavior represented by the dynamic model of development (Assaiante & Amblard, 1995). The model points out an overall abrupt decline in the effectiveness of balance control between the ages of 5 and 8, as well as a specific decline associated with the ability of generating anticipatory postural responses (Riach & Hayes, 1990; Shumway-Cook & Woollacott, 1985). It was established that although anticipatory postural responses appear to be present in a child's balance control repertoire as early as 4 years of age, the highest consistency in terms of timing, frequency and amplitude is not reached till the age of 10 to 13, when adult-like responses are being generated (Hay & Redon, 1999; Riach & Hayes, 1990).

The first, explanation for the existence of such behavior may be related to size of the base of support. The older group was found to have a significantly larger support space (feet) ($F(1,35) = 36.14$, $p < .001$), and as a result, the COP had more "room" to be displaced when compared to younger boys with smaller feet (Holbein & Redfern, 1997; Odenric & Sandstedt, 1984; Usai et al., 1995; Winter, 1995). However, as much as the size of the base of support is important from a biomechanical stand point, morphological factors overall play merely a secondary role when balance performance is examined (Riach & Hayes, 1990).

It has been proposed that multi-modal sensory conflicts, affecting the information processing sequence, may be the primary causes of motor output delay among younger children. The caused delay, subsequently, forces them to generate faulty or incomplete balance responses which jeopardize their equilibrium and may result in staggering or falls (Shumway-Cook & Woollacott, 1985). This informational "chaos" is caused when the CNS undergoes a variety of changes in terms of interpretation and encoding of vast amounts of various incoming sensory information. As a result, the large chunks of information that would be complimentary and useful in the case of older children, become conflicting among their younger peers.

These conflicts have also been found to be caused by biomechanical constraints. During early childhood, children experience an excessive amount of background, chaotic sway which has a detrimental effect on the reaction time and consistency of responses. Children are found to be "less able to anticipate postural disturbances caused by self-initiated movements, and match postural adjustments with movement execution" (Riach & Hayes, 1990, p. 265). In other words, their ability to scale postural responses according to the demands of the perturbation varies.

As a consequence of the sensory and biomechanical constraints facing younger children, it has been hypothesized that increasing velocity and resulting decrease in the time of sway, may have the most detrimental effect on their performance. As the velocity of sway decreases with age in late childhood (Baloh et al., 1994; Figura et al., 1991), the time cycle available for the generation of motor output increases (McCollum & Leen, 1989; Slobounov et al., 1997). Therefore, the child has more time to process information and construct an adequately scaled response, a sequence of events which is jeopardized when the responses are quick and involuntary-like (i.e., feedback-like).

Condition and developmental differences.

As hypothesized, performance on balance space provided a significant interaction effect between the groups. The ability to generate effective anticipatory postural responses was related to age as well as skill level. The older children with no DCD nor balance problems (Group 2) performed significantly better than any other group. When the four groups were further examined, older children performed better than younger ones within both the control and experimental group. Also, the difference between the two younger groups was less pronounced than the difference between the two older groups. This fact may indicate that, although balance control improved with age in both groups, the gap between children with and without balance problems increased instead of decreasing with age. Finally, the performance of older children with DCD (Group 4) was more similar to the performance of younger, control children (Group 1) than to younger children with DCD (Group 2). As a result, it may be hypothesized that children with DCD at 9 to 13 years of age, exhibit postural responses similar to those of younger healthy children, while their same-age peers reach an adult-like pattern of responses.

In relation to the above mentioned results, as well as issues investigated in the past, two common questions emerged: a) are the children with DCD able to grow out of their "clumsiness", and b) if not, how much delay in terms of age-appropriate skill level, do they experience? As the data showed, balance performance of children with DCD improved with age, as they scored higher than the younger DCD group (3 vs 4) (see Appendix H1), however their improvement was significantly smaller when compared to the difference between older and younger controls. Therefore, it appears that children with DCD do not "catch up" to the expected standards of performance set by their peers, and the gap between the age appropriate skill level and their performance actually expands.

These speculations have support in previous literature which proposed that children with DCD consistently experience overall as well as specific balance control delays, which diminish with age but do not disappear. In this context, it has been postulated that the growth spurt around ages 10 to12 enhances motor abilities of children with developmental difficulties due to CNS rearranging. However, this improvement is only marginal as it enhances but does not eliminate their motor difficulties (Visser et al., 1998). The literature, in balance control context, regarding time guideline for the possible amount of delay, is limited. Wann et al., (1998), investigated balance control performance of children with DCD in a "swinging room" phenomena. The study indicated that age-matched control children performed significantly better than children with DCD, and moreover, the balance control pattern of older, DCD children was similar to the pattern of behavior exhibited by younger healthy children. They concluded, similarly to this investigation, that older children (ages 8-10) experienced delays in balance performance equal to 3 to 4 years, as they exhibited balance control characteristics of children ages 3 to 5.

Overall, longitudinal studies have concluded that children who experience motor difficulties during early childhood improve with age, but are still unable to meet the age appropriate performance levels in the future (Barnet et al., 1998; Geuze & Borger, 1993; Visser et al., 1998). As the present study was not of longitudinal type, and further attempt at testing these hypotheses should be taken undertaken.

Sagittal and lateral sway.

Based on the inverted pendulum approach, it is assumed that postural responses generated in balance space tasks incorporate an ankle strategy, which allows the person to displace his/her vertical body alignment in the sagittal and lateral plane (McCollum & Leen, 1982). Generating sway in these directions results from two different, yet related mechanisms. Anterior-posterior excursions are generated by COP excursions compensating for COG displacement, whereas lateral sway is generated by "load-unload" tactics (Winter, 1995). In terms of these measures, the hypothesis was partially confirmed, as swaying in AP direction was found to be greater than displacement in the lateral plane when the main effect for condition was considered but not when developmental differences were examined. When the boys with and without DCD were examined, more skillful balancers were able to sway significantly further in AP sway (F (1,35) = 13.303, p <.001), while the Lat sways were the same (see Appendix G1). Since control children were able to explore their tolerance region better than experimental children, and also sway further in the sagittal plane, it could be postulated that the source of the difference is an overall ability to generate anticipatory responses in the sagittal plane. Lack of previously established trends suggests that further investigation of this relationship is warranted as there is no current literature.

In contrast to the results obtained when control and experimental groups were compared, the developmental differences did not support the initial hypothesis. When the two groups were examined, older children were able to sway further than their younger peers in both directions. Riach and Hayes (1990), supported these findings as older children in their study were also able to sway further in both planes. They proposed that from a developmental stand point, the two different mechanisms regulating these sways have different, yet related patterns of maturation. The anticipatory responses in the lateral direction appear earlier than the responses incorporated in the sagittal plane, nevertheless they both reach their maturation about the same time, when the child is between the ages of 8 and 10. However the understanding of the concepts related to the development of mechanisms regulating AP and Lat sway remains unresolved as some studies support the phenomena that occurred in the present investigation, while others find no differences between the two sways (Blaszczyk et al., 1993; Blaszczyk et al., 1994; Schieppati et al., 1994).

Results

Quiet standing tasks

The second type of task that participants were involved in was quiet standing, with eyes open and closed. Each boy was encouraged to stand as firmly as possible rather than move to the borders of his tolerance region. This task required using a feedback type strategy in order to accomplish the task efficiently (Clark & Watkins, 1984; Diener et al., 1984; Foudriat et al., 1993). The four dependent variables used were the same as balance space measures (area of sway, path length, AP and Lat sway). However this time, a better, more skilled balance performance was associated with a lower score (see Table 4). When describing the results obtained in the quiet standing task an additional section pertaining to the differences between swaying with eyes open and closed will be included.

Quiet standing (eyes open)

A 2 x 2 (age x condition) MANOVA indicated a significant main effect for age (F (4,32) = 2.62, p = .054), and no significant main effect for condition (F (4,32) = 1.67, p = .181), and no significant interaction (F (4,32) = 1.88, p = 138).

Developmental differences

The examination of factorial ANOVA indicated a significant main effect in path length (F (1,35) = 9.536, p <.05). Older children scored lower than younger children and as a result were able to maintain their balance more efficiently.

Quiet standing (eyes closed)

In quiet standing with eyes closed, the lower scores were once again associated with a better performance (see Table 4). The children exhibited a similar pattern of behavior to that observed in the eyes open task, as MANOVA revealed no main effect for condition (F (4,32) =1.097, p = .375) and no significant interaction effect (F (4,32) = 2.37, p = .073). The only difference between the groups studied was due to the significant main effect for age (F (4,32) = 3.25, p <.05).

Developmental differences.

Older children were able to control their balance better than younger children, as all scores decreased with age. The factorial ANOVA carried out for each dependent variable revealed a significant main effect for age in path length (F (1,35) = 4.451, p <.05), Lat sway (F (1,35) = 5.047, p <.05) and AP sway (F (1,35) = 6.016, p < .01). Also, older children were able to control AP and Lat sways significantly better than younger children (see Table 4).

Table 4 Performance in quiet standing with eyes open and closed tasks, based on area of sway (Ao), path length (L), anterior-posterior (AP) and lateral (Lat) sway (means and standard deviations).

Variables	Groups	n	DCD open x̄ (SD)	DCD closed x̄ (SD)	no DCD open x̄ (SD)	no DCD closed x̄ (SD)
Ao (cm2)	6-8	10	.53 (.31)	.64 (.30)	.40 (.16)	.58 (.21)
	9-13	10	.5 (.27)	.56 (.30)	.27 (.19)	.36 (.24)
	Total	20	.52 (.05)	.60 (.06)	.34 (.05)	.47 (.06)
L (cm)	6-8	10	41.14 (13.5)	45.78 (13.6)	33.19 (5.49)	39.85 (5.8)
	9-13	10	28.85 (6.68)	36.19 (11.1)	28.08 (6.84)	35.72 (8.2)
	Total	20	35.0 (2.1)	40.99 (2.32)	30.63 (1.96)	37.78 (2.26)
AP sway (cm)	6-8	10	2.32 (.63)	2.63 (.57)	1.74 (.46)	2.33 (.52)
	9-13	10	1.93 (.74)	2.26 (.68)	1.58 (.77)	1.75 (.62)
	Total	20	2.12 (.14)	2.44 (.13)	1.66 (.14)	2.04 (.13)
Lat sway (cm)	6-8	10	2.18 (.87)	2.29 (.85)	1.97 (.55)	2.4 (.72)
	9-13	10	2.09 (.68)	2.06 (.80)	1.41 (.55)	1.62 (.64)
	Total	20	2.14 (.15)	2.18 (.17)	1.70 (.15)	2.06 (.17)

Discussion

Quiet standing with eyes open and closed.

The results of performance in quiet standing did not support the hypothesis, as there were no group differences due to condition, but there were significant developmental differences in both the eyes open and eyes closed task. Overall, it is clear that the differences between the groups in the quiet standing task, did not reveal the consistent differences seen in the balance space task. However since this type of investigation had no precedence in terms of tasks and population incorporated, further theoretical examination of the data was incorporated. It was suggested that the lack of statistical significance should not negate the suggestive pattern of behavior exhibited by the groups, especially since the differences between the groups were clearly evident when the children completed the Movement ABC. Therefore, it is proposed by the author and confirmed by the literature, that the lack of consistency between statistical results in posturography and actual skill level exhibited by children in screening, may be due to the small participant sample (Gay, 1987), as well as to the simplicity of a task such as quiet standing (Blaszczyk et al., 1993; Blaszczyk et al., 1994; Brouwer et al., 1998; Holbein & Chaffin, 1997; McCollum & Leen, 1989; Schieppati et al., 1994).

Based on the actual mean scores, a similar pattern of individual group's behavior in both tasks may be suggested, as the same groups exhibited similar performance characteristics in balance space and quiet standing tasks (see Figure 4). Children who were older and had no DCD were most effective at perceiving their balance space and at maintaining a steady position in the quiet standing task. On the other hand, younger children with DCD were the least efficient at maintaining a stable position and at perceiving their tolerance region. Also, when the two remaining groups were examined, their performance seemed to be similar within each task, suggesting that the amount of delay exhibited in feedback balance control may be related to the amount of delay in feedforward mechanisms. This similar pattern of performance exhibited by each group in both tasks provides some indication of the developmental relationship of voluntary and involuntary balance control mechanisms. However, more research into this phenomenon is encouraged.

As a step further into the exploration of the hypothesis regarding the possible existence of a relationship between the two tasks, dependent measures such as area of sway and AP sway were investigated. They were chosen because they were the two most significantly related variables in both the balance space ($r = .73$, $p \leq .001$), and quiet standing task ($r = .66$, $p < .001$). When the two were correlated in a cross-over, between task method, a non significant, negative correlation between the two tasks was obtained (area of sway ($r = -.18$, $p < .29$), AP sway ($r = -.22$, $p < .19$)). Although it is perceived that the child who is a more skillful balancer should be able to explore his tolerance region to a further extent in balance space and maintain a steadier, vertical position in quiet standing, the findings of this study do not support the relationship.

Speculations about the effect of each of these independent postural mechanisms on the development of the overall balance repertoire of children have seldom been made. From the developmental stand point, this inverse relationship has support (Riach & Hayes, 1990). Although, both of these balance control mechanisms are based on different biomechanical, sensory and neuromuscular mechanisms, their development is interdependent. Feedback based postural responses, which are initially incorporated as the child learns to stand, are replaced by feedforward responses later on in childhood as balance control mechanisms become more sophisticated. In other words, the quality of performance based on one mechanism is related to the efficiency of the other, as with age they are used interchangeably (Riach & Hayes, 1990; Shumway-Cook & Woollacott, 1995). Overall, considering the suggestive results of this investigation and existing support from the literature, it seems logical for this relationship to exist. However, further investigations need to be carried out, especially regarding children with balance difficulties since they experience visible problems when attempting to carry out balance responses involving either mechanism.

In terms of feedback based balance control and the importance of visual input the results do only partially confirm the stated hypothesis. The lack of visual input did affect the performance of younger boys when compared to older peers, but made no difference to performances based on group condition. Also, the lack of significant differences between children with and without DCD when visual input was available was surprising as the past literature quite extensively underlined the problems children with motor difficulties exhibit when processing of visual input is required in order to generate motor output (Dwyer & McKenzie, 1994; Geuze & Kalverboer, 1987; Hulme et al, 1982a, 1982b; Lord & Hulme, 1987, 1988; Skorji & McKenzie, 1997; Wilson & McKenzie, 1998; Van Der Muelen et al., 1991). However, even more unexpectedly, when the visual input was denied and the differences between groups were expected to be more pronounced than in the eyes open task, the two groups once again did not differ from each other. These results led to the speculation that children with DCD are able to generate involuntary postural responses similar to those exhibited by able bodied peers when visual information is not provided. It may be argued that for children experiencing motor difficulties resulting from faulty CNS processing, not having to process visual input actually facilitates the information processing schema. In fact, children with DCD have been known to often experience sensory organization deficits as incoming information from various sensory sources becomes conflicting instead of complimentary (Riccio & Stoffregen, 1988; Wall & Taylor, 1982; Willoughby & Polatajko, 1995). As a result, minimizing the amount of incoming information may actually enhance the performance of these children simply due to the diminished complexity of the task and body constraints.

From the developmental perspective, the most evident differences in performance were obtained when children performed the quiet standing task with eyes closed. Based on the differences in means and considering the significant main effects obtained, it is obvious that younger children were not able to maintain their balance as effectively as older children in the eyes closed task. It seems that as visual input was removed, the older children were able to excel and their static balance was much more proficient than that of younger children. These findings confirmed previous research which pointed out that as the CNS matures, in terms of sensory information available for balance control mechanisms, children tend to rely on more sophisticated, complex sources of sensory information (Butterworth & Cicchetti, 1978; Foudriat et al., 1993; Hytonen et al., 1993; Riach & Hayes, 1987; Odenric & Sandstedt, 1984; Shumway-Cook & Woollacott, 1995; Wolff et al., 1998). As a result, it could be stipulated that as children reach the age of 9-10, their balance control schema relies more extensively on vestibular and somatosensory based information in order to control balance, compared to younger children who are very much dependent on visual information.

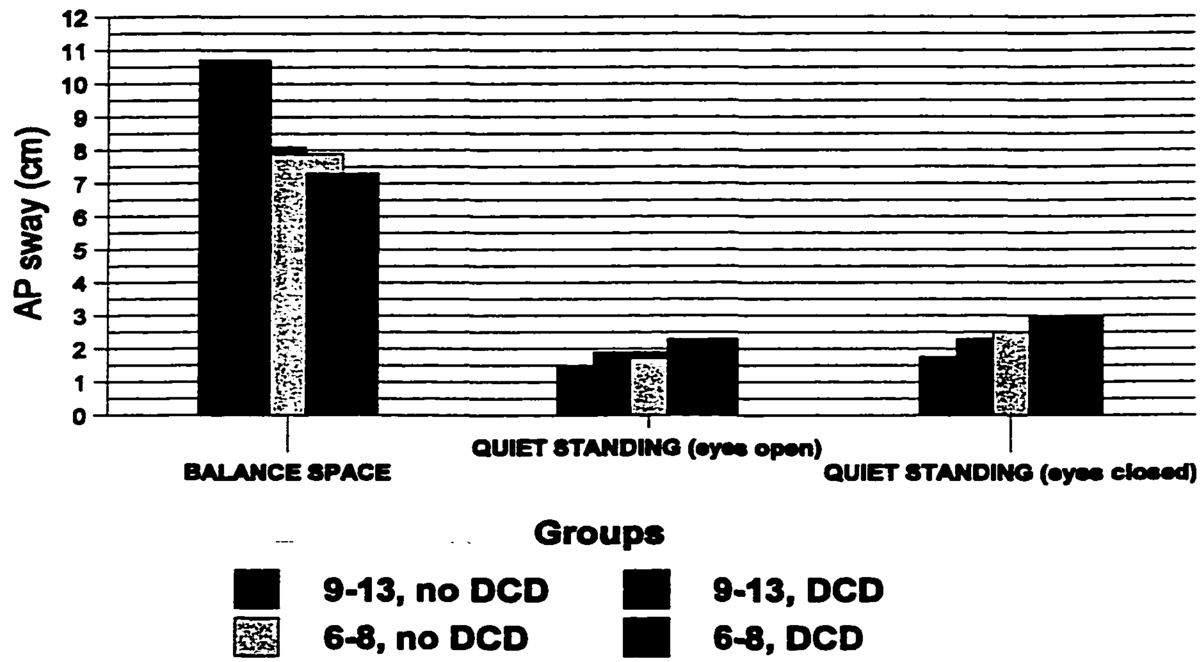


Figure 4 Performance patterns of individual groups based on AP sway scores within feedforward (balance space) and feedback tasks (quiet standing).

Results

Task effectiveness

One of the purposes of this study was to investigate the ability of different tasks (balance space and quiet standing) and their variations (eyes open vs closed task, one vs two feet balance) to effectively discriminate between the performance of children of different ages and skill level. This analysis is important for two reasons; a) there are no studies that have incorporated both, feedback and feedforward tasks in one analysis of balance control performance; and b) it has been suggested that quiet standing tasks may be too simple and one dimensional therefore the obtained performance may not reflect the actual balance control repertoire (Blaszczyk et al., 1993; Blaszczyk et al., 1994; Brouwer et al., 1998; Holbein & Chaffin, 1997; McCollum & Leen, 1989; Schieppati et al., 1994).

Since this kind of analysis had no precedence, it was crucial to identify criteria that would justify calling one task more efficient than the other. These criteria are a) the ability of children to successfully complete the task according to the protocol; b) ability of the task to demonstrate differences based on skill, age and the combination of the two independent variables; and c) evidence of logical relationships between the dependent measures based on the literature.

Balance space

All of the children were able to complete this task. Furthermore, the task was effective in showing main effects for age and condition, as well as interaction effects (see Appendix G1). Also the differences in swaying in the AP and lateral direction existed among children with and without DCD. In terms of dependent variables describing the task, factorial ANOVA indicated that area of sway and AP sway provided the greatest number of differences. The relationship between the two variables was also confirmed by Pearson partial correlation analysis, as the two measures were found to be most significantly correlated among all four variables ($r = .73$, $p < .001$) (see Appendix K). Also, a significant, negative relationship was found between the MABC TIS score (Total Impairment Score) and area of sway ($r = -.38$, $p < .05$), as well as AP sway ($r = -.52$, $p < .01$) (see Appendix K). These correlations support consensus that motor difficulties identified by the assessment tool were associated with poor performance on the balance space task and vice-versa.

Quiet standing (eyes open)

All of the participants were able to complete this task, however, MANOVA analyses provided only one significant main effect for age based on path length (see Appendix G 2). The correlations performed between the dependent variables and the MABC score did not reveal any significant relationships (see Appendix K).

Quiet standing (eyes closed)

This task was also successfully carried out by all of the participants, and similarly to the eyes open task, the MANOVA provided only a significant main effect for age (see Appendix G 2). When the strength of the relationship between dependent variables and MABC TIS score was examined, the relationship was found to be negatively significant, however not as strong as when the balance space measures were compared (see Appendix K).

Quiet standing (eyes open, on one leg)

This was the last task in the protocol and it examined the ability of children to stay as still as possible on either preferred or non preferred leg. Although the time requirement was reduced from the initial 20 seconds to 10 seconds, children still had to maintain a one leg stance without moving their foot or putting the non-supporting foot on the ground.

Even with the alterations to the protocol, children still experienced a lot of difficulties with this task. In the experimental group only five children were able to complete the task (two 6-8 year old, and three 9-13 year old). Of the five children, three of them (participant # 6, 18,and 42), were placed in the "at risk" (5-10% score) or "average" (at or above 15%) group, when assessed on the Total Balance Score from MABC. In the control group only four children were not able to complete the task (three 6-8, and one 9-13 year old) (see Appendix F).

Considering the performance of the experimental group it was not possible to include this particular task in the analysis, as overall 19 out of 40 children were not able to complete it. It was concluded that the task was too difficult, especially for children with balance difficulties.

Discussion

In investigations where there is no previous literature regarding the protocol or actual participants' behavior, it is difficult to judge if the occurring behavior is due to the manipulation of the task and the exhibited differences in skill, or it is due to other residual factors. The present investigation attempted to devise an unprecedented, more complex, approach to look at balance control, as well as to investigate the importance and sensitivity of the tasks in regards to age and skill level differences. Considering the criteria that were established as the ground rules for the evaluation and applicability of each task, it seems that the balance space task met all of the criteria most proficiently.

The first essential criterion considered, regards the ability of children to carry out the task. All of the children were able to perform the balance space task and quiet standing task with eyes open and closed. Standing on one leg turned out to be too difficult for children with balance problems, what may have been expected, as the majority of these children failed the static balance portion of Movement ABC assessment tool. When the balance space task is considered, it may be hypothesized that swaying as far as possible may cause falling or taking a step, especially when balance control mechanisms are not very efficient. However, in this study children in both groups were able to perceive their stability limits well enough to keep their feet motionless on the platform and avoid falling.

In terms of the tasks being able to dissociate groups based on different ages and skill levels, balance space appeared to be the most efficient. Since the pre-selection process (MABC) revealed significant differences in balance control abilities between the participants involved, it was expected that the different tasks would also provide significant statistical differences. In terms of developmental differences balance space and quiet standing with eyes open and closed tasks were able to differentiate between the younger and older children. However, when the differences between the children with DCD and no DCD were compared, balance space was the only task able to differentiate them. The most illuminating discrepancy in terms of exposing between group differences was evident when the interaction effects were examined. The quiet standing tasks failed to show any significant interaction effects, while balance space task provided three. Also, when the relationship between the sway in sagittal and lateral directions was considered, the balance space task was able to identify differences in both sways due to age and skill level, whereas the quiet standing task failed consistently. Overall, it was concluded that when the balance space task was the most sensitive in terms of detecting between group differences due to main and interaction effects, quiet standing tasks were much more sensitive to developmental differences than they were to the differences due to condition.

In recent years, the literature regarding balance control development has begun to emphasize the complexity of balance control mechanisms, and the subsequent need to address these issues (Blaszczyk et al., 1993; Blaszczyk et al., 1994; Holbein & Redfern, 1997; McCollum & Leen, 1989; Riach & Hayes, 1987; Schieppati et al., 1994). The new approach evident in the literature not only predicts the advantages of more complex approaches to the topic, but also points out the disadvantages of using only one specific approach. It was proposed that quiet standing tests may be too easy to illustrate differences a) between individuals with and without balance problems; b) young and old adults; and c) children and adults (Baloh et al., 1994; Stribley et al., 1974; Osinski et al., 1994; Perrin et al, 1997).

Overall, considering the results obtained in this study as well as the contribution from the previously quoted literature, balance control investigations should address the complexity of balance control mechanisms by incorporating most importantly feedforward tasks. Additionally, the relationship between the two tasks and related balance mechanisms, although presumed to exist based on present results, should be further explored.

SUMMARY AND RECOMMENDATIONS

The present study is a unique attempt at investigating phenomena that have either not been examined to a sufficient extent, or have not been examined at all. For that reason, the implications of this investigation have been presented in both statistical and theoretical terms.

Overall, the results partially supported the primary hypothesis that children with DCD and balance difficulties would be unable to generate balance responses as effectively as children without DCD. These differences however were not seen in the quiet standing task. Developmentally, younger children were also found to be less efficient balancers than their older peers in both, balance space and quiet standing with eyes open and closed. In addition, results on the balance space task showed that older boys from the control group were the most efficient balancers, whereas younger boys with DCD were the least efficient. Based on the pattern of results and related literature, it was suggested that boys with balance control difficulties performed similarly to boys from the control group who were 2 to 3 years younger. Despite the cross-sectional nature of this study, it was noted that the discrepancy between young and old children was greater in the experimental group than in the control group.

Analysis of performance in quiet standing, provided interesting insight into the ability to maintain balance with and without vision. The lack of visual input was detrimental to the performance of younger, but not older boys, confirming the negative relationship between the role of vision and balance control abilities. For children with balance problems, it was interesting to observe that balancing with eyes closed was not detrimental to their performance when compared to the control group. It was suggested that for children with motor difficulties, it may actually be easier to process information and carry out a motor output when sensory inputs are limited.

When the preliminary pilot study was carried out two objectives were set. Could the protocol distinguish between various skill levels of balance control, and would the results yield a logical conclusion concerning the relationship between the two tasks? Based on the results of this study, the balance protocol incorporated was able to distinguish groups based on skill level due to age and condition in balance space but not in the quiet standing tasks. In relation to the second objective, a negative relationship between the two tasks was tentatively proposed. More effective balancers scored higher on the balance space task and lower on the quiet standing task, reverse behavior occurring among the less efficient balancers. As a result, "good" balancers were better at perceiving their tolerance region and maintaining a steadier position than children who were less effective balancers. It was concluded that balance control abilities depend on the development and cooperation of both mechanisms.

Since the study had no precedence, there are a number of recommendations that could be made. Further analysis of both interrelated mechanisms should be carried out in order to: a) establish with more certainty their developmental pattern; b) their interrelationship; c) if experiencing problems in one area will evoke problems in the other; and d) if there is an age-related guideline for these problems to appear, plateau or disappear. Also incorporation of a longitudinal type of research is feasible as it may provide more insight into questions of persistence, and degree of delay. Finally, the results of this investigation as well as the possible follow ups, should be interpreted and incorporated in terms of generating a screening or assessment tool for children with balance difficulties.

BIBLIOGRAPHY

Amblard, B., & Carblanc, A. (1980). Role of foveal and peripheral visual information in maintenance of postural equilibrium in man. Perceptual and Motor Skills, 51, 903-912.

American Psychiatric Association (1994). Diagnostic and statistical manual of mental disorders, 4th edition. Washington. DC: American Psychiatric Association.

Advanced Mechanical Technology Incorporated (1997). Bio-Soft program. Watertown, Massachusetts: A.M.T.I.

Allum, J. H., & Honegger, F. (1993). Synergies and strategies underlying normal and vestibular deficient control of balance: implication for neuroprosthetic control. Progressive Brain Research, 97, 331-348.

Assaiante, C., & Amblard, B.(1995). An ontogenetic model for the sensorimotor organization of balance control in humans. Human Movement Science, 14, 13-43.

Bai, D., Bertenhal, B., & Sussman, M. (1987). Children's sensitivity to optical flow information for the control of stance. Abstracts of the third annual east coast clinical gait laboratory conference, (p.124).

Bairstow, P. J., & Laszlo, J. I. (1981). Kinaesthetic sensitivity to passive movements and its relationship to motor development and motor control. Developmental Medicine and Child Neurology,23, 606-616.

Bairstow, P. J., & Laszlo, J. I. (1989). Deficits in the planning, control and recall of hand movements in children with perceptuo-motor dysfunction. British Journal of Developmental Psychology, 7, 251-273.

Baloh, R., Fife, T., Zwerling, L., Socotch, T., Jacobson, K., Bell, T., & Beykirch, K. (1994). Comparison of static and dynamic posturography in young and older normal people. Journal of American Geriatric Society, 42 (4), 405-412.

Baloh, R., Jacobson, K., Beykirch, K., Honrubia, V. (1998). Static and dynamic posturography in patients with vestibular and cerebellar lesions. Archives of Neurology, 55 (5), 649-654.

Bauer, T., & Zerpa, C. (1997). Biomechanics laboratory operating manual. School of Kinesiology, Lakehead University, Thunder Bay, Canada.

Barona, R., Zapater, E., Montalt, J., & Armengot, M. (1994). The effects of visual feedback on balance. Acta Otolaryngol, 45, 161-165.

Berger, W., Discher, M. & Trippel, M. (1992). Developmental aspects of stance regulation. Experimental Brain Research, 90,610-619.

Blaszczyk, J., Hansen, P., Lowe, D. (1993). Postural sway and perception of the upright stance stability borders. Perception, 22, 1333-1341.

Blaszczyk, J., Hansen, P., Lowe, D. (1994). Ranges of postural stability and their changes in the elderly. Gait & Posture, 2, 11-17.

Brouwer, B., Culham, E., Liston, R., Grant, T. (1998). Normal variability of postural measures: implications for the reliability of relative balance performance outcomes. Scandinavian Journal of Rehabilitation and Medicine, 30, 131-137.

Bouffard, M., Strean, W., & Davis, W. (1998). Questioning our philosophical and methodological research assumptions: psychological perspective. Adapted Physical Activity Quarterly, 15, 250-268.

Butterworth, G., & Cicchetti, D. (1978). Visual calibration of posture in normal and motor retarded Down's Syndrome infants. Perception, 7,513-525.

Butterworth, G., & Hicks, L. (1977). Visual proprioception and postural stability in infants. Perception, 6, 255-262.

Burton, W., A., & Davis, E.(1992). Assessing balance in adapted physical education: fundamental concepts and applications. Adapted Physical Activity Quarterly, 9, 14-46.

Burton, A. W., & Miller, D., E. (1998). Movement skill assessment. Champaign, Illinois: Human Kinetics.

Causgrove-Dunn, J., & Watkinson, J. (1994). A study of relationship between physical awkwardness and children's perceptions of physical competency. Adapted Physical Activity Quarterly, 11, 275-283.

Clark, E., & Watkins, L., D. (1984). Static balance in young children. Child Development, 55, 854-858.

Collins, J., J., & De Luca, C. (1995). The effects of visual input on open-loop and closed-loop postural control mechanisms. Experimental Brain Research, 103, 151-163

Crowe, T. K., & Horak, F. B. (1988). Motor proficiency associated with vestibular deficits in children with hearing impairments. Physical Therapy, 68, 1493-1499

Davis, W., & Van Emmerik, R. (1995). An ecological task analysis approach for understanding motor development in mental retardation: research questions and strategies. Medicine and Sports Science, 40, 33-66.

Dichgans, J. & Diener, H. C. (1986). Different forms of postural ataxia in patients with cerebral diseases. In: Disorders of Posture and Gait (p. 54). Amsterdam , Holland: Elsevier.

Diekhoff, G. (1992). Statistics for the social and behavioral science: univariate, bivariate, multivariate. Dubuque: Wm. C. Brown Publishers.

Diener, H.C., Dichgans, J., Bachner, M., Gompf, B. (1984). Quantification of postural sway in normals and patients with cerebellar diseases. Electroencephalography and clinical Neurophysiology, 57, 134-142.

Diener, H.C., Hoare, J. Ivry, R. & Dichgans, J. (1993). Cerebral dysfunction of movement an perception. Canadian Journal of Neurological Science, 3, S62-69.

Dietz, V., Horstmann, G.A., & Berger, W. (1989). Significance of proprioceptive mechanisms in the regulation of stance. Progressive Brain Research, 80, 419-423.

Dwyer, C. & McKenzie, B. (1994). Impairment of visual memory in children who are clumsy. Adapted physical Activity Quarterly, 11, 179-189.

Enbom, H., Magnusson, M., Pyykko, I. (1991). Postural compensation in children with congenital or early acquired bilateral vestibular loss. Annual Otoloryngological Rhinola Lryngol, 100 (6), 472-478.

Ekdahl, C., & Jarnlo, G., B. (1989). Standing balance in healthy subjects. Scandinavian Journal of Rehabilitation and Medicine, 21, 187-195.

Fisher, A., Murray, E., & Bundy, A. (1991). Sensory integration: theory and practice. Philadelphia: E. F. Davis.

Figura, F., Cama, G., Capranica, L., Guidetti, L., & Pulejo., C. (1991). Assessment of static balance in children. Journal of Sports Medicine and Physical Fitness, 31(2), 235-242.

FitzGerald, J., Murray, A., Elliot, C., & Birchall, W. (1993). Comparison of balance assessment by sway magnotometry and force platforms. Archives of Otolaryngology and Head and Neck Surgery, 119 (1), 41-46.

Frank, J., & Earl, M. (1990). Coordination of posture and movement. Physical Therapy, 70, 855 - 861.

Fondriate, B., Di Fabio, R., Anderson, J. (1993). Sensory organization of balance responses in children 3-6 years of age: a normative study with diagnostic implications. International Journal of Pediatric Otorhinolaryngology, 27, 255-271.

Furman, M., J. (1993). Assessment: Posturography. Neurology, 43, 1261-1264.

Forssberg, H., & Nashner, L. (1982). Ontogenetic development of postural control in man: adaptations to altered support and visual conditions during stance. Journal of Neuroscience, 2, 545-552.

Fougue, F., & Bardy, B. (1997). Effects of postural stability on perception-movement coupling. Studies in Perception and Action, France: University of the Mediterranean Press.

Gantchew, G. N., & Draganova, N. (1986). Muscular synergies during different conditions of postural activity. Acta Physiologica Pharmacologica (Bulgaria), 12, (4), 58-65.

Gatev, P., Thomas, S., Lou, J. S., Lim, M., & Hallett, M. (1996). Effects of diminished and conflicting sensory information on balance in patients with cerebral deficits. Movement Disorders, 11, (6), 654-655.

Gay, L., R. (1987). Competencies for analysis and application (Third edition). Toronto, Canada: Merrill Publishing Company,

Gesell, A. (1946). The ontogenesis of infant behaviour. Manual of child psychology. New York: John Wiley & Sons.

Geurts, A., Nienhuis, B., Eng, M., & Mulder, T. (1993). Intra participant variability of selected force-platform parameters in the quantification of postural control. Archives of Physiology and Medical Rehabilitation, 74, 1144-1150.

Geuze, R. & Kalverboer, A. (1987). Inconsistency and adaptations in timing of clumsy children. Journal of Human Movement Studies, 13, 421- 431.

Geuze, R., & Kalverboer, A. (1994). Bimanual rhythmic coordination in clumsy and dyslexic children. Laboratory for Experimental Clinical Psychology. Groningen, The Netherlands.

Geuze, R., (1994). Static balance and developmental coordination disorder. Developmental & Experimental Clinical Psychology. Groningen, The Netherlands.

Geuze, R., & Borger, H. (1993). Children who are clumsy: Five years later. Adapted Physical Activity Quarterly, 10, 10-21.

Gipsman, S. C. (1981). Effect of visual condition on use of proprioceptive cues in performing a balance task. Visual Impairment and Blindness, 75, 50-54.

Goldie, P., Timothy, M., Owen, M., Evans, M. (1989). Force platform measures for evaluating postural control: reliability and validity. Archives of Physical Medicine and Rehabilitation, 70, 510-517.

Hass, G., Diener, H. & Bacher, M., & Dichgans, J. (1986). Development of postural control in children. Short, medium and long latency EMG responses of leg muscles after perturbation of stance. Experimental Brain Research, 64, 127-132.

Hay, L., & Redon, C. (1999). Feedforward versus feedback control in children and adults subjected to a postural disturbance. Experimental Brain Research, 125, (2), 153-162.

Hayes, K., C. (1982). Biomechanics of postural control. Exercise and Sport science Reviews, 10, 363-391

Henderson, S., & Sugden, D. (1992). Movement assessment battery for children. Manual. Harcourt Brace and Company, London, England.

Hirasawa, Y. (1979). An observation on standing ability of Japanese males and females. Journal of Anthropological Society of Japan, 87, 81-92.

Hirshfeld, H. (1992). On the integration of posture, locomotion and voluntary movements in humans: normal and impaired development. Nobel Institute for Neurophysiology. Stockholm, Sweden.

Hoare, D. (1994). Subtypes of developmental coordination disorder. Adapted Physical Activity Quarterly, 11, 158-169.

Hoare, D., & Larkin, D. (1991). Kinesthetic abilities of clumsy children. Developmental Medicine and Child Neurology, 33, 671-678.

Hoare, F., Henry, S., & Shumway-Cook, A. (1997). Postural perturbations: New insights for treatment of balance disorders. Physical Therapy, 517-533.

Holbein, M. A., & Chaffin, D. (1997). Stability limits in extreme postures: effects of load positioning , foot placement and strength. Human Factors, 39 (3), 456-468.

Holbein, M., & Redfern, M., S. (1997). Functional stability limits while holding loads in varius positions. International Journal of Industrial Ergonomics, 19 (5),387-395.

Horak, F. B. (1987). Clinical measurement of postural control in adults. Physical Therapy, 67, 1881-1885. In, Burton, A .W & Davis, W. E (1992). Assessing balance in Adapted physical education: fundamental concepts and application. Adapted Physical Activity Quarterly, 9, 14-46.

Horak, F., & Diener, H., C. (1994). Cerebral control of postural scaling and central set in stance. Journal of Neurophysiology, 72, 479-491.

Horak, F., & Nashner, L. (1986). Central programming of postural movements. Journal of Neurophysiology, 16, 1374 - 1381.

Horak, F., Nashner, L. M. & Diener, H. C. (1990). Postural strategies associated with somatosensory and vestibular loss. Experimental Brain Research,82, 167-177.

Hu, M., Hung, Y., Huang, Y., Peng, C., & Shen, S. (1996). Validity of force platform measures for stance stability under varying sensory conditions. Progressive National Science Council of Republic of China, 20 (3), 78-86.

Hufschmidt, A., Dichgans, J., Mauritz, K., H., & Hufschmidt, M. (1980). Some methods and parameters of body sway quantification and their neurological applications. Archives of Psychiatry and Neurological Sciences, 228, 135-150.

Hulme, C., Biggerstaff, A., Moran., & McKinlay, I. (1982a). Visual, kinaesthetic and cross-modal judgments of length by normal and clumsy children. Developmental Medicine and Child Neurology, 24, 461-471.

Hulme, C., Smart, A., & Moran, G. (1982b). Visual perceptual deficits in clumsy children. Neuropsychology, 20, 475-481.

Hulme, C., Smart, A., Moran, G., & Raine, A. (1983). Visual, kinaesthetic and cross-modal development: relationship to motor skill development. Perception, 12, 477-483.

Hulme, C., Smart, A., & Moran, G., & McKinlay, I. (1984). Visual, kinaesthetic and cross-modal judgments of length by normal and clumsy children. A comparison with young normal children. Child: Care, Health and Development, 10, 117-125.

Hytonen, M.., Pyykko, I., Aalto, H., & Starck, J. (1993). Postural control and age. Acta Otolaryngol, 113 (2), 119-122.

Jeong, Y., B. (1994). Contour representation of sway area in posturography and its application. The American Congress of Rehabilitation Medicine and Rehabilitation.

Jouen, F. (1984). Visual-vestibular interaction in Infancy. Infant Behaviour and Development, 7, 135-145.

Keshner, E. (1990). Controlling stability of a complex movement system. Physical Therapy, 70, 98-109.

Kuo, A.D., & Zajac, F. E. (1993). Human standing posture: multi-joint movement strategies based on biomechanical constrains. Progressive Brain Research, 97, 349-358.

Laszlo, J. & Bairstow, P. (1983). Kinaesthesis. Its measurement, training and relationship to motor control. Quarterly Journal of Experimental Psychology, 35, 411-421.

Laszlo, J., Bairstow, P. J., Bartrip, J., & Rolfe, U. T. (1989). Process oriented assessment and treatment of children with perceptuo-motor dysfunction. British Journal of Developmental Psychology, 7, 251-273.

Lee, D., & Aronson, E. (1974). Visual proprioceptive control of standing in human infants. Perceptual Psychophysics, 15, 529-532.

Lee, W., & Deming, L. (1987). Correlation between age and the size of the normalized static support base while standing. Proceedings of the 1987 Annual Meeting of the North American society of the Psychology of Sport and Physical Activity, 41.

Lee, D. N., & Lishman, J. R. (1975). Visual proprioceptive control of standing in human infants. Perception and Psychophysics, 15, 529-532.

Lefebvre, C., & Reid, G. (1998). Prediction in ball catching by children with and without a Developmental Coordination Disorder. Adapted Physical Activity Quarterly, 15, 299-315.

Lehman, F., Boswell, S., Price, A., Burleigh, A., deLateur, J., Jaffe, K., & Hertling, B. (1990). Quantitative evaluation of sway as an indicator of functional balance in post-traumatic brain injury. Archives of Physical Medicine and Rehabilitation, 71, 955-961.

Leonard, J. A. (1969). Static and mobile balance performance of blind adolescence grammar school children. New Outlook for the Blind, 63, 185-196.

Lestienne, F., Soechting, J., & Berthoz, A. (1977). Postural readjustments induced by linear motion of visual scenes. Experimental Brain Research, 28, 363-384.

Lord, R., & Hulme, C. (1987). Perceptual judgments of normal and clumsy children. Developmental Medicine and Child Neurology, 29, 250-257.

Lord, R., & Hulme, C. (1988). Visual perception and drawing ability in clumsy and normal children. British Journal of Developmental Psychology, 6, 1-9.

Massion, J.(1994). Movement, posture and equilibrium: interaction and coordination. Progress in Neurobiology, 38, 35-56.

McCollum, G., & Leen, T. (1989). Form and exploration of mechanical stability limits in erect stance. Journal of Motor Behaviour, 21, 225-244.

Missiuna, C., & Polatajko, H. (1995). Developmental dyspraxia by any other name: are they just clumsy children? The American Journal of Occupational Therapy, 49, 619-627.

Missiuna, C. (1994). Motor skill acquisition in children with Developmental Coordination Disorder. The American Journal of Occupational Therapy, 47, 214-233.

Mon-Williams, M., Pascal, E., & Wann, J. (1994). Ophthalmic factors in Developmental Coordination Disorder. Adapted Physical Activity Quarterly, 11, 170-178.

Mon-Williams, M., Tresilian, J. R., Wann, J. P. (1999). Perceiving limb position in normal and abnormal control: An equilibrium point perspective. Human Movement Science, 18, 397-419.

Nakagawa, H., Ohashi, N., & Watanabe, Y. (1993). The contribution of proprioception to posture control in normal subjects. Acta Otolaryngol, 504, 112-116.

Nashner, L., M., Black, F. O. & Wall, C. (1982). Adaptations to altered support and visual conditions during stance. Patients with vestibular deficits. Journal of Neuroscience, 2,536-544.

Nashner, L., M., Shumway-Cook, A., & Marin, O. (1983). Stance posture control in select groups of children with cerebral palsy. Deficits in sensory organization and muscular coordination. Experimental Brain Research,49, 393- 409.

Nashner, L., M., & McCollum, G. (1985). The organization of human postural movements. Behavioral and Health Science, 8,135-172.

Newnham, C., & McKenzie, B., E. (1993). Cross-modal transfer of sequential visual and haptic shape information by clumsy children. Perception, 22, 1061-1073.

Odenric, P., & Sandstedt, P. (1984). Development of postural sway in the normal child. Human Neurobiology, 3,241-244.

Osinski, W., Kowalczyk, J., Szeklicki, R., & Maciaszek., J. (1994). Measurement of static body balance by computer posturomentry. Biology of Sport, 11, 123-130.

Panzer, V., Bandinelli, S., & Hallet, M. (1995). Biomechanical assessment of quiet standing changes associated with aging. Archives of Physical Medicine and Rehabilitation, 76 (2), 151-157.

Parker, H., Larkin, D., & Ackland, R. (1993). Stability and change in children's skill. Psychological Research, 55, 182-189.

Perrin, P., Jeandel, C., Perrin, A., & Bene, M. (1997). Influence of visual control, conduction, and central integration on static and dynamic balance in healthy older adults. Gerontology, 43 (4), 223-231.

Peterka, R., Black, F.O. (1987). Normal and abnormal human vestibular ocular function. NASA Cooperative Agreement, NCC 9-8.

Piek, J., & Coleman-Carman, R. (1995). Kinaesthetic sensitivity and motor performance of children with Developmental Coordination Disorder. Developmental Medicine and Child Neurology, 37, 976-984.

Prat, NE. (1991). Clinical musculoskeletal anatomy. Philadelphia. Pa.. JB Lippincott Co.

Prechtl, HFR. (1986). Prenatal motor development. From model of development in children: aspects of coordination and control. Dodrecht, Germany: Martinus Nighoff.

Prieto, T., Myklebust, J., Hoffmann, R., Lovett, E., & Myklebust, B. (1996). Measures of postural steadiness: differences between healthy young and elderly adults. Trans-Biomedical Engineering,43 (9), 956-966.

Redfern , M., & Furman, J. (1994). Postural sway of patients with vestibular disorders during optic flow. Department of Otolaryngology, University of Pittsburgh, 4, 221-230.

Riach, L. & Hayes, C. (1990). Anticipatory postural control in children. Developmental Medicine and Child Neurology, 32, 250-266.

Riach, L., & Hayes, C. (1987). Maturation of postural sway in young children. Developmental Medicine and Child Neurology, 29, 650-658.

Riccio, G., & Stoffregen, T. (1988). Affordances as constraints on the control of stance. Human Movement Science, 7, 265-300.

Ring, C., Nayak, S., & Isaacs, B. (1989). The effect of visual deprivation and proprioceptive change on postural sway in healthy adults. Journal of American Geriatric Society, 37 (8), 745-749.

Rogers, M., Kukulka, C., & Soderberg, G. (1988). Age-related changes in postural responses preceding rapid self - paced and reaction time arm movements. Journal of Gerontology, 47, 159-165.

Runge, C. F., Shupert, C. L. Horak, F. B. & Zajak, F. (1998). Role of vestibular information in initiation of rapid postural responses. Experimental Brain Research, 122, 403-412.

Schieppati, M., Hugon, M., Grasso, M., Nardone, A., & Galante, M. (1994). The limits of equilibrium in young and elderly normal subjects and in parkinsonians. Electroencephalography and Clinical Neurophysiology, 93, 286-298.

Sherrill, C. (1998). Adapted physical Activity, Recreation and Sport. Cross disciplinary and Life span. Boston: WCB, McGraw-Hill.

Shumway-Cook, A. (1985). Dynamics of postural control in the child with Down syndrome. Physical Therapy, 65 (9), 1315-1322.

Shumway-Cook, A., & Horak, F. (1987). A critical examination of vestibular function in motor impaired learning-disabled children. International Journal of Pediatric Otorthinorynalogy, 14, 21-30.

Shumway-Cook, A., & Horak, F. (1990). Rehabilitation strategies for patients with vestibular deficits. Diagnostics Neurology, 8, 441-457.

Shumway-Cook, A., & Woollacott, M. (1985). The growth of stability: postural control from a developmental perspective. Journal of Motor Behaviour, 2, 131-147.

Shumway-Cook, A., & Woollacott, M. H. (1995). The growth of stability: postural control from a developmental perspective. In (Eds.), Motor control: theory and practical applications (p.143-165). Baltimore: Williams and Wilkins.

Sims, K., Henderson, S., Hulme, C., & Morton, J. (1996). The remeditiation of clumsiness. (1996). Development Medicine and Child Neurology, 38, 976-987.

Skorji, V., & McKenzie, B., E. (1997). How do children who are clumsy remember modelled movements? Developmental Medicine and Child Neurology, 39, 404-408.

Slobounov, S., & Newell, K. (1992). Postural dynamics in upright and inverted stance. Journal of Applied Biomechanics, 12, 185-196.

Slobounov, S., Slobounov, E., & Newell, K. (1997). Virtual time to collision and human postural control. Journal of Motor Behaviour, 29, 263-281.

Smyth, T. R. & Glencross, D. J. (1986). Information processing deficits in the clumsy children. Australian Journal of Psychology, 38, 13-22.

Smyth, T., R. (1991). Abnormal clumsiness in children: a defect of motor programming?. Child, Health, Care and Development, 17, 283-294.

Smyth, M., & Mason, U. (1997). Planning and execution of action in children with and without DCD. Journal of Child Psychology and Psychiatry, 38, 1023-1037.

Starkes, J., & Riach, C., L. (1990). The role of vision in postural control of children. Clinical Kinesiology, 44, 72-77.

Stoffregen, T. A. (1985). Flow structure versus retinal location in the optical control of stance. Journal of Experimental Psychology: Human Perception and Performance, 11, 554-565.

Stoffregen, T. A. (1986). The role of optical velocity in the control of stance. Perception and Psychophysics, 39, 355-360.

Stoffregen, T., Schmuckler, M., & Gibson, E. (1987). Use of central and peripheral optical flow in stance and locomotion in walkers. Perception, 16, 113-119.

Stribley, R., Albers, W., Tourtellotte, W., & Cockrell., L. (1974). A quantitative study of stance in normal subjects. Archives of Physical Medicine and Rehabilitation, 55, 74-80.

Sugden, D., & Sugden, L. (1991). The assessment of movement skill problems in 7- and 9- year old children. British Journal of Educational Psychology, 61, 329-345.

Suomi, R., & Koceja, D. (1994). Postural sway patterns of normal men and women and men with mental retardation. Physical Medicine and Rehabilitation, 75,205-219.

Taylor, J. (1984). Assessing physical awkwardness: A learning disability. In A. Brown, D. Brickell, L. Groves, E. McLeish, P. Morris, D. Sugden (Eds.). Adapted physical activities. Bishop Stortford, UK: Jenny Lee.

Taylor, J. (1993). Assessment and prescription for children who are physically awkward: A manual. Thunder Bay, Canada: Lakehead University Press.

Thomas, J. R., & Nelson, J. K. (1996). Research methods in physical activity. Champaign, Illinois, Human Kinetics.

Usai, N., Maekawa, K., & Hirasawa, Y. (1995). Development of the upright postural sway of children. Developmental Medicine and Child Neurology, 37, 985-996.

Vamos, L., & Riach, C. L. (1992). Postural stability limits and vision in the older adult. Posture and Gait: Control Mechanisms. University of Oregon Books, Eugene, OR.

Van Dellen, T., & Geuze, R. H. (1988). Motor response processing in clumsy children. Journal of Child Psychology and Psychiatry, 29, 489-500.

Van Dellen, T., & Geuze, R. H. (1990). Experimental studies on motor control in clumsy children. In A.F. Kalverboer (Ed.). Developmental biopsychology: Experimental and observational studies in children at risk (pp187-205). Ann Arbor, MI: University of Michigan Press.

Van der Muelen, J. H. P., Denier van der Gon, J. J., Gielen, C. C. A., Gooskens, R., H., & Willemse, J. (1991). Visuomotor performance of normal and clumsy children. Fast goal-directed arm movements with and without visual feedback. Developmental Medicine and Child Neurology, 33, 40-54.

Van der Linden, D.W., Carlson, SJ., & Hubbard, RL. (1992). Reproducibility and accuracy of angle measurements obtained under static conditions with motion analysis video system. Physical Therapy, 1992, 300-305.

Vidal, P. P., Berthoz, A., & Millanvoy, M. (1982). Difference between eye closure and visual stabilization in the control of posture in man. Aviation, Space, and Environmental Medicine, 53,166-170.

Visser, J., Geuze, R., H, Kalverboer, A., F. (1998). The relationship between physical growth, the level of activity and the development of motor skill in adolescence: Differences between children with DCD and controls. Human Movement Science, 17, 573-608.

Wall, A. E., & Taylor, J. (1984). Physical awkwardness: A motor development approach to remedial intervention. In A. Brown, D. Brickell, L. Groves, E. McLeish, P. Morris, D. Sugden (Eds.). Adapted physical activities. Bishop Stortford, UK: Jenny Lee.

Wann, J. P., Mon-Williams, M., & Rushton, K. (1998). Postural control and co-ordination disorders: The swinging room revisited. Human Movement Science, 17, 491-513.

Weber, P., & Cass, P. (1993). Clinical assessment of postural stability. The American Journal of Ontology, 14,566-573.

Weir, J. (1992). Teacher identification of physically awkward school children. Unpublished Master's Thesis, University of Alberta, Edmonton.

Westcott, S., Pax Lowes, L., & Richardson, P. (1997). Evaluation of postural stability in children: current theories and assessment tools. Physical Therapy, 77, 629-643.

Williams, H. G., Fisher, J. M. & Tritschler, K., A. (1983). Descriptive analysis of static postural control in 4, 6, and 8 year old normal and motorically awkward children. American Journal of Physical Medicine, 62, 12-26.

Williams, H. G., McClenaghan, B., & Ward, D. S. (1985). Duration of muscle activity during standing in normally and slowly developing children. American Journal of Physical Medicine, 64, 171-189.

Willoughby, C., & Polatajko, H. (1994). Motor problems in children with Developmental Coordination Disorder: review of literature. The American Journal of Occupational Therapy, 49, 787-793.

Wilson, P H., & Maruff, P. (1999). Deficits in the endogenous control of covert visuospatial attention in children with Developmental Coordination Disorder. Human Movement Science, 18, 421-442.

Wilson, P H., & McKenzie, B. E. (1998). Information deficits associated with Developmental Coordination Disorder: a meta analysis of research findings. Journal of Child Psychology and Psychiatry, 39,829-840.

Winter, D.(1993). Human balance and posture control during standing and walking. Department of Kinesiology, University of Waterloo.

Wolff, D., Rose, J., Jones, K., Bloch, D., Oehlert, J., & Gamble, J. (1998). Postural balance measurements for children and adolescence. Journal of Orthopaedic Research, 16, 271-275.

Woollacott, M. H., & Shumway-Cook, A. (1990). Changes of posture control across the life span- a system approach. Physical Therapy, 70, 799-807.

Woollacott, M. H., Burner, P., Jensen, J., Joysticks, J., Roncevalles, N., & Sveistrup, H. (1998). Development of postural responses during standing in healthy children and children with spastic diplegia. Neuroscience and Behavioral Reviews, 22 (4), 583-589.

Woollacott, M., Debu, B., & Mowatt, M. (1987). Neuromuscular control of posture in the infant and child: is vision dominant. Journal of Motor Behavior, 19, 167-186.

Woollacott, M., & Shumway-Cook, A. (1996). Concepts and methods of assessing postural instability. Journal of Aging and Physical Activity, 4, 214-233.

Woolley, S., Rubin, M., & Kantner, R., M & Armstrong, C. W. (1993). Differentiation of balance deficits through examination of selected components of static stabilometry. Journal of Otolaryngology, 22, 368-378.

Wright, H., Ng, R., Sugden, D., & Tan, J. (1994). Identification of children with movement problems in Singapore: usefulness of the movement ABC checklist. Adapted Physical Activity, 11, 150-157.

Wright, H., & Sugden, D. (1996). The nature of Developmental Coordination Disorder: inter- and intra-group differences. Adapted Physical Activity Quarterly, 13, 357-371.

Zernicke, R., Gregor, R., & Cratty, B. (1982). Balance and visual proprioception in children. Journal of Human Movement Science, 8, 1-13.

APPENDIX A
PILOT STUDY RESULTS

Table A1. Correlation matrix between balance space dependent variables.

	Path length	AP sway	Lat sway
Area of sway	0.72	0.82	0.78
Path length	----------------------	0.67	0.87
AP sway		----------------------	0.79

$p < .05$

Table A2. Correlation matrix between quiet standing dependent measures.

	Path length	AP sway	Lat sway
Area of sway	0.69	0.88	0.79
Path length	----------------------	0.71	0.76
AP sway		----------------------	0.8

$p < .05$

Table A3. Correlation matrix between balance space and quiet standing dependent measures.

	QS Path length	QS AP sway	QS Lat sway
BS Area of sway	-0.49	-0.29	-0.43
BS Path length	----------------------	-0.54	-0.53
BS AP sway		----------------------	-0.48

$p < .05$

Note1: BS (balance space), QS (quiet standing)

APPENDIX B
TEACHER COVER LETTER

COVER LETTER

Dear Teacher:

Dr. Jane Taylor, from kinesiology Department of Lakehead University, and I, Eryk Przysucha, have been involved in an international study with colleagues from University of Groningen, Holland. The study regards the development of balance control in children with and without Developmental Coordination Disorder.

The purpose of this study is to identify the differences in balance performance between children with and without motor deficiencies. It will also investigate the developmental differences between age groups, based on performance on dynamic and static balance tasks. The ultimate goal is to map the sources of balance problems that children with poorer physical abilities experience, and create a research tool that would successfully identify these problems.

In order to perform this study, a group of children with Developmental Coordination Disorder is required. Considering the age group that the study is focused on, we would be interested in using children from Your class. There will be two stages involved in the screening process of children with motor problems: a screening process completed by You, the teacher, in the school environment, based on a ten questions questionnaire: the "Motor Behavior Checklist", and a formal physical efficiency test (Movement ABC), carried out at Lakehead University. The process of checklist administration will be explained to You by one of the study coordinators. This particular tool has been used successfully in previous studies involving a screening process of school children with motor deficiencies. The completion of the attached questionnaire should not take longer than 20 minutes.

If You are interested in participating in this study, please MAIL YOUR SIGNED CONSENT FORM TODAY, in the envelope attached. Any questions or concerns related to the content of the questionnaire, or to the information based on it, will be addressed on individual bases with the study coordinator: Dr. Jane Taylor or Eryk Przysucha. You will be also provided with a summary of results of the testing carried out after Your referral.

ANY INFORMATION CONTAINED IN THE QUESTIONNAIRE IS STRICTLY CONFIDENTIAL, AND MAY NOT BE RELEASED WITHOUT A WRITTEN CONSENT OF THE CHILD'S PARENTS.

Sincerely,

Dr. __________
and __________

343 - 8752

APPENDIX C
PARENTS COVER LETTER

COVER LETTER

Dear Parent:

Dr. Jane Taylor, from kinesiology Department of Lakehead University, and I, Eryk Przysucha, have been involved in an international study with colleagues from University of Groningen, Holland. The study regards the development of balance control in children with and without Developmental Coordination Disorder.

The purpose of this study is to identify the differences in balance performance between children with and without motor deficiencies. It will also investigate the developmental differences between age groups, based on performance on dynamic and static balance tasks. The ultimate goal is to map the sources of balance problems that children with poorer physical abilities experience, and create a research tool that would successfully identify these problems.

The process of sample selection and balance testing consists of three steps: screening process by teachers, administration of a formal physical efficiency test (Movement ABC) by research personal at Lakehead University, and lastly the actual balance test.

The teacher of Your child expressed concern about Your child's motor skill development, subsequently referring him/her as a possible candidate for the study. In order to assess your child's physical performance a series of physical tests, such as catching, throwing, manual dexterity and balance, would be administered. The test would take place at Lakehead University, at Your time convenience, and it should take about 30 minutes. If the results of the test comply with the referral and the requirements for the study, Your child will be subsequently tested on balance performance. This test would also take place at Lakehead University at the time convenient to You.

The balance test will be performed on a stationary balance platform, and it will consist of a series of tasks such as swaying in different directions, standing on one or two feet, and standing on one or two feet with eyes open or closed. This is a standard balance test that has been effectively in other studies of this kind. The tasks at hand are safe, and it will take about 45 minutes.

The results of the Movement ABC and of balance testing are strictly confidential, and it will be only released to You, and Your child's teacher, on your prior consent.

Sincerely,

Dr. __________
and __________

APPENDIX D
PARENTS CONSENT FORM

PARENTS COVER LETTER
A COMPARISON OF BALANCE PERFORMANCE
IN BOYS WITH AND WITHOUT
DEVELOPMENTAL COORDINATION DISORDER

CONSENT FORM

My signature on this form indicates that my son will participate in a study by Dr. Jane Taylor, and Eryk Przysucha, on development of balance control.

I have received an explanation about the nature of the study and its purpose.

I understand the following:

1. My child will be initially assessed by his home room teacher.
2. All information collected during the study will be number coded and the name of my child will not be used at any time in reporting or use of information collected.
3. My child is a volunteer and can withdraw from the study at any time.
4. There appears to be no danger of physical or psychological harm.
5. The data provided by my child will remain confidential, and be stored for seven(7) years in the School of Kinesiology, at Lakehead University.
6. I will receive a summary of the project, upon request, following the completion of the study.

Please return this form to your child's teacher as soon as possible.

____
Signature of Parent or Guardian Date

____
Phone number of Parent or Guardian

To arrange test time call Eryk Przysucha at 343-8752.

APPENDIX E
MOTOR BEHAVIOR CHECKLIST

MOTOR BEHAVIOUR CHECKLIST

Teacher's Name ______________________ Student's Name ____________________

School ______________________________ Birthdate ____________________

Sex _____________ Age __________ Grade _________

Please answer the following question.

<u>I am concerned about the motor development of this child.</u> YES NO

If you answered YES, please complete the rest of the form.

1. When running this child is usually:

/______________________/___________________/______________________/

very uncoordinated | uncoordinated | coordinated | very coordinated

2. This child dresses quickly and efficiently before recess:

/______________________/___________________/______________________/

rarely | sometimes | usually | always

3. This child uses playground equipment:

/______________________/___________________/______________________/

rarely | sometimes | usually | always

4. This child usually catches a ball:

/______________________/___________________/______________________/

awkwardly | fairly well | easily | very easily

5. This child participates in ball games:

rarely	sometimes	usually	always

6. This child enjoys playing on climbing equipment:

rarely	sometimes	usually	always

7. This child tires easily and needs frequent rests:

rarely	sometimes	usually	always

8. This child seems to be:

very unfit	unfit	fit	very fit

9. This child avoids participating in games with his/her peers:

rarely	sometimes	usually	always

10. This child avoids participating in physical education classes:

rarely	sometimes	usually	always

APPENDIX F
PARTICIPANTS PERFORMANCE ON MABC AND CRITERIA CONSIDERED FOR GROUP SELECTION

Table. Individual performance of participants on selection criteria.

PARTICIP. NUMBER	GROUP	AGE	MABCRS	%MABC	MABC TBS	% TBS	ST	DB	Check List	# of CRITERIA MET
5	1	7	3	65	2	15	2	0	no	0
8	1	6	1	89	0	15	0	0	no	0
14	1	6	9	18	5	15	3	2	no	0
47	1	7	4.5	15	0.5	15	0.5	0	no	0
19	1	8	3	65	0	15	0	0	no	0
23	1	7	8	22	0	15	0	0	no	0
26	1	6	6.5	32	4.5	15	4.5	0	no	0
32	1	7	6.5	32	0	15	0	0	no	0
36	1	7	2	79	0	15	0	0	no	0
46	1	8	9	18	3	15	3	0	no	0
1	2	9	0	100	0	15	0	0	no	0
9	2	12	2	84	0	15	0	0	no	0
11	2	12	8	22	3	15	3	0	no	0
13	2	11	5	45	4	15	4	0	no	0
17	2	11	4	54	1	15	0	1	no	0
24	2	11	4	54	3	15	3	0	no	0
25	2	11	3	65	3	15	3	0	no	0
29	2	9	3	65	0.5	15	0.5	0	no	0
30	2	11	5	45	5	15	3	2	no	0
33	2	10	1	93	0	15	0	0	no	0
12	3	8	21	3	7.5	5	4.5	3	yes	3
15	3	6	12.5	7	8.5	5	4.5	4	yes	2
21	3	7	15.5	3	7.5	5	3.5	4	yes	3
28	3	6	17.5	1	9	5	4	5	yes	3

39	3	8	17.5	1	10	5	5	5	yes	3
40	3	6	20.5	1	10.5	5	5	5.5	yes	3
41	3	8	29.5	<1	14.5	5	4.5	10	yes*	3
42	3	7	18	1	3.5	15	3	0.5	yes	2
44	3	7	17	2	8.5	5	5	3.5	yes	3
18	3	8	15	5	6.5	3665 5	3.5	3	yes	2
7	4	12	15	5	7	3665 5	5	2	yes	2
10	4	10	12	8	8	5	4	4	no	2
20	4	11	20	<1	12	5	5	7	yes	3
35	4	9	15.5	3	12	5	3	9	yes	3
37	4	9	26	<1	11	5	2	9	yes	3
38	4	10	17.5	1	8.5	5	5	3.5	yes	3
43	4	13	27.5	<1	9.5	5	5	4.5	yes*	3
45	4	9	23	<1	5	15	5	0	yes*	2
6	4	11	17	2	7.5	5	4	3.5	no	2

Note1: MABCRC (Movement Assessment Battery for Children Total Raw Score), %MABC (raw score transformed into percentile on MABC), MABCTBS (MABC Total Balance Score), %TBS (raw balance score transformed into percentile on balance portion of MABC), ST (MABC static balance score), BD (MABC dynamic balance score), Check List (Motor Behavior Checklist, "yes"identifies children with motor problems, "no" identifies children with no balance problems).

Note 2: * participants that were evaluated to have motor problems based on referral and not Motor Behavior Checklist.

APPENDIX G
FACTORIAL ANALYSIS OF VARIANCE (ANOVA)
BALANCE SPACE AND QUIET STANDING TASKS

Table G1.

Summary of ANOVA analysis for main effects for Age and Condition and Age x Condition interaction effects, based on area of sway, path length, AP and Lat sway in balance space task.

Dependent Measures	df	Mean Square	F
Area of sway			
Between groups	3	236.618	19.773***
Condition	1	241.694	20.157***
Age	1	380.913	31.767***
Condition x Age	1	68.53	5.716*
Within groups	36	11.991	
Path Length			
Between groups	3	1165.165	5.28**
Condition	1	651.94	2.956
Age	1	1277.44	5.791*
Condition x Age	1	1492.34	6.766*
Within groups	36	220.574	
AP sway			
Between groups	3	21.78	12.21***
Condition	1	23.73	13.303***
Age	1	31.39	17.599***
Condition x Age	1	8.57	4.806*
Within groups	36	1.78	
Lat sway			
Between groups	3	12.307	7.341**
Condition	1	5.22	3.115
Age	1	29.43	17.556***
Condition x Age	1	1.36	.815
Within groups	36	1.677	

Note: * significant at $p < .05$, ** $p < .01$, *** $p < .001$.

Table G2.
Summary of ANOVA for main and interaction effects, based on area of sway, path length, AP and Lat sway in quiet standing with eyes open and closed tasks.

Dependent Measures	Variance	Eyes open			Eyes closed		
		df	MS	F	df	MS	F
Area of sway							
	Between groups	3	.144	2.401	3	.152	1.920
	Condition	1	.334	5.571*	1	.162	2.043
	Age	1	6.625	1.106	1	.230	2.894
	Condition x Age	1	2.579	.431	1	5.34	.673
	Within groups	36	5.989		36	7.94	
Path Length							
	Between groups	3	353.47	4.575**	3	212.32	2.06
	Condition	1	185.23	2.398	1	99.87	.972
	Age	1	736.75	9.536**	1	457.48	4.451*
	Condition x Age	1	125.44	1.624	1	72.57	.706
	Within groups	36	77.26		36	102.77	
AP sway							
	Between groups	3	1.07	2.28	3	1.31	3.623*
	Condition	1	2.07	4.701*	1	1.54	4.265*
	Age	1	.743	1.6846	1	2.18	6 .016*
	Condition x Age	1	.125	.283	1	.106	.294
	Within groups	36	.441		36	.362	
Lat sway							
	Between groups	3	1.15	2.53	3	1.388	2.407
	Condition	1	1.85	4.086*	1	.131	.227
	Age	1	1.01	2.223	1	2.91	5.047*
	Condition x Age	1	.506	1.113	1	1.01	1.757
	Within groups	36	.455		36	.577	

Note1: * significant at $p < .05$, ** $p < .01$, *** $p < .001$

APPENDIX H
PLANNED COMPARISONS

Table H1.
A t-test, planned comparisons in balance space task based on area of sway, path length, AP and Lat sways.

Compared Groups	Area of sway t	Path length t	AP sway t	Lat sway t
1 vs 2	5.754***	3.590***	4.579***	3.651***
1 vs 3	1.505	-0.632	1.043	0.618
1 vs 4	-0.8	-0.48	-0.382	-1.692
2 vs 3	-7.259***	-2.958**	-5.622***	-4.269***
2 vs 4	-4.809***	-3.014**	-4.07***	-1.861
3 vs 4	2.264 *	-0.136	1.397	2.294*

Note 1: Group1 (control 6-8), Group 2 (control 9-13), Group3 (experimental 6-8), Group 4 (experimental 9-13)

Table H2.
A t-test, planned comparisons in quit standing task with eyes open an closed based on area of sway, path length, AP and Lat sways.

Groups	Area of sway t		Path length t		AP sway t		Lat sway t	
	open	closed	open	closed	open	closed	open	closed
1 v 2	1.224	1.808	1.300	.910	.549	2.14*	1.85	2.56*
1 v 3	-1.19	-.436	-2.023	-1.30	-1.93	-1.092	-.683	.608
1 v 4	-.913	.190	1.074	.784	-.607	.270	-.375	1.23
2 v 3	2.44*	2.24*	3.324**	2.21*	2.48*	3.23**	2.484*	1.95*
2 v 4	2.105*	1.570	.191	.102	1.14	1.819	2.175*	1.81

Note 1: Group1 (control 6-8), Group 2 (control 9-13), Group3 (experimental 6-8), Group 4 (experimental 9-13)

Note: * significant at p <.05, ** p < .01, *** p <.001

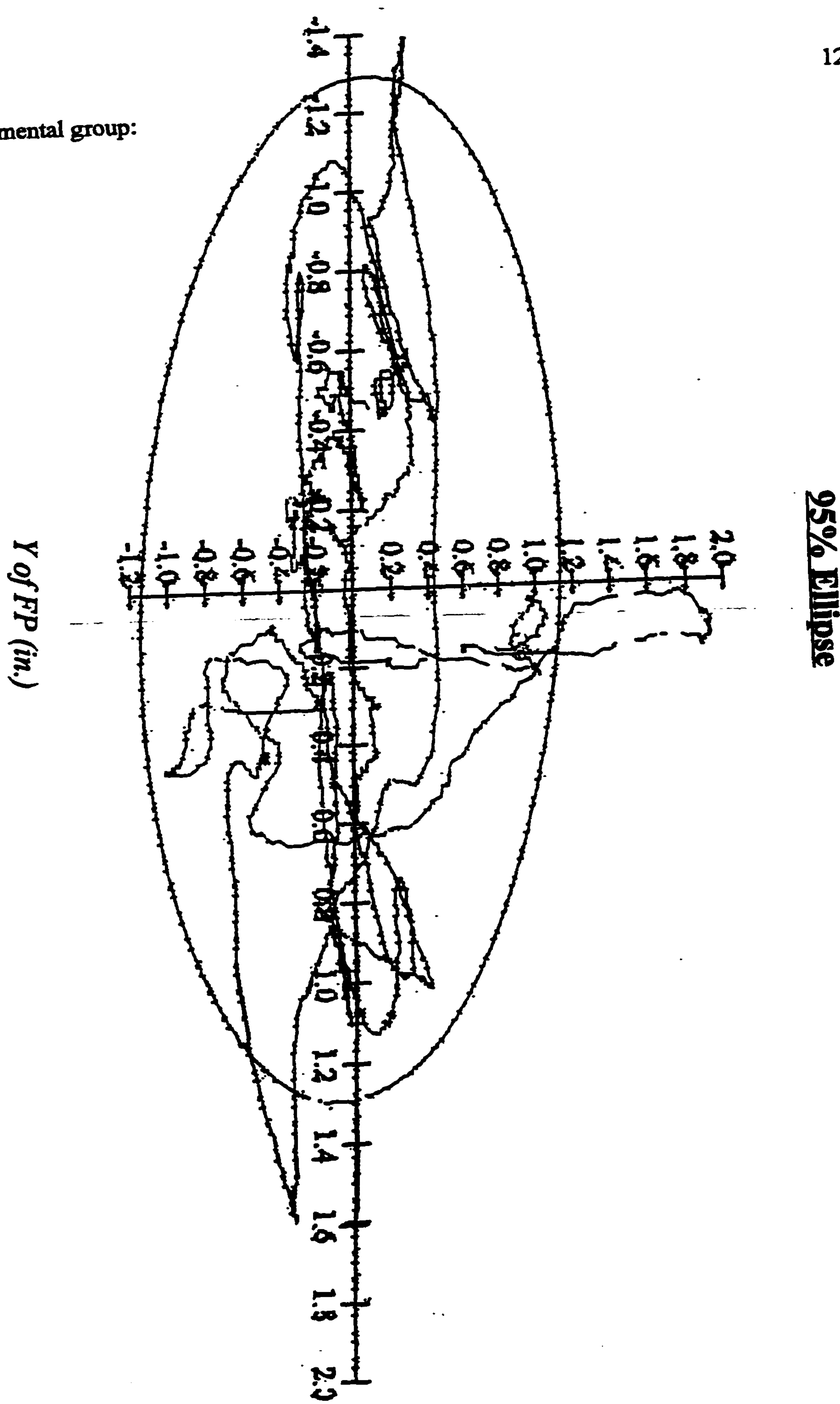
APPENDIX I
ANTERIOR-POSTERIOR AND LATERAL SWAYS IN THE THREE TASKS

Table I1.
Means and standard deviations for anterior-posterior (AP) and lateral (Lat) sways based in balance space and quiet standing with eyes open and closed tasks.

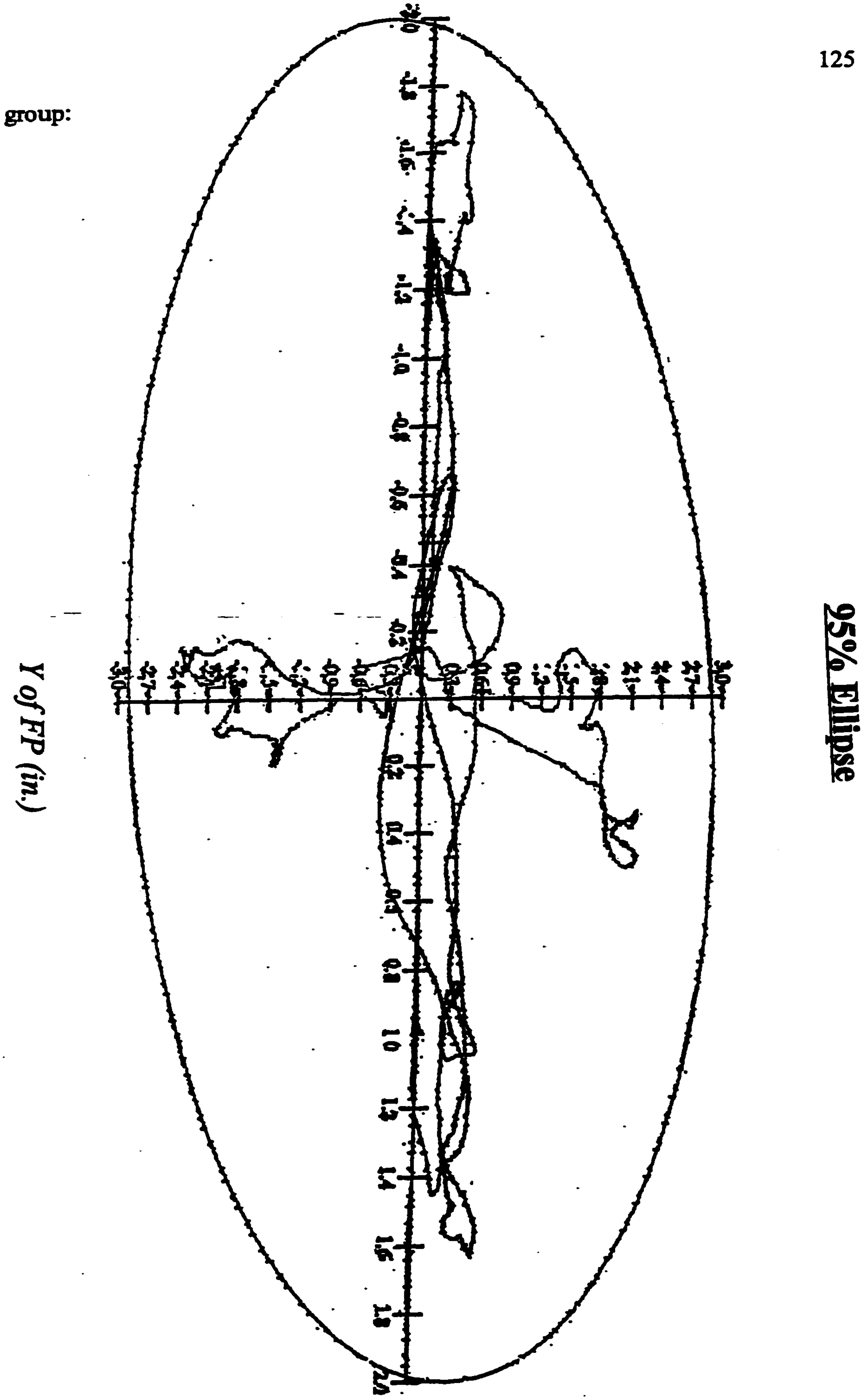
Groups	Balance Space		Quiet Standing (Eyes open)		Quiet Standing (Eyes Closed)	
	AP	Lat	AP	Lat	AP	Lat
Group1	7.93 (.42)	8.10 (.40)	1.74 (.46)	1.97 (.55)	2.33 (.52)	2.49 (.72)
Group2	10.66 (.42)	10.21 (.40)	1.58 (.77)	1.41 (.55)	1.75 (.62)	1.62 (.64)
Group3	7.30 (.42)	7.74 (.40)	2.32 (.63)	2.06 (.90)	2.63 (.57)	2.29 (.85)
Group4	8.16 (.44)	9.10 (.43)	1.93 (.74)	2.09 (.68)	2.26 (.68)	2.06 (.80)

APPENDIX J
ANALYSIS OF COP EXCURSION DURING BALANCE SPACE TASK

A) Experimental group:



B) Control group:



APPENDIX K
PEARSON CORRELATIONS BETWEEN MEASURES OF BALANCE SPACE AND QUIET STANDING TASKS

Table K 1.
Pearson correlations between balance space measurers and Total Impairment Score from MABC assessment tool.

Dependent variable	Path length	AP sway	Lat sway	TIS
Area of sway	.33*	.73***	.53**	-.38*
Path length	————	.60***	.56***	-.60***
AP sway		————	.50**	.-52**
Lat sway			————	-.51**

Table K 2.
Pearson correlations between quiet standing measures in eyes open (A) and closed (B) conditions and Total Impairment Score from MABC assessment tool.
A)

Dependent variable	Path length	AP sway	Lat sway	TIS
Area of sway	.65***	.66***	.86***	-0.17
Path length	————	.53***	.58***	-0.35
AP sway		————	.38*	-0.11
Lat sway			————	-0.12

B)

Area of sway	.64***	.38**	.67***	-.38**
Path length	————	.64***	.83***	-.60***
AP sway		————	.32*	-.52***
Lat sway			————	-.51***

Note1: * significant at p <.05, ** p <.01, *** p<.001