Control of Stance and Developmental Coordination Disorder: The Role of Visual Information

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The purpose of this study was to compare the postural sway profiles of 20 boys with and without Developmental Coordination Disorder (DCD) on two conditions of a quiet standing task: eyes open and eyes closed. Anterior-posterior (AP) sway, medio-lateral sway (LAT), area of sway, total path length, and Romberg’s quotient were analyzed. When visual information was available, there was no difference between groups in LAT sway or path length. However, boys with DCD demonstrated more AP sway (p < .01) and greater area of sway (p < .03), which resulted in pronounced excursions closer to their stability limits. Analysis of Romberg’s quotient indicated that boys with DCD did not over-rely on visual information.

Controlling balance has been perceived as an integral part of skilled motor performance and from a developmental perspective, has been considered an important prerequisite for the emergence of efficient voluntary movements in the maturing child (Thelen, 1986). Adapting to postural demands of various functional tasks is a complex perception-action process involving various sensory systems and a number of major muscle groups (Riley, Balasubramaniam, Mitra, & Turvey, 1998). Completion of basic movement skills such as walking, kicking, catching, and even standing on a moving bus, demands a certain amount of postural stability (Burton & Miller, 1998). In the simple feedback/feedforward-based control model, the central nervous system (CNS) detects the body’s deviation from vertical alignment and matches it with an appropriate muscular response that may prevent staggering, taking a step, or falling (Peterka, 2000). The effectiveness of this matching mechanism depends on the ability of the neuromuscular system to mediate the postural demands of the task based on sensory information provided by visual (e.g., Brandt, Paulus,
& Straube, 1985), proprioceptive (e.g., Hass, Diener, Bacher, & Dichgans, 1986), and vestibular systems (e.g., Diener, Dichgans, Bruzek, & Selinka, 1982). Although development of this “scaling” mechanism does not occur in a linear sequence, a typical balance control repertoire reaches adult-like status between 9 and 12 years of age (Woollacott, Shumway-Cook, & Williams, 1989). By this time, the functional complexity of the CNS and of relevant neurophysiological and anatomical structures allows a person to negotiate appropriate postural adjustments when faced with increasingly more complex movement tasks (Williams, 1983).

Gathering relevant information regarding the nature of the task goal as well as the alignment of different body segments involved in movement is a multisensory process. Visual information appears to play the central role in the achievement of balance during the first 6 or 7 years of life (Woollacott et al., 1989). Visual feedback provides relevant information about the position and velocity of different body segments in relation to spatial demands of tasks and the environment (Gibson, 1966), and it constitutes the most sensitive means of perceiving sway during unconstrained standing (Lacour et al., 1997). Vision also “calibrates” proprioception (Woollacott, 1986), as removal of visual cues heightens sensitivity to information provided from muscle spindles (type Ia and II), Golgi tendon organs (Ib), and/or joint receptors (McComas, 1996).

When vision dominates balance control, children tend to be especially vulnerable to postural threats involving incomplete, inaccurate, or missing visual information (e.g., Clark & Watkins, 1984; Odenric & Sandstedt, 1984). With maturity, children begin to rely on multimodal sources of sensory information and in particular, proprioceptive cues (Nashner & Berthoz, 1978; Woollacott, Debu, & Mowatt, 1987). The shift from visual to proprioceptive dependence corresponds to postural responses that demonstrate less variability, shorter latency, and decreased postural sway; hence, they are more adult-like (Shumway-Cook & Woollacott, 1995).

This developmental pattern of balance control, although typical for most children, does not appear to hold for all individuals, in particular, those with movement difficulties. Children with Developmental Coordination Disorder (DCD), who are sometimes referred to as clumsy or awkward, exhibit difficulties in seemingly simple movement activities such as running, catching, throwing, and kicking (Sugden & Wright, 1998; Wall & Taylor, 1984). Recently, the American Psychiatric Association (1994) described the population of children with DCD as those who exhibit developmental delays in a variety of gross and fine motor skills compared to their same-age unaffected peers in the presence of normal intelligence (e.g., Polatajko, Fox, & Missiuna, 1995) and no known neurological disorders (e.g., Hall, 1988). However, due to the heterogeneity of this population (Hoare, 1994), it has been difficult to establish what a typical child with DCD is like (Macnab, Miller, & Polatajko, 2001). It appears that some children with DCD demonstrate movement difficulties on some tasks, while performing up to age-expected levels on others (Hulme & Lord, 1986). Despite little agreement regarding the intraindividual diagnostic criteria of children with DCD (Henderson & Barnett, 1998), it appears that inefficient postural strategies exhibited by these children may prevent them from effectively carrying out motor tasks where postural threats are present (Cermak & Larkin, 2002; Williams, Woollacott, & Ivry, 1992); however, the nature of the underlying sensory-motor mechanisms is neither well understood nor well documented.
Electromyographic (EMG) analysis of balance responses incorporated by children with DCD shows that although they do not differ from their typically developing peers in terms of latency of response onset, they are significantly more variable (Williams & Woollacott, 1997). Furthermore, they incorporate a reverse, proximal-to-distal sequence of muscle triggering when compared to children without DCD (Williams & Castro, 1997; Williams, 2002). These different and possibly less sophisticated strategies may explain their “jerky” and rigid behaviors when executing various movement tasks (Larkin & Hoare, 1992; Williams, Fisher, & Tritschler, 1983).

In a recent study, Geuze, de Jong, and Taylor (1999) examined the ability of children with and without DCD to maintain static balance. In addition to EMG analysis, postural sway characteristics based on center of pressure (COP) displacement were investigated. The EMG analysis supported the results of previous investigations, indicating that children with DCD exhibit less efficient and more energy-consuming responses while attempting to maintain a balanced posture. However, the examination of both anterior-posterior (AP) and medio-lateral (Lat) sway revealed no significant differences between groups. In a subsequent investigation of the same two groups, a perturbation task was added (Geuze, de Jong, & Reitsma, 2002). Although children with DCD were found to take longer to recover from the perturbation, this discrepancy in time of recovery was only evident during the first few trials. The authors concluded that once children with DCD assumed a controlled position, their responses did not appear to differ from the comparison group, unless a large perturbation occurred.

The EMG findings indicate that children with DCD negotiate stance differently from children without DCD. Nevertheless, analysis of postural sway indicates that these strategies, although possibly less efficient, do not lead to increased sway or actual failure to perform the task. As a result, it is possible that the postural strategies employed by children with DCD may not be delayed or inappropriate, but rather adaptive and functionally relevant (Latash & Anson, 1996). However, in the domain of balance control, support for this hypothesis requires a more in-depth analysis, as previous research was based on a limited number of sway measures (e.g., Geuze et al., 2002).

The role of visual information in the movement status of children with DCD has been consistently examined (Hulme, Biggerstaff, Moran, & McKinlay, 1982; Lord & Hulme, 1987). Past research has also revealed that visual processing difficulties in children with DCD are due to factors other than primary, low-level processing, such as visual acuity, vergence control, and accommodation (Mon-Williams, Pascal, & Wann, 1994). According to the meta-analysis of Wilson and McKenzie (1998), higher levels of visuospatial and visuoperceptual processing may be the primary causes of motor problems that children with DCD exhibit. More specifically, these difficulties may be attributed to poor visual perceptual discrimination and perceptual judgments (Henderson, Barnett, & Henderson, 1994), visual memory (Dwyer & McKenzie, 1994) and rehearsal (Skorji & McKenzie, 1997). Despite the impressive amount of research devoted to the potential link between less than optimal movement patterns and faulty visual processing, this hypothesis has been questioned (e.g., Barnett & Henderson, 1992). Analysis of fast goal-directed movements, such as reaching or catching, revealed that differences in performance between children with DCD and their typically developing peers may be due to their reliance on feedback control in situations where anticipatory,
feedforward control is required (e.g., Forsstrom & von Hofsten, 1982; Rösblad & von Hofsten, 1994).

In the domain of balance control, the existing research regarding perceptual causes of balance control problems of children with DCD remains unclear (Williams, 2002). Wann, Mon-Williams, and Rushton (1998) compared the balance performance of children with DCD, same age peers without DCD, nursery school children, and adults and found that children with DCD swayed significantly more with eyes open and closed than the other groups. Also, only children with DCD swayed significantly more with eyes closed than with eyes open. The authors concluded that (a) children with DCD exhibit more postural instability in visually-based feedback tasks when compared to individuals with no balance difficulties, and (b) they appear to be slower at developing the capacity to process sensory information other than the visual when attempting to maintain stance. However, these results were not confirmed by Jung-Potter and colleagues (2002), who found no significant differences in lateral sway when children with and without DCD were asked to control their balance in semitandem stance with eyes closed. Furthermore, Geuze and colleagues (1999) found no significant differences between the groups in terms of the amount of sway exhibited with eyes open and closed. Similar results were obtained in a follow-up study that also incorporated Romberg’s quotient (RQ) to examine whether children with DCD overrelied on visual information when compared to their peers without DCD (Geuze et al., 2002). Although both groups swayed more with eyes closed than eyes open, the increase in sway was proportionally similar. According to these studies, it appears that children with DCD have neither statistically nor functionally significant sensory organization difficulties when accomplishing this particular motor task.

As a result, the evidence regarding the role of sensory information in maintaining feedback-based quiet stance by children with DCD is both limited and contradictory. Past research, due to its methodological limitations associated with small sample sizes (Wann et al., 1998) and research protocols based on a limited number of dependent measures, may not fully encompass the characteristics of postural sway exhibited by children with and without DCD. Consequently, the purpose of this investigation was to examine the postural sway characteristics of children with and without DCD when attempting to control balance in feedback based quiet stance. In addition, the impact of the removal of visual information on the postural sway characteristics of both groups was examined.

Method

Participants

The sampling design was purposive (Sherrill & O’Connor, 1999). Fifty-two boys were recruited from regular classroom settings in Thunder Bay, Canada with the assistance of principals and teachers. All of the volunteers were of normal intelligence and had no specific neurological diagnoses. The sample was limited to boys in order to maximize its size and homogeneity. A three-stage screening process was used to delineate the sample. Based on observations from recess and physical education class, teachers completed a Motor Behavior Checklist (MBC; Weir, 1992) for each student involved in the study. The MBC, which takes approximately 10 minutes to complete, has been used reliably in past investigations (Lefebvre &
Reid, 1998; Weir, 1992). Each teacher answered (Yes/No) to the statement, “I am concerned about the motor development of this child.” If concern was indicated, then the teacher completed 10 additional questions that described general motor abilities, performance of simple everyday activities, and behavioral patterns of each student. The checklist has a four point likert scale of descriptors ranging from well-coordinated behavior (e.g., very fit, very coordinated) to those associated with a performance below the expected level of proficiency (e.g., very uncoordinated, awkward, very unfit).

In the next stage of screening, the boys performed the Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1982). The testing, which took place in the Motor Development Clinic at Lakehead University, took approximately 45 minutes per participant. Scores on the MABC provided information on each participant’s overall motor skill level, as well as his balance control abilities. The Total Impairment Score (TIS) reflects a combined score for manual dexterity, ball skills, and balance, whereas the Total Balance Score (TBS) describes the performance of the child on static and dynamic balance tasks.

Children assigned to the DCD group (a) were assessed by the teacher as having visible movement difficulties, (b) performed at or below the 5th percentile on the TIS, and (c) were at or below the 5th percentile on the TBS. This rigorous screening procedure (Mon-Williams, Tresilian & Wann, 1999; Smyth, Anderson, & Churchill, 2001) ensured that participants assigned to the group of interest had DCD as well as specific balance difficulties. The comparison group consisted of boys who, in the teacher’s opinion, did not exhibit movement difficulties and who scored above the 15th percentile on both the TIS and the TBS (Henderson & Sugden, 1982). The resulting sample comprised 40 boys of similar age, 20 with DCD (M = 8 years, 7 months; SD = 2 years, 1 month), and twenty without DCD (M = 8 years, 6 months; SD = 2 years), t (38) = -11.609, p < .001, and the TBS, t (38) = -9.939, p < .001.

Apparatus

An AMTI strain gauge force platform was connected to the standard amplifier to record the changes in displacement of center of pressure (COP). The platform measures three ground reaction forces along axes in the medio-lateral, anterior-posterior, and vertical direction. The gain was set at 4,000 and the filter was set at 10.5 Hz. Data were collected at a sampling rate of .01 seconds (100 HZ) and were reduced and analyzed through the AMTI AccuSway Plus system. The system provides sway displacement measures such as path length (L) (cm), anterior-posterior sway (AP) (cm), lateral displacement (LAT) (cm), and area of sway (Ao) (cm²).

Balance Testing Procedure

A week after they were screened with the MABC, participants returned to the quiet environment of the Motor Development Clinic where they completed individual balance testing. Measurements of height and foot size were taken prior to the testing session. Each participant stood barefoot on the built-in platform while foot contour was outlined to ensure proper centering on the force plate and a consistent foot placement throughout the trials. The testing session, including pretesting
measurements and two twenty-second trials (the first with eyes open and the second with eyes closed), lasted approximately 15 minutes. In the eyes open task, the child was asked to stand as still as possible with arms crossed at the chest and look at a white X on a brown screen located at eye height 5 meters away. The same protocol was used in the eyes closed task, except that the participant was asked to close his eyes just prior to the beginning of the trial. This procedure has been a standard protocol in past investigations of balance control performance during quiet stance (e.g., Foudriate, Di Fabio, & Anderson, 1993; Riach & Hayes, 1987). To rule out the impact of morphological differences on balance control status, a series of independent sample t tests was carried out at .05 alpha level. There were no significant differences between the groups in height, $t (38) = -.475$, $p < .638$ and in size of base of support (foot length), $t (38) = -.900$, $p < .374$.

Data Analysis

The analysis of postural sway profiles was incorporated into this study to investigate the status of the balance control repertoire. Dependent measures included anterior-posterior (AP) and lateral (Lat) sway, path length (L), and area of sway (Ao). Whereas the first three variables describe the amount of COP displacement, Ao (cm²) indicates the range and size of the area created during the COP migration. The reliability of these measures has been established in past investigations involving individuals with (e.g., Benvenuti et al., 1999; Levine, Whittle, Beach, & Ollard, 1996) and without balance control difficulties (e.g., Geurts, Nienhuis, & Mulder, 1993; Ishizaki, Pyykko, Aalto, & Starck, 1991). To verify their reliability in the present investigation, the interclass correlation coefficient (Pearson Product-Moment Correlation Coefficient; PPMC) was calculated for each measure (Baumgartner & Jackson, 1991).

All four variables were also translated into Romberg’s quotient (RQ; eyes closed/eyes open × 100%) to determine whether (a) the balance control of both groups was affected when visual information was removed, and (b) this effect was proportionally similar for both groups. In this analysis, an RQ score larger than 100% indicates more sway with eyes closed than open. Hence, the larger the deviation from 100%, the more pronounced the effect of removing vision on balance performance during stance (Elliot, FitzGerald, & Murray, 1998; FitzGerald, Murray, Elliott, & Birchall, 1994; Van Parys & Njikoktjen, 1976). The consistency of RQ ratios for each dependent measure was estimated based on coefficient of variation (CV; standard deviation/ mean × 100; Geurts et al., 1993).

Initially, the present design included an age factor. Each group of participants (DCD and no DCD) was further divided into a younger (6-8) and an older group (9-13) in order to investigate the developmental delay hypothesis. Due to the lack of significant interaction effects, on any of the variables examined, younger and older children were included in the same group. As a result, a 2 by 2, group (DCD or no DCD) by condition (eyes open or eyes closed) mixed factorial design was incorporated in this study. A series of 2 × 2 ANOVA procedures with a repeated measure on the second variable was carried out for AP, Lat, L, and Ao dependent measures. To determine whether both groups reacted similarly to the removal of visual information, RQ ratios, calculated for each of the four dependent measures described above, were entered simultaneously into a multivariate analysis of
variance (Hotteling’s $T^2$). All statistical procedures were carried out at $\alpha = .05$, and means, standard deviations, and effect sizes ($\eta^2$) were calculated for each comparison.

**Results**

The analysis of interclass correlations indicated that path length was most consistent ($r = .89, p < .01$), followed by area of sway ($r = .71, p < .01$), lateral sway ($r = .70, p < .01$), and AP sway ($r = .60, p < .01$). The consistency of RQ ratios calculated for children with DCD and balance difficulties showed the most consistent and stable parameter, quantifying the amount of sway with and without vision, was path length (14%), followed by lateral sway (22%), AP sway (34%), and area of sway (33%), respectively. In the comparison group, path length was once again most consistent (14%), followed by AP sway (34%), area of sway (44%), and lateral sway (45%). Although most of these coefficients appear to be rather high (> 20%), they compare to past investigations of this kind (Elliott et al., 1998; Geurts et al., 1993; Riach & Hayes, 1987).

Due to the presence of a repeated factor in the design, homogeneity of variance (Levene’s test) and sphericity assumptions (Mauchly’s test) were tested for each analysis. All of the ANOVA procedures that were carried out satisfied both assumptions. The effect sizes (eta-squared) were acceptable, ranging from medium (> .04) to predominately large (> .12; Cohen, 1977). Since the ANOVAs revealed no significant interaction effects on any of the dependent measures, the two main effects will be reported first, followed by the multivariate analysis.

**DCD Vs. No DCD**

A significant main effect for group was found in AP sway, $F(1, 38) = 6.50, p < .01$, $\eta^2 = .15$, and Ao, $F(1, 38) = 4.88, p < .03$, $\eta^2 = .12$. Children with DCD and balance control difficulties swayed significantly more (AP sway) and further away (area of sway) from the vertical alignment than did the comparison group. There was no difference between the groups based on path length, $F(1, 38) = 1.75, p < .19$, $\eta^2 = .04$, and lateral sway, $F(1, 38) = 1.71, p < .19, \eta^2 = .04$ (see Table 1).

**Vision Vs. No Vision**

Across groups, children swayed significantly more when visual cues were absent. This result was confirmed by all four measures: AP sway, $F(1, 38) = 12.47, p < .001$, $\eta^2 = .25$; lateral sway, $F(1, 38) = 5.10, p < .03$, $\eta^2 = .12$; path length, $F(1, 38) = 70.71, p < .001$, $\eta^2 = .65$; and area of sway, $F(1, 38) = 12.67, p < .001, \eta^2 = .25$ (see Table 1).

A multivariate analysis of variance (MANOVA) was carried out, with the four dependent measures considered simultaneously. Hotteling’s tests statistic, $F(4, 34) = .84, p < .51$, revealed no significant differences between the groups on any of the RQ scores examined (see Table 2). Also, both groups had consistently larger RQ values (> 100%), indicating that eye closure provoked more postural sway than when balancing with sight.
Table 1  Means and Standard Deviations of Quiet Standing With and Without Vision for Boys With and Without DCD Based on Anterior-Posterior (AP) and Lateral Sway (Lat), Path Length (L), and Area of Sway (Ao)

<table>
<thead>
<tr>
<th>Conditions</th>
<th>AP</th>
<th>Lat</th>
<th>L</th>
<th>Ao</th>
<th>AP</th>
<th>Lat</th>
<th>L</th>
<th>Ao</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes Open</td>
<td>M</td>
<td>2.14</td>
<td>2.12</td>
<td>35.39</td>
<td>.52</td>
<td>1.66</td>
<td>1.90</td>
<td>30.63</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>.68</td>
<td>.74</td>
<td>11.98</td>
<td>.28</td>
<td>.52</td>
<td>.70</td>
<td>6.58</td>
</tr>
<tr>
<td>Eyes Closed</td>
<td>M</td>
<td>2.47</td>
<td>2.20</td>
<td>41.18</td>
<td>.63</td>
<td>2.04</td>
<td>2.06</td>
<td>37.78</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>.62</td>
<td>.81</td>
<td>12.80</td>
<td>.33</td>
<td>.63</td>
<td>.80</td>
<td>7.27</td>
</tr>
<tr>
<td>Total</td>
<td>M</td>
<td>2.31*</td>
<td>2.16</td>
<td>38.29</td>
<td>.578*</td>
<td>1.85*</td>
<td>1.88</td>
<td>34.21</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>.16</td>
<td>.19</td>
<td>2.18</td>
<td>.05</td>
<td>.12</td>
<td>.15</td>
<td>2.18</td>
</tr>
</tbody>
</table>

*Note. AP, Lat, and L are measured in centimeters, Ao in centimeters squared. *p < .05.

Table 2  Means and Standard Deviations of RQ Scores (eyes closed/eyes open × 100%) Based on Anterior-Posterior (AP) and Lateral Sway (Lat), Path Length (L), and Area of Sway (Ao) for Boys With and Without DCD

<table>
<thead>
<tr>
<th>Variables</th>
<th>DCD</th>
<th>No DCD</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>M</td>
<td>125.61</td>
<td>133.45</td>
<td>.309</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>41.64</td>
<td>46.15</td>
<td></td>
</tr>
<tr>
<td>Lat</td>
<td>M</td>
<td>104.11</td>
<td>129.69</td>
<td>3.129</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>23.18</td>
<td>58.82</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>M</td>
<td>117.75</td>
<td>124.81</td>
<td>1.622</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>16.83</td>
<td>17.74</td>
<td></td>
</tr>
<tr>
<td>Ao</td>
<td>M</td>
<td>127.89</td>
<td>157.24</td>
<td>2.432</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>44.43</td>
<td>69.61</td>
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</tr>
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</table>

Discussion

DCD and Feedback Balance Control

At the functional level, our results compare with past findings (e.g., Wann et al., 1998; Williams & Castro, 1997). Children with and without DCD are equally efficient at completing the task without losing balance, staggering, or taking a step. The lack of differences between groups on lateral sway measures is also supported by recent studies using similar protocols (Geuze et al., 1999, 2002; Jung-Potter et al., 2002); however, in our study, children with DCD demonstrate more sway in the AP plane. Methodological differences may, at least in part, explain the lack of
differences in AP sway in past investigations. Only a few studies have included an explicit measure of balance control in the screening protocol (e.g., Geuze et al., 2002), while others have either not assessed participants’ balance at all (e.g., Jung-Potter et al., 2002) or included children with and without balance problems in the same DCD cohort (Wann et al., 1998).

Although area and path length were incorporated in this study to increase understanding of how children with and without DCD manage the demands of tasks requiring feedback based control, they do not initially appear to clarify the issue at hand. Both groups appear to differ on some measures (AP, Ao) yet perform similarly on others (path length, lateral sway). This pattern of results has been observed in past investigations (Horak, Nutt, & Nashner, 1992; Schieppati, Hugon, Grasso, Nardone, & Galante, 1994; Vuillerme, Marin, & Debu, 2001), where individuals who exhibit balance control difficulties differed from their neurologically intact counterparts on some balance measures but not others. Under an implicit assumption that COP migration patterns are complex and structured rather than random or chaotic (Collins & DeLuca, 1993; Duarte & Zatsiorsky, 1999; Newell, Slobounov, & Molenaar, 1997; Riley et al., 1998), this kind of research stresses the importance of examining behaviors involved in control of balance in their complexity, rather than simply considering each measure individually.

Given the nature of the measures used, the present results allow us to speculate regarding the sway patterns exhibited by both groups. First, it appears that regardless of the direction (anterior-posterior or lateral), the two groups exhibit similar amounts of COP displacement as expressed in the total amount of sway (path length). Path length, which describes the overall amount of COP migration, has been found to (a) be a primary indicator of balance control status and (b) provide the greatest sensitivity for detecting differences in body sway (FitzGerald et al., 1994; Jeong, 1994). However, despite the fact that the COP displacement was similar when the two groups were compared, the nature of their excursions differed. Significantly larger AP sway in the performance of children with DCD indicates their tendency to settle in the anterior-posterior plane of displacement, whereas boys with no DCD do not appear to show any directional bias in their COP excursions.

Also, when considering the shape of the area of sway, children with no DCD seem to converge onto a fixed point around their initial location of COP, whereas those with balance difficulties exhibit more pronounced excursions away from the vertical, stable position. These pendulum-like cycles of displacement put the COP of individuals with DCD closer to their stability limits. The closer the COP is to one’s stability boundary, the higher the risk of colliding with it or requiring more pronounced postural adjustments to prevent a fall (e.g., step, lean against another surface; Blaszczyk, Hansen, & Lowe, 1993; van Emmerik & van Wegen, 2000). Although none of our participants lost their balance, children in the comparison group appear to exhibit a “safer” strategy in maintaining a balanced stance when compared to those with DCD.

There are two important findings to reiterate from the literature regarding balance control of children with DCD. One, they use different, possibly less efficient balance control strategies (e.g., Williams & Castro, 1997), and two, on a functional level, children with and without DCD are equally successful at maintaining stance without staggering or falling (Geuze et al., 1999; Wann et al., 1998), offsetting the detrimental effects of perturbations (Geuze et al., 2002; Williams & Woollacott, 1997; Williams & Castro, 1997) and meeting the demands of the moving room
task (Wann et al., 1998). To some extent, the present results confirm both of these findings. In terms of the outcomes, none of the participants failed the task. However, in terms of the process, as was the case in the studies incorporating neuromuscular methodology (e.g., Williams & Castro, 1997), the nature of feedback mechanism used by the two groups differs. Children with DCD seem to exhibit control strategies that allow their COP to come closer to their stability limits, running a greater risk of colliding with it, leading to balance loss. Children with no balance difficulties, on the other hand, initiate corrections, which allow them to keep their COP safely away from their stability limits. Overall, we feel that these results confirm previous findings emphasizing that children with DCD, who exhibit balance difficulties, use different, possibly less optimal strategies when maintaining stance. However, given the functional success of these children, we are not convinced whether we could or should interpret their movement patterns as pathological or delayed. Clearly, additional research is required to gain further appreciation regarding the nature of these strategies (Collins & De Luca, 1993; Duarte & Zatsiorsky, 1999), particularly their stability and/or flexibility, when adapting to changing task and environmental constraints (Newell, 1986; van Emmerik, Sprague, & Newell, 1993).

Vision and Balance Control

In order to investigate whether postural sway patterns of children with and without DCD were affected similarly by the removal of visual input, Romberg’s quotient (RQ) was used. It has been consistently reported that less than optimal processing of visuospatial properties of motor tasks may have detrimental consequences on the motor performance of children with DCD (e.g., Hulme, Smart, & Moran, 1982; Lord & Hulme, 1987) or that their balance difficulties are due to slower postural adjustments that are associated with visual information (Williams, 2002). Wann and colleagues (1998) found that children with DCD swayed more with eyes closed when compared to older children and adults without movement difficulties. The authors interpreted this finding as an indication that at least some children with DCD over-rely on visual information to maintain stance. Implicitly, the increase in sway may indicate that children with DCD are not able to rely on somatosensory information from their feet to control balance when vision is removed (Shumway-Cook & Horak, 1986; Shumway-Cook, 1989). However, the results of the present investigation do not support these views.

None of the RQ ratios revealed significant differences between the two groups. Although both groups swayed more with eyes closed, as indicated by scores higher than 100%, this increase in instability was proportionally similar for all children. In other words, although the nature of sensory information incorporated by both groups is not known, they both appear to compensate adequately for the lack of visual input. The present findings confirm results of Geuze and colleagues (2002) and Jung-Potter and colleagues (2002), who also found no significant differences between children with and without DCD when postural sway with eyes closed was examined.

In conclusion, this investigation does not support the hypothesis that children with DCD over-rely on vision to maintain stance. Based on their sway characteristics, boys with DCD and balance difficulties are able to compensate as effectively as those without DCD for the loss of visual input while maintaining quiet stance. However, the interpretation of postural sway exhibited during the eyes open
task is not as straight forward. The overall amount of sway is similar, however the
distribution of sway within the stability limits differs. Children with DCD exhibit
much more pronounced excursions away from the initial COP location, particularly
in the AP plane. We speculate that this pattern of behavior may put children with
DCD at greater risk of losing balance when attempting to maintain stance, if a
larger perturbation is present (Geuze et al., 2002). This may be associated with less
than optimal feedback based control, a hypothesis that was originally presented in
research devoted to neuromuscular control of stance exhibited by this population
(e.g., Williams & Castro, 1997). However, the fact that children with DCD are
as functionally sound as their non DCD peers when controlling stance makes it
problematic to judge whether the patterns exhibited are inefficient, and as a result
delayed, or different, adaptive and as a result effective (Larkin & Hoare, 1992;

We acknowledge the limitations in our methodology regarding the nature of
the sample, the task, and the measures used. First, the heterogeneity of the DCD
population does not allow us to completely dismiss the possibility that some boys
with DCD may exhibit balance difficulties at a different level of analysis. Second,
the inferences made here should be limited to boys only, as no girls were included
in the sample. More research is required to investigate whether or not gender may
be a confounding variable when DCD and balance control is examined. Finally,
we are convinced that analysis of balance strategies involved in tasks other than
quiet stance is required. It appears that movement difficulties of this population
may be nested within mechanisms responsible for motor control that are other
than feedback-based (Burton & Davis, 1992; Rösblad, 2002). However, to our
knowledge, there has been only one attempting to examine balance control behavior
of children with DCD during more complex, dynamic tasks demanding feedforward,
anticipatory balance control mechanisms (e.g., reaching; Johnston, Burns, Brauer,
& Richardson, 2002).

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