The Nature and Control of Postural Adaptations of Boys With and Without Developmental Coordination Disorder

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This study compared the nature of postural adaptations and control tendencies, between 7 (n = 9) and 11-year-old boys (n = 10) with Developmental Coordination Disorder (DCD) and age-matched, younger (n = 10) and older (n = 9) peers in a leaning task. Examination of anterior-posterior, medio-lateral, maximum and mean area of sway, and path length revealed one significant interaction as older, unaffected boys swayed more than all other groups (p < .01). As a group, boys with DCD displayed smaller anterior-posterior (p < .01) and area of sway (p < .01). Analysis of relative time spent in the corrective phase (p < .002) revealed that boys with DCD spent 54% under feedback control while boys without DCD spent 78%. This was attributed to reduced proprioceptive sensitivity, as confirmed by significant differences between the groups (p < .009) in spectral analysis of peak frequency of sway.

The delineation of perceptuo-motor limiters is essential for gaining an insight into the causes of movement difficulties exhibited by children with Developmental Coordination Disorder (DCD; American Psychiatric Association, 1994). The DCD diagnosis implies a marked impairment in movement organization, when compared to same-age unaffected peers (e.g., Polatajko, Fox, & Missiuna, 1995) that is due to factors other than cognitive or known neurological disorders (e.g., Hall, 1988). As DCD implies, these difficulties have been attributed to developmental delay, as the performance of children with DCD often appears to mirror that of younger, typically developing individuals. Some cross-sectional studies, comparing younger (6 ± 1 year) and older (11 ± 1 year) children with and without DCD have supported this pattern of results (e.g., Geuze, 2003; Raynor, 2001). Other studies, however, either showed this pattern of results on some measures and not others (Zoia, Castiello,
Blason, & Scabar, 2005) or failed to reveal it all together (Larkin & Hoare, 1992; Williams & Woollacott, 1997), implying that the difficulties in movement may be due to less than optimal status of perceptuo-motor functioning.

One way of examining control issues involves the analysis of balance control and/or postural adaptations. This approach is particularly feasible when it comes to children with DCD (Geuze, 2005). Literature reviews (e.g., Cermak & Larkin, 2002) and sub-type analyses (e.g., Macnab, Miller, & Polatajko, 2001) have agreed that a majority of these individuals experience problems in different domains of balance control. Nevertheless, recent research has shown only subtle or no differences between groups in quiet standing, and no evidence that children with DCD over-rely on visual input to maintain stance (e.g., Geuze, 2003; Przysucha & Taylor, 2004), as was previously postulated (Wann, Mon-Williams, & Rushton, 1998). These findings suggest that maintaining bi-pedal stance, with and without vision, may not be problematic for these children. Rather, the issues may be rooted in control mechanisms responsible for performance of more dynamic tasks, such as those involving voluntary, goal-directed adaptations of body/limbs in space. The analysis of the self-initiated movements involved in pendulum-like leaning constitutes a methodology that can illustrate how children with DCD compare to their unaffected peers when performing postural adaptations (Koozekanani, Stockwell, McGhee, & Firoozmand, 1980; McCollum & Leen, 1989). Explicitly, either not leaning far enough, resulting in smaller COP excursions (smaller stability region), or leaning too far, leading to a step or fall, are both indicators of a less than optimal estimation of the available stability limits. According to Riach and Starkes (1993) the ability to lean as far as possible from the vertical reaches adult-like levels around 7 to 8 years of age. However, other researchers report that the ability to perform such adaptations is not mastered until the age of 10 or 11 (Schmid, Conforto, Lopez, Renzi, & D’Alessio, 2005; Usai, Maekawa, & Hirasawa, 1995).

Conceptually, performance of self-initiated postural adaptations can be used as a “window” into the nature of (motor) control underlying emerging voluntary movements, more specifically the status of an integrated type of control (e.g., Gahery & Massion, 1981; Taguchi & Tada, 1988). Generally, open-loop control is responsible for altering the location of the body segment or limb in space to position it in the ballpark of the desired location (Gahery & Massion, 1981), whereas on-line sensory adjustments fine-tune the position of COP within the base of support through successive feedback-based corrections (Kirshenbaum, Riach, & Starkes, 2001). The extent to which either control mechanism is involved in the action depends on the task constraints (Hatzitaki, Zisi, Kollias, & Kioumourtzoglou, 2002) and as we suspect the status of the performer’s intrinsic dynamics. In quiet stance, it appears that children may be able to integrate both types of control between 6 and 8 years of age (Kirshenbaum et al., 2001; Riach & Starkes, 1994) and similarly may also adapt to postural tasks involving self- and externally-initiated unloading of a weight (Hay & Redon, 1999). Other research has reported that the ability to appropriately allocate either mode of control, however, does not mature until the age of 11 (Hatzitaki et al., 2002).

The reliance on feedback control dominates when speed has to be sacrificed for accuracy (Kirshenbaum et al., 2001; Riach & Starkes, 1994). In balance control, such a tendency was evident in the performance of 8-year-old children, when compared to younger individuals (Riach & Starkes, 1994) and in healthy adults
when compared either to those with balance-related deficits (e.g., van Wegen, van Emmerik, & Riccio, 2002) or to healthy elderly populations (Collins, De Luca, Burrows, & Lipsitz, 1995). All in all, these investigations suggest that the delay of involvement of closed-loop control coincides with less than optimal performance when spatial accuracy is critical. This delay is attributed to reduced proprioceptive sensitivity to the changes of COP. The ability to absorb and process proprioceptive information is crucial to balance control (Shumway-Cook & Woollacott, 1985).

In the context of DCD, less than optimal integration of open and closed loop control has been suggested as a possible limiter in children with coordination problems (Goodgold-Edwards & Cermak, 1989), but it has only been examined in reaching and aiming tasks and the results are mixed. Zoia and colleagues (2005) showed no substantial differences in the extent to which children with and without DCD relied on feedback-type of control. The tendency to ignore on-line monitoring, jeopardizing terminal control of accuracy, however, was observed in another reaching study (Smyth, Anderson, & Churchill, 2001).

It is evident from the review of the relevant literature that studies examining the performance of children in more dynamic postural adaptations are lacking. Also, it appears that the analysis of such actions represents a useful approach to expand our understanding of control issues underlying the performance of voluntary actions in typically and atypically developing children. As a result, the purpose of this investigation was two-fold. The first purpose was to compare postural adaptations of younger (7-year-old) and older (11-year-old) boys with and without DCD in a leaning task. The second purpose was to delineate the nature of control tendencies exhibited by children with DCD and their unaffected peers.

**Method**

**Participants**

The sampling design was purposive (Sherrill & O’Connor, 1999). Following ethical approval of the protocol from the university ethics board and the school board and informed consent, participants were recruited from regular classroom settings in Thunder Bay, Ontario, with the assistance of principals and teachers. All children had an intelligence level consistent with typically developing children and had no specific neurological diagnoses. The sample was limited to boys in order to enhance its homogeneity. A stringent, three-stage screening process was used to select participants (Przysucha & Taylor, 2004). Based on observations during recess and gym class, teachers filled out a Motor Behavior Checklist (MBC; Weir, 1992), indicating whether they were concerned about the overall status of the child’s motor development, rating it based on a four point Likert scale. Next, the age-appropriate band of the Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1992) was administered to each participant by a trained, experienced researcher. The Total Impairment Score (TIS), combining manual dexterity, ball skills, and balance reflected the overall movement proficiency, whereas the Total Balance Score (TBS) was used to infer proficiency in balance.

As a result, 36 boys were assigned to their respective groups. Children in 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 detailed screening process (Mon-Williams, Tresilian, & Wann, 1999; Smyth, Anderson, & Churchill, 2001) established a group that displayed both DCD and specific balance difficulties. The comparison group, on the other hand, consisted of children who in the opinion of the teacher had no general movement problems and scored above the 15th percentile on both the TIS and the TBS. Subsequently, the sample was divided into four groups: 9 younger boys with (M = 7 years, SD = .86) and 10 without DCD (M = 6.9, SD = .73), as well as 8 older boys with (M = 10.50, SD = 1.50) and 9 without DCD (M = 10.65, SD = 1.20). Children with DCD performed more poorly in terms of both TIS and TBS scores, as evidenced in higher scores. As indicated in Table 1, no significant differences were found between children with and without DCD in terms of height, foot width, possible anterior (PAS), and possible posterior sway (PPS). PAS and PPS were calculated according to the method reported by Usai and colleagues (1995).

**Balance Testing Procedure and Task**

After the measurements of height and foot size were taken, each participant was asked to stand barefoot on the built-in force platform. The contour of the feet was outlined to ensure consistent foot placement throughout the trials. The child was asked to stand with his feet together, arms crossed on the chest, and to look at a point on the wall approximately 5 meters away from the force plate. He leaned from the

<table>
<thead>
<tr>
<th>Variables</th>
<th>DCD</th>
<th>No DCD</th>
<th>F</th>
<th>P</th>
<th>η²</th>
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<tbody>
<tr>
<td></td>
<td>Young (n = 9)</td>
<td>Older (n = 8)</td>
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<tr>
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<td>M 18.61</td>
<td>19.16</td>
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<td>104.69</td>
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<td></td>
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<td>104.69</td>
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<td>TBS</td>
<td>M 8.55</td>
<td>8.38</td>
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<td>75.89</td>
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<td>SD .92</td>
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<td>PAS</td>
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<td>2.83</td>
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<td>SD .88</td>
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<tr>
<td>PPS</td>
<td>M 7.46</td>
<td>9.27</td>
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<tr>
<td>Height</td>
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<td>146.66</td>
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<td></td>
<td>SD 7.86</td>
<td>10.46</td>
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*Note. Foot width, PAS, PPS and height are measured in centimeters.*

* p < .001
initial, vertical alignment as far as possible in the forward direction. After returning to the initial position, he leaned backward, then right and left consecutively. Each participant was asked not to bend at the hip or knees or lift his toes/heels off the platform. Every child performed two practice and three formal trials. If finished earlier, he stood motionless until the end of the required 20-second period.

**Apparatus and Data Analysis**

An AMTI strain gauge force platform was connected to the standard amplifier to record changes in displacement of center of pressure (COP). The platform measures three ground reaction forces along the axis in the medio-lateral, anterior-posterior, and vertical directions. The signals from the force platform were amplified and filtered. The gain was set at 4,000 and the filter at 10.5 Hz, with a sampling rate of .01 seconds (100 HZ). An AMTI AccuSway Plus system was used for data-reduction and to derive the measures of postural sway. Also, the Matlab system (Mathworks, Inc., Natick, MA) was incorporated to further analyze the COP positional data and its derivatives as well as to estimate the frequency composition of the COP sway based on power spectra analysis (McClenaghan et al., 1996). Of the four different directions, we only considered frontal sway for the purpose of Matlab analyses. Lateral sway was not used, as we only found significant inter-group differences in a sagittal plane of motion. Also, we did not consider examining posterior sway as previous research revealed significant differences between children with and without DCD in frontal and not backward conditions (Williams & Woollacott, 1997). Thus, if there were differences between the groups, in the nature of underlying control mechanisms, we speculated that they would likely be most pronounced during the anterior excursions. To parse the forward translation from a 20-second trial, the movement onset was defined as the point at which the velocity of COP exceeded 10% of the peak velocity for a particular trial (e.g., Seidler-Dobrin & Stelmach, 1998). Movement offset (reversal), on the other hand, was defined as a point at which the COP position reached its maximum displacement (see Figure 1, top panels). This was an instance when a child leaned forward as far as he could, without falling, and subsequently started to lean back to the initial, vertical position.

**Measures and Statistical Analysis**

To describe the nature of postural adaptations, five measures of postural sway were used: anterior-posterior (AP; cm) and lateral (Lat) sway (cm), path length (L; cm), maximum (Aomax) and mean area of sway (Aomean; cm$^2$). The AP and Lat sway describe the amount of COP displacement in the respective directions, and path length expresses the total amount of COP movement. The Aomean and Aomax constitute more direct indicators of the ability to project COP as far as possible toward the stability limits. They quantify the range/size of the area created by the COP during the voluntary excursions made in anterior, posterior, and lateral directions combined.

The nature of control involved in the emerging adaptations can be inferred from velocity-based COP derivatives (Kirshenbaum et al., 2001). Three measures were derived from the positional data of forward translation of COP. Movement time (MT; sec) was defined as the amount of time between the movement onset and
Figure 1—The parsed radius of displacement, expressed as centre of pressure (COP) position (top panels), and corresponding COP velocity profiles (bottom panels), for a boy without DCD (upper pair of profiles) and a boy with DCD (lower pair of profiles). Note the differences in the magnitude of relative time spent in the corrective phase (RTCP).

offset (movement reversal). The time to peak velocity (TTPV; sec), inferred from the COP velocity profile, constituted an instance in time when velocity reached its highest point during the forward translation (see Figure 1, bottom panels). To infer the extent to which the system relied on a particular control mode, we calculated the relative time spent in the corrective phase (RTCP; %; 100 – [time
to peak velocity/movement time x 100], e.g., Smyth et al., 2001). Explicitly, the involvement of a ballistic, preplanned motor program was determined from the proportion (%) of total movement time spent in the acceleration phase of movement up to peak velocity (Meyer, Abrams, Kornblum, Wright, & Smith, 1988). On the other hand, the extent of the closed-loop involvement was inferred from the portion of the total movement time spent during the deceleration phase, hence the time between peak velocity and the movement offset (Smyth et al., 2001). Thus, larger RTCP values coincided with the prevalence of open-loop control, whereas smaller RTCP values and resulting larger TTPV indicated more reliance on corrective adjustments associated with closed-loop control. The trials without a distinct acceleration phase, hence pronounced forward lean, were not used for the extraction of COP derivatives. Also, Fast Fourier Transform (FFT) was used to estimate the frequency components of the COP velocity signal, reflecting the nature of corrective adjustments exhibited during the forward translation (McClenaghan et al., 1996). The peak frequency of COP profiles (fpeak; Hz) was extracted to infer the dominant frequency of the power spectra with larger values indicating higher rate in changes in the position of COP.

A 2 by 2, group (DCD or no DCD) by age (younger vs. older) factorial design was incorporated. A series of 2 × 2 ANOVA procedures were carried out for each dependent measure (AP, Lat, L, Aomax, Aomean, TTPV, MT, RTCP, fpeak). In the case of a significant interaction effect, Tukey post-hoc comparisons were used. All statistical procedures were carried out at .05, and the means and effect sizes (η²) were calculated for each comparison. Except for the Aomax variable, the magnitude of sway measures (Aomean, AP and LAT sway, L) and the derivatives (TTPV, MT, RTCP, fpeak) were averaged across three trials for each participant. Also, standard deviations, calculated across the three trials, were used to measure variability.

Results

All of the ANOVA procedures satisfied the homogeneity of variance assumption (Levene’s test). The effect sizes (η²) were acceptable, ranging from medium (> .09) to predominately large (> .29; Cohen, 1977). To verify within-subject reliability, a series of Pearson product-moment correlation coefficients and dependent samples t-tests were calculated for the second and third trials, independently for children with and without DCD. For the comparison group, Aomean (r = .87), L (r = .63), AP (r = .82), Lat (r = .77), TTPV (r = .59), RTCP (r = .69) and fpeak (r = .63) were all significant at p < .01, whereas MT was significant at p < .05 (r = .56). For the DCD group, Aomean (r = .75), AP (r = .67), MT (r = .76), TTPV (r = .76), and RTCP (r = .78) were all significant at p < .01, whereas the fpeak (r = .55), L (r = .56), and Lat (r = .55) were significant at p < .05. No significant differences between the trials were evident when t-tests were examined. Given these results, the reliability of COP measures and their derivatives was deemed satisfactory.

Nature of Postural Adaptations

The statistical analysis of measures describing postural adaptations revealed only one significant interaction effect for path length (L). Older children with no DCD exhibited more overall sway than the three remaining groups, with no significant
differences between the latter, $F(1, 32) = 6.76, p < .01, \eta^2 = .17$. The analysis of range of COP excursions revealed a significant main effect for group in Aomean, $F(1, 32) = 15.44, p < .01, \eta^2 = .32$ and Aomax, $F(1, 32) = 14.47, p < .01, \eta^2 = .09$. The boys in the comparison group leaned significantly further when the maximum ($M = 14.89, SD = 5.94$) and averaged area of sway ($M = 12.93, SD = 5.32$) were compared to the performance of boys with DCD ($M = 10.05, SD = 4.95$ and $M = 8.75, SD = 4.26$, respectively). Significant differences were also found between boys with ($M = 7.56, SD = 1.37$) and without DCD ($M = 9.09, SD = 1.57$) in AP, $F(1, 32) = 13.37, p < .01, \eta^2 = .29$, but not in lateral sway ($M = 8.96, SD = 1.41$ vs. $M = 8.37, SD = 1.69$). The qualitative reflection of these postural adaptations described by the COP measures is clearly demonstrated in Figure 2.

**Figure 2** — Centre of pressure (COP) displacement profiles of two boys without DCD (upper) and with DCD (lower). Displacement along the X and Y axis represents sway in AP and Lat planes, respectively. Note: the circular area represents 95% of the COP points, when normally distributed.
Underlying Control

The analysis of the nature of underlying control tendencies revealed no significant effects for MT, as children with (M = 2.3 sec, SD = .75) and without DCD (M = 2.7 sec, SD = .74) spent approximately the same amount of time performing the anterior translation. However, a significant main effect for group in TTPV, $F(1, 32) = 6.19, p < .05, \eta^2 = .12$, showed that children with DCD reached peak velocity significantly later during the movement (M = .95 sec, SD = .12) when compared to boys with no DCD (M = .52 sec, SD = .11). These differences were also confirmed when RTCP was examined, $F(1, 32) = 11.45, p < .002, \eta^2 = .26$. Thus, children without DCD, as a group, spent a significantly larger portion of total movement time (M = 78.64%, SD = 12.66) after peak velocity, as compared to children with DCD (M = 54.09%, SD = 18.69; see Figure 1). The examination of the spectral composition of sway revealed, once again, a main effect for group, as boys with DCD exhibited a significantly higher $f_{peak}$ (M = 1.40 Hz, SD = .34) than the comparison group (M = 1.00 Hz, SD = .26), $F(1, 32) = 7.77, p < .009, \eta^2 = .26$. In terms of movement variability, no significant differences between the groups were found on any of the measures, except RTCP, $F(1, 32) = 4.91, p < .05, \eta^2 = .13$.

Overall, the results revealed no significant differences in lateral sway, movement time, and the measures of variability, except in RTCP. Only one interaction effect was found. Older boys with no DCD exhibited a significantly larger path length than the three other groups. In the remaining analyses of area of sway and AP sway, main effects for group revealed differences between boys with and without DCD. A similar pattern of group differences was also evident in measures describing underlying control mechanisms (TTPV, RTCP, $f_{peak}$).

Discussion

Developmental Issues

The analysis of COP measures and their derivatives revealed no significant differences between the younger and older typically developing children. Thus, our findings confirmed that the ability to make effective postural adaptations, as inferred from leaning, emerges as early as 7-8 years of age and coincides with the maturation of an integrated type of control (Riach & Starkes, 1993, 1994). Our results are also in line with literature suggesting that more optimal performance of tasks involving spatial accuracy requires greater contribution from on-line, rather than open loop control (Hay, 1979; Kirshenbaum et al., 2001).

To support the developmental delay hypothesis, we expected that older children with DCD would resemble the performance of younger, unaffected individuals (e.g., Geuze, 2003). Often this pattern of results, as inferred from measures of coordination and/or control, implies that the differences between typically and atypically developing children may be due to developmental delay. Our data, with the exception of one variable (path length), did not reveal such a pattern, however. Although we concede that other research designs may be better suited to examine this issue, our conclusion is consistent with the interpretation put forward in other investigations of children with and without DCD of different ages in balance (Williams & Woollacott, 1997), namely, that movement difficulties associated with the
DCD deficit may be due to less than optimal status of perceptuo-motor functioning rather than a developmental delay.

**Nature of Postural Adaptations**

As expected, the overall picture that emerged from the analysis of COP measures is that typically developing boys exhibited a larger stability region, swaying significantly further away from the vertical, when compared to their peers with DCD. This difference was confirmed by averaged (Aomean) and maximum (Aomax) area of sway. Although our results cannot be compared to other investigations involving children with DCD performing this type of task, the pattern of our results is consistent with literature comparing younger and older children (Riach & Starkes, 1993), and adults (Blaszczyk, Hansen, & Lowe, 1993; van Wegen et al., 2002), and individuals with and without neurological deficits (e.g., Parkinson’s Disease; van Wegen, van Emmerik, Wagenaar, & Ellis, 2001).

To further examine the possible differences in sway characteristics, we incorporated measures reflecting the amount of sway in the sagittal (AP sway) and lateral planes (Lat sway). Unaffected boys exhibited larger anterior-posterior sway when compared to boys with DCD. These results imply that the previously discussed differences, evident from area of sway measures, may be primarily due to differences in AP but not lateral sway. Although there is no support for this finding in the DCD literature during dynamic postural adaptations, similar results were found in the leaning performance of young and elderly individuals (Blaszczyk et al., 1996; van Wegen et al., 2002) and during quiet standing in children with DCD (Przysucha & Taylor, 2004). A possible explanation for this pattern of results is that the postural behaviors emerging in the respective planes of motion are controlled by different mechanisms (Horak & Moore, 1993; Winter, 1995). Thus, it is plausible that the status of control responsible for lateral sway is comparable in children with and without DCD. For that reason, we examined possible between-group differences in underlying control tendencies, based on COP excursions exhibited during a frontal lean exclusively.

**Qualitative Analysis of Postural Adaptations**

To substantiate the quantitative differences between the groups in the nature of emerging postural adaptations, we performed a qualitative analysis of the COP profiles of each group. The examination of COP projections confirmed the differences emerging in measures describing the range of voluntary leaning (Aomax, Aomean). As the upper panel of Figure 2 shows, boys from the comparison group swayed further away from the vertical as evident in larger ellipses, representing 95% of all COP points. In addition, their COP projections were consistent with the leaning directions explicitly specified in the protocol (AP and lateral excursions). Also, the transitions between anterior-posterior and left and right displacements were relatively smooth as evident from a small congestion of COP tracings around the (0, 0) coordinates, representing the approximate location from which each performer initiated his leaning. A distinctly different pattern of (COP) behavior emerged in the performance of selected children with DCD (see Figure 2, lower panels). They exhibited a smaller range of excursions (smaller 95% ellipses), and
more frequent and chaotic changes in the COP displacement. This uncontrolled behavior was inferred from the COP excursions occurring away from the x and y-axis, as well as from an abundance of COP corrections around the initial, vertical position (0, 0). In our opinion, these condensed areas resulted from shorter than expected excursions generated while leaning away, particularly in the anterior direction, as well as when leaning back toward the initial vertical position. In fact, perception of (postural) verticality constitutes a fundamental egocentric reference for spatial orientation, and it may be a potential limiter in balance control and/or self-initiated postural perturbations (Newell & Morrison, 1996).

**Underlying Control Tendencies**

The second purpose of the study was to examine the nature of control tendencies underlying the performance of children with and without DCD. The analysis of TTPV revealed that typically developing individuals switched from open to closed loop control relatively early during the movement and thus spent approximately 78% (RTCP) of their total movement time performing on-line corrections to the location of COP in space. A different control tendency typified the performance of children with DCD. They delayed the transition from open to closed loop control, spending only about 54% of total movement time under closed-loop control. Given the goal of the present task, it was expected that greater reliance on sensory monitored corrections would lead to more optimal performance of this task, namely further excursion from the vertical. The differences in sway measures (AP sway, area of sway), described in the proceeding sections, substantiated such an hypothesis.

The literature examining the control issues in balance of children with DCD has mainly focused on examining the status of feedback (e.g., Przysucha & Taylor, 2004) or feedforward control (e.g., Johnston, Burns, Brauer, & Richardson, 2002). Thus far, the status of an integrated type of control in this population has only been investigated based on discrete, goal-directed tasks. In one of these studies, Smyth and colleagues (2001) carried out a series of experiments examining the role of visual information and the nature of underlying control in children with and without DCD in reaching. Their overall conclusion, similar to our findings, was that children with DCD spent less time in the deceleration phase of the movement (time after peak velocity) when compared to typically developing peers. Also, children with DCD were found to make movements more quickly and had higher velocity when contacting the target, thus jeopardizing the spatial precision of their actions. More reliance on ballistic, rather than feedback-type of control, was associated with less responsiveness of children with DCD to the accuracy demands of the task. Taken together, based on our results and inferences from relevant research involving children with (Smyth et al., 2001) and without DCD (Kirshenbaum et al., 2001), we believe that the differences children with DCD exhibit in postural adaptations are due to the degree to which they rely on open-loop control, when greater contribution from feedback control is desired.

**Perceptual Limiters**

Reduced reliance on feedback control, and consequent larger involvement of a preprogrammed mode, has been linked to less than optimal ability to absorb and
process sensory information (e.g., Collins et al., 1995). In fact, Riccio and Stoffregen (1988) have argued that the essential variable responsible for effective postural adaptations is perceptual sensitivity. Research examining the nature of postural adaptations of adults who are healthy (e.g., Blaszczyk et al., 1993), as well as those affected by neurological impairment (e.g., Parkinson’s Disease; van Wegen et al., 2001) supports this hypothesis. Reduced perceptual sensitivity is considered as a predictor of balance problems and a consequent increased risk of falling. The implementation of tighter constraints on the postural system, leading to limited range of lean, is viewed as a way the system compensates for reduced perceptual sensitivity, particularly in the proprioceptive domain (Massion, 1992; van Wegen et al., 2001).

The performance of a leaning task, although inevitably affected to some extent by visual input, is predominantly dependent on feedback from muscle spindles (type I and II), Golgi tendon organs and joint receptors (Haas, Diener, Rapp, & Dichgans, 1989; Morasso, Baratto, Capra, & Spada, 1999). Thus it is intuitively pleasing to expect that since children with DCD are known to exhibit problems in processing these types of inputs, this would jeopardize their ability to make effective postural adaptations regarding the position/movement of a limb or body component in space (e.g., Bairstow & Laszlo, 1981; Coleman, Piek, & Livesey, 2001).

To substantiate our hypothesis, we examined the spectral characteristics of sway, where COP peak frequency represents the frequency dominating a person’s postural sway (McClenaghan et al., 1996). At the behavioral level, the presence of lower frequency sway (e.g., .5-1 Hz) coincides with slower, more subtle and more controlled drifts of COP resulting in large amplitude of sway (McClenaghan et al., 1996). On the other hand, higher frequency sway (>1 Hz) coincides with chaotic and abrupt changes in COP velocity, likely resulting in movements that are jittery and lack smoothness. The presence of this type of response is induced by less than optimal functioning of the CNS (Oppenheim, Kohen-Raz, Alex, Kohen-Raz, & Azarya, 1999), and it is also evident in spectral characteristics of individuals exhibiting difficulties absorbing and processing proprioceptive inputs (Riach & Hayes, 1987). Our analysis revealed that children with DCD in fact exhibited a larger peak frequency (1.4 Hz) when compared to individuals without DCD (1 Hz). The pattern of differences emerging in our study, between typically and atypically developing individuals, is consistent with differences Riach and Hayes (1987) found examining children of different ages. In their study, higher frequency sway was evident in postural adjustments of younger (1 to 2 Hz), but not older children (.5 to .7 Hz). The authors attributed this high frequency sway to “the relative immaturity of (their) proprioceptive systems or of the central processing of proprioceptive input” (Riach & Hayes, 1987, p. 656). Given the relevant literature, we suspect that less than optimal use of proprioceptive inputs may be a significant limiter for children with DCD in the performance of this type of postural task. It is clear that a more explicit examination of this issue is warranted.

Alternative Explanations

As a number of factors may constitute limiters in the acquisition of effective balance control and postural adaptations (Horak, 1997), it is important to consider some of these alternative explanations. From the biomechanical perspective, physical dimensions as well as strength intuitively may be responsible for the emerging
differences. In relation to the former issue, research has shown that factors other than physical dimensions (e.g., perceptuo-motor development) contribute to the differences in balance control of typically developing children over 6 to 7 years of age (Lebiedowska & Syczewska, 2000). In our study, height, length (PAS, PPS), and width of the base of support was comparable in younger and older children, and there were no significant differences between same age children with and without DCD. Thus it appears that subtle structural differences do not account for the observed differences. In relation to the latter issue, anecdotal reports often suggest that strength is a limiter underlying the performance of children with DCD in physical activities. Nevertheless, to our knowledge the existing empirical evidence for this hypothesis is limited to the study by Raynor (2001). Furthermore, even if there were differences between the groups in strength, it has been shown that they would have to be substantial (50% of normal level) in order to affect the range of COP excursions (Pai & Patton, 1997).

Past research comparing underlying control issues in balance performance, between children with and without DCD, emphasized the accuracy of feed forward control alone as a movement limiter underlying the emerging differences (e.g., Johnston et al., 2002; Williams & Woollacott, 1997). Children with DCD exhibited greater amplitude of force during balance tasks, when compared to typically developing peers (e.g., Williams & Castro, 1997). Given the measures used here, this hypothesis cannot be directly addressed. If, in fact, hyper-activation alone was responsible for the differences in movement product, it would be expected that these forceful outputs would likely lead to overshooting of the stability limits resulting in a step or fall. Such outcomes, however, were not evident in the performances of children with and without DCD. In terms of movement time, which is another measure often used to infer programming issues, we found that children with and without DCD spent approximately the same amount of time leaning forward. This result supports the findings of Geuze (2003), who examined the nature of muscle activity during anterior sway due to subtle perturbation. He found that the differences in the nature of muscular responses (movement time and latency) of the lower leg muscles (tibialis, soleus, gastrocnemius) were only evident initially, and disappeared across trials. These subtle group differences, in the activation of ankle muscles during anterior sway, were also found by Williams and Woollacott (1997). We do not discard the plausibility of the hypothesis that the differences between the groups of interest in balance control may be due to accuracy in pre-programming. We feel, however, that less than optimal use of feedback control, due to proprioceptive issues, is a plausible explanation for the degree to which children with DCD use both types of mechanisms in the context of an integrated model of movement control.

Conclusion

Boys with and without DCD exhibited different postural adaptations, as evidenced by the quantitative measures of movement outcome (area of sway measures and AP) and qualitative analysis of resulting COP tracings. The analysis of COP derivatives also showed that the differences in postural adaptations coincided with different control tendencies. The group with DCD relied to a greater extent, when compared to unaffected boys, on a ballistic type of control that lacks the accuracy needed to satisfy the spatial demands of the present task (Kirshenbaum et al., 2001).
Functionally, none of the participants in the present study failed the task; however, the detrimental effects of over-reliance on preprogrammed control may translate into failures in tasks demanding the precise coordination of limbs in space and time, such as interceptive tasks (e.g., catching, kicking, batting).

The examination of spectral characteristics of sway revealed that over-reliance on open loop control coincided with postural adaptations characterized by a higher frequency sway component (McClenaghan et al., 1996). The prevalence of this (high frequency) sway is often evident in balance control/postural adaptations of individuals who have difficulties absorbing and processing proprioceptive information. Considering the extent to which proprioceptive information is involved in leaning (Haas et al., 1989), and that at least some children with DCD exhibit problems with use of such inputs (Bairstow & Laszlo, 1981), we believe that the emerging differences in the nature of postural adaptations and underlying control tendencies can be attributed to reduced perceptual sensitivity to proprioceptive inputs. Research examining the sensory/perceptual issues in balance control/postural adaptations in adults with balance deficits (e.g., van Wegen et al., 2002) and children of different ages (Riach & Hayes, 1987) appears to support this hypothesis.

References


