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Contributions of trunk muscles to anticipatory postural control in children with and without developmental coordination disorder

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ABSTRACT

Current evidence suggests that movement quality is impacted by postural adjustments made in advance of planned movement. The trunk inevitably plays a key role in these adjustments, by creating a stable foundation for limb movement. The purpose of this study was to examine anticipatory trunk muscle activity during functional tasks in children with and without developmental coordination disorder (DCD). Eleven children with DCD (age 7 to 14 years) and 11 age-matched, typically-developing children performed three tasks: kicking a ball, climbing stairs, and single leg balance. Surface electromyography (EMG) was used to examine the neuromuscular activity of bilateral transversus abdominis/internal oblique, external oblique and L3/4 erector spinae, as well as the right tibialis anterior and rectus femoris muscles. Onset latencies for each muscle were calculated relative to the onset of rectus femoris activity. In comparison to the children with DCD, the typically-developing children demonstrated earlier onsets for right tibialis anterior, bilateral external oblique, and right transversus abdominis/internal oblique muscles. These results suggest that anticipatory postural adjustments may be associated with movement problems in children with DCD, and that timing of both proximal and distal muscles should be considered when designing intervention programs for children with DCD.

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1. Introduction

Children with developmental coordination disorder (DCD; American Psychiatric Association, 2000) are at risk of pervasive, long-term difficulties associated with various aspects of neuromuscular activation and postural control. Problems with anticipatory postural adjustments (APAs) in this population of children have been identified during upper extremity pointing (Huh, Williams, & Burke, 1998; Johnston, Burns, Brauer, & Richardson, 2002), precision grasping (Jucaite, Fernell, Forssberg, & Hadders-Algra, 2003), and fine motor tasks (Smits-Engelsman, Wilson, Westenberg, & Duysens, 2003). Altered reactive postural adjustments (RPAs), difficulty in processing sensory inputs, and inconsistent and inefficient neuromuscular activation sequences, timing, and force production (Geuze, 2003; Lundy-Ekman, Ivry, Keele, & Woollacott, 1991; Piek & Skinner, 1999; Raynor, 2001; Volman, Laroy, & Jongmans, 2006; Williams, 2002; Williams & Woollacott, 1997) may also contribute to postural control problems.

Typically-developing children integrate movement and posture so effortlessly that the underlying control processes are not generally considered. This complex synthesis is ensured by the interplay of two central strategies that are designed to minimize the effects of equilibrium disturbances: APAs, which involve prediction of upcoming perturbations, and RPAs, which are based on sensory feedback received after perturbations occur (Massion, Alexandrov, & Frolov, 2004). APAs are particularly important, as they support a state of postural readiness, contribute to force generation necessary for movement, and enable efficient recovery from perturbations (Ledebt, Bril, & Brenière, 1998; Patla, 2003). As such, altered use of anticipatory strategies is likely to impair the performance of daily activities requiring postural control.

1.1. Anticipatory trunk muscle activation and postural control

By its central location in the body, the trunk is optimally situated to support distal limb segment mobility, providing a stable base for movement tasks such as reaching or walking (Forssberg, 1999; Massion et al., 2004), and facilitating force generation and transfer to more distal segments during coordinated multi-joint movement (Anderson & Behm, 2005; Hodges, 2003; Kibler, Press, & Sciascia, 2006; Massion et al., 2004). Although the passive structure of the spine (i.e., that created by the bones and ligaments) contributes to its ability to resist compression and shearing forces, coordinated spinal muscular activity ultimately determines the stability of those joints (Gardner-Morse & Stokes, 1998; McGill, Grenier, Kavcic, & Cholewicki, 2003; Panjabi, 1992).

Stability (or stiffness) of the spine is partially dependent on the dynamic co-contraction of numerous synergist and antagonist muscles, in order to limit excessive joint motion while allowing generation of the necessary torques and desired movement (Gardner-Morse & Stokes, 1998; Hodges, 2003; Lee, Rogers, & Granata, 2006; McGill et al., 2003). In general, all trunk muscles are thought to contribute equally to the stability of that region (Cholewicki, Panjabi, & Khachatryan, 1997; Cholewicki & VanVliet, 2002; McGill, 2002; McGill et al., 2003); therefore, depending on the task, modest levels of abdominal and extensor muscle co-contraction are sufficient to ensure stability (Cholewicki et al., 1997; Kavcic, Grenier, & McGill, 2004; McGill et al., 2003). In addition, accurate control of the spine depends on central prediction of the anticipated and temporal demands of stability (Hodges, 2003; Hodges & Richardson, 1997). Thus, the role of anticipatory trunk muscle activity has become the subject of much study and discussion, in an attempt to describe the optimal determinants of stability for movement and musculoskeletal function (e.g., Hodges, 2003; Kibler et al., 2006; McGill et al., 2003).

To date, most of this research has focused on adult populations. As such, little is known about the developmental aspects of anticipatory trunk muscle activation or the muscles' impact on coordinated movement in individuals with neurodevelopmental disabilities such as DCD. For children with DCD, for whom postural control processes may not function optimally, a better understanding of trunk muscle function may have important implications for both assessment and intervention.

1.2. Postural control and neuromuscular activation in children with DCD

Altered anticipatory and reactive neuromuscular activation involving both the trunk and the extremities may interfere with the initiation and execution of coordinated movement, helping to ex-

plain why tasks requiring precise muscular timing and coordination are often difficult for children with DCD (Geuze, 2003; Johnston et al., 2002; Williams & Woollacott, 1997). While the trunk is surprisingly understudied in the DCD literature, the neuromuscular activation characteristics of these children have primarily been generalized from studies that examine limb muscle activity during relatively isolated upper extremity movements like pointing and grasping (Huh et al., 1998; Jucaite et al., 2003; Williams, McClenaghan, & Ward, 1985), knee motion (Raynor, 2001), and sustained postures (Geuze, 2003; Williams, Fisher, & Tritschler, 1983).

It has been reported that children with coordination difficulties produce excessive levels of EMG activity compared to their typically-developing peers (Williams et al., 1983; Wilson & Trombly, 1984). Prolonged muscular co-contraction around the ankle (Geuze, 2003) and knee (Raynor, 2001), and prolonged erector spinae activity (Williams et al., 1985) have also been described. However, when trunk muscle timing is considered with respect to the limb muscle responsible for shoulder movement, children with DCD demonstrate deficient anticipatory trunk muscle activity in the form of longer onset latencies (Johnston et al., 2002). Interestingly, Johnston and colleagues (2002) also found that the delayed trunk muscle activity was accompanied by earlier activation of certain shoulder girdle muscles, which have been reported elsewhere to produce excessive EMG activity (Wilson & Trombly, 1984). Thus, it appears that neuromuscular timing (i.e., its association with APAs or RPAs) is pertinent to the interpretation of amplitude data as well as to the descriptions of neuromuscular activation.

For children with DCD, evidence of deficient anticipatory trunk muscle activity and excessive co-contraction of extremity muscles suggests fundamental differences in neuromuscular recruitment. This highlights the need to specifically consider the role of the trunk muscles during movement, rather than simply extrapolating from lower or upper extremity data. While the existing literature provides a basis for the understanding of neuromuscular recruitment in children with DCD, there is insufficient evidence to draw conclusions about how these children recruit trunk muscles during functional multijoint tasks (i.e., the types of tasks that often present the greatest challenges).

Therefore, the purpose of this study was to examine the relationship between the timing of trunk muscle activity and movement onset in children with DCD as compared to typically developing children, with respect to anticipatory and reactive muscle activity, during meaningful postural tasks. Because the children with DCD were expected to demonstrate less evidence of APAs in comparison to typically-developing peers, it was hypothesized that: (1) for the anticipatory period relative to the reactive period, the mean EMG amplitude of bilateral erector spinae (ES), transversus abdominis/internal oblique (TA/IO), external oblique (EO), and tibialis anterior (TbA) muscles would be greater for the control group than the DCD group; and (2) the onset latencies of those muscles would be delayed for children with DCD.

2. Methods

2.1. Participants

Participants were eleven children with DCD, aged 7–14 years (9 boys, 2 girls, mean age 11 years), and a convenience sample of age- and sex-matched typically-developing children without DCD (9 boys, 2 girls, mean age 10 years, 11 months). Each participant provided informed assent, and a parent/guardian provided informed consent. The study was approved by the Research Ethics Boards of the authors' university and the regional health authority.

Inclusion criteria for the DCD group included: (1) a diagnosis of DCD; and (2) a score on the Movement Assessment Battery for Children, Second Edition (M-ABC-2) (Henderson, Sugden, & Barnett, 2007) at or below the 15th percentile. All children in the DCD group had been referred to the first author for physical therapy by a developmental pediatrician, but had not yet started therapy. There were no significant between-group differences in age, height or body weight (Table 1), however there were large differences between groups for the MABC-2 scores (Table 2).

Children were included in the control group if their M-ABC-2 score was above the 25th percentile. A medical screening questionnaire (adapted by the first author based on the developmental pediatrician's clinical questionnaire), completed by parents prior to participation, indicated that none of the children had any acute injuries, back pain, scoliosis, or other conditions that might affect coordination.

Table 1
Mean values for age, height, weight, and Body Mass Index (BMI) for each group.

	Group	
	DCD	Control
Age (years)	11.1 (Range 7.17–14)	10.92 (Range 6.67–14.6)
Height (cm)	167.5 (Range 122–168)	146.6 (Range 128–170)
Weight (kg)	40.1 (Range 22–54)	38.4 (Range 28–57)
BMI	28 (Range 18–32)	26 (Range 21-34)

Table 2
Group means and ranges for MABC-2 scores.

MABC-2 Subtest	Group	
	DCD Mean (Range)	Control Mean (Range)
Manual dexterity percentile	8 (0.5–16)	43 (9–75)
Aiming & catching percentile	30 (5–40)	64 (25–98)
Balance percentile	11 (5–25)	69 (16–91)
Overall percentile rank	6 (1–15)	60 (25–75)

2.2. Assessment tools

2.2.1. M-ABC 2

The M-ABC 2 is a standardized, norm-referenced motor proficiency measure for children aged 3–16 years, which is composed of eight skills divided into three areas: aiming and catching, balance, and manual dexterity. While there is no "gold standard" for motor assessment in DCD (Civetta & Hillier, 2008), the M-ABC has been one of the most commonly used tools to evaluate the motor skills of children with DCD (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001).

2.3. Tasks

Children performed three tasks requiring postural stability and unilateral hip flexion, using a two-choice reaction paradigm to avoid preparatory muscle activation prior to the data collection period (Johnston et al., 2002; Mercer & Sahrmann, 1999). That is, the participants did not know which leg was to be moved until a "go" signal started the movement trial. The task uncertainty associated with this paradigm was intended to minimize the preparatory muscle activity that may occur when a participant knows in advance which limb is to be moved. Children were instructed to perform all tasks at their preferred pace to maximize performance accuracy and improve the functional relevance of the tasks. Task paradigm and equipment set-up were similar for all three tasks (Fig. 1). To begin each trial, participants stood on an outline of two footprints, positioned next to a force plate, and facing the computer screen on which the visual signals were displayed. On the examiner's cue, the child stepped forward onto two different footprint outlines, centered on the force plate. The recording of force plate and EMG data was triggered when the first foot contacted the force plate. In order to standardize the child's starting position, the footprints were laterally spaced 10 cm apart (Mercer & Sahrmann, 1999).

Visual signals were produced using a Visual BASIC program and displayed on a computer monitor. The child was instructed to stand still while waiting for the visual signal. A "get ready" signal (i.e., yellow screen) was followed by a "go" signal (i.e., a large green rectangle on either the right or left half of the screen, indicating which leg was to be moved) at a random interval of 1–3 s (Mercer & Sahrmann, 1999). Trials were repeated if the child visibly shifted his or her weight to the wrong side first. For each task, children performed 1 practice trial on each leg. Approximately twelve trials were performed,

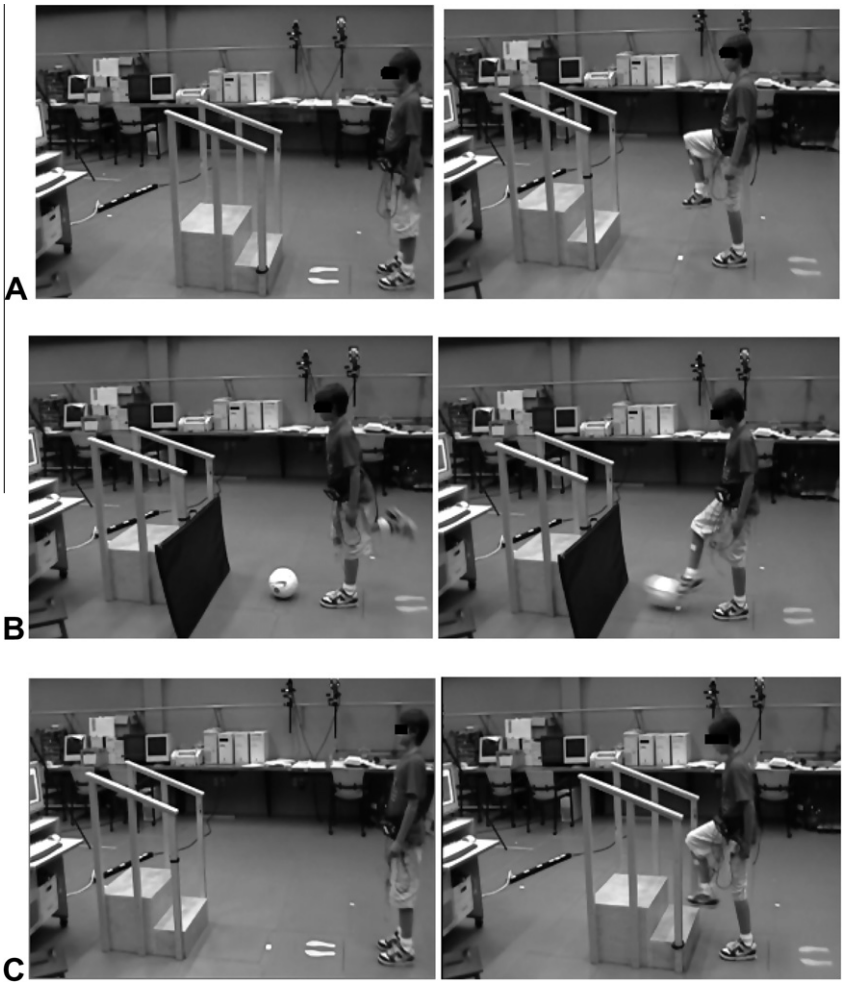

Fig. 1. Experimental set-up for the three tasks: A. single leg balance; B. kicking; C. step up.

randomized between legs. Only trials involving the right leg were recorded and testing continued until six trials were recorded from the right leg.

2.3.1. Balance task

The equipment was set up as in Fig. 1A. The child lifted the leg on the side indicated by the "go" signal, with the hip and knee being flexed to approximately 90°. The children were instructed to perform the movement this way, to maximize recruitment of the rectus femoris muscle, which was considered the prime mover or focal muscle for all three tasks. Children were instructed to balance on one foot as long as possible.

2.3.2. Kicking task

A standard soccer ball was positioned on a mark centered 0.4 m ahead of the footprint outlines on the force plate (Fig. 1B). As a target, a gym mat was secured, perpendicular to the floor, in front of the ball marker. Participants were asked to kick the ball at the target using the foot indicated by the "go" signal. They were asked to contact the ball with the dorsum of the foot in order to bias the hip movement toward flexion and standardize the motion as much as was practical.

2.3.3. Step up task

A wooden stair case was positioned just ahead of the force plate (Fig. 1C). Upon seeing the "go" signal on the computer screen, the child stepped up onto the lowest step (18 cm high), leading with the leg indicated by the signal, and then placing the other leg beside it on the same step. Trials in which the participant touched the handrail were repeated.

2.4. Apparatus

Surface electromyography (EMG) was used to examine the anticipatory neuromuscular activation characteristics of eight trunk and lower extremity muscles during performance of the three tasks. Each task was performed while standing on a force plate to record center of pressure (COP) movement.

2.4.1. Surface EMG data collection

Surface EMG data was collected using an eight-channel EMG telemetry system (Myomonitor IV, Delsys, Inc.). Parallel-bar EMG sensors with 10 mm contact spacing (Delsys, Inc.) were used to collect data from three groups of trunk muscles: (1) ipsilateral and contralateral transversus abdominis/internal oblique (I and C TA/IO; placed 2 cm medial and inferior to the anterior superior iliac spine [ASIS], oriented vertically; Marshall & Murphy, 2003); (2) ipsilateral and contralateral lumbar erector spinae (I and C ES; oriented vertically, placed 3 cm lateral to the spine and near the level of the iliac crest between the L3 and L4 vertebrae; Escamilla et al., 2006); and (3) ipsilateral and contralateral external oblique (I and C EO; placed above the ASIS at the level of the umbilicus, oriented vertically; Escamilla et al., 2006; Marshall & Murphy, 2003).

On the right leg, the tibialis anterior (TbA; placed at 1/3 of the way along the line between the tip of the fibula and the tip of the medial malleolus, oriented along this line) and the rectus femoris (RF; placed at 50% of the way along the line from the ASIS to the superior patella, oriented along this line) muscles were monitored, with electrodes placed according to SENIAM guidelines (Surface Electromyography for the Non-Invasive Assessment of Muscles, n.d.). The TbA is known to be activated early and consistently during stepping, and RF was selected as the prime mover or focal muscle for the tasks because of its close temporal association with movement onset during stepping tasks (Mercer & Sahrmann, 1999). Prior to electrode placement, all sites were prepared by vigorously cleaning the skin with alcohol. EMG signals were sampled at 2000 Hz, and synchronized with the force plate.

2.5. Data analysis

2.5.1. Muscle onset identification and calculation of onset latencies

For each muscle, in each trial, the onset latency was determined relative to the onset of the RF. Onset was identified as the point at which the mean of 50 consecutive samples (i.e., 25 ms when sampling at 2000 Hz) exceeded 3 standard deviations from the mean baseline activity (Hodges & Bui, 1996; Hodges & Richardson, 1997). For RF, the baseline was selected as the 50 ms period preceding lateral weight shift (based on COP excursion), while the child was standing still at the start of the trial. Trunk muscle EMG data was noted to contain other periods of activity, apparently tonic in nature and therefore related to the maintenance of standing posture, that were not related to task performance. Therefore, in order to ensure that the onset most relevant to task performance was identified in each of these trials, the final burst (with respect to the onset of RF) of trunk muscle activity that exceeded 3 standard deviations was selected as the onset. For each of the other muscles, a 50 ms portion of that muscle's recording with the lowest and most consistent amplitude was identified as the baseline.

Off-line processing included band pass filtering between 30 and 500 Hz using a 4th order Butterworth finite impulse response digital filter (EMGWorks Analysis 3.6.0.0, Delsys, Inc.). The 30 Hz high pass cut-off was selected to minimize the electrocardiogram artifact present in the trunk muscle EMG data (Drake & Callaghan, 2006) and was effectively utilized during pilot testing. Onset determination was accomplished using a Visual BASIC program, and each onset time was checked visually.

Onset latencies were calculated in milliseconds (ms). EMG onsets were considered to be anticipatory (i.e., APAs) if they occurred between 150 ms before and 50 ms after RF activation (Aruin & Latash, 1995; Hodges & Richardson, 1997; Latash & Hadders-Algra 2008; Liu, Zaino, & Westcott McCoy, 2007).

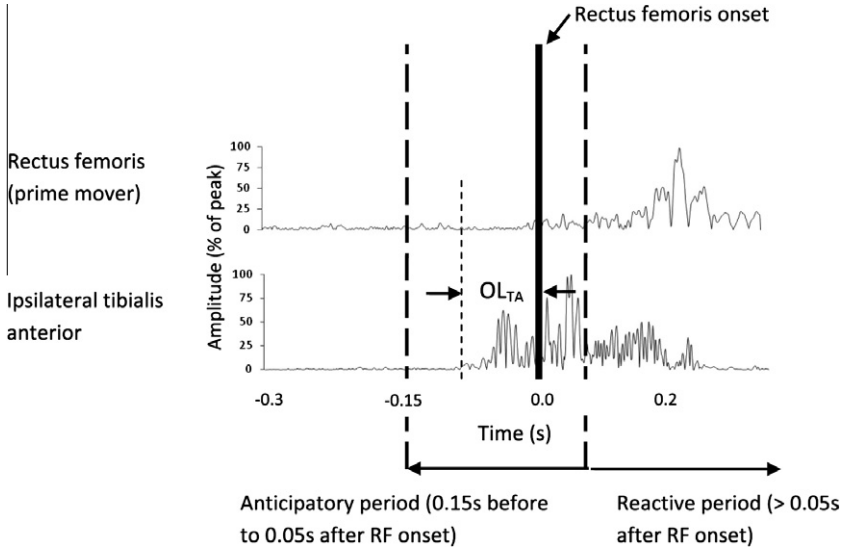

Fig. 2. Example of smoothed EMG data from 2 muscles, recorded during the kicking task from a child in the control group, illustrating the temporal relationship between EMG onsets. Rectus femoris onset (0 ms) is indicated by the solid vertical line. Thick dashed lines indicate the anticipatory period. The thinner dashed line indicates ipsilateral tibialis anterior muscle onset. An example of a relative onset latency for an anticipatory postural response (i.e., occurring within 150 ms prior to 50 ms after rectus femoris onset) is shown for ipsilateral tibialis anterior (OL_{TA}).

Onsets that occurred after this "anticipatory period" (i.e., >50 ms after the RF onset) were considered to contain more RPA activity associated with the focal movement of interest (i.e., RPA related to the postural disturbance created by RF contraction), in addition to APA activity associated with other aspects of the task (Fig. 2).

2.5.2. Mean EMG amplitude

In order to compare the magnitude of trunk muscle APAs between groups, the mean EMG amplitude in the anticipatory period was normalized by expressing it as a percentage of the mean EMG activity for the 1-s period following the anticipatory period (i.e., the "reactive period"). As with the onset latency data, it should be noted that signal data acquired during this period of time likely contained elements of both anticipatory and reactive postural activity; however, reliably identifying or separating these components within the EMG signal was neither necessary nor possible. For each child, the mean of six trials was calculated.

2.6. Statistical analysis

To determine the suitability of the data for parametric analysis, measures of central tendency and the distribution's normality were examined visually and using Fisher's Skewness Coefficient. Repeated measures analysis of variance (RM-ANOVA) was used as an omnibus test to examine the individual effects of group (between subjects) and task (within subject), as well as the interaction of group and task for: (1) EMG onset latencies; and (2) mean EMG amplitude. For this analysis, a total of eight RM-ANOVAs were performed for amplitude (i.e., one for each muscle) and seven RM-ANOVAs were performed for onset latency (i.e., one for each muscle except rectus femoris). To further explore the strength of the relationship between onset latency and group, an estimate of effect size (Cohen's *d*) was calculated. An effect size of .8 was considered to be a large effect. An additional RM-ANOVA was then used – as the omnibus test did not reveal any significant group by task interactions – to

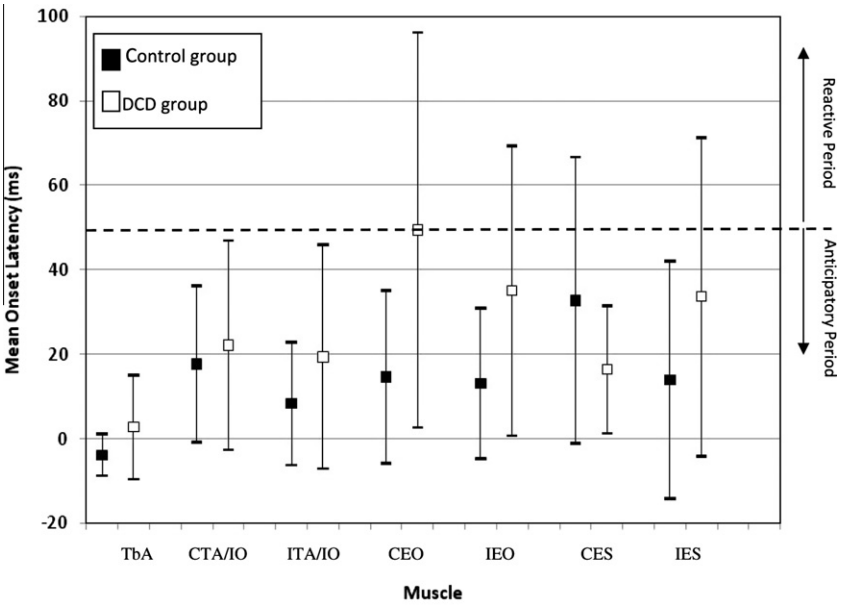

Fig. 3. Graph showing mean onset latencies (ms) for each muscle by group, for all tasks combined. Error bars represent 1 standard deviation above and below the mean. Results of ANOVA indicate significant difference between groups ($p = .01$). TbA: Ipsilateral tibialis anterior; ITA/IO: Ipsilateral transversus abdominis/internal oblique; CTA/IO: Contralateral transversus abdominis/internal oblique; IEO: Ipsilateral external oblique; CEO: Contralateral external oblique; IES: Ipsilateral erector spinae; CES: Contralateral erector spinae.

examine the main effects of group (between-subjects variable) and muscle (within-subjects variable) on onset latency.

With the exception of the effect size measure, which was calculated manually using Microsoft Excel, all analyses were conducted using Statistical Package for the Social Sciences software, version 11.0 (SPSS, Inc., Chicago, IL). Statistical significance was set at $p < .05$.

3. Results

3.1. Emg

3.1.1. Mean onset latencies

Mean onset latencies, expressed relative to RF onset are displayed in Fig. 3. For both groups, the mean onsets for all muscles except TbA in the control group were after RF onset but still within the anticipatory period (i.e., <50 ms after RF onset). For all comparisons, except CES, the control group's mean onset times were earlier than those of the DCD group.

Results of the omnibus RM-ANOVA identified significant between-group differences for IEO, CEO, and ITA/IO. As well, differences approached significance for TbA. Means and standard deviations for each group and muscle, along with effect size calculations (Cohen's d) and significance (p) values, are presented in Table 3. There were no significant interactions between group and task, indicating that task was not a factor with respect to between-group differences. Estimates of effect size were large for all comparisons between groups except for the IES and CTA/IO muscles.

Results of the second (group by muscle) RM-ANOVA indicated that overall, the mean onset times for all muscles were significantly later for the DCD group than for the control group, $F(1, 20) = 7.34$, $p = .01$. Differences between groups were largest for CEO and smallest for CTA/IO muscles (Fig. 3).

Table 3
Mean onset latencies for each muscle by group

Muscle	Onset latency (ms): mean (*SD*)		*F* value ($df_{:1,20}$)	Significance (*P* value)	Cohen's *d*
	Control group	DCD group			
TbA	−3.81 (3.48)	2.744 (10.71)	3.729	0.07*	0.92‡
ITA/IO	8.31 (9.04)	19.41 (15.32)	4.288	0.05*	0.91‡
IEO	15.57 (8.57)	35.078 (22.46)	7.24	0.01*	1.26‡
IES	22.84 (22.41)	33.61 (29.51)	.931	0.35	0.42‡
CTA/IO	20.89 (12.23)	22.15 (17.5)	.038	0.85	0.08
CEO	17.33 (11.09)	49.42 (34.03)	8.84	0.008*	1.42‡
CES	32.75 (9.32)	16.36 (10.29)	2.59	0.123	1.67‡

TbA: Ipsilateral tibialis anterior; ITA/IO: Ipsilateral transversus abdominis/internal oblique; CTvA/IO: Contralateral transversus abdominis/internal oblique; IEO: Ipsilateral external oblique; CEO: Contralateral external oblique; IES: Ipsilateral erector spinae; CES: Contralateral erector spinae.
* Denotes that value was significant or approached significance.
‡ Large effect.

3.1.2. Mean EMG amplitude for the anticipatory period

Mean EMG amplitudes for the anticipatory period were expressed as a percentage of those for the reactive period. Overall, the mean EMG amplitudes (averaged across tasks and muscles) were similar for both groups: 94% (*SD* 50%) for the control group and 94% (*SD* 47%) for the DCD group. These values (being just less than 100%) indicate that, for both groups, mean neuromuscular recruitment during the anticipatory period was slightly less than that of the reactive period. Mean EMG amplitudes ranged from approximately 50–175% (Fig. 4). There were no significant differences between groups for any of the comparisons, nor were there any significant group by task interactions.

4. Discussion

This study compared the way 22 children with and without DCD utilized APAs during three functional tasks involving the maintenance of postural control over a changing base of support. Analyses of mean EMG onset latencies and amplitudes supports the notion that the timing rather than the relative quantity of muscle activation (i.e., the ratio of APA activity to activity after the APA) may be altered in children with DCD. These results, which enhance the current understanding of how children with DCD move, support previous reports that these children have difficulty producing timely, consistent adjustments in muscle activation in order to anticipate the dynamic biomechanical demands of movement (Geuze & Wilson, 2008; Johnston et al., 2002; Jucaite et al., 2003; Williams & Wollacott, 1997). Given the importance of APAs to the production of coordinated movement, it is likely that the neuromuscular timing of these postural adjustments is associated with coordination difficulties in children with DCD.

4.1. Anticipatory trunk muscle onsets

Apart from the contralateral ES muscle, the DCD group's mean onset times (relative to RF onset) were later than those of the control group, with significant differences between groups for the ipsilateral TA/IO and TbA, and bilateral EO muscles. Estimates of effect size are consistent with the ANOVA results and support previous reports that anticipatory postural control processes may not function optimally for children with DCD. For this group of children, greater variability in the onset latency data was also observed, suggesting that children with DCD may use less consistent movement strategies than typically developing children.

Few pediatric studies have examined trunk muscle onset latencies, and those that have done so used a two-choice reaction upper extremity pointing task. Our results are comparable to those reported previously for children with and without DCD (Johnston, et al., 2002; Woo, Burns, & Johnston 2003). Similar to our findings, Johnston and colleagues (2002) reported delayed onset of four trunk muscles (bilateral IO, contralateral EO, and rectus abdominis) with respect to the anterior deltoid muscle in children with DCD. Comparison of mean onset latency times between the current study and

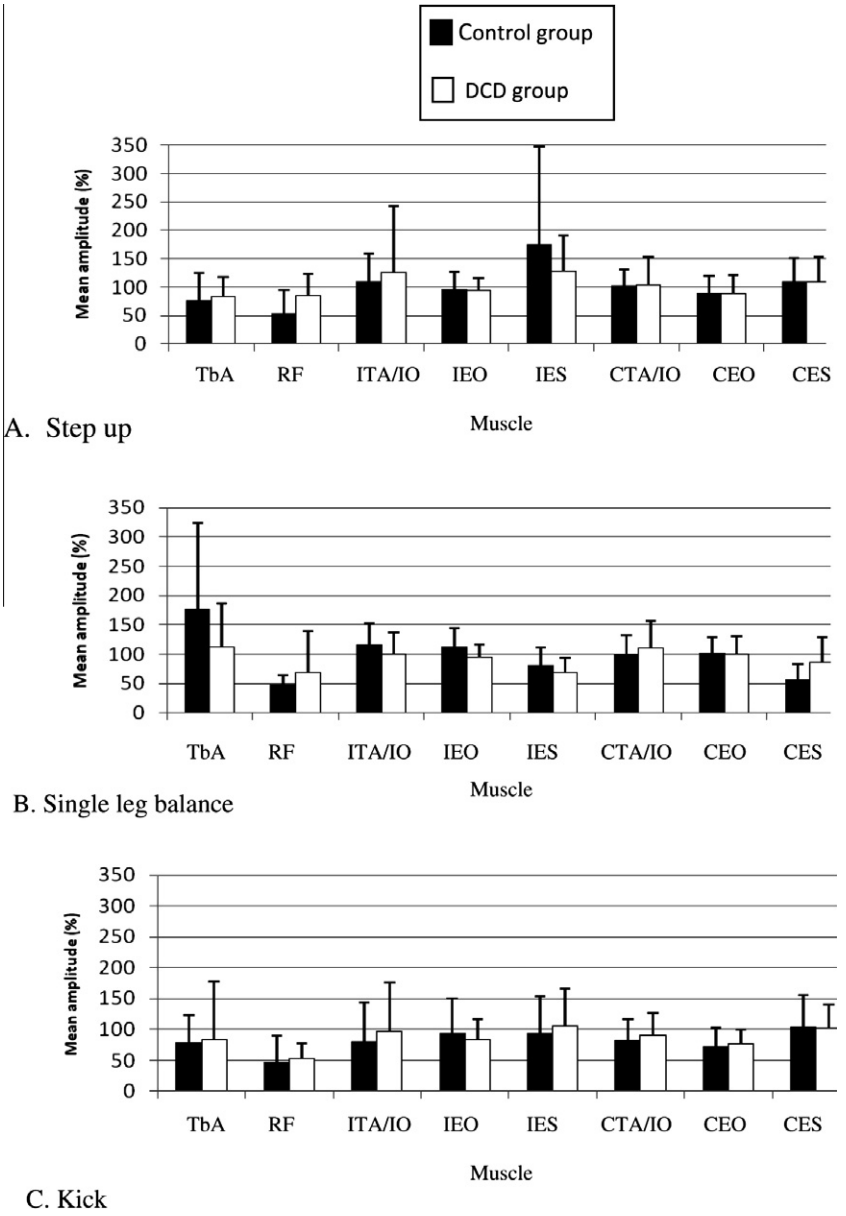

Fig. 4. Mean EMG amplitudes for the anticipatory period (expressed as a percentage of the mean for the reactive period) for each group, for each task. TbA: Ipsilateral tibialis anterior; RF: Ipsilateral rectus femoris; ITA/IO: Ipsilateral transversus abdominis/ internal oblique; CTA/IO: Contralateral transversus abdominis/internal oblique; IEO: Ipsilateral external oblique; CEO: Contralateral external oblique; IES: Ipsilateral erector spinae; CES: Contralateral erector spinae. Error bars represent 1 standard deviation of the mean.

these two others (which ranged from 84 ms prior to 90 ms after the onset of the prime mover) suggests subtle differences in the temporal demands for dynamic stability between upper extremity and lower extremity tasks. At the same time, however, the recognition of anticipatory activity in a variety of tasks – in children both with and without DCD – highlights the value of preparatory trunk control and stability for proficient movement.

To our knowledge, this is the first study to illustrate anticipatory trunk and lower extremity muscle activity during functional tasks involving lower extremity movement. For children in both groups, the observed muscle activity likely served to mitigate the destabilizing effects of lower extremity movement and ensure postural stability as they moved from bilateral to unilateral stance. As such, the trunk muscles are thought to contribute to dynamic trunk and postural stabilization (Johnston et al., 2002), in addition to stability of the spinal segments. A lack of timely preparatory muscle activity, as identified in the children with DCD, may result in impaired responses to dynamic stimuli or rapidly changing environments (Geuze & Wilson, 2008), deficient proximal stability and impaired distal limb segment control (Wilson & Trombly, 1984), greater reliance on RPAs for postural control (Smits-Engelsman et al., 2003), and may necessitate excessive muscle co-contraction in order to compensate for the lack of proximal stability (Johnston et al., 2002). In addition, the neuromuscular patterns observed in the DCD group may be indicative of adaptive motor behavior or normal movement variability; and although potentially inefficient, these movement strategies were apparently effective, allowing all children to achieve the desired functional outcomes.

4.2. Mean EMG amplitude

The hypothesis that mean EMG amplitudes would reflect higher levels of anticipatory activity for the control group than the DCD group was not supported. Although mean values were comparable between groups, means for individual muscles varied within each group. These observations are consistent with the idea that movement requires the flexible and dynamic interaction of anticipatory and reactive muscle activity in order to balance the demands of stability and mobility (Aruin & Latash, 1995; Massion et al., 2004; Riach & Hayes, 1990).

However, these findings appear to be inconsistent with previous reports that children with DCD produce higher levels of EMG activity than typically-developing children. Methodological differences (e.g., muscles studied, data processing and analysis methods) could account for some of the disparity. For example, Williams and colleagues (1983) based their findings on visual inspection of unnormalized peak EMG amplitude, while Wilson and Trombly (1984) normalized their data to the maximum voluntary contraction. As well, in both of those studies, EMG amplitude was evaluated during task performance, while we normalized the mean for the anticipatory period (relative to task initiation) to that which occurred afterward (i.e., during task performance).

Given that the muscles we examined function both to move and to stabilize the spine (Bergmark, 1989), the EMG activity that was recorded may have served either purpose. Consistent with generally accepted movement descriptions, children in the DCD group were observed visually to demonstrate more obvious postural sway and less fluid movement in comparison to the children in the control group. Therefore, more of the DCD group's EMG activity may have been movement-related (i.e., associated with postural corrections to maintain or regain equilibrium), while the control group might have produced more activation for the purpose of stability, with activation patterns indicative of fluid and coordinated movement.

A better understanding of the relationship between delayed anticipatory recruitment and EMG amplitude, and the examination of other key muscles (such as the hip extensors and abductors) in relation to the trunk may help to clarify the interpretation of EMG data during complex, multi-segmental tasks and the implications for postural control strategies in children with DCD. Future research designs should incorporate kinematic data to inform the interpretation of EMG data, acknowledging the effects of posture and alignment on trunk muscle activation (e.g., O'Sullivan et al., 2002). Examining lower extremity muscle timing and amplitude in relation to that of the trunk muscles, and in relation to measures of task performance and outcome, may further elucidate the role of the trunk muscles within the context of coordinated movement patterns and functional performance.

4.3. Methodological limitations

To date, the most common paradigm for studying trunk muscle APAs has been unilateral shoulder elevation, a task with fewer degrees of freedom (and therefore requiring fewer muscles and less EMG activity for joint stability or movement) than those in the current study. Thus, we observed multiple

trunk muscle bursts in many trials, sometimes prior to the time period traditionally recognized as the neuromuscular "anticipatory period". Because of the fluidity of coordinated movement and the coordinated interplay of anticipatory and reactive processes, it was not possible to identify the purpose of this muscle activity (i.e., whether it was "anticipatory" to some upcoming aspect of movement or "reactive" to a different aspect that had already occurred). However, our observations indicated that these other bursts were not relevant to the initiation of the tasks we were investigating.

Because natural, coordinated movement is both dynamic and continuous, the EMG amplitudes of various muscles fluctuated throughout the trials. Even before the start of the trial, participants were likely making postural adjustments to prepare for the "go" signal. This type of general "readiness to move" has been described as lacking in children with DCD (Missiuna, Rivard, & Bartlett, 2003), and indeed, these bursts of tonic activity seemed to occur more often for the children in the control group.

5. Conclusion

Coordinated movement requires appropriately timed and sequenced activation of proximal and distal muscles, involving the complex interaction of anticipatory and reactive processes – mechanisms that are often described as being impaired for children with DCD (Gueze & Wilson, 2008; Huh et al., 1998; Lundy-Ekman et al., 1991; Williams 2002). The trunk plays a key role in these processes, and as our results suggest, delayed anticipatory responses (i.e., delayed generation of APAs involving the trunk with relation to the limbs) may be associated with differences in movement performance for children with DCD. While there is an important association between neuromuscular timing and anticipatory postural control, it is not known how these deficits fit within the broader developmental context of sensory processing and motor control in general.

It is our hope that the results of this study will inform the design of assessment and intervention strategies for children with DCD. Future research should explore whether neuromuscular retraining programs that focus on trunk muscle recruitment can help to promote more timely activation of these muscles, and whether these programs impact functional movement outcomes and quality of life for this group of children.

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