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Human Movement Science 21 (2002) 583–601
HUMAN MOVEMENT SCIENCE
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Differences in postural control and movement performance during goal directed reaching in children with developmental coordination disorder

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Abstract

Poor upper-limb coordination is a common difficulty for children with developmental coordination disorder (DCD). One hypothesis is that deviant muscle timing in proximal muscle groups results in poor postural and movement control. The relationship between muscle timing, arm motion and children's upper-limb coordination deficits has not previously been studied. The aim of this study was to investigate the relationship between functional difficulties with upper-limb motor skills and neuromuscular components of postural stability and coordination. Sixty-four children aged 8–10 years, 32 with DCD and 32 without DCD, participated in the study. The study investigated timing of muscle activity and resultant arm movement during a rapid, voluntary, goal-directed arm movement. Results showed that compared to children without DCD, children with DCD took significantly longer to respond to visual signals and longer to complete the goal-directed movement. Children with DCD also demonstrated altered activity in postural muscles. In particular, shoulder muscles, except for serratus anterior, and posterior trunk muscles demonstrated early activation. Further, anterior trunk muscles demonstrated delayed activation. In children with DCD, anticipatory function was not present in three of the four anterior trunk muscles. These differences support the hypothesis that in children with DCD, altered postural muscle activity may contribute to poor

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0167-9457/02/$ - see front matter
doi:10.1016/S0167-9457(02)00153-7

proximal stability and consequently poor arm movement control when performing goal-directed movement. These results have educational and functional implications for children at school and during activities of daily living and leisure activities and for clinicians assessing and treating children with DCD.

PsycINFO classification: 2330
Keywords: Developmental coordination disorder; Postural control; Goal-directed reaching; Electromyography

1. Introduction

Poor motor coordination in school-aged children is a significant problem with at least 6% of children aged 5–11 years presenting with developmental coordination disorder (DCD). In DCD, coordination is substantially below the normal range for the child's age and intelligence (American Psychological Association, 1994). Prevalence is much higher than other well-known paediatric conditions such as cerebral palsy, muscular dystrophy or premature birth (Fox & Lent, 1996). In DCD, poor coordination results in difficulties with functional motor skills. This negatively affects academic achievement, recreation and activities of daily living (American Psychological Association, 1994; Drillien & Drummond, 1977; Fox & Lent, 1996; Gubbay, Ellis, Walton, & Court, 1965; Henderson & Sugden, 1992; Losse et al., 1991; Watter & Bullock, 1983, 1989). Consequences of poor coordination are not limited to functional motor problems. An alarming number of secondary characteristics have also been identified, including problems with self-concept, low achievement and emotional and behavioural difficulties (Henderson & Sugden, 1992; Losse et al., 1991; Skinner & Piek, 2001). These can persist into adolescence if poor coordination is unresolved (Losse et al., 1991). Although DCD is well recognised by clinicians, therapists, teachers and families, the precise nature of this condition, particularly the neuromuscular dysfunction which underlies it is poorly understood. Investigation of neuromuscular function, such as muscle activation timing using sensitive assessment tools is required to increase the understanding of this disorder of movement.

An important component of motor coordination is skilled control of upper-limb movement during tasks such as reaching and grasping, writing, dressing and sports. In fact, reach-to-grasp is one of the most frequently performed activities in daily life (Wang & Stelmach, 2001). One of the most common problems experienced by children with DCD is difficulty with skilled upper-limb movements. Skilled movement is characterised by precise control of voluntary movement initiation, execution and completion. Accompanying skillful voluntary movement are postural adjustments, complex patterns of postural muscle excitation and inhibition, which contribute to the efficiency of task performance (Williams, Fisher, & Tritschler, 1983). Postural muscle activity controls the position of the body in space, for the dual purpose of stability (maintaining the centre of mass (COM) within the base of support (BOS)) and orientation (relationship of body segments and environment) (Shumway-Cook

& Woollacott, 1995). Postural muscle activity provides a foundation for movement and is an important part of the neurophysiological mechanism that underlies motor coordination (Williams et al., 1983).

In this study, postural muscle activity will be described as either anticipatory postural adjustments (APA) or reactionary postural adjustments (RPA). APA occur during voluntary movement. They are generated in a feedforward manner and act to maintain postural stability by preventing disruption of the COM. To do this, APA are activated before, or simultaneous to the prime mover. APA activity may be identified between 150 ms before (−150 ms) to 50 ms after (+50 ms) onset of prime mover activity (Hodges, 1996). Activation earlier than −150 ms is not likely to be associated with the particular prime mover activity identified and activity after +50 ms is likely to be a reactive muscle response to the movement outcome of the prime mover. RPA are generated as a response to events which have already impacted on the individual's stability and act to return the COM over the BOS. RPA are identified as activity occurring in postural muscles after the impact of an external force in the case of external perturbations, or at least 50 ms after the prime mover, to ensure feedback activation, in the case of voluntary movement (Hodges, 1996). Fine tuning of this complex arrangement of muscle activity is essential for skilled movement. As such, altered timing of this postural muscle activity resulting in inadequate background postural control and poor execution of skilled movement is likely to be a major contributor to upper-limb coordination difficulties in children with DCD.

Currently, clinical and functional assessments are used for children with DCD, such as described by Burns (1992), Henderson and Sugden (1992) and Watter and Bullock (1983). However if muscle timing is a contributor to poor coordination, more specific assessment of neuromuscular function must be conducted to guide treatment intervention.

To understand the deficiencies or differences contributing to coordination difficulties in children with DCD, coordination and motor control in the typically developing population must also be understood. While development of motor skills is well addressed in the literature, the underlying development of postural control is more limited, especially in relation to execution of skilled movement. Studies of postural muscle function in children to date have focussed on activation for maintenance of stability after external perturbations (Berger, Quintern, & Deitz, 1985; Forssberg & Nashner, 1982; Hadders-Algra, Brogren, & Forssberg, 1996a,b, 1998; Horak, Shumway-Cook, Crowe, & Black, 1988; Shumway-Cook & Woollacott, 1985a,b). Collectively these studies demonstrate that children with typical motor development demonstrate directional responses that appear after the child is able to sit or stand, however multi-muscle patterns remain variable and immature up to 7.5 years of age. After this age, patterns become more similar but are not identical to adult responses (Shumway-Cook & Woollacott, 1985b). These studies, although important in describing reactionary postural muscle activity, provide no information about programming of anticipatory muscle function required for voluntary movement.

Studies investigating postural muscle activity during voluntary upper-limb movement have been conducted with adults since the 1960s (e.g., Aruin & Latash, 1996;

Belen'kii, Gurfinkel, & Pal'tsev, 1967; Crosbie, Shephard, & Squire, 1995; Dean, Shephard, & Adams, 1999; Freidli, Hallet, & Simon, 1984; Hodges & Richardson, 1996; Lee, 1980; Lee, Buchanan, & Rogers, 1987; Pal'tsev & El'ner, 1967; Teyssedre, Lino, Zattara, & Bouisset, 2000; Wang & Stelmach, 2001; Zattara & Bouisset, 1988). However, a much smaller number of studies looking at postural responses during upper-limb movement have been published on infants and children (Conway, 1998; Hayes & Riach, 1989; Sheather, 1997; Steele, 1987, 1994; Woo, 2001). These studies have begun to shape knowledge about motor programming and postural control associated with voluntary movement.

In an early study, Hayes and Riach (1989) detected anticipatory sway adjustments in 33 children with typical motor development aged 4–14 years before voluntary arm movement in standing. While this implied presence of APA producing compensatory body sway, no muscle activity samples were recorded. Using this arm raise paradigm, a series of pilot EMG studies have been conducted by our research team with children between 8 and 18 years with typical motor development (Conway, 1998; Sheather, 1997; Steele, 1987; Woo, 2001). These studies revealed the presence of APAs in leg and trunk muscles during rapid arm movement in all age groups. They also showed that patterning remains more variable and immature compared to adult responses. These studies highlight the presence of anticipatory activity during voluntary movement in children and the changes occurring in the motor control system with age and development.

Information about postural muscle function in children with DCD is limited. In a pilot study of children aged 8–12 years with and without DCD, Steele (1994) recorded postural muscle activity from muscles of the legs and trunk as children performed a rapid, voluntary arm movement. This study found a relationship between the presence of DCD and altered muscle timing. Williams et al. (1983) investigated differences in shoulder and hip muscle function as children aged 4–8 years with and without coordination difficulties, attempted to maintain static postures such as four point kneeling or high kneeling. Results from the typically developing group showed that average amplitude of EMG activity decreased with increasing age. When compared to children of the same age, children with coordination difficulties demonstrated greater amounts of muscular activity. Also, muscle activity profiles of the motorically awkward group were clearly unlike that of the typically developing group rather than being simply delayed in development. These authors concluded that neuromuscular development in children with typical motor development was characterised by a gradual refinement of both localisation and level of muscular activity (Williams et al., 1983). Conversely, the lack of precise postural or balance control was evident in motorically awkward children (Williams et al., 1983). Information regarding timing of shoulder and trunk muscles primarily used for skilled arm movement has not been reported in children either with or without DCD.

The visible outcome of muscle activation occurring at a neuromuscular level is the performance of movement, including reaction time (RT) and movement time (MT). Some research has been conducted investigating RT and MT of movement performed by children with and without coordination difficulties under simple- and

choice-RT conditions. Compared to children with typical motor development, children with coordination difficulties have been shown to take longer to initiate movement(s) (Henderson, Rose, & Henderson, 1992; Piek & Skinner, 1999; Schellenkens, Scholten, & Kalverboer, 1983; Smyth & Glencross, 1986; Van Dellen & Geuze, 1988) and longer to complete movement(s) once started (Henderson et al., 1992). Increased variability in MT has also been demonstrated (Geuze & Kalverboer, 1987, 1994). However, while these studies have provided information about movement outcome, research that simultaneously investigates muscle activity together with RT and MT during movement by children is limited.

Two unpublished theses (Steele, 1994; Woo, 2001), have reported simultaneously evaluated muscle function and movement timing. Woo (2001) evaluated lower-limb postural muscle function in standing during an arm raise task under simple- and choice-RT conditions. Results showed that children with typical motor development demonstrated longer RT under choice- compared to simple-RT conditions. Delayed muscle onset latencies in the supporting lower limbs were demonstrated in conjunction with the longer RT. In view of the information processing required, this is likely to result from the stimulus recognition and response selection components required in the choice task (Anson, 1982). In support of this, MT was not significantly different, showing that once the response had been selected, it was carried out similarly under both conditions. Steele (1994) included children with and without DCD in a study evaluating postural muscle function during an arm raise task under simple-RT conditions. MT was represented as the speed of arm movement over a fixed distance. No difference in MT was demonstrated between DCD and non-DCD groups, despite differences in muscle function. RT data was not reported in this study. As data are currently limited, and results are mixed, further investigation of these parameters is indicated.

From the literature reviewed above, it appears that in children with DCD, altered postural muscle function may be present and contribute to difficulties with upper-limb coordination. The aim of this study was to investigate the neuromuscular components of postural stability and coordination in children with and without functional difficulties in upper-limb motor skills. Objectives were firstly to collect normative data on timing of postural muscle activity and the resultant arm movement parameters of RT and MT during a rapid, voluntary, goal-directed arm movement. The second objective was to compare responses of children with and without DCD to determine if there are differences in postural preparation and movement control during voluntary upper-limb movement.

2. Method

A cross-sectional study design was used to investigate the differences in muscle function and movement performance between children with and without DCD when performing a rapid, voluntary, goal-directed arm movement. Ethical approval for this study was gained from the Medical Research Ethics Committee at the University of Queensland.

2.1. Participants

Sixty-four children participated in the study. Males and females aged 8–10 years of age were included to exclude potential performance variability due to the transitional period of development and puberty. Children were recruited as volunteers from local schools, through print media and through the physiotherapy clinic at the University of Queensland. Children were excluded from participation if parents reported any of the following: skin conditions precluding the use of adhesive EMG electrodes; concomitant medical conditions (e.g., cardiac complaints); neurological conditions (e.g., cerebral palsy); degenerative neuromuscular conditions (e.g., muscular dystrophy); pervasive developmental disorder (e.g., autism); mental retardation; musculoskeletal conditions (e.g., scoliosis); uncorrected poor visual acuity; or pre-term birth (<37 weeks gestation (Tudehope & Thearle, 1984)). Parents and children completed consent forms prior to participation in the study.

Children were allocated to DCD and non-DCD groups. Presence of DCD was determined according to DSM-IV criteria (American Psychological Association, 1994), and motor skills performance on the movement ABC standardised test (Henderson & Sugden, 1992). The movement ABC test comprises three subsections, manual dexterity, ball skills and balance, where the sum of the section scores creates a total impairment score. This score can be converted to a percentile rank reflecting the child's motor ability compared to normative values. Children included in the DCD group scored below the 15th percentile on the total impairment score (Henderson & Sugden, 1992). In addition, to recruit a population with noted upper-limb coordination difficulties, children recruited in the DCD group also scored below the 15th percentile on at least one of the subgroups involving upper-limb skills (i.e., manual dexterity or ball skills). Children with a total score above the 15th percentile were placed in the non-DCD group.

Thirty-two children were recruited to each group. Children were age matched between groups. No significant difference was identified by independent samples *t*-test on mean age and Fisher's exact test showed no difference in sex distribution between groups (Table 1).

Table 1
Group characteristics

Group characteristics	Group		*t*	*p*-Value
	Non-DCD ($n = 32$)	DCD ($n = 32$)		
Age (years)	9.3 (0.9)[a]	9.3 (0.9)	−0.30	0.767
Height (cm)	138.4 (12.0)	137.8 (7.3)	0.24	0.809
Weight (kg)	34.5 (13.9)	35.1 (8.2)	−0.22	0.834
Sex (male:female)	15:17[b]	22:10		0.128
Handedness (R:L)	31:1	27:5		0.196

[a] Age, height and weight expressed as: group mean (standard deviation).
Difference between means tested with independent samples *t*-tests.
[b] Sex and handedness expressed as ratios.
Difference between groups tested using Fischer's exact tests.

Independent samples *t*-tests were used to detect differences between groups for movement ABC variables of subsection scores, total impairment scores and percentile rankings (Table 2). Children from the DCD group demonstrated a higher mean total impairment score that was significantly different from the non-DCD group. This resulted in a lower mean percentile rank that was also significantly different from the non-DCD group. Significant differences were identified between groups on all subsection means: manual dexterity, ball skills, and static and dynamic balance. In each case, mean subsection scores for the DCD group were below the 15th percentile and those for the non-DCD group were above the 15th percentile. Based on these scores, clear separation was demonstrated between groups.

All children participated in a short physical examination to screen for exclusion criteria and to collect anthropometric measures for the movement ABC, postural control assessments and between groups comparisons of body height and weight.

Acromial height in standing and arm length from the acromion process to the tip of the index finger with the arm at 90° flexion were measured to enable standardisation of children's positioning during postural control assessment. Height and weight were measured to ensure body parameters were not different between groups. Scoliosis screening was conducted according to the protocol documented by Kerr (1996) to identify children with a significant spinal curve (>10 mm difference between right and left rib hump heights), who were not included in the study. Assessment of visual acuity was performed according to Curpax (1975) to ensure children could see the required visual signals at a distance required for the study. Handedness was assessed according to Denckla (1973) to identify the skill-preferred arm for the Movement ABC test and to determine the side from which recordings would be made during the postural control assessment. During this test children were asked to demonstrate (without the actual object) how they would perform five tasks (e.g., 'show me how you brush your hair'). The side used for the majority of tasks was denoted the skill preferred side. Between groups comparisons were conducted to ensure equal distribution of height, weight and handedness (Table 1). Independent samples *t*-tests identified no significant difference between groups on mean height or weight and Fisher's exact test showed no difference in handedness.

Table 2
Movement ABC results according to group

Movement ABC scores	Group		Difference between means	*t*	*p*-Value
	Non-DCD ($n = 32$)	DCD ($n = 32$)			
Manual dexterity	2.2 (1.6)[a]	8.6 (2.8)	6.4	−11.13	<0.001
Ball skills	0.6 (1.0)	4.3 (2.0)	3.7	−9.26	<0.001
Balance	1.0 (1.3)	5.6 (3.1)	4.6	−7.68	<0.001
Total impairment	3.9 (2.3)	18.8 (5.9)	14.9	−13.33	<0.001
Percentile rank	57.7 (21.4)	2.9 (4.4)	−54.8	14.18	<0.001

[a] All data expressed as: group mean (standard deviation).

2.2. Equipment and measures

2.2.1. Target movement

A rapid, goal-directed pointing task with the preferred limb was the target movement investigated (Fig. 1A). The task involved a rapid arm raise from 0° to 90° flexion ending on a target. The task combined the characteristics of the rapid-arm-flexion manoeuvers, shown to be repeatable in the studies outlined in the introduction (e.g., Hodges, 1996; Hodges & Richardson, 1997a,b) with the added requirement to reach for a specified target, as may be required during functional reach.

Children began by standing at rest with their arms by their side and the preferred hand against a start movement sensor. The start movement sensor was light sensitive and when uncovered at the commencement of movement registered a positive voltage (Start). Matching end movement targets, 2.5 cm square buttons one for the preferred and non-preferred sides, were positioned in a standardised manner for each child at acromial height and one arm length on each side. The target button was activated when depressed, generating a positive square-wave voltage pulse at the end of movement (End). The start movement sensor and the end movement target were wired in series and powered to produce a single continuous voltage trace with an output in millivolts collected by AmlabII data acquisition system (Associated Measurements).

A computer screen for demonstrating visual signals was positioned at eye height between the two targets. A computer running LabVIEW software (National Instruments) generated the signals that included a central warning signal, followed by a right or left reaction signal (Go), which indicated to the child which arm to raise and when to start each arm movement (Brauer, 1998) (Fig. 1B). When signaled, children raised the nominated arm as fast as possible and depressed the nominated target with the index finger to signal the end of the movement. LabVIEW simultaneously generated a voltage trace reflecting the timing of visual signals. AmlabII sampled and recorded all data at 1000 Hz.

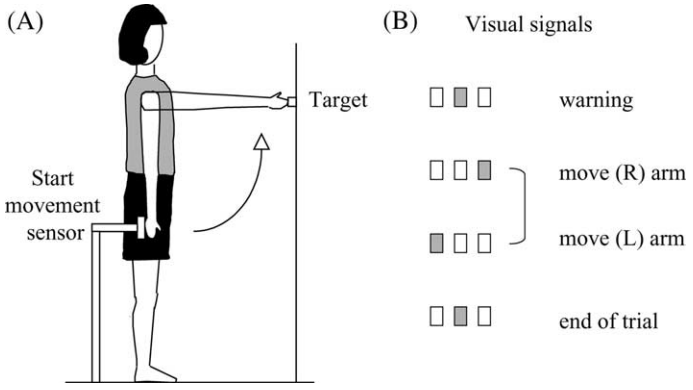

Fig. 1. Depiction of (A) target movement: rapid, goal-directed point, and (B) visual signals under a choice-RT paradigm.

2.2.2. Postural muscle activation timing: Electromyography

Surface electromyography (EMG) was used to record muscle activation of postural muscles of the shoulder and trunk. Muscles investigated around the shoulder girdle included the prime mover anterior deltoid (AD) and ipsilateral muscles of the shoulder region: upper trapezius (UT), lower trapezius (LT), serratus anterior (SA), and latissimus dorsi (LD). These muscles were recorded because of their contribution to arm movement control during shoulder flexion (Norkin & Levangie, 1989; Watson, 1999) and access for surface EMG. Muscles of the trunk investigated were: ipsilateral (IOI) and contralateral internal oblique (IOC), contralateral external oblique (EO), rectus abdominis (RA) and erector spinae (ES). These muscles were chosen based on their role in postural control, particularly trunk stabilisation, during arm movement (e.g., Hodges, 1996; Sheather, 1997; Steele, 1994).

Myoelectric activity of the selected muscles was collected using DelSys DE-2.1 single-differential, surface EMG electrodes (DelSys Incorporated). Electrodes were applied to the nominated muscles according to recommended anatomical landmarks (Basmaijian & Blumenstein, 1980; Hodges, 1996; Ng, Kippers, & Richardson, 1998) and confirmed by test manoeuvers (Lehmkuhl & Smith, 1983; Perotto, 1994), muscle palpation (Brauer, 1998; Hodges, 1996) and visualisation of computer signal display. Electrodes were applied using a small line of electrode gel along the electrode bars to ensure a continuous skin-electrode interface during signal recording (Brauer, 2000). To minimise movement artifact, double-sided hypoallergenic skin tape was applied between the electrode housing and the skin and a strip of sports tape was applied across the top surface of the electrode to the skin. The ground electrode, a self-adhesive electrocardiogram electrode was placed on the contralateral fibular head (Brauer, Burns, & Galley, 2000). EMG data was sampled at 1000 Hz by AMLABII (Marschall, Harrington, & Steele, 1995) and filtered at a frequency of 20.67 Hz to reduce motion artifact and unwanted signals from quasi-random firing of motor units (Wolbarsht, 1964).

2.3. Procedure

Using the arm length and acromial height measures, children were positioned at one arm's length from the end movement targets so that they could be depressed with the extended index finger of each arm when elevated to 90° shoulder flexion. The start movement sensor was adjusted to meet the rear of the preferred hand, as the child stood relaxed with the arms by the side. To maintain a constant body position during standing tasks, foot position was drawn onto paper fixed to the floor so that if the child should move, the same position can be regained. Together the hand and foot start positions comprised the 'ready' position. Children were cued to assume this position before each trial to ensure standardised data collection.

Before data collection began, children were given a standard explanation, demonstration of the target movement, and the opportunity to practice the task twice with each arm. Trials were presented randomly for the preferred and non-preferred sides under a two-choice-RT paradigm, to reduce presetting of muscles and the likelihood of anticipating the reaction signal. Sixteen trials were signaled in total, with eight

trials signaled for the preferred arm. Recordings were made from the eight trials delivered to the preferred side. Missed trials were repeated at the end to ensure eight recordings during each session. Timing between warning and Go signals was randomised to between 1 and 3 s delay.

2.4. Data management

Customised LabVIEW software was used for all data analyses. Muscle onset times were detected using an established algorithm (Hodges & Bui, 1996). Onsets selected by the algorithm were checked visually to screen for those selected incorrectly due to heartbeat or artifact. Trials were excluded if the onset of muscle activity was obstructed by heartbeat or movement artifact, if an equipment fault occurred or if no increase in muscle activity could be detected (Brauer, 1998; Hodges, 1996). Relative latencies for each muscle were calculated from these onsets according to their position relative to onset of the prime mover AD. A similar algorithm, was used to determine the timing of Go from the visual signal trace. These selections were also checked visually to screen for those selected incorrectly due to artifact. Start and End movement parameters were determined manually from the movement sensor

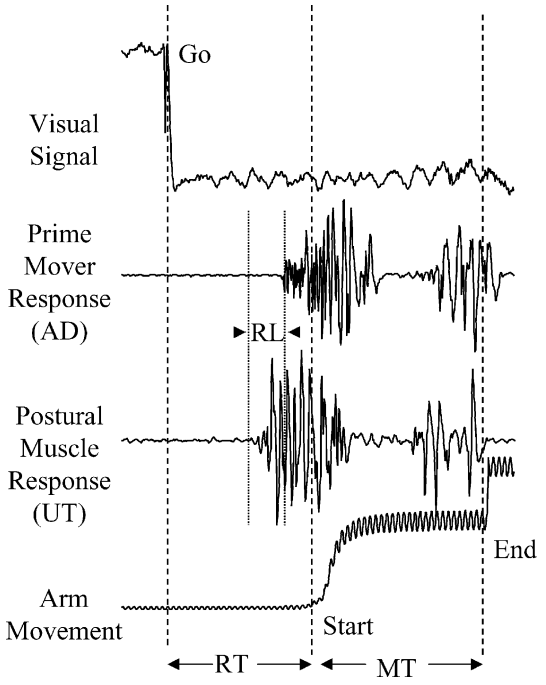

Fig. 2. Example of raw data traces from a child in the non-DCD group for the visual response signal (Go), hand movement (start), target depression (end), prime mover activity (AD) and postural muscle activity. Measures demonstrated are relative latency of the postural muscle to onset of AD (RL), and movement parameters of RT and MT.

trace. RT was defined as the time interval between Go and Start. MT was defined as the time interval between Start and End. The relationship between these parameters is depicted in Fig. 2. Independent samples *t*-tests were used to investigate differences on each parameter between groups. All statistical analyses were performed using SPSS version 11.0 (Lead Technologies, Inc.).

3. Results

3.1. Percentage of valid muscle onsets

For each muscle, the number of EMG traces where valid muscle onset datum was available for analysis was calculated as a percentage of total trials recorded (Table 3). Criteria for trial exclusion were outlined in Section 2.4. Muscles where onsets could be selected in greater than 85% of trials for both groups included UT, LT, LD, SA, IOI, IOC and ES. For EO (non-DCD 79.30, DCD 75.00) and to a greater degree for RA (non-DCD 52.73, DCD 39.45), the occurrence of heartbeat interference on raw EMG traces and lower levels of activation resulted in fewer trials available for analysis. These findings should be considered when reviewing the following data analyses.

3.2. Analysis of differences between groups

Independent samples *t*-tests, were performed for each variable to test for differences in mean relative latencies, mean RT and mean MT between groups. Table 4 presents the results of these tests.

In the non-DCD group, onsets for all trunk muscles occurred in the anticipatory period, with all muscles also being activated prior to the prime mover, AD. When compared to the non-DCD group, onsets from the DCD group were significantly later for all anterior trunk muscles: IOI, EO, RA and IOC. In contrast, ES, the only

Table 3
Number of EMG traces where valid muscle onset datum was available for analysis expressed as a percentage of total trials recorded

Muscles	% valid trials	
	Non-DCD ($n = 32$)	DCD ($n = 32$)
UT	95.7	93.7
LT	93.8	90.6
LD	92.6	88.3
SA	88.7	93.4
IOI	85.4	87.1
IOC	92.2	86.7
EO	79.3	75.0
RA	52.7	39.5
ES	94.1	90.6

Table 4
Between groups comparisons of movement parameters and mean relative latencies of muscle activity

Movement and muscle parameters	Group		Levene's test *p*-value	*t*	*p*-Value[a]
	Non-DCD ($n = 32$)	DCD ($n = 32$)			
RT[b]	424 (86)	488 (68)	0.161	−2.33	0.010
MT	444 (82)	499 (109)	0.096	−2.33	0.027
UT[c]	−16 (16)	−53 (30)	<0.001	5.06	<0.001
LT	9 (16)	−49 (36)	<0.001	4.71	<0.001
LD	14 (19)	−38 (34)	0.008	2.85	<0.001
SA	−14 (13)	−18 (17)	0.144	1.26	0.189
IOI	−84 (24)	55 (57)	<0.001	−5.96	<0.001
IOC	−58 (26)	−25 (44)	0.007	−2.88	0.001
EO	−34 (42)	90 (67)	0.020	−6.53	<0.001
RA	−70 (37)	173 (99)	0.002	−8.49	<0.001
ES	−8 (31)	−33 (40)	0.208	1.35	0.007

[a] Calculated from independent samples *t*-tests.
[b] Movement parameters expressed as mean (standard deviation), both in milliseconds.
[c] Muscle relative latencies (compared to the prime mover AD) expressed as mean (standard deviation), both in milliseconds. Variables include movement parameters: reaction time (RT) and movement time (MT), and muscles: upper trapezius (UT); lower trapezius (LT); latissimus dorsi (LD); serratus anterior (SA); ipsilateral (IOI) and contralateral (IOC) internal oblique; external oblique (EO); rectus abdominis (RA) and erector spinae (ES).

posterior trunk muscle, showed an earlier mean relative latency in the DCD group. Children in the DCD group showed activation of only IOC and ES in the anticipatory period. The remaining muscles, IOI, EO and RA were activated both after AD and outside the anticipatory period.

In the non-DCD group, mean relative latencies for all shoulder muscles occurred in the anticipatory period with UT and SA being activated prior to AD, and LT and LD being activated after AD. In the DCD group, mean relative latencies of all shoulder muscles also occurred during the anticipatory period. However, all shoulder muscles, except SA, showed significantly earlier mean relative latencies in the DCD group. Like the results from the non-DCD group, mean relative latencies for UT and SA occurred prior to AD. However, unlike the non-DCD group, mean relative latencies for LT and LD also occurred before AD. Relative Latencies of both shoulder and trunk muscles in relation to AD are depicted in Fig. 3.

RT and MT were both significantly longer in the DCD group (Table 4). Children in the non-DCD group demonstrated a mean RT of 424 ms and a mean MT of 444 ms. Values for the DCD group were larger at 488 ms for RT and 499 ms for MT.

3.3. Comparison of variances between groups

Initial examination of standard deviations reported by descriptive analyses highlighted apparent unequal variances between groups. On Levene's tests (Table 4), seven out of 10 variables demonstrated significantly different variance between groups (UT, LT, IOI, RA, IOC, LD and EO), with MT also approaching significance.

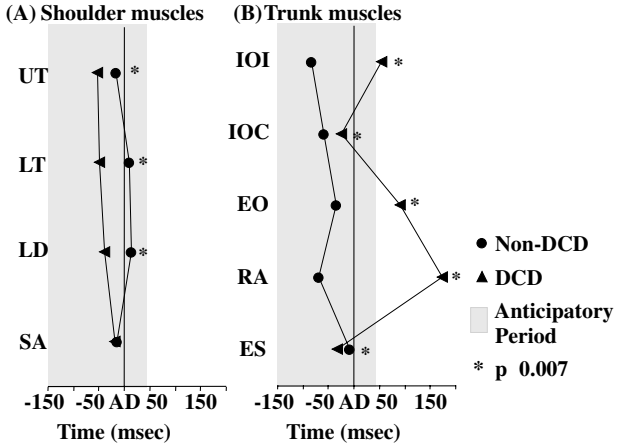

Fig. 3. Mean relative latencies of muscles of (A) the shoulder and (B) the trunk for each group depicted with reference to the anticipatory period, −150 to +50 ms in relation to AD.

Except for RT, results from all other variables showed that regardless of timing of onset, children with DCD performed with greater variability than children without DCD.

4. Discussion

Children with DCD demonstrated altered muscle timing during a rapid, voluntary, goal-directed arm movement when compared to the non-DCD group of children. This investigation is the first reported study utilising EMG to investigate a rapid goal-directed pointing movement in children with and without DCD. Four studies involving children aged 8–10 years, which utilised a rapid arm flexion manoeuver were available for comparison (Sheather, 1997; Steele, 1987, 1994; Woo, 2001), however none required goal-directed pointing.

In children without DCD, onset of all trunk muscles occurred within the anticipatory period and prior to the onset of AD. Findings for ES (−8 ms) are similar to results from previous simple-RT arm raise studies with children in this age group. Activation of ES in those studies occurred in the anticipatory period shortly before (Steele, 1994: −18 ms), not significantly different from (Sheather, 1997; Steele, 1987) or shortly after (Woo, 2001: simple 12 ms, choice 19 ms) AD. In those studies where IOC was evaluated, onset was also within the anticipatory period either shortly after (Woo, 2001: simple 7 ms, choice 19 ms) or not significantly different from (Sheather, 1997) AD. Earlier activation of IOC (−58 ms) in the current study is likely to be the result of early trunk rotation required to better position the hand for reaching the goal. Early activation of RA (−70 ms) in the current study in comparison to others (Sheather, 1997: 0 ms; Woo, 2001: simple 118 ms, choice 132 ms) may also be due to the requirement for early trunk positioning to complete the specific reaching movement. EO activity has not been reported in previous studies with children during arm

movement. Activation of anterior and posterior trunk muscles preceding or simultaneous to AD onset is attributed to the role of stabilising the trunk prior to arm movement (e.g., Hodges, 1996; Hodges & Richardson, 1996, 1997a,b). Results from this study show those trunk muscles act in a similar manner in children without DCD. In addition, positioning the trunk and upper limb for goal-directed reaching was important in this task.

In contrast, children with DCD showed activation of only two of five trunk muscles in the anticipatory period. Later activation times were demonstrated in all anterior trunk muscles: IOI, EO, RA and IOC, where IOC was the only muscle active in the anticipatory period. No studies are available to compare activity of these muscles in children with DCD. Unlike the anterior muscles of the trunk, ES demonstrated earlier activation times in children with DCD. This is in contrast to the results of Steele's study (1994), where ES onset was reported 30 ms after AD. This difference is likely to reflect differences in muscle function required for goal-directed and non-specific tasks. Altered timing in trunk muscle activity in the DCD group suggests a deficient ability to contribute to stabilising the trunk. Without trunk stability, control of the position of the body in space, for stability and orientation (Shumway-Cook & Woollacott, 1995) is likely to be compromised.

In children without DCD, mean onset of all shoulder muscles occurred in the anticipatory period with UT and SA being activated prior to AD and LT and LD being activated after AD. Although no studies are available to compare activity of these muscles in children, function can be compared to biomechanical reports. Muscles investigated in this study were identified as those contributing to support of scapulohumeral rhythm (Norkin & Levangie, 1989) or control of the extent of arm flexion. During scapulohumeral rhythm, UT, LT and SA combine to produce upward rotation of the scapula (Jenkins, 1991; Norkin & Levangie, 1989). Scapular motion occurs concurrently with glenohumeral motion and is complete by 90–100° of total elevation of the humerus (Norkin & Levangie, 1989), thus activity of the muscles producing this movement would be required to begin along with humeral elevation. In children without DCD in this study, activity of this nature is reflected by the early onset of SA and UT with LT closely related to AD activation.

Where the concentric action of LD is humeral extension, internal rotation and adduction (Jenkins, 1991), the function of LD of interest in this study is its eccentric function in controlling the limit of shoulder flexion. It is expected that eccentric activation would build after the peak of concentric flexor activity of the prime mover and increase throughout the deceleration phase of the arm movement. The later onset of LD by children without DCD in this study reflects this function in controlling arm movement.

In contrast, except for SA, children with DCD demonstrated significantly earlier activation times for all shoulder muscles. As timely shoulder muscle activation is imperative for adequate control of scapular and humeral motion, altered timing of activation is likely to interfere with coordinated, well-timed arm movement. Where UT and LT are involved in upward rotation of the scapula (Jenkins, 1991; Norkin & Levangie, 1989), early activation of these muscles in children with DCD is likely to lead to earlier scapular movement, rather than smooth scapulohumeral rhythm.

Activation of UT prior to AD may lead to shoulder hitching, rather than humeral flexion, as an abnormal initiating movement in raising the arm. It is likely that this would alter arm trajectory and contribute to poor coordination of the arm toward a target in space. LD, which was also activated earlier, may act as an antagonist to flexion if activated early, halting or hindering smooth elevation. Considering the alteration in abdominal muscle activation, early activation in shoulder muscles may be initiated as an attempt to compensate for late or absent activation of trunk muscles that normally provide postural stabilisation.

RT of children without DCD on this task (424 ms) was longer than reported for children of the same age performing either a simple-RT arm raise (334 ms, Woo, 2001) or a choice-RT arm raise (401 ms, Woo, 2001). The cumulative information processing required to select and generate the motor commands to perform a goal-directed versus simple arm movement together with completing stimulus recognition and response selection components are likely to have contributed.

Compared to children without DCD, children with DCD took longer (488 ms) to begin the goal-directed pointing movement. This supports data collected by other researchers (Henderson et al., 1992; Piek & Skinner, 1999; Schellenkens et al., 1983; Smyth & Glencross, 1986; Van Dellen & Geuze, 1988) who also showed that children with DCD were slower to respond during a RT task. Delay in RT may have occurred due to the latency of trunk muscle activation, usually occurring early to pre-stabilise the body. In the absence of such stability, the movement must eventually be initiated albeit using alternative muscle patterning. When considering skilled movement, which requires precise initiation, execution and completion, disruption of timely initiation is likely to lead to movement which is poorly executed. Difficulties in this area would be particularly problematic in tasks requiring coincidence timing with another object, for example during sports such as soccer, tennis or baseball. Tasks requiring timely initiation of muscle activity to maintain postural control and balance would also be affected, for example when maintaining postural stability riding on a moving bus, or when jostled in a crowd, or during sports such as skating or gymnastics. While errors may have occurred at various stages of information processing in this choice task (Anson, 1982), stimulus recognition and response selection required for generating motor commands are likely contributors.

Children without DCD also demonstrated longer MT (444 ms) in the current study, compared to that displayed by children of the same age and ability in Woo's study (simple: 268 ms, choice: 283 ms) (Woo, 2001). However, as the goal-directed reach in this study required greater accuracy than the simple rapid arm raise in Woo's (2001) study, it is reasonable to expect increased MT as speed may need to have been traded to achieve this end.

Children with DCD demonstrated longer MT (499 ms) than children without DCD to complete the goal-directed arm movement. Demonstration of longer MTs was demonstrated in Henderson et al.' study (1992) where children with DCD were slower than children without DCD in completing a goal-directed RT task. In Steele's study (1994) however, children with and without DCD showed no difference in movement speed when performing a rapid-arm-flexion manoeuver, which if movement is over an equal distance, indicates a non-significant difference in MT. The most likely

explanation for the non-significant difference in Steele's study is that this simple-RT arm raise task did not require the same degree of movement accuracy or the response selection required in the current study and the study by Henderson et al. (1992). It is likely in the current study that the prolonged movement phase is related to the altered and inefficient muscle pattern used by children with DCD. For example, alteration of antagonist timing (i.e., early LD onset) may be one cause of movement slowing as activation of LD opposes full shoulder flexion. Alternatively, early UT activation may have resulted in shoulder hitching rather than shoulder flexion during movement initiation, therefore requiring later additional movement adjustments to reach the target. Other errors at various stages of information processing may also have altered task performance. Many movements require precise completion timing, particularly when performed in series with other movements, for example during writing, or running. Other movements require precise completion timing to achieve interception with another object, for example when catching or hitting a ball. If skilled movement requires precise execution and completion, difficulty arriving at a desired endpoint in a timely manner is likely to again lead to movement which is poorly executed.

5. Conclusion

DCD is a condition characterised by significant functional problems in motor skill. Poor upper-limb coordination is a common problem for these children and poor postural muscle function is a hypothesised contributor to this problem. This study is the first to investigate postural muscle function in muscle groups of the shoulder and trunk and resultant arm motion in children with DCD. Results show that when performing a rapid, voluntary, goal-directed arm movement under a choice-RT paradigm, children with DCD took significantly longer to respond to visual signals and longer to complete the goal-directed movement than children of the same age who did not meet the criteria for DCD. Children with DCD also demonstrated altered activity in postural muscles that function to provide a stable basis for the movement. In particular, posterior trunk muscles and three from four shoulder muscles demonstrated early activation, whereas anterior trunk muscles demonstrated delayed activation. In children with DCD, anticipatory postural activity was absent in three of four anterior trunk muscles. These differences supported the hypothesis that in children with DCD, altered postural muscle activity may contribute to poor proximal stability and poor arm movement control when aiming for specific targets. This study has provided new knowledge regarding postural control development in children with and without DCD.

Acknowledgements

We would like to thank Mr. Peter Condie, Engineer, for his technical assistance in devising apparatus for the study protocol and Mr. Ross Darnell, Statistician, for his

assistance in evaluating the results of the study. We would also like to acknowledge the assistance of the Australian Physiotherapy Association, Queensland Branch, for the Dorothy Hopkins Award for Clinical Research, the Mater Misericordiae Health Services for the John P. Kelly Mater Research Foundation Grant, and The Queen's Trust Australia for the Queen's Trust for Young Australian's Grant which have contributed towards conducting this research.

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