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Reactive balance performance and neuromuscular and cognitive responses to unpredictable balance perturbations in children with developmental coordination disorder

Yoyo T.Y. Cheng[a], William W.N. Tsang[b], Catherine Mary Schooling[a,c], Shirley S.M. Fong[a,*]

[a] School of Public Health, University of Hong Kong, Hong Kong
[b] Department of Rehabilitation Sciences, Hong Kong Polytechnic University, Hong Kong
[c] Graduate School of Public Health and Healthy Policy, City University of New York, New York, NY, USA

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ABSTRACT

Developmental coordination disorder (DCD) is a common motor disorder affecting balance performance. However, few studies have investigated reactive balance performance and the underlying mechanisms in children with DCD. This study aimed to compare the reactive balance performance, lower limb muscle reflex contraction latency and attention level in response to unpredictable balance perturbations between 100 typically developing children and 120 children with DCD (with and without comorbid autism spectrum disorder) aged 6–9 years. Reactive balance performance was evaluated using a motor control test (MCT) conducted on a computerized dynamic posturography machine. The lower limb postural muscle responses and attention level before, during and after a MCT were measured using surface electromyography and electroencephalography, respectively. The results revealed that relative to typically developing children, those with DCD had a significantly longer MCT latency score in the backward platform translation condition ($p = 0.048$) but a significantly shorter latency score in the forward platform translation condition ($p = 0.024$). The MCT composite latency scores and the corresponding lower limb muscle onset latencies were similar between the groups. Children with DCD also demonstrated a lower attention level during and after sudden backward ($p = 0.042$) and forward ($p = 0.031$) platform translations, compared to typically developing children. Children with DCD were less attentive in response to postural threats, and their balance responses were direction-specific. Balance training for children with DCD might require an additional emphasis on sudden posterior-to-anterior balance perturbations, as well as on problems with inattention.

1. Introduction

Developmental coordination disorder (DCD) is a neurodevelopmental disorder affecting approximately 5–6% of primary school-aged children [1]. This disorder, which is more common in boys than in girls, affects motor planning and coordination and severely interferes with a child's daily activities and academic performance [1]. Impaired balance control is the most significant of the many motor deficits presenting in children with DCD, affecting 73–87% of the DCD population [2]. Specifically, reactive balance control is the most concerning issue for parents and children, as it is the first line of defense against unexpected balance perturbations and is essential for many daily activities, such as standing in a moving bus [3,4].

To date, few studies have investigated reactive balance performance and the underlying mechanisms in children with DCD. To the best of our knowledge, only 3 research teams have assessed reactive balance performance and the associated neuromuscular responses in this population [4–6]. Williams and Castro [5] first reported that children with and without DCD exhibited similar latency in postural muscle activation onset in response to an unexpected platform translation. This finding was concurred by Geuze [6], who perturbed participants at the trunk level to elicit postural responses. However, when using a setup similar to that used in the study by Geuze [6], we recently found that children with DCD had delayed lower limb muscle activation onset times, which were related to poor motor (ball) skills [4]. We postulated that this discrepancy in findings between studies could be attributed to differences in experimental setups and methodologies. Therefore, standardized laboratory measures were needed to verify the results.

Balance reactions are not fully automatic reflex actions. Emerging evidence has shown that these reactions require attention, especially in

* Corresponding author at: School of Public Health, University of Hong Kong, Pokfulam, Hong Kong.
E-mail address: smfong@hku.hk (S.S.M. Fong).

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children with disabilities [7,8]. For example, children with dyslexia had significantly impaired balance reactions when their attention was split between a balance task and a secondary counting/reaction time task [7]. Additionally, we found that children with DCD exhibited inferior motor and functional balance performances and were less attentive to movements than were their typically developing peers. Inattention explained 14.1–17.5% of the variances in motor performance (including balance performance) in the DCD population [9]. However, no previous study has specifically examined attention during reactive balance tasks in children with DCD.

Therefore, the present study aimed to compare the reactive balance performances, lower limb muscle reflex contraction latencies and attention levels in response to unpredictable balance perturbations between children with DCD and typically developing children. This study hypothesized that children with DCD would exhibit inferior reactive balance control, a longer leg muscle reflex contraction latency and a lower attention level in response to unpredictable balance perturbations, compared to their typically developing peers.

2. Methods

2.1. Participants

Children with DCD and typically developing children were recruited from local primary schools, non-government organizations that provide rehabilitation services for children with special needs, child assessment centers where DCD was diagnosed, parent groups and our database of DCD participants via poster-based advertising, invitation letters, WhatsApp and online social media. All children were screened by two experienced physiotherapists via telephone and face-to-face assessments, using the following criteria. The inclusion criteria for the DCD group were: an age of 6–9 years, a formal diagnosis of DCD based on the Diagnostic and Statistical Manual of Mental Disorders 5 [1], a total impairment score corresponding to ≤15th percentile on the Movement Assessment Battery for Children (MABC) [10], a total score of ≤46 (5–7 years 11 months old) or ≤55 (8–9 years 11 months old) on the DCD questionnaire 2007 [11], attendance at a mainstream school, an intelligence level within the normal range and no experience with the Brain Computer Interface system or a similar apparatus. The inclusion criteria for the control group (i.e., typically developing children) were similar to those of the DCD group, except that children in the control group did not have a diagnosis of DCD nor meet the criteria of DCD on MABC.

The exclusion criteria for both groups were: comorbid attention deficit hyperactivity disorder (ADHD) or a T score of ≥70 on the Child Behavior Checklist (CBC) [12]; any significant cognitive, psychiatric (comorbid autism spectrum disorder [ASD] was included), congenital, musculoskeletal, movement, neurological or cardiopulmonary disorder that could affect cognitive or motor performance; receipt of active treatments; demonstration of excessive disruptive behavior or an inability to follow instructions.

Ethical approval was provided by the Human Research Ethics Committee of the University of Hong Kong. A detailed explanation was given to each participant and parent and written informed consent was obtained. Data collection was performed by two experienced physiotherapists and trained research assistants in the Balance and Neural Control Laboratory of the Hong Kong Polytechnic University. All procedures were performed in accordance with the principles of the Declaration of Helsinki [13].

2.2. Outcome measurements

Reactive balance performance was measured using the standardized motor control test on a computerized dynamic posturography (CDP) machine (Smart Equitest, NeuroCom International Inc., Clackamas, OR, USA) [14]. The motor control test (MCT) assesses a participant's ability to recover from an unexpected platform perturbation. Before the test, each participant was instructed to stand with their bare feet placed shoulder width apart, eyes open and arms by the side of the body on the dual forceplates of the CDP machine. Next, the platform was translated posteriorly or anteriorly at 3 amplitudes (in inches)—small (0.5 x height/72), medium (1.25 x height/72) and large (2.25 x height/72)—scaled to the height of the participant. Each platform translation was completed in < 1 s, and each testing condition comprised 3 trials. The CDP machine automatically calculated the latency score (in ms), defined as the time between the onset of the platform translation and the force response in each lower limb registered by the dual forceplates. A latency score was then obtained for each lower limb per condition, with a higher score indicating a prolonged reactive postural response [14]. The latency scores of the dominant lower limb during the medium-amplitude anterior and posterior platform translations were selected for analysis because they best reflect the reactive balance response of the children participants. The composite latency score (i.e., the average of all condition-specific latency scores during medium- and large-amplitude platform translations) [14] was also used in the analysis.

Lower limb postural muscle responses to the MCT support surface perturbation were measured using surface electromyography (EMG) (Biometrics, Newport, UK). An accelerometer (ACL300, Biometrics) was attached to the movable platform on the afore-mentioned CDP machine to register the initiation of translation. Postural muscle activities (i.e., the medial hamstrings and gastrocnemius for backward platform translation, and the rectus femoris and tibialis anterior for forward platform translation [3,4]) were monitored before and after the platform movement. It is because physiologically, a sudden backward platform translation would trigger reflexive contractions of the hamstrings and gastrocnemius, and a sudden forward platform translation would trigger reflexive contractions of the rectus femoris and tibialis anterior, allowing the participant to maintain postural stability [3,4]. Circular Ag/AgCl bipolar surface EMG active electrodes (diameter = 1 cm, between electrode distance = 2 cm) were placed longitudinally at the center of each muscle belly and a reference electrode was fixed on the ipsilateral lateral malleolus. The skin at the electrode placement sites was prepared by cleansing with alcohol swabs, and hair was shaved whenever necessary to reduce skin impedance [15]. The EMG signals were sampled at 1000 Hz and amplified by a gain factor of 1000. Other parameters included a bandwidth of 20–460 Hz, an input impedance of > 10^{15} Ω and a common mode rejection ratio of > 96 dB [16].

All electrodes were connected to a DataLOG (Biometrics) that was securely attached to the participant's waist to reduce artifacts. The DataLOG employed both a high-pass filter (20 Hz) and a low-pass filter for frequencies > 450 Hz and stored EMG data for offline analysis. Signals from the EMG electrodes and the accelerometer were post-processed using the Biometrics EMG analysis software. The accelerometer signal onset was defined as the point at which the signal amplitude differed from the resting value by 0.20 m/s^2, whereas the postural muscle response onset was defined as an EMG value 2 standard deviations from the mean resting EMG value with a duration of > 25 ms [17]. The muscle onset latency, defined as the time interval (in ms) between the onset of the accelerometer signal and the first discernible EMG activity in each muscle, was then extracted [17]. The average muscle onset latencies of 3 medium-amplitude anterior and posterior platform translation trials were calculated and used for analysis.

The attention level during MCT was measured concurrently using a Mindwave Mobile electroencephalographic (EEG) headset recording device (NeuroSky Inc., San Jose, CA, USA). This instrument is valid and accurate for measuring the attention levels of children with DCD [18]. The active electrode of the headset was placed on the left forehead (position Fp1 [19]), and a reference electrode was clipped to the left earlobe. EEG activity in the prefrontal cortex was recorded 3 s before, during and 3 s after the MCT platform perturbation. EEG signals were