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Direction-specific impairment of stability limits and falls in children with developmental coordination disorder: Implications for rehabilitation

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ABSTRACT

Limit of stability (LOS) is an important yet under-examined postural control ability in children with developmental coordination disorder (DCD). This study aimed to (1) compare the LOS and fall frequencies of children with and without DCD, and (2) explore the relationships between LOS parameters and falls in the DCD population. Thirty primary school-aged children with DCD and twenty age- and sex-matched typically-developing children participated in the study. Postural control ability, specifically LOS in standing, was evaluated using the LOS test. Reaction time, movement velocity, maximum excursion, end point excursion, and directional control were then calculated. Self-reported fall incidents in the previous week were also documented. Multivariate analysis of variance results revealed that children with DCD had shorter LOS maximum excursion in the backward direction compared to the control group ($p = 0.003$). This was associated with a higher number of falls in daily life (rho = −0.556, $p = 0.001$). No significant between-groups differences were found in other LOS-derived outcomes ($p > 0.05$). Children with DCD had direction-specific postural control impairment, specifically, diminished LOS in the backward direction. This is related to their falls in daily life. Therefore, improving LOS should be factored into rehabilitation treatment for children with DCD.

1. Introduction

Developmental coordination disorder (DCD) is one of the most common neurodevelopmental motor disorders, affecting about 6% of typically-developing children during the primary-school years. Classic features include clumsiness, poor coordination, slowness and inaccuracy of motor skills and poor postural control [1–3]. It has been reported that 73–87% of children with DCD suffer from balance problems [4] that interfere with participation in day-to-day activities and increase the risk of falls [2,5]. Suboptimal balance ability in children with DCD is therefore a concern of many parents and clinicians.

Balance (postural control) requires the ability to control the center of gravity (COG) within the base of support (BOS). The perimeter of the BOS is known as the limit of stability (LOS). During erect standing, the LOS defines the area in space through which a person can lean his or her body without altering the BOS. If the body sways beyond the LOS boundary, a corrective step will be elicited (stepping strategy) to re-establish a new BOS or else a fall will occur [6,7].

It is widely acknowledged that the LOS of an individual is affected by both mechanical (e.g., range of joint motion and postural alignment) and neural (e.g., muscle response latency and sensorimotor integration) factors [6–9]. Children with DCD exhibit neural deficits involving the central nervous system (e.g., parietal cortex and cerebellum) [10,11] and peripheral nervous system (e.g., muscle activation) [12,13] that may adversely affect their LOS. Previous studies have reported that children with DCD demonstrate poorer static [2,12,14], reactive [14] and anticipatory [13] postural control compared to their typically-developing peers. It is plausible that their LOS are affected as well. Examining LOS characteristics in children with DCD is very important, as stability is fundamental to many daily tasks such as reaching for objects,

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leaning back for hair washing, and walking. Movements exceeding the LOS will result in falls and injuries [6,15]. However, this specific, yet important, aspect of balance performance is under-examined in the DCD population.

To the best of our knowledge, only Johnston et al. have examined the LOS characteristics of children with DCD. They reported that during a reaching forward task, some of the anterior trunk muscles in the DCD-affected children demonstrated delayed activation or even absent anticipatory muscle action [13]. We hypothesized that poor proximal trunk control may affect forward reaching distance and LOS in the antero-posterior directions. However, information about the actual LOS deficit in children with DCD remains elusive. Moreover, no information on comorbid conditions was provided in Johnston et al.'s study [13]. Because comorbidities (e.g., attention deficit hyperactivity disorder) can influence the nature and severity of sensorimotor deficits and possibly LOS performance [16], it is important to assess a homogeneous sample of children with DCD. The objectives of this cross-sectional, case-control and exploratory study were: (1) compare the LOS and fall frequencies of children with DCD (without comorbidities) and age- and sex-matched typically-developing children, and (2) explore the relationships between LOS parameters and falls in the DCD population.

2. Methods

2.1. Participants

Children with DCD were recruited from child assessment centers, non-government organizations, local primary schools, and parents' groups through flyer and website advertising. All child volunteers were screened and assessed by two physiotherapists to determine their eligibility to participate in the study. The inclusion criteria were: (1) a diagnosis of DCD based on the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) [1]; (2) a total impairment score of <5th percentile on the Movement Assessment Battery for Children (MABC) [17]; (3) a total score of <46 (for children aged 5 years to 7 years 11 months), <55 (for children aged 8 years to 9 years 11 months), or <57 (for children aged 10 years) on the DCD questionnaire (2007 version) [18]; (4) aged between 6 and 10 years; and (5) studying in a mainstream primary school. Exclusion criteria were: (1) comorbid conditions such as attention deficit hyperactivity disorder or dyslexia; (2) diagnosis of cognitive, psychological, emotional, neurological or other motor disorders; (3) known significant congenital, musculoskeletal, visual, vestibular or other sensorimotor disorders that might affect balance; (4) receiving rehabilitation services; or (5) unable to follow the assessor's instructions.

Typically-developing children were recruited from mainstream primary schools as controls. The eligibility criteria were the same as those for the DCD group, except that eligible control children did not have a diagnosis of DCD; obtained a total impairment score of >15th percentile on the MABC [17]; and had a total score of >46 (for children aged 5 years to 7 years 11 months), >55 (for children aged 8 years to 9 years 11 months), or >57 (for children aged 10 years) on the DCD questionnaire (2007 version) [18]. Ethical approval was obtained from the Human Research Ethics Committee of the administering university. Each child and parent gave informed written consent before data collection. Data collection was performed by an experienced physiotherapist and a trained assistant. All experimental procedures were conducted in accordance with the Declaration of Helsinki for human experiments.

2.2. Outcome measurements

Participants' relevant personal information, medical history, and number of falls in the previous week were obtained by interviewing them and a parent. Physical activity level (in metabolic equivalent (MET) hours per week) was estimated based on the self-reported physical activity intensity (light, moderate or hard), duration (hours), frequency (times per week), and the assigned MET value of the specific activity according to the Compendium of Energy Expenditures for Youth [19]. Body height and weight of each child were measured using a mechanical scale equipped with a height rod. Body mass index (BMI, in kg/m^2) was then calculated using the equation: weight/height^2. In addition, each child was assessed on their motor proficiency using MABC [17] and the parent was invited to fill in the DCD questionnaire (2007 version) [18].

A computerized dynamic posturography (CDP) machine (Smart Equitest, NeuroCom International Inc., Oregon, USA) with dual force plates and a video screen was used to perform the LOS test. This test assesses the participant's ability to intentionally shift his or her weight (i.e., displace their COG) in eight spatial directions (four cardinal and four diagonal directions) within a fixed BOS, and to briefly maintain stability at these target positions (Fig. 1). Each participant was instructed to stand barefoot on the force platform of the CDP machine with standardized foot placement. A safety harness was used to prevent falls. During the test, the initial center of pressure (COP) was displayed on the screen of the CDP machine together with eight target positions–front, right-front, right, right-back, back, left-back, left and left-front (Fig. 1). These target positions represent the perimeter of the theoretical LOS, which is determined automatically by the machine based on the sway angle of the COG of the participant: 8° right side, 8° left side, 8° anteriorly, and 4.5° posteriorly. On command (a visual cue and an auditory cue), the participant moved his or her COP trace to hit one of the eight randomly selected spatial target positions located on the LOS perimeter as fast, accurately, and smoothly as possible and then briefly maintained this position (COP as close to the target as possible) (Fig. 1). To do this, each participant needed to lean his or her body as far as possible in a given direction without losing balance, stepping, or reaching for assistance. The displacements of COP were displayed on screen in real time (as visual feedback) (Fig. 1) and recorded automatically [15,20].

The LOS test measured the following parameters for each movement direction (note that only the four cardinal directions were included in the statistical analysis): (1) reaction time (in seconds), the time between the presentation of a visual-auditory cue and onset of voluntary shifting of the participant's COP toward the designated target; (2) movement velocity (in°/s), the average velocity of COP movement quantified for 5% to 95% of the distance from the initial position to the target position; (3) maximum excursion (in % LOS), the maximum distance traveled by the COP during a trial, including movements that passed beyond

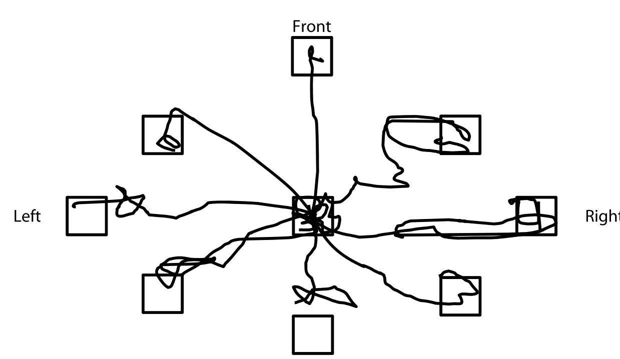

Fig. 1. Trajectories of the center of pressure (COP) of a participant during the limits of stability test moving the COP from a central square (representing COP in erect standing) to target squares in eight different directions (representing 100% limits of stability).