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Impaired postural control in children with developmental coordination disorder is related to less efficient central as well as peripheral control

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ABSTRACT

Background: Developmental coordination disorder (DCD) is a neurodevelopmental impairment that affects approximately 6% of children in primary school age. Children with DCD are characterized by impaired postural control. It has yet to be determined what effect peripheral and central neuromuscular control has on their balance control.
Objective: The aim of this study was to investigate the underlying mechanisms to impaired postural control in children with DCD using the rambling-trembling decomposition of the center of pressure (CoP).
Method: Nine children with DCD (9.0 ± 0.5 years, 7 boys, 2 girls) and 10 age- and gender-matched typically developing children (TD) with normal motor proficiency (9.1 ± 0.4 years, 7 boys and 3 girls) performed 3×30 s bipedal standing on a force plate in six sensory conditions following the sensory organization procedure. Sway length was measured and rambling-trembling decomposition of CoP was calculated in medio-lateral (ML) and anterior-posterior (AP) direction.
Results: Both rambling and trembling were larger for the children with DCD in AP ($p = 0.031$; $p = 0.050$) and ML direction ($p = 0.025$; $p = 0.007$), respectively.
ML rambling trajectories did not differ in any conditions with fixed support surface. In ML direction children with DCD had a lower relative contribution of rambling to total sway ($p = 0.013$).
Conclusion: This study showed that impaired postural control in children with DCD is associated with less efficient supraspinal control represented by increased rambling, but also by reduced spinal feedback control or peripheral control manifested as increased trembling.

1. Introduction

Developmental coordination disorder (DCD) is a neurodevelopmental impairment that affects approximately 6% of children in primary school age [1]. Children with DCD are characterized by poor gross motor control and impaired postural control which may interfere with activities of daily living and participation in sports [2]. Despite considerable efforts to understand the underlying mechanisms of the atypical development of children with DCD, a comprehensive understanding of the etiology of the disorder is still lacking [2,3].

Because poor balance plays a major role in the motor impairments associated with the DCD, postural control has been studied extensively in the literature [4–6]. The ability to stabilize the upright bipedal standing position is a basic motor function and less affected by experience than more skill-based motor tasks, which makes it a suitable task when investigating basic motor function in children with DCD. Furthermore, still standing is a complex highly automated function that requires optimal central processing and command as well as proper peripheral control and response [7]. A majority of studies suggest that the impaired postural control can be ascribed to a deficit in central control and sensory organization rather than in sensory modalities [2,5,6,8,9].

A few studies over the recent years have shown a difference in reflex response and muscle control in children with DCD compared

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with typically developed children (TD), which could indicate that there might be a peripheral control deficit contributing to the observed impairment of postural control. Several studies report slowed muscle force production, longer muscle activation latencies and an increased patellar reflex response [6,10–14]. Additionally, Fong et al. (2015) reported that postural control are associated with deficits in lower limb muscle reflex contraction latency and peak force [10]. It has yet to be determined what effect these differences in peripheral and central muscular control have on balance control in children with DCD, and what the relative contribution of central and peripheral mechanisms are to postural control.

Using rambling and trembling decomposition of the center of pressure (CoP) trajectory during bipedal standing [15,16], it is possible to analyze the contribution of two distinct control mechanisms behind postural sway. Rambling is proposed to represent a certain amount of natural variability in CNS or an exploratory process updating sensory information. It is interpreted as the higher supra-spinal perceptual control mechanism. Trembling, on the other hand, is an expression of peripheral feed-back control of restoring forces, which in the clinical sense represents a discrepancy between motor planning and output as well as mechanical properties of muscles and joints [15,17]. Analyzing postural sway using this method will thus aid the understanding of whether the observed static sway is a result of deficits in supra-spinal control and processing of sensory information, or if impaired postural control also can be explained by a poorer peripheral feed-back control of restoring forces.

The aim of this study was to investigate the underlying mechanisms to impaired postural control in children with DCD using the rambling-trembling decomposition of the CoP trajectory. Our hypothesis is that impaired peripheral control and discrepancy between planned movement and output contributes significantly to balance impairments in children with DCD.

2. Method

2.1. Participants

Nine children with DCD and ten age- and gender-matched TD children with normal motor proficiency were recruited (Table 1). The DCD group was recruited through licensed and specialized children's physiotherapists and occupational therapists from the capital area of Denmark as well as the Danish Parents Association for DCD.

Motor performance was assessed using the Movement Assessment Battery for children (MABC-2), which is a norm-referenced basic motor abilities assessment tool containing fine motor, ball handling, and balance tasks [18]. Inclusion criteria for the children with DCD were that they met the official criteria for DCD according to the DSM-IV [1], had no co-morbid neurodevelopment disorders, scored below the 15th percentile in the MABC-2. The children were diagnosed with DCD previous to participation by a qualified health professional. To avoid confounding factors, we did not include children with co-morbidities. Inclusion criteria for the TD-children were no neurodevelopment disorders and a score above the 16th percentile in the MABC-2. Informed written consent was obtained from a legal guardian. The experimental protocol was approved by the Capital Region Committee on Health Research Ethics, Denmark (ref.: H-4-2013-144).

Table 1
Participant Characteristics.

	DCD group (n = 9)	Control group (n = 10)	P-Value
Age, year	9.0 ± 0.5	9.1 ± 0.4	0.867
MABC-2 percentile	2.6 ± 1.2	73.3 ± 5.2	0.001
Gender (Male/female), n	7/2	7/3	0.658
Height, cm	139.9 ± 2.5	141.1 ± 3.0	0.775
Body mass, kg	33.1 ± 2.3	33.7 ± 1.8	0.568

2.2. Procedure

Static bipedal standing balance was tested on a force plate in different combinations of visual and support surface conditions inspired by the method used in the sensory organization test [8,19–21]. Six sensory conditions were created by alternating firm or compliant support surface and visual input with the purpose of manipulating visual and proprioceptive feed-back and test the effect on the underlying mechanisms of postural control (Table 2). Compliant support surface was created using a 7 cm thick foam pad with the same dimensions as the force plate. Unreliable vision was created using a half dome placed over child's head offering no reliable spatial information. This modification has been validated in typically developed children from 7 to 12 years [21] and has shown a strong test-retest reliability [20]. The condition with firm support surface and open eyes (EOFS) was defined as baseline where all sensory input was reliant and available, and thus resembles the everyday conditions. The participants were tested barefoot, with the feet positioned 5 cm apart, and the hands placed on the stomach. The instruction was to stand as still as possible for 30 s and the test was repeated three times in each condition with minimum one minute break between trials [22].

2.3. Data acquisition and analysis

Force recordings from the force plate (AMTI OR6-7, Advanced Mechanical Technology, Inc., Watertown, MA, USA) were collected at 1000 Hz and down-sampled to 100 Hz post capture. All data processing and calculations were performed using customized MATLAB (The MathWorks, Inc., Natick, MA, USA) scripts.

Sway length was calculated as the total displacement of CoP and mean of three trials in each test condition was used to quantify performance of static postural control.

CoP displacement was decomposed into two components, rambling and trembling in anterior-posterior (AP) and medio-lateral (ML) direction, using the method described by Zatsiorsky and Duarte [16]. In brief, the method assumes two contributing components of CoP; the sum of which equals the total CoP. Rambling quantifies the migration of a moving reference point in relation to the body's equilibrium, and has been suggested to represent the supra-spinal component of the CoP trajectory. Trembling quantifies the oscillations around the reference point, and has been suggested to represent the spinal and peripheral component of the CoP trajectory.

To estimate the rambling trajectory the instant equilibrium positions were identified as the CoP positions when the horizontal force $F_{hor} = 0$, and interpolated using a cubic spline function. To obtain the trembling trajectory, the deviations of the CoP trajectory from the interpolated instant equilibrium positions trajectory were determined [16,23]. Rambling and trembling trajectories were quantified by computing root mean square (RMS) in AP and ML direction. Finally, the relative contribution of rambling and trembling to total sway was quantified in ML and AP direction as the rambling ratio. The rambling ratio quantifies rambling contribution to total sway length based on the assumption that total sway is the sum of rambling and trembling [16] and was calculated as $\frac{Rambling(RMS)}{Rambling(RMS)+Trembling(RMS)}$