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# Statistically characterizing intra- and inter-individual variability in children with Developmental Coordination Disorder

Bradley R. King [a,*], Jeffrey R. Harring [b], Marcio A. Oliveira [a], Jane E. Clark [a,c]

[a] Cognitive Motor Neuroscience Laboratory, Department of Kinesiology, University of Maryland, College Park, MD, USA
[b] Department of Measurement, Statistics & Evaluation, University of Maryland, College Park, MD, USA
[c] Graduate Program in Neuroscience and Cognitive Science, University of Maryland, College Park, MD, USA

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ABSTRACT

Previous research investigating children with Developmental Coordination Disorder (DCD) has consistently reported increased intra- and inter-individual variability during motor skill performance. Statistically characterizing this variability is not only critical for the analysis and interpretation of behavioral data, but also may facilitate our understanding of the processes underlying DCD. Thus, the primary purpose of this research was to demonstrate the utility of a flexible statistical technique, a random coefficient model (RCM), that characterizes the increased intra- and inter-individual variability in children with and without DCD. We analyzed data from a sensorimotor adaptation task during which participants executed discrete aiming movements under conditions of rotated visual feedback. To highlight the advantages of this statistical approach, we contrasted the results from the RCM with those from a traditionally employed general linear model (GLM). The RCM revealed differences between the two groups of children that the GLM did not detect; and, characterized trajectories of change for each individual. The RCM provides researchers an opportunity to probe behavioral deficits at the *individual* level and may provide new insights into the behavioral heterogeneity in children with DCD.



## 1. Introduction

Developmental Coordination Disorder (DCD) is an idiopathic condition that is characterized by impaired performance in activities of daily living that require motor coordination (APA, 2000). Previous research investigating children with DCD has consistently reported two characteristics: (1) increased within-subject variability; and, (2) substantial heterogeneity (i.e., inter-individual variability) of behavioral deficits across children. These characteristics have been demonstrated across a range of tasks, including discrete reaching (Kagerer, Bo, Contreras-Vidal, & Clark, 2004), syncopated clapping and marching (Mackenzie et al., 2008), multi-digit torque control (Oliveira, Shim, Loss, Petersen, & Clark, 2006), visuo-motor integration and visual perception (Schoemaker et al., 2001), bimanual coordination (Volman & Geuze, 1998), and continuous and discontinuous drawing (Bo, Bastian, Kagerer, Contreras-Vidal, & Clark, 2008). While theoretically important, these performance characteristics can hinder the analysis and interpretation of behavioral data. Statistically characterizing this increased intra- and inter-individual variability is thus critical for understanding the individual

* Corresponding author at: Cognitive Motor Neuroscience Laboratory, Department of Kinesiology, 2351 SPH Building, University of Maryland, College Park, MD 20742-2611, USA. Tel.: +1 301 405 2574; fax: +1 301 405 5578.
*E-mail address:* bking7@umd.edu (B.R. King).

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behavioral deficits as well as the more global impairments underlying the population of children with DCD; this issue is the focus of the current paper.

General linear models (GLMs) have traditionally been employed to compare children with DCD to typically-developing (TD) controls (e.g., Kagerer et al., 2004; Mon-Williams, Wann, & Pascal, 1999; Wilson, Maruff, & Lum, 2003). Although these models probe the behavioral differences between groups (i.e., TD vs. DCD), GLMs are limited if the *individuals*' motor performances are of interest. To address this problem, researchers have employed a number of alternative statistical approaches (e.g., clustering). For example, Hoare (1994) attempted to identify sub-types of DCD based on the relationships among multiple dependent measures from each individual. This approach provided insights into the heterogeneity of DCD as it focused on each individual's performance, but this approach is extremely sensitive to the measures included in the analysis and the interpretation of the sub-types is subjective. More recent studies have used 'developmental landscapes' to make comparisons between children with and without DCD (Bo et al., 2008; Kagerer, Contreras-Vidal, Bo, & Clark, 2006). These landscapes consist of a large cross-sectional age range of TD children that form an age-based regression. Children with DCD outside the upper prediction limit of the TD regression are considered to have impaired performance on that particular task. This approach also emphasizes individualized performance and it compares the children with DCD to a much larger group of TD children with a more expansive age range. However, the approach is limited as it does not examine population level effects; and, differences at the individual level may be difficult to detect if the between-subject variability of the TD children is large.

The limitations of these previous approaches have motivated us to examine a statistical technique for longitudinal data that may better characterize the increased intra- and inter-individual variability evident in DCD. This technique, the random coefficient model (RCM) (Cudeck, 1996; Cudeck & Harring, 2007; Davidian & Giltinan, 1995; Fitzmaurice, Laird, & Ware, 2004), allows for the description of both average change in the target populations as well as subject-specific change unique to each *individual*. To demonstrate the efficacy of this statistical approach, we contrasted the results obtained from the RCM with those from the more commonly employed GLM. We used repeated measures data from a small sample of children with DCD, which is not atypical for studies on special populations, and a larger sample of TD children. Participants completed a visuomotor adaptation experiment during which discrete aiming movements were made to peripherally-located visual stimuli under conditions of rotated visual feedback. The primary purpose of this research was to demonstrate the utility of an analytic technique that statistically characterizes behavioral variability in children with DCD. Our secondary aim was to interpret the results of the RCM in the contexts of sensorimotor adaptation and DCD in order to highlight the advantages of this approach that were not afforded by a traditional statistical model.

## 2. Methods

To better understand the implementation of the RCM, information about the experiment and data set are provided. The methodology is thus divided into two sections. The details on the visuomotor experiment, including the outcome variable, are described in Section 2.1. Section 2.2 describes the statistical analyses employed.

### *2.1. Visuomotor experiment*

#### *2.1.1. Participants*

Seven children diagnosed with DCD and 14 typically-developing (TD) children who participated in a visuomotor adaptation study were included in this analysis. Inclusion criteria for children with DCD were: (1) Movement Assessment Battery for Children (MABC) score below the 5th percentile (Henderson & Sugden, 1992); (2) a pediatrician's independent diagnosis of DCD, including a medical history and a screening for neurological disorders (Physical and Neurological Examination for Subtle Signs; PANESS) (Denckla, 1985); and, (3) typical cognitive development as determined by the Woodcock–Johnson Psycho-Educational Battery–Revised. The TD participants demonstrated MABC scores above the 20th percentile and were included as part of a developmental landscape in a previous publication (King, Kagerer, Contreras-Vidal, & Clark, 2009). All participants were right-handed, as defined based on everyday activities such as eating and handwriting and confirmed by the MABC handedness criteria (Henderson & Sugden, 1992). Detailed participant information is included in Table 1. Prior to participation, each child's parent or legal guardian provided informed consent. All procedures were approved by the Institutional Review Board at the University of Maryland, College Park. Children received a toy prize and a small monetary compensation for their participation.

#### *2.1.2. Procedures*

Participants were asked to complete discrete aiming movements with a computer pen on a digitizing tablet positioned below a horizontally-oriented computer monitor. The monitor provided real-time visual feedback of the participants' movements as well as the start and target circles. Vision of the hand was occluded. The tablet recorded Cartesian ($x/y$) coordinates of the computer pen (sampling frequency = 99 Hz). Participants executed aiming movements to one of three visual target positions located 9 cm from the centrally-located start circle (positioned 25°, 90°, or 155° with respect to the start position). During task performance, the visual feedback of the participants' movement paths provided on the computer monitor was rotated 60° clockwise (CW); thus, exposing participants to a visuomotor distortion (126 trials, 42 per target). This sensorimotor distortion results in an initial decrease in performance. With practice, participants adapt to the imposed