Human Movement Science 58 (2018) 148–154

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Spatial and temporal analysis center of pressure displacement during adolescence: Clinical implications of developmental changes

Catherine Quatman-Yates[a,b,c,*], Scott Bonnette[b,d], Resmi Gupta[e], Jason A. Hugentobler[a], Shari L. Wade[f], Tracy A. Glauser[g], Richard F. Ittenbach[e], Mark V. Paterno[a,b], Michael A. Riley[d]

[a] *Cincinnati Children's Hospital Division of Occupational and Physical Therapy, USA*
[b] *Cincinnati Children's Hospital Division of Sports Medicine, USA*
[c] *The Ohio State University, Department of Physical Therapy, USA*
[d] *University of Cincinnati Department of Psychology and Center for Action and Perception, USA*
[e] *Cincinnati Children's Hospital Division of Biostatistics and Epidemiology, USA*
[f] *Cincinnati Children's Hospital Division of Physical Medicine and Rehabilitation, USA*
[g] *Cincinnati Children's Hospital Division of Neurology, USA*

A R T I C L E I N F O

Keywords:
Postural control
Center of pressure displacement
Adolescence
Development
Spatial and temporal analysis

A B S T R A C T

This study aimed to provide insight into the development of postural control abilities in youth. A total of 276 typically developing adolescents (155 males, 121 females) with a mean age of 13.23 years (range of 7.11–18.80) were recruited for participation. Subjects performed two-minute quiet standing trials in bipedal stance on a force plate. Center of pressure (COP) trajectories were quantified using Sample Entropy (SampEn) in the anterior-posterior direction (SampEn-AP), SampEn in the medial–lateral direction (SampEn-ML), and Path Length (PL) measures. Three separate linear regression analyses were conducted to predict the relationship between age and each of the response variables after adjusting for individuals' physical characteristics. Linear regression models showed an inverse relationship between age and entropy measures after adjusting for body mass index. Results indicated that chronological age was predictive of entropy and path length patterns. Specifically, older adolescents exhibited center of pressure displacement (smaller path length) and less complex, more regular center of pressure displacement patterns (lower SampEn-AP and SampEn-ML values) compared to the younger children. These findings support prior studies suggesting that developmental changes in postural control abilities may continue throughout adolescence and into adulthood.

1. Introduction

Good postural control is necessary for purposeful and safe movement while performing functional activities. Even a seemingly simple task such as sitting quietly requires intricate coordination of multiple forms of sensory information into appropriate motor outputs. The refinement of effective and efficient postural management is a developmental process that unfolds slowly. (Shumway-Cook & Woollacott, 1985) Postural control continues to develop throughout childhood, but conflicting accounts surround the age at

* Corresponding author at: The Ohio State University, Department of Physical Therapy, USA.
E-mail address: catherine.quatman@osumc.edu (C. Quatman-Yates).

https://doi.org/10.1016/j.humov.2018.02.002
Received 24 April 2017; Received in revised form 23 January 2018; Accepted 5 February 2018
0167-9457/

which children achieve postural control abilities comparable to that of adults. (Barozzi et al., 2014; Quatman-Yates, Quatman, Meszaros, Paterno, & Hewett, 2011) Some studies indicate that adult-like abilities are reached by 10 years, (Shumway-Cook & Woollacott, 1985; Wolff et al., 1998) while others suggest that maturation of postural control abilities continues beyond 15 years. (Barozzi et al., 2014; Cumberworth, Patel, Rogers, & Kenyon, 2007; Ferber-Viart, Ionescu, Morlet, Froehlich, & Dubreuil, 2007; Gouleme, Ezane, Wiener-Vacher, & Bucci, 2014; Hirabayashi & Iwasaki, 1995; Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006) The reason for this discrepancy is not entirely clear but is likely related, at least in part, to varying measurement approaches and study designs. (Steindl et al., 2006) Methods to evaluate postural control have become more sophisticated, and our capacity to understand the maturation of postural control has progressed. (Riley & Turvey, 2002) Exploration of postural control evolution throughout childhood and adolescence could provide new insights into typical and atypical development and healthy versus impaired states (Barozzi et al., 2014; Quatman-Yates et al., 2011).

The evaluation of the temporal order and structure of the variability in center of pressure (COP) displacement patterns has progressed considerably methodologically and clinically over the last decade. (Riley, Balasubramaniam, & Turvey, 1999; Riley & Turvey, 2002; Stergiou, Harbourne, & Cavanaugh, 2006) The emergence of complexity and systems science approaches in the biomedical sciences has led to increasing recognition that the temporal order and structure of the variability in physiologic and behavioral signals (e.g., heart rate variability and COP displacement variability) may provide powerful insights into the underlying health and physiological state of the body. (Goldberger, 1997; Goldberger et al., 2002; Lipsitz & Goldberger, 1992; Stergiou et al., 2006) Specifically, the temporal order and structure of the variability in these signals are theorized to reveal the degree of integrated and coordinative activity of the systems involved in producing the signal. Consequently, there has been a surging interest in attempts to integrate temporal and structural variability analyses of physiological and behavioral signals into healthcare practices to evaluate for impairments and monitor recovery. (Cavanaugh et al., 2006; Chesnokov, 2008) Prevalent examples include the use of entropy and fractal measures to evaluate postural control impairments in individuals with concussions, (Cavanaugh et al., 2006) developmental delay, (Deffeyes, Harbourne, Stuberg, & Stergiou, 2010) and Parkinson's disease. (Schlenstedt et al., 2016; Schmit et al., 2006).

Mechanistically the temporal order and structure of variability differs in cases of injury and disease. However, clinical interpretation of these signals can be complicated, particularly for younger and older individuals, as postural control abilities are expected to improve with maturation and then decline later in life. (Hytonen, Pyykko, Aalto, & Starck, 1993; Shumway-Cook & Woollacott, 1985) In order to better evaluate the validity of the diagnostic and clinical utility of these signals, it is necessary to expand our understanding of the way these signals can be affected by natural growth and development processes. The purpose of this study was to investigate the impact of adolescent development on COP displacement dynamics in quiet stance for a large cohort of healthy children. It was hypothesized that developmental changes in COP displacement dynamics would be observed and indicative of maturational improvements in postural control.

2. Methods

2.1. Participants

All study methods were completed in accordance with an Institutional Review Board approved protocol. Participants were recruited from physical education classes and extracurricular activities (e.g., chess team, debate team, and sports teams) from one middle school and one high school in a large metropolitan area. The overall recruitment strategy was designed to capture children with a wide range of physical and cognitive abilities. To avoid self-selection bias, we invited all students who were members of these classes and programs to enroll as participants. We then excluded cases for analysis based on the following reasons: 1) the consenting guardian or child reported any pre-existing health conditions with the potential to significantly alter COP displacement (e.g., developmental delay, cerebral palsy, documented central nervous system abnormalities or significant musculoskeletal conditions/injuries); 2) the child had a current acute lower extremity injury leading to the use of an assistive device, brace, or immobilizer; or 3) a study administrator reported doubts about concentration, effort, or compliance with the assessment instructions for the child.

Legal guardians and students were notified by school administrators, teachers, and the study staff about potential participation for the study via newsletters, announcements sent home to families, and word-of-mouth. Each school was compensated with $25 per child enrolled. Study packets with details regarding study procedures, a physical activity questionnaire, a medical history questionnaire, and parental permission forms were sent home to legal guardians. Legal guardians were first asked to read the study materials and indicate their decision to allow or not allow their child to participate. If permission was granted, the guardian was asked to complete the enclosed activity and medical history forms for the child. If permission was not granted, the guardian was asked to return the packet with those forms blank. School-designated administrators collected all of the folders and only provided study staff the folders of children whose parents granted permission for participation. Assent by the child was obtained at the time of the first in person visit.

2.2. Procedures

A quiet room at each school was selected for the study procedures. Participants' height and body mass were assessed using a tape measure and a Tanita digital scale. Force plate assessments were administered using one of two portable AccuSway+ force plates (AMTI, Boston, Massachusetts) and Balance Clinic software. Center of pressure (COP) trajectories were collected at 50 Hz for two 2-min trials (1 trial with eyes open, 1 trial with eyes closed) for each participant. This protocol aligned with a previously published protocol which demonstrated high test-retest reliability in a small sample of high-school students. (Quatman-Yates et al., 2013, 2015)