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Gait parameters associated with balance in healthy 2- to 4-year-old children

Keegan Guffey [a], Michael Regier [b], Corrie Mancinelli [c], Paola Pergami [a,*]

[a] Department of Pediatrics, Child Neurology, West Virginia University, P.O. Box 9214, 1 Medical Center Drive, Morgantown, WV 26506, United States
[b] Department of Biostatistics, West Virginia University, P.O. Box 9190, G104F HSC North, Morgantown, WV 26506, United States
[c] Division of Physical Therapy, West Virginia University, P.O. Box 9226, 7310 HSC South, Morgantown, WV 26506, United States

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ABSTRACT

The use of validated measurements of gait and balance are crucial to establish baseline function and assess effectiveness of therapeutic interventions. Gait in children changes with motor development requiring frequent observations to effectively track progress. Standardized baseline spatiotemporal measurements and a greater understanding of the relationship between gait and balance would provide important feedback to clinicians regarding the effectiveness of rehabilitation and guide treatment modifications. 84 subjects (2.0–4.9 years) walked along the GAITRite®, a walkway that records spatiotemporal parameters. The Pediatric Balance Scale (PBS) was administered to assess balance. Comparison of spatiotemporal parameter means between age groups showed trends associated with motor development similar to the ones described in the literature such as decreased cadence and increased step/stride length with increasing age. However, no significant differences in normalized spatiotemporal parameters were found between age groups. Age, leg length, cadence, step/stride length, step/stance time, and single/double support time showed significant correlation with balance scores. When the parameters were grouped into spatial, temporal, and age-related components using principal components analysis and included in a multiple regression model, they significantly predicted 51% of the balance score variance. Age-related components most strongly predicted balance outcomes. We suggest that balance can potentially be evaluated by assessment of spatial, temporal, and age-related characteristics of gait such as step length, cadence, and leg length. This suggests the possibility of developing new gait measurement technology that could provide functional assessment and track improvements during rehabilitation regimens. If the same model can be applied to monitor treatment efficacy in children with gait abnormalities remains to be addressed.

1. Introduction

Gait abnormalities in children associated with developmental delay, injury, or illness can be severely debilitating and persist through childhood to adulthood. In these children, ambulatory ability generally worsens over time in relation to increased body weight, decreased mobility and development of joint contractures. Aggressive early interventions are fundamental to support gait development in these children, as it is crucial to accurately assess motor function and to monitor patients' progress using validated measures.

Generally, these evaluations are provided by specialized personnel, with the support of specialized equipment. For example, the GAITRite® system has proven reliability and validity for recording spatiotemporal parameters in adults [1–3], and children [4,5]. This equipment consists of an electronic walkway with embedded sensor pads that capture foot pressure data as the patient walks across its surface; spatiotemporal gait parameters such as step length, velocity, and cadence are automatically calculated [6].

Gait changes due to growth and development dictates the need for frequent observations to effectively track progress over the first few years of life. The gait of a new walker is characterized by high cadence, small steps, stride variability, and postural instability. At age two, lower extremities grow longer than the torso [7], shifting

* Corresponding author.
E-mail addresses: kguffey@mix.wvu.edu (K. Guffey), mregier@hsc.wvu.edu (M. Regier), cmancinelli@hsc.wvu.edu (C. Mancinelli), ppergami@hsc.wvu.edu (P. Pergami).

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the center of mass lower in the body and contributing to the development of more adult-like gait with increased step and stride length and decreased cadence [8,9]. The most significant changes have been reported to occur by age 3 [9], with mature gait developed by age 5 [10], and constant relationship between height and step frequency afterwards [11].

In the first few years, any attempt to classify gait development should include standardized baseline of spatiotemporal parameter values with narrow age-intervals in order to provide accurate normative data.

Many published studies investigating this topic included large patient samples but only reported wide age ranges [9,12], and/or lack of body size normalization [11]; studies with narrow age groups had insufficient sample sizes to accurately characterize children's gait [13]. To date, only a few studies had a sufficient sample size and narrow age ranges to thoroughly observe gait changes occurring during the early years of gait development [14].

In this study, evaluated changes of spatiotemporal parameters, using narrow age ranges, during the window of rapid child development occurring before the age of five. The primary aim of this study was to establish standardized normative spatiotemporal parameters from typically developing children for future comparison with children with pathological gait.

The secondary aim of this study was to investigate the relationship between gait and balance in typically developing children in order to explore alternative methods to assess motor function. Because balance is a very important functional feature of gait, tracking changes in subjects' balance can give clear insights regarding the effectiveness of rehabilitation. Additionally, balance can be easily measured without the use of sophisticated equipment by observing patients perform everyday balance-related tasks. Determining the relationship between balance and gait may serve to strengthen our understanding of how they relate to motor function and potentially improve treatment outcomes. The Berg Balance Scale is a reliable method for assessment of balance and motor function in older adults [15,16]. A modified version more suitable for balance assessment in children is available and is known as the Pediatric Balance Scale (PBS). Modifications include test order, scoring criteria, time allotted for tests, and special directions specifically designed for young children [17,18].

2. Methods

The study was approved by the West Virginia University Institutional Review Board for the Protection of Human Subjects. Signed consent/assent was obtained.

2.1. Subjects

Eighty-four healthy and typically developing children aged 2–4.9 years were recruited from the WVU Hospital Pediatric Clinic and WVU Day Care. All children were meeting normal developmental milestones for age, and had normal gait, tone and cognition on neurologic examination. All subjects had no history of neurologic or orthopedic conditions, or injury that could affect their walking or balance ability. The children were age-stratified into groups of 6 months (e.g. $2 \leq \text{age} < 2.5$ years, $2.5 \leq \text{age} < 3$ years).

2.2. Data collection and reduction

Subjects' shoes were removed and leg length from greater trochanter to the bottom of the foot during standing was recorded. Subjects were asked to walk at their comfortable pace across the GAITRite® walkway. The start and finish lines were placed several step lengths away on either side of the carpet to avoid recording acceleration or deceleration in stride. If the subjects stopped, walked too fast, ran, turned around, stepped off the carpet, or displayed any other unusual walking behaviors, they were asked to repeat the trial until they completed three walks with no errors. Partial or improperly recorded footfalls were omitted from analyses. The three walking trials were combined and the GAITRite® software calculated all spatiotemporal parameters using pre-programmed definitions and calculations (see Appendix B) [6].

Functional balance was measured using the PBS (see Appendix A) [18]. The PBS consists of a series of 14 tasks, each scored on a five-point scale from 0 to 4. A score of 0 denotes a complete inability to perform the task, and a score of 4 denotes the ability to safely perform the task without support. The overall balance score is represented as a percentage of points earned in relation to total points possible.

2.3. Data analysis

The spatiotemporal parameters recorded by the GAITRite® were step and stride length, velocity, cadence, step time, cycle time, stance time, swing time, single support time, and double support time. Pearson product–moment correlations were used to examine the degree of dependence between left and right bilateral parameters. Parameters that exhibit strong positive correlation demonstrate bilateral dependence. All pairs of bilateral parameters showed correlation coefficients greater than 0.95, so the average between left and right parameters was used for all further analyses. Spatiotemporal parameters were normalized by the dimensionless normalization method outlined by Hof [19] for descriptive statistics to account for the effect of leg length on gait. The normalized parameters were used only for reporting normative descriptive data; all other analyses used non-normalized parameters. Descriptive statistics and box plots were used to determine outliers, and 5 outliers were removed prior to analysis. These subjects displayed outlier values for most spatiotemporal parameters which were likely a result of having difficulty in following the protocol.

Pearson product–moment correlations were used to examine the relationship between spatiotemporal parameters, age, leg length, and balance features. Mean values of the individual task sub-scores were evaluated to determine the most "difficult" tasks. The total PBS score and the average scores from the most difficult tasks were used to determine the correlation between spatiotemporal parameters and balance among all age groups.

One-way ANOVA with age in years as an independent variable was used to compare spatiotemporal parameters between each 6-month age group. Significant differences ($p < 0.05$) were investigated with Scheffe post hoc test.

Before using the collected gait variables in a linear regressions model to predict the outcome of PBS scores, multi-collinearity among the gait variables and between the gait variables and leg length and age was assessed. To account for multi-collinearity we used principal components analysis (PCA) with orthogonal varimax rotation and Kaiser Normalization [20] to identify key ambulatory and size components. The resulting components were used in a PCA regression analysis with balance scores as an outcome. Leg length and age were included alongside spatiotemporal parameters to account for possible interactive effects. Because leg length was included in the regression, normalization of spatiotemporal parameters was not necessary for this analysis. Effect sizes, using two-sided tests, were determined to be statistically significant at the 0.05 alpha level. All statistical analyses were completed using IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp [21].