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

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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

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can be applied to monitor treatment efficacy in children with gait abnormalities remains to be addressed.

Keywords

Gait; GAITRite®; Balance; Pediatric; Normative data; Spatiotemporal

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],[2], [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; spatio-temporal 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 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 2.0 to 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 age < 2.5 years, 2.5 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 0–4. 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 amongst 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].

3. Results

3.1 GAITRite® parameters by age group

The 79 subjects included in the analysis had a mean age of 3.54 ± 0.84 years. Table 1 shows the values (mean $\pm$ SD) of spatial parameters, normalized for leg length and non-normalized for each age group. One-way ANOVA revealed velocity ($p = 0.417$) and normalized velocity ($p = 0.804$) did not significantly differ between age groups and showed no apparent trend with increasing age. There was a significant difference between step ($F(2,76) =$

17.774, $p < 0.001$) and stride length ($F(2,76) = 17.052, < 0.001$) and age groups. A Scheffe post-hoc test revealed that step and stride length increased by 14% ($p = 0.001$) between ages 2 and 3 and 20% ($p < 0.001$) between ages 2 and 4.

There was no significant difference in normalized step ($p = 0.733$) and stride length ($p = 0.762$) between age groups.

Table 2 shows the non-normalized and dimensionless normalized temporal parameters for each age group. One-way ANOVA revealed there was no significant differences in normalized parameters of cadence ($p = 0.461$), step time ($p = 0.340$), stance time ($p = 0.397$), single support time ($p = 0.281$), and double support time ($p = 0.800$) between age groups. With ANOVA and Scheffe's post-hoc test, standard cadence ($F(2,76) = 7.846, p = 0.001$) was shown to decrease by 15% from 2 to 4 years ($p = 0.001$). Step time ($F(2,76) = 7.326, p = 0.001$), stance time ($F(2,76) = 5.709, p = 0.001$), and single support time ($F(2,76) = 9.658, p = 0.001$) showed a general trend of increasing with age and significantly differed between years 2 and 4. Double support time showed no significant differences between age groups ($p = 0.267$).

3.2 Relationship between balance and gait

The mean total PBS score was 86% for age 2, 94% for age 3, and 99% for age 4. Older children (age four) generally achieved a perfect score for most tasks; this ceiling effect suggested that the PBS is not accurate for measuring balance in typically-developing children over 3. Of the 14 tasks, only 3 showed any variation in scores between subjects—almost every subject scored perfect scores on the remaining 11 regardless of age. Therefore, we focused on three specific tasks that were more difficult for children to perform: #7, standing with feet together; #8, standing with one foot in front, and #9, standing on one foot. Table 3 shows the correlation between different spatiotemporal parameters and balance scores (overall score and scores for the three selected tasks) for all age groups. Step and stride length, cadence, step time, swing time, stance time, and single support time were found to significantly correlate with total balance scores and with scores from the three most difficult tasks.

3.3 Principal Components Analysis

Given the potential for multicollinearity amongst the spatiotemporal parameters, we performed principal component analysis to reduce the set of collinear gait variables to set of interpretable independent variables. Although the first 2 components were the only ones to display eigenvalues greater than 1, the scree test suggested that 3 components were meaningful. Components 1, 2, and 3 accounted for 95% of the total variance with a Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) of 0.6. Variables related to balance and corresponding factor loadings are presented in Table 4.

In interpreting the rotated component matrix, factors listed under each component are said to load with that component. A higher value indicates a higher loading to that particular component. Factor loadings of less than 0.34 were suppressed for ease of interpretation. Components 1, 2, and 3 were respectively interpreted as temporal, size, and spatial

parameters. Component 1 included step time, cadence, single support time, stance time, and velocity. Component 2 included leg length and age. Component 3 included step length and velocity.

3.4 Principal Component Regression

Table 5 summarizes the results for multiple regression between the PCA components and total PBS score. The inclusion of collinear variables in a regression model will result in inaccurate estimates of the regressor-regress and relationship. To ameliorate this problem, we performed principal component analysis to identify a set of components that are uncorrelated and explain 94.5% of the variability in the data. The identified components were interpreted and used as the regressors in a linear regression (i.e. principal component regression). All three regressors strongly correlated ($R=0.711$, $p<0.001$) with the outcome. The principal components regression suggests a strong relationship between the identified principal components (Table 4) and the outcome PBS balance score (adjusted $R^2 = 0.506$, $p<0.001$). Of the 3 components, Age/size contributed most to balance with a standardized coefficient of 0.623 ($p<0.01$). Temporal and spatial components were similar in strength of relation to PBS balance scores with standardized coefficients of 0.275 ($p<0.01$) and 0.248 ($p<0.01$), respectively.

4. Discussion

The purpose of the present study was to examine changes in spatiotemporal gait parameters that occur between the ages of 2 to 4 years and determine the relationship between these parameters and balance in typically developing children.

Previous studies have shown that spatial gait parameters change with age; in particular step and stride length, and temporal gait cycle parameters increase with age, whereas cadence has been shown to decrease [9], [22], [14]. Dusing and colleagues [14] reported that normalized step length and velocity increase from ages one to four. We do observe a confirmatory general trend for normalized step length, yet our data did not demonstrate statistically significant differences between age groups on these normalized measures. This difference could result from different methods of normalization; both studies implemented the Hof dimensionless normalization, but Dusing's work utilized subject's height and we used leg length to normalize spatial dimensions. Additionally, Dusing did not report statistical significance for their findings or use statistical comparison of means to draw more definitive conclusions. Our study shows similar general trends reported in previous reports, but demonstrates that differences in *normalized* spatiotemporal parameters across age groups are not statistically significant. These findings are in accordance with Sutherland and co-author [9] reporting that spatiotemporal parameters are largely matured by age 3, and with other authors who showed that stride length remains a constant percentage of height at the various ages [10]. Differences in spatiotemporal parameters up to age 5 were reported by studies using body height for normalization. We believe that leg length is a more appropriate parameter for normalization, as during early growth (age 2–4) the proportion between leg and torso is progressively changing. Other parameters known to change with early gait development (i.e appearance of heel stride, increased knee and hip extension) were not tested by this study.

Previous studies have attempted to develop quantitative, standardized measurements of gait parameters for assessment of motor function, but so far only with limited success in children. For instance, the Functional Ambulation Profile (FAP) [23] and Functional Ambulation Performance Score (FAPS) [24] reliably utilize normalized velocity and step length, base of support, step time, and step variability values to calculate a numerical score indicative of functional gait ability in adults. However, these measures of function cannot be reliably applied to assess children below 12 years [25].

For this population, the principal component regression shows a strong relationship between the identified principal components and PBS balance scores. As balance is a very important feature of gait, this model could provide insights regarding the effectiveness of rehabilitation interventions in children with gait abnormalities. The three components - temporal parameters, age/leg length, and spatial parameters – captured 94.5% of the variability in the original data, thus there was negligible information loss by using the independent PCA components in the regression analysis rather than the original set of gait variables. These components contributed significantly to the variance in balance score suggesting a strong functional relation with balance. Furthermore, this suggests that evaluation limited to only a few gait parameters that include temporal and spatial components could potentially be sufficient to monitor subjects' progress during the implementation of rehabilitation regimens.

Our model has potential to be improved by future research and implemented in technologies like the GAITRite® or other similar gait measurement equipment to provide functional assessment of balance in children based on raw spatiotemporal gait parameter measurements.

This study has several limitations. The subjects walked at a self-selected speed that could cause variations in spatial and temporal gait parameters. However, we believe this would best reflect each subject's typical gait pattern rather than using a predefined speed that would result in a less natural gait. Due to the very young age of the subjects, some children had difficulty following directions and could be easily distracted. Many parents were eager to leave to return to work and hence, the data collection was often completed with a limited amount of time. Ideally, more than 3 trials per subject should have been obtained to reduce variability in the data. Additionally, younger subjects had problems understanding directions for some of the tasks. At times, it was difficult to determine if a subject's low score was due to balance problems, inability to follow directions or unwillingness to perform the task.

Older children generally achieved perfect scores for most PBS tasks, and a ceiling effect was demonstrated in most normally developing four year-olds. This effect is to be expected considering the PBS is designed to assess balance deficiencies not usually present in typically developing children. Three sub-tests (item #7, standing with feet together, #8 standing with one foot in front, and #9 standing on one foot – appendix A) demonstrated higher sensitivity in the older group hence, we suggest that a limited evaluations of balance using these 3 items only, could be a more accurate but still easy to implement functional assessment of gait in this age group. Future development should include children with pathological gait or balance difficulties to validate the model in this population. The

multiple regression model could be improved by use of additional variables such as height, step width, or variability in spatial and temporal parameters.

5. Conclusion

The changes in spatiotemporal gait parameters do not occur as drastically as expected in young typically developing children.

Balance in young children, a functionally important measure of motor development or effective rehabilitation interventions, can potentially be evaluated by assessment of spatial, temporal, and age-related characteristics of gait. This suggests the possibility of developing new gait measurement technology that could provide functional assessment and track improvements during rehabilitation regimens.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Select three balance tasks for assessing balance
- Describe normative gait characteristics by age group
- Identify gait parameters correlated with balance
- Examine association between balance, age and spatiotemporal gait measures

Table 1
Normalized and non-normalized (standard) spatial gait parameters by age group (mean $\pm$ S.D.).

Age Group	Step Length		Stride Length		Velocity	
	Standard	Normalized	Standard	Normalized	Standard	Normalized
2 to 2.5 (N= 14)	32.9 $\pm$ 5.0	0.90 $\pm$ 0.16	66.3 $\pm$ 10.2	1.81 $\pm$ 0.33	96.7 $\pm$ 26.7	5.12 $\pm$ 1.50
2.5 to 3 (N= 8)	33.9 $\pm$ 6.5	0.91 $\pm$ 0.14	68.1 $\pm$ 13.2	1.82 $\pm$ 0.28	90.5 $\pm$ 23.6	4.79 $\pm$ 1.13
3 to 3.5 (N= 16)	38.3 $\pm$ 4.5	0.93 $\pm$ 0.10	76.9 $\pm$ 9.0	1.88 $\pm$ 0.21	99.7 $\pm$ 14.8	4.98 $\pm$ 0.73
3.5 to 4 (N= 13)	39.2 $\pm$ 4.8	0.93 $\pm$ 0.14	78.6 $\pm$ 9.6	1.86 $\pm$ 0.27	101.6 $\pm$ 7.4	5.00 $\pm$ 0.44
4 to 4.5 (N= 15)	39.5 $\pm$ 4.3	0.89 $\pm$ 0.10	79.2 $\pm$ 8.5	1.78 $\pm$ 0.19	99.5 $\pm$ 21.6	4.77 $\pm$ 1.03
4.5 to 5 (N= 13)	43.6 $\pm$ 3.9	0.97 $\pm$ 0.16	87.4 $\pm$ 7.9	1.94 $\pm$ 0.32	102.9 $\pm$ 17.6	4.89 $\pm$ 0.97

Normalized (N) and non-normalized (standard, S) temporal parameters for each age group (mean $\pm$ S.D.).

Table 2

Age Group	Cadence		Step Time		Stance time		Single Support Time		Double Support Time	
	S	N	S	N	S	N	S	N	S	N
2 to 2.5 (N= 14)	174.7 $\pm$ 29.2	337.2 $\pm$ 51.9	0.35 $\pm$ 0.06	0.18 $\pm$ 0.03	0.41 $\pm$ 0.09	0.21 $\pm$ 0.04	0.30 $\pm$ 0.03	0.16 $\pm$ 0.01	0.13 $\pm$ 0.04	0.066 $\pm$ 0.02
2.5 to 3 (N= 8)	158.6 $\pm$ 15.9	309.5 $\pm$ 38.0	0.38 $\pm$ 0.04	0.20 $\pm$ 0.03	0.46 $\pm$ 0.07	0.24 $\pm$ 0.04	0.30 $\pm$ 0.02	0.16 $\pm$ 0.01	0.16 $\pm$ 0.06	0.083 $\pm$ 0.03
3 to 3.5 (N= 16)	156.1 $\pm$ 12.0	318.9 $\pm$ 24.5	0.39 $\pm$ 0.03	0.19 $\pm$ 0.02	0.46 $\pm$ 0.04	0.22 $\pm$ 0.02	0.32 $\pm$ 0.02	0.15 $\pm$ 0.01	0.15 $\pm$ 0.03	0.071 $\pm$ 0.01
3.5 to 4 (N= 13)	156.7 $\pm$ 12.1	325.9 $\pm$ 28.9	0.39 $\pm$ 0.03	0.19 $\pm$ 0.02	0.46 $\pm$ 0.03	0.22 $\pm$ 0.02	0.32 $\pm$ 0.03	0.15 $\pm$ 0.02	0.14 $\pm$ 0.02	0.068 $\pm$ 0.01
4 to 4.5 (N= 15)	150.7 $\pm$ 25.6	320.7 $\pm$ 55.2	0.41 $\pm$ 0.08	0.19 $\pm$ 0.04	0.49 $\pm$ 0.10	0.23 $\pm$ 0.05	0.33 $\pm$ 0.06	0.16 $\pm$ 0.03	0.15 $\pm$ 0.05	0.071 $\pm$ 0.02
4.5 to 5 (N= 13)	141.1 $\pm$ 14.7	304.1 $\pm$ 34.1	0.43 $\pm$ 0.06	0.20 $\pm$ 0.03	0.51 $\pm$ 0.09	0.24 $\pm$ 0.04	0.35 $\pm$ 0.03	0.16 $\pm$ 0.02	0.16 $\pm$ 0.05	0.076 $\pm$ 0.02

Table 3

Pearson correlations between variables and balance scores

	PBS Total	Feet Together	One Foot In Front	Stand On One Foot
Age	0.711 [*]	0.409 [*]	0.668 [*]	0.647 [*]
Leg Length	0.602 [*]	0.426 [*]	0.521 [*]	0.566 [*]
Velocity	0.096	0.061	0.105	0.075
Step Length	0.485 [*]	0.354 [*]	0.489 [*]	0.390 [*]
Stride Length	0.478 [*]	0.341 [*]	0.485 [*]	0.388 [*]
Cadence	-0.403 [*]	-0.325 [*]	-0.385 [*]	-0.320 [*]
Step Time	0.371 [*]	0.289 [*]	0.351 [*]	0.303 [*]
Stance Time	0.354 [*]	0.279 [*]	0.331 [*]	0.273 [*]
Single Support Time	0.365 [*]	0.273 [*]	0.359 [*]	0.342 [*]
Double Support Time	0.156	0.098	0.160	0.088

* Correlation is significant at the 0.05 level (2-tailed).

Table 4

Principal Components rotated component matrix

	Component		
	1	2	3
Step Time	0.972		
Cadence	−0.946		
Single Support Time	0.932		
Stance Time	0.923		
Leg Length		0.918	
Age		0.834	
Step Length			0.923
Velocity	−0.562		0.819
% Variance explained	56.608	29.028	8.852
Cumulative % variance	56.608	85.636	94.488

Multiple regression analysis indicating relationship between gait and age/size components and total PBS balance score

Table 5

Model	Unstandardized Coefficients		Standardized Coefficients		t	Sig.
	B	Std. Error	Beta			
(Constant)	.933	.005			172.102	.000
1. Temporal Component	.019	.005		.275	3.458	.001
2. Age/size Component	.043	.005		.623	7.835	.000
3. Spatial Component	.017	.005		.248	3.112	.003