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SPATIOTEMPORAL GAIT PARAMETERS ARE ASSOCIATED WITH ANTHROPOMETRIC INDICES OF 2–3 YEARS CHILDREN IN KUMASI, GHANA: A CROSS-SECTIONAL STUDY
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ABSTRACT

Background: **Spatiotemporal gait parameters provide objective markers of locomotor development, and their association with anthropometric indices in children aged 2–3 years may offer critical insights into growth and motor maturation.**
Objective: **To establish the correlation between spatiotemporal gait parameters and anthropometric characteristics of 2–3 years in Kumasi, Ghana.**
Methods: **Descriptive cross-sectional study design was employed. Thirty-two healthy children (19 girls,13 boys) were recruited from four pre-primary schools in Kumasi, Ashanti region of Ghana. The primary outcomes were spatiotemporal data (step length, stride length, step width, cadence, & gait**

speed) and their associations with anthropometric indices (height, weight, body mass index, & waist to hip ratio).
Results: **Waist-to-hip was negatively correlated with step length (r = -0.43, P < 0.05) and stride length (r = -0.35, P < 0.05). Stride length was significantly correlated with step length (r = 0.82, P < 0.01). Gait speed showed positive associations with both step width (r = 0.38, P < 0.05) and cadence (r = 0.62, P < 0.01). No significant sex differences were observed.**
Conclusions: **Body mass index and waist-to-hip ratio correlate with the step length, stride length, step width, cadence, and gait speed of the children in this study. Since the waist-to-hip ratio showed significant negative correlations with step and stride length, while gait speed correlates positively with cadence and step width, clinical interventions should emphasise weight and central adiposity management in early childhood to promote more efficient gait development and prevent long-term locomotor limitations.**

INTRODUCTION

Gait and the gait cycle are fundamental components of human living, enabling independence in daily and social activities [1,2]. It is a basic motor ability that, if not mastered in childhood, can hinder the acquisition of complex motor skills such as running and jumping [3]. Walking requires coordinated interaction between the neuromuscular and skeletal systems, developing from infancy through transitions such as sitting, crawling, standing, and eventually independent ambulation, which typically emerges between 9 and 18 months [4–6]. This period is marked by rapid anatomical and neuromuscular growth, yet the precise role of age in shaping gait parameters remains debated; some researchers suggest gait matures by three years, while others extend this to five years [4,7]. Consequently, understanding gait variations between ages one and four, which represents the transition from infancy to toddlerhood, is of particular interest [6].

Abnormal gait in early childhood may persist and worsen over time, compounded by increasing body weight, which can lead to reduced mobility, higher fall risk, and joint contractures [8]. Early identification is therefore critical for optimising prognosis and preventing long-term musculoskeletal complications [6]. Spatiotemporal parameters such as step length, stride length, cadence, and support phases are widely used in diagnosing gait deviations and monitoring motor development [4,7]. Research demonstrates significant gait changes by age three, reinforcing the need to establish normative reference values as benchmarks for clinical screening and evidence-based interventions [8–11]. Such reference values provide clinicians with tools to detect subtle gait abnormalities that may not be observable during routine developmental assessments [6,12].

Early childhood is marked by substantial changes in body size, proportions, and neuromuscular control, all of which influence the maturation of walking patterns [6]. Recent evidence shows that early gait development is closely associated with anthropometric indices[1,2]. In children aged 2–4.9 years, leg length correlates significantly with cadence, step/stride length, and support times, explaining over 50% of the variance in balance performance[3,4]. Similarly, waist height and walk ratio increase with age, while knee-to-knee distance and trunk sway decrease, reflecting anthropometric-gait links in toddlers. Longitudinal studies further suggest that leg length growth contributes to improvements in gait speed, whereas body mass has less impact [13–15]. Collectively, these findings indicate that age and growth-related body dimensions strongly mediate spatiotemporal gait patterns, underscoring the need for population-specific reference data.

By examining these relationships in a community-based sample, this study aims to clarify how variations in body size and proportions relate to emerging gait patterns in early childhood, thereby providing context-specific normative data and improving understanding of normal motor development in this age group

While spatiotemporal gait characteristics such as step length, cadence, walking speed, and stance time are commonly used indicators of locomotor development, their association with anthropometric measures, including height, weight, body mass index, and limb dimensions, remains significantly underexplored in young African populations. Despite extensive research elsewhere also [1,2,5,6], little is known about spatiotemporal gait variations in relation to anthropometry among typically developing children in Ghana. The present study investigates the relationship between spatiotemporal gait parameters and anthropometric indices in children aged 2–3 years in Kumasi, a critical period of rapid growth and motor development.

METHODS

Study Design: This study employed an analytical cross-sectional research design. The study has children between the ages of 2-3 years who were recruited from four nursery schools: KNUST Nursery School, Good Shepherd Nursery School, Bethelinter Academy, and Hannah Montessori School. All in Ashanti region of Ghana.

Participants recruitment: The cooperation of the participants was sought via a letter of introduction sent to the pupil's parents/guardians, proprietor/proprietress, head / Head-Teacher, pupil's class teacher. After three months of notice, awareness interactions were conducted, and the benefits of the study were explained to those who volunteered for their children to participate. Determination of the specific sample size for the population was difficult as established[7]. However, a priori sample size calculation for detecting a correlation was performed using G*Power 3.1 (Heinrich Heine University Düsseldorf); with $\alpha = 0.05$ (two-tailed), power = 0.80, and an anticipated effect size r = 0.48, the required sample size was N = 32. A convenience sampling technique was employed to recruit the thirty-two (32) volunteer children who met the inclusion criteria for the study. Although the sample size was inherently small, literature supports a small sample size in a study on this sample population due largely to the availability of the children [8], the reluctance of parents to release and subject their little children to research rigour [9], and ultimately the fear of potential harm to their children [10]. An informed consent form was also signed by their headteachers, class teachers, and parents of the children. Children who were apparently healthy, typically developing children with no gait pathology, aged from 1 to 4 years, and who could understand and cooperate with instruction during the assessment were sought for the study. However, only children between the ages of 2-4 who were able to execute the desired test were included, while those with known cardiac or respiratory disorders, with any musculoskeletal injuries/disorders, or living with a disability were excluded. Parameters excluded were swing phase time, step time, stride time, double support time, and stance phase time.

Instrumentation

The biodata form was used to document participant information like ID, age, gender, height, weight, and waist-hip ratio. The height and weight were measured with the i-Snow Height Weight stadiometer (SNO-HW01). The basin contained diluted acrylic poster colour, and cardboard papers were ground to a smooth, flat floor for participants to walk on while the walkway was marked and measured. Acrylic poster colour was used to paint the feet of the children with foam. It served as the ink to record the footprints on the white cardboard paper. The white cardboard paper used has a 1m 60gsm dimensions. A Flott Professional Stopwatch was used to record the time. A Botao 20m/66ft fiberglass measuring tape was used to measure distances on the ground and marked with chalk. The 60 inches/150 cm flexible fiberglass tape measure was used to measure the waist and hip circumference. GemRed digital angle measuring rules were used to measure the joint range of motion (ROM) of the lower limbs in flexion.

Letters were submitted to the heads of the schools for approval. Informed consent was also given to the parents of each participating child for approval. The data was collected in the schools of the participants. Using the footprint method for gait analysis, [11] a 1m white paper was placed on the ground. A walkway of length 30m and width 0.76m, which is the same width as the white paper, was measured with the 20m/66ft tape measure and marked with masking tape on the ground. Therefore, the total walkway created with the paper and masking tape was 31m by 0.76m. A bowl containing diluted poster colour was placed at the edge of the paper, which is the starting point of the walkway. The biodata and anthropometric measurements of each participant were documented and presented in a table in tables 1 and 2. The foam was dipped into the paint and applied to the feet of the participant. The participant was instructed to walk across the 1m paper and continue to the ground along the marked walkway for 30s at a self- selected speed.

The number of steps after the 30s was recorded as their cadence. The walking distance covered in the 30s was marked, measured, and recorded. The gait speed was obtained by dividing the distance covered by the time (30s). The step length, step width, and stride length were measured from the recorded footprints on the 1m white paper. The assessment of the spatial parameters (step length, stride length and step width) was obtained with a 30cm ruler. The step length, measured in centimeters, was measured from the geometrical heel center of one footprint to the equivalent of the next footprint on the opposite foot, while the measurement of stride length was obtained from the line of progression between the heel points of two repeated footprints of the same foot. The step width was assessed as the spatial distance between the reference points of the two heel strikes along the lines of progression of both feet.

Statistical analysis

Data collected was entered into Microsoft Excel and exported to Statistical Package for Social Sciences (SPSS) version 27.0 for analysis. Descriptive analysis was used to represent the data as means, standard deviations and frequency. Pearson's correlation and the Independent T-test were used to determine the correlation between the variables at a significance level of 0.05.

Ethical Compliance Statement

The research was carried out in compliance with the principles outlined in the Declaration of Helsinki. Written informed consent explaining the details of every procedure was given to parents or guardians, class teachers, and school management of each of the children who participated for approval, which was obtained. The approval letter received from the parents or guardians, class teachers, and school management of each of the children who participated in the study was added to the materials submitted for ethical approval. The methodology and techniques used in the study received approval from the Committee on Human Research Publication and Ethics of Kwame Nkrumah University of Science and Technology (Our Ref:CHRPE/AP/398/23). All authors have read and complied with the Journal's Ethical Publication Guidelines and confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this work is consistent with those guidelines.

RESULTS

A total of 32 (mean ± SD = 2.53± 0.51years) children participated in the study. 19 participants (59.4%) were females, and 13 participants (40.6%) were males. Among the participants, 15(49.9%) were 2 years old, and 17 (53.1%) were 3 years old. The average ages for males and females were 2.46 ± 0.52 and 2.58 ± 0.51, respectively. The temporal parameters of the participants on average indicated that males had a cadence of 58.85±8.3 steps in 30s and a mean gait speed of 0.76 ±0.2 m/30s. Whereas, females had a mean cadence of 58.58±6.9 steps in 30s and a mean gait speed of 0.77±0.14 m/30s. The minimum number of steps per 30 seconds (cadence) of the population was 46 steps, and the maximum number of steps was 78. The minimum gait speed was0.4m/30s and the maximum was 1.08m/30s.No significant differences exist between male and female gait parameters.

Table 1

Comparison of Characteristics by Gender

Characteristics	**Gender**	**Mean±SD**	**T**	**Pvalue**	**95% CI**
					Lower, Upper
Age (years)	Male	2.46±0.52	-1.372	0.180	-0.614, 0.121
	Female	2.58±0.51			
Height (cm)	Male	93.90±3.40	2.263	0.031*	0.2738, 5.3424
	Female	91.08±3.48			
Weight (kg)	Male	14.75±2.04	1.561	0.129	-0.2889,2.1650
	Female	13.82±1.37			
BMI (kg/m^2)	Male	16.65±1.66	0.147	0.884	-1.03299,1.19356
	Female	16.57±1.41			
WH ratio (cm)	Male	0.94±0.04	-1.090	0.284	-0.04421, 0.01344
	Female	0.96±0.04			
left hip flexion (º)	Male	127.66±13.95	-1.478	0.150	-22.5729,3.6158
	Female	137.16±19.98			
right hip flexion (º)	Male	127.18±11.65	-1.288	0.207	-20.2789,4.5907
	Female	135.02±19.66			
left knee flexion (º)	Male	130.31±13.67	0.018	0.985	-21.0922,21.4760
	Female	130.12±35.67			
right knee flexion (º)	Male	131.51±11.97	0.212	0.833	-20.1274,24.7955
	Female	129.17±38.22			
left ankle dorsiflexion (º)	Male	32.39±6.53	-1.173	0.250	-14.7758,3.9977
	Female	37.77±15.60			
Right ankle dorsiflexion (º)	Male	32.77±9.61	-0.745	0.462	-13.6882,6.3684
	Female	36.44±15.77			

**Difference is significant at the 0.05 level*

From table 1, there were no significant differences between males and females in all the characteristics measured in the study, except that males were significantly taller than their female counterpart 93.90±3.40 >91.08±3.48, P<0.05, with a mean difference of 2.82 ± 0.08cm.

Table 2

Correlation Between Selected Anthropometric Characteristics of the Participants

Anthropometric Characteristics		**Age**	**Height**	**Weight**	**BMI**
Height	R	0.215			
	P value	0.238			
Weight	R	-0.076	0.664**		
	P value	0.678	0.000		
BMI	R	-0.335	-0.025	0.727**	
	P value	0.0061	0.890	0.000	
WH ratio	R	0.091	-.0316	-0.091	0.152
	P value	0.620	0.078	0.622	0.407

***Correlation is significant at the 0.01 level (2-tailed). BMI-Body Mass Index*

In Table 2, a significant positive correlation exists between weight and height (r= 0.664, P<0.01) and weight and BMI (r= 0.727, P<0.01).

Table 3

Comparing Gait Parameters of Male and Female Participants

Gender		**Mean ± SD**	**Mean Rank**	**Sum of Ranks**	**U**	**P**
Step Length	Male	19.35±6.79	16.50	214.50	123.500	1.000
	Female	19.23±5.73	16.50	313.50		
Stride Length	Male	40.59±12.38	15.31	199.00	108.000	0.552
	Female	43.56±10.20	17.32	329.00		
Step Width	Male	12.72±3.61	15.42	200.50	109.500	0.591
	Female	13.33±3.72	17.24	327.50		
Cadence	Male	58.85±8.33	16.15	210.00	119.000	0.862
	Female	58.58±6.82	16.74	318.00		
Gait Speed	Male	0.76±0.20	16.85	219.00	119.000	0.863
	Female	0.77±0.14	16.26	309.00		

The spatial parameters of the participants in Table 3 showed that there was no significant difference in the gait parameters between male and female participants in the study, although females tend to have higher stride length, step width, and gait speed

Table 4

Correlation Between the Gait Parameters of the Participants

Gait Parameters		Step Length	Stride Length	Step Width	Cadence
Stride Length	R	0.817**			
	P value	0.000			
Step Width	R	-0.094	-0.028		
	P value	0.611	0.880		
Cadence	R	0.155	0.320	0.316	
	P value	0.397	0.074	0.078	
Gait Speed	R	0.107	0.124	0.376*	0.619**
	P value	0.560	0.500	0.034	0.000

**. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).*

Table 4 revealed that stride length had positively significant correlation with step length. Also gait speed had positively significant correlation with Step Width and cadence. A significant correlation existed between gait speed and step width (r= 0.376, P<0.05), gait speed and cadence (r=0.619, <0.01) stride length and step length (r=0.817, P<0.01).

Table 5

Correlation Between the Spatiotemporal Gait and Anthropometric Parameters

Parameters		Step Length	Stride Length	Step Width	Cadence	Gait Speed
Age	R	-.0162	-0.155	-0.179	-0.240	0.017
	P value	0.375	0.398	0.326	0.186	0.925
Height	R	0.159	-0.034	0.123	-0.057	0.162
	P value	0.385	0.854	0.502	0.755	0.377
Weight	R	-0.085	-0.128	0.312	0.059	0.151
	P value	0.642	0.487	0.082	0.750	0.411
BMI	R	-0.231	-0.124	0.290	0.115	0.037
	P value	0.203	0.500	0.108	0.531	0.840
WH ratio	R	-0.430*	-0.353*	0.172	-0.076	-0.123
	P value	0.014	0.048	0.348	0.678	0.503

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

Tables 5 showed revealed WHR as the only parameter that has a significant negative correlation with step length and stride length; WHR and step length (r=0.430, P<0.05), WHR and stride length (r=0.353, P<0.05).

DISCUSSION

The present study establishes the relationship between spatiotemporal gait parameters and anthropometric indices in children aged 2–3 years in Kumasi, a critical period of rapid growth and motor development. The results in table 1 showed an average height of 92.2cm, average weight of 14.2kg, average, BMI of 16.6kg/m², average waist: hip ratio of 0.9cm, average ROM in lower limb joints flexion of 133.3º left hip flexion, 131.8º right hip flexion, 130.2º left knee flexion, 130.3º right knee flexion, 35.6º left ankle dorsiflexion and 34.9º right ankle dorsiflexion for the population. The average spatiotemporal gait parameters were 19.28cm step length, 42.38cm stride length, 13.08cm step width, cadence of 59 steps and gait speed of 0.4m/30s. The findings on the lower limb goniometric variables slightly differed from the previous report. [12] Although a consensus of the specific averages for the various gait and anthropometric parameters of typically developing children has not yet been obtained, several studies conducted in several countries compare their findings to already existing data sets in the country [13–17] where the study was conducted. The studies conducted in other countries also did not specifically assess the parameters for children specifically, 1-3 years old. There were significant differences in height and weight between the genders (Table 2). However, several studies conducted among older age groups showed significant differences between the genders in most of the other parameters. CDC and WHO, however, recommend the use of standard growth charts to measure the anthropometry of developing children.[18]

The study on the relationship between step width and gait speed in toddlers sheds light on this population's normal step width range as well as how it relates to gait speed[19]. From the study, step width has a significant effect on gait speed (Table 3). This information on step width and gait speed can add to the knowledge already available on child development in the following ways: In healthy young and older people, step width variability is a sensitive indicator of locomotor control and age-related alterations in gait. [20,21]. The study on toddler gait and step width reveals data on the correlation between toddler step width and gait speed, which can help us better understand how this population controls their locomotion (tables 3-4). The study's findings on toddler gait and step width also add to the body of knowledge on the connection between step width and gait speed by describing the typical range of toddler step width and how it relates to gait speed.

Adiposity, as determined by waist circumference (the waist-to-hip ratio), has been linked to gait characteristics such as stride length, step length, and stride width in previous studies.[22] From the findings in Table 5, the waist: hip ratio has a significant negative correlation with step length and stride length. Therefore, as the stride length and step length increase, the waist: hip ratio decreases. This is consistent with studies from[23] who suggested that the stride length of young boys dropped as their body fat percentage increased, and there was a nonlinear relationship between stride length and their waist-to-hip ratio. The same study, however, found that healthy older adults' waist-hip ratios were positively correlated with step width variability. Another study[24] found that step length and waist: hip ratio were negatively correlated in elementary school students. Although step width variability and waist: hip ratio are not directly addressed in this study on toddler gait, the findings on stride length and step length contribute to this literature by providing information on the relationship between waist: hip ratio and stride length and step length in toddlers. Gait variability of spatial parameters, including stride length and step length, is a more important indicator of locomotion control. Hence, the study on toddler gait and waist-hip ratio contributes to this literature by providing information on the relationship between waist-hip ratio and stride length and step length in toddlers, which can inform our understanding of locomotion.

Strengths and limitations of the study

The findings from the study provide several clinically relevant insights into the relationships between anthropometric characteristics and spatiotemporal gait parameters, with important implications for assessment, interpretation, and intervention planning in clinical and rehabilitation settings.

In the first instance, the absence of significant sex differences in most measured characteristics, except for height, suggests that gait parameters and related functional measures may be interpreted using largely similar clinical reference frameworks for males and females, particularly in populations comparable to the present sample. Although males were significantly taller than females (mean difference ≈ 2.8 cm), this isolated difference in stature did not translate into widespread sex-based differences in gait performance. Clinically, this supports the use of function-based rather than sex-based criteria when evaluating gait characteristics, prescribing interventions, or monitoring outcomes, while still accounting for body size where necessary.

In another pattern, the strong positive relationship between stride length and step length highlights their biomechanical interdependence. Clinically, this implies that interventions aimed at improving one (e.g., increasing step length through strength, flexibility, or motor control training) are likely to produce parallel improvements in the other. This is particularly useful in gait retraining programs for patients with reduced step or stride length due to neurological, musculoskeletal, or age-related conditions.

Also, the significant positive correlations between gait speed and cadence, and between gait speed and step width, emphasise that gait speed is a multifactorial outcome influenced by both temporal (cadence) and spatial (step width) parameters. From a clinical standpoint, this supports the use of gait speed as a global functional indicator, while also encouraging clinicians to examine how speed is achieved—whether through increased step frequency, altered base of support, or changes in step length. This is especially relevant in populations where compensatory strategies (e.g., wider steps for stability) may be adopted to maintain or increase walking speed.

Subsequently, the observed negative correlations between waist–hip ratio (WHR) and both step length and stride length have important implications for understanding the impact of central adiposity on gait mechanics. Clinically, this suggests that individuals with higher WHR, reflecting greater central fat distribution, may adopt shorter steps and strides, possibly as a strategy to enhance stability or reduce mechanical demand. This finding highlights the importance of considering body fat distribution, in addition to body weight and BMI, in gait assessment and rehabilitation planning. It also supports the integration of weight management and trunk conditioning strategies into programmes aimed at improving gait efficiency and functional mobility.

Finally, these findings reinforce the value of a multidimensional gait assessment approach that considers anthropometry, spatiotemporal gait parameters, and body fat distribution. Clinically, this allows for more individualised interpretation of gait deviations, more targeted intervention strategies, and more meaningful monitoring of functional outcomes in both healthy individuals and clinical populations.

Although the study have significant strengths including being one of the first Ghanaian studies in the specific focus, it is without limitations. Firstly, the sample size was thirty-two (32) and this may have affected the detection of significant correlation between spatiotemporal gait parameters and anthropometric characteristics among the population. Additionally, the cross-sectional nature of the study may restrict outcomes as compared to when a countrywide study that would desirably help to identify the full national database on this issue.

CONCLUSION

The study provides insights into the average gait patterns of typically developing children in our country in terms of spatial and temporal parameters in a gait cycle. The findings indicate that the step length, stride length, step width, cadence, and gait speed of typically developing children are influenced by weight, height, BMI, and WHR. Therefore, it is important to conduct thorough gait assessments against standard parameters of a particular population to describe the walking/gait pattern of that population and identify gait pathologies. To better understand the gait cycle of this population and the relationship of the gait parameters with anthropometric parameters, larger sample sizes and longitudinal studies with the same methodology are recommended. It is also recommended to monitor the growth charts and physical activity level of this population to ensure comparison against other population norms. This will serve as a repository of information to provide early warning of developmental problems.

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