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ANALYSIS OF KINEMATIC PARAMETERS OF GAIT IN BRAZILIAN CHILDREN USING A LOW-COST PROCEDURE

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ABSTRACT
Purpose. The aim of the study was to describe the gait kinematic behaviour of healthy Brazilian children aged 6–11 years old and examine the influence of age and gender on the analysed kinematic characteristics. **Methods.** A descriptive study that investigated the gait of 119 children (60 boys and 59 girls) aged 6–11 years was conducted. Data were stratified according to age (6–7 years, 8–9 years, 10–11 years) and gender and its impact over spatiotemporal gait parameters was assessed. An inexpensive yet satisfactorily valid and objective motion capture system was employed to compute gait parameters. **Results.** Non-normalised and normalised averages of stride length, step length, cadence and velocity from 119 participants were 1.23 ± 0.17 m and 1.8 ± 0.2, 0.63 ± 0.11 m and 0.9 ± 0.1 m, 117.9 ± 11.4 steps/min and 311.9 ± 23.9 steps/min, 72.5 ± 11.1 m/min and 27.9 ± 4.5 m/min, respectively. Stance and swing means (%GC) were 58.1% ± 3.3% and 41.9% ± 3.3%, respectively. Step and stride length increased with advancing age, while cadence decreased. A significant difference ($p = 0.005$) was found between Group 2 (8–9 years) and 3 (10–11 years) for normalised velocity. No significant differences between groups were found for other non-dimensional variables. Comparisons between boys and girls showed no differences ($p > 0.05$) in any spatiotemporal gait parameters. **Conclusions.** The gait kinematic behaviour of 119 Brazilian children was described using a low-cost instrumented gait analysis system. Gender was not a significant modifying factor for gait among the examined children. Our findings suggest a partially immature gait kinematic pattern in children aged between 6 to 11 years. Additional studies are needed to examine whether the differences between our results and those reported in the literature are due to issues of internal or external validity.

Key words: gait patterns, children, biomechanics, motor development, low-cost analysis

Introduction

It is well documented that an understanding of age-related changes in walking patterns is essential for diagnosing and treating pathological gaits in children [1–4]. However, the development of human motor behaviour might vary due to differences in factors such as individual biology, tasks and environmental influences [5]. For example, there is evidence that Brazilian children reach a mature pattern in basic motor skills later than children of other nationalities [6, 7].

Specifically in the case of locomotion, Moreno-Hernàndez et al. [8] compared the biomechanics of gait patterns between Mexican and American children and found significant differences between these groups. Findings such as these suggest that children from different nationalities can exhibit different gait patterns. This may be due, in part, to socio-cultural differences between these populations [9]. Therefore, it would be imprudent to use one specific gait pattern as a universal parameter to examine walking in children in different populations.

In the case of the Brazilian population, the demand for research is even greater because there is little information about the biomechanical gait patterns in this paediatric population [10]. This lack of knowledge may compromise the quality of clinical assessments in Brazilian children because it is unknown whether data obtained from studies in other populations are applicable to the Brazilian population. Furthermore, another issue that should be addressed is clinical gait analysis. It is known that observational gait analysis is widespread in the clinical setting [11, 12]. However, a qualitative assessment of human movement has lower accuracy and reliability than quantitative analysis [13]. Indeed, instrumented movement analysis systems are considered the gold standard for gait analysis [14], but its high cost prevents the use of such tools in routine clinical use [11]. Thus, the applicability of more accessible instrumented gait analysis systems would be important to improve the accuracy and reliability of clinical assessments, even as to add more detailed information when observational gait analysis may not be enough to detect and/or explain gait deviations. Moreover, the accessibility of instrumented gait analysis systems could allow for additional study so as to create a normative database for gait in Brazilian children.

Therefore, the purpose of this study was to identify the gait kinematic behaviours of healthy Brazilian children, aged 6 to 11 years old, while ambulating at a comfortable and self-paced speed and to examine how

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these behaviours were influenced by age and gender using a low-cost instrumented gait analysis system.

It was hypothesized that both age and gender would not influence gait kinematic parameters of children when normalised for anthropometric characteristics, as it had been previously reported that children between 6 and 11 years old present mature walking kinematics [1, 4] and that these parameters are not gender specific [8].

Material and methods

One-hundred-and-nineteen (n = 119) volunteer children aged 6–11 years old were randomly recruited to participate in the study. Sample extraction was conducted within a population of students from a Brazilian public school located in an area of low socio-economic status in Niteroi, in the state of Rio de Janeiro.

The study was conducted in association with the Biomechanics and Motor Behaviour Laboratory of the State University of Rio de Janeiro, Brazil, which provided technical support for this investigation. Ethical approval for this study was obtained from the University Ethics Committee and parental consent and child assent was obtained prior to participation in the study.

Exclusion criteria included a leg length discrepancy of > 2 cm or a history of injury or disease that could affect gait. As a result, three groups of children were formed based on the following age divisions: (1) children 6–7 years old (n = 22); (2) children 8–9 years old (n = 49); and (3) children 10–11 years old (n = 48). Subject demographics are provided in Table 1.

The temporal and spatial gait parameters of healthy children were then measured. As modifying factors of gait, age and gender were included in the study as independent variables. A pilot study was first conducted in our laboratory with participants who were recruited from the same study population. No significant differences were found between the right and left leg in either step length or stride length, corroborating findings from previous research [1]. Additionally, recent studies indicate a high correlation (0.90–1.00) between the right and left legs for step length, stride length, stance and swing phases of gait cycle (GC) in ambulating children [4, 8].

Considering these previous findings and the need to adjust for the walking environment, it was decided to record locomotion data from only the right leg. For this purpose, a one-camera SkillSpector 1.2.4 motion capture system (Video4coach, Denmark) was used to track the two-dimensional trajectories of reflective markers placed on the subjects' skin [15]. Motion data was sampled at a frequency of 30 Hz, fast enough for the study of human gait in motion at self-paced speed [16, 17]. A weight scale and a standard measuring tape were used to obtain anthropometric measures for each subject. The reflective markers (20 mm spheres) were placed at anatomical landmarks: the lateral calcaneous and the fifth metatarsal on the participants' right side and the medial calcaneous on the participants' left side. The raw values from the markers' coordinates were transformed into 2D global coordinates and processed using the SkillSpector software [14].

Due to the inability to study a large number of children in a laboratory setting, research was conducted at a local school that was properly prepared for data collection.

Children were directed to walk barefoot at comfortable and self-paced speed on a 10-meter walkway installed horizontally on a level surface floor. Only GC performed in the middle (four meters) of the walkway were used in data processing [18, 19]. Data from the first three meters at the beginning and the last three meters at the end of the walkway were discarded to minimise the effects of acceleration [18]. Participants performed three to six practice trials before motion capture to allow participants to acclimate to the task [2, 3]. After the practice trials, three trials were recorded per subject. Anthropometric data such as body weight, height and leg length were also measured. Leg length was estimated by the distance between the greater trochanter and floor [20].

Temporal-spatial measurements in stride and step length (m), velocity (m/min), cadence (steps/min), swing and stance phases were computed for each GC using a validated system for motion capture data [15]. Based on protocols described in the literature [3, 21], the single GC that most closely approximated the individual means of all six measurements of GC was used in the analysis.

Data analysis was executed using SPSS ver. 8.0 software (IBM, USA). Stride length, step length, cadence and velocity were normalised using non-dimensional normalisation procedures described by Hof [20], which are as follows: normalised stride length = SL/LL, normalised step length = sL/LL, normalised cadence = $C/(g/LL)^{1/2}$, and normalised velocity = $V/(g \times LL)^{1/2}$; where LL is leg length, SL is stride length, sL is step length, C is cadence, V is velocity and g is acceleration due to gravity.

Table 1. Subject demographics by age group (mean ± *SD*)

Age intervals (years)	*n*	Age (years)	Body Mass (kg)	Height (m)	Leg length (m)
All participants (6–11)	119 (59 boys, 60 girls)	8.9 ± 1.5	31.4 ± 7.9	1.34 ± 0.09	0.68 ± 0.04
Group 1 (6–7)	22 (8 boys, 14 girls)	6.5 ± 0.5	24.3 ± 3.4	1.21 ± 0.05	0.61 ± 0.04
Group 2 (8–9)	49 (23 boys, 26 girls)	8.7 ± 0.5	31.2 ± 6.6	1.33 ± 0.05	0.70 ± 0.04
Group 3 (10–11)	48 (28 boys, 20 girls)	10.4 ± 0.5	35.1 ± 8.4	1.40 ± 0.08	0.73 ± 0.05

Descriptive statistics were employed to explore all variables, from which the gait pattern of the 119 participants was estimated. The Kolmogorov-Smirnov test confirmed acceptable normality of the data distribution. To identify differences between the groups, one-way ANOVA was performed. Scheffé post-hoc analysis was used to identify which age groups differed. Student's *t* test for paired samples was used to compare groups according to gender. A significance level of 5% ($p = 0.05$) was adopted for all statistical tests. The effect size for the sample was 0.28 (moderate to high), giving a statistical power of 0.80 [22].

Results

Mean values of the analysed gait parameters were as follows: 1.23 m ± 0.17 for stride length, 0.63 ± 0.11 m for step length, 117.9 ± 11.4 steps/min for cadence, 72.5 ± 11.1 m/min for velocity, 1.8 ± 0.2 m for normalised stride length, 0.9 ± 0.1 m for normalised step length, 311.9 ± 23.9 m for normalised cadence, 27.9 m ± 4.5 for normalised velocity, 58.1% ± 3.3% for stance (%GC) and 41.9% ± 3.3% for swing (%GC).

Comparisons between boys and girls showed no significant differences ($p \geq 0.05$) in any temporal or spatial gait parameters.

Table 2 shows gait kinematics stratified by age. Normalised and non-normalised values for step length, stride length, cadence and velocity are displayed graphically (Fig. 1).

Demographic data show that the discrepancy in height and leg length was greater between Groups 1 and 2 than between Groups 2 and 3. Significant differences were found between Groups 1 and 2 for step length ($p = 0.01$), stride length ($p < 0.0001$), cadence ($p = 0.035$) and velocity ($p = 0.013$). Between Groups 2 and 3, significant differences were found in cadence ($p = 0.002$), velocity ($p = 0.044$) and normalised velocity ($p = 0.005$).

Stance and swing showed mean and standard deviation values very similar among the three age groups. In fact, no significant differences were found between groups in these gait parameters ($p > 0.05$). Step length and stride length showed increasing magnitude with advancing age (Fig. 1a and 1b). However, this trend was observed only up to the 8–9 year olds; median and interquartile range values for Groups 2 and 3 were similar (Fig. 1a and 1b). ANOVA confirmed these findings for both variables, where significant differences were found between Groups 1 and 2 ($p \leq 0.05$) but not between Groups 2 and 3 ($p > 0.05$).

Cadence decreased with advancing age (Fig. 1c). Statistically significant differences ($p \leq 0.05$) were found between each age group in this spatiotemporal gait parameter.

Measures of median and interquartile range for velocity were similar between Groups 1 and 3 (Fig. 1d). Group 2, however, had greater velocity than the other groups. Significant differences were found between Groups 1 and 2 ($p = 0.013$) and between Groups 2 and 3 ($p = 0.044$).

Figures 1e–h suggests that non-dimensional performance variables are similar in the three groups. However, a significant difference ($p = 0.005$) was found between Groups 2 and 3 for normalised velocity. No significant differences between groups were found for the other non-dimensional variables ($p \geq 0.05$).

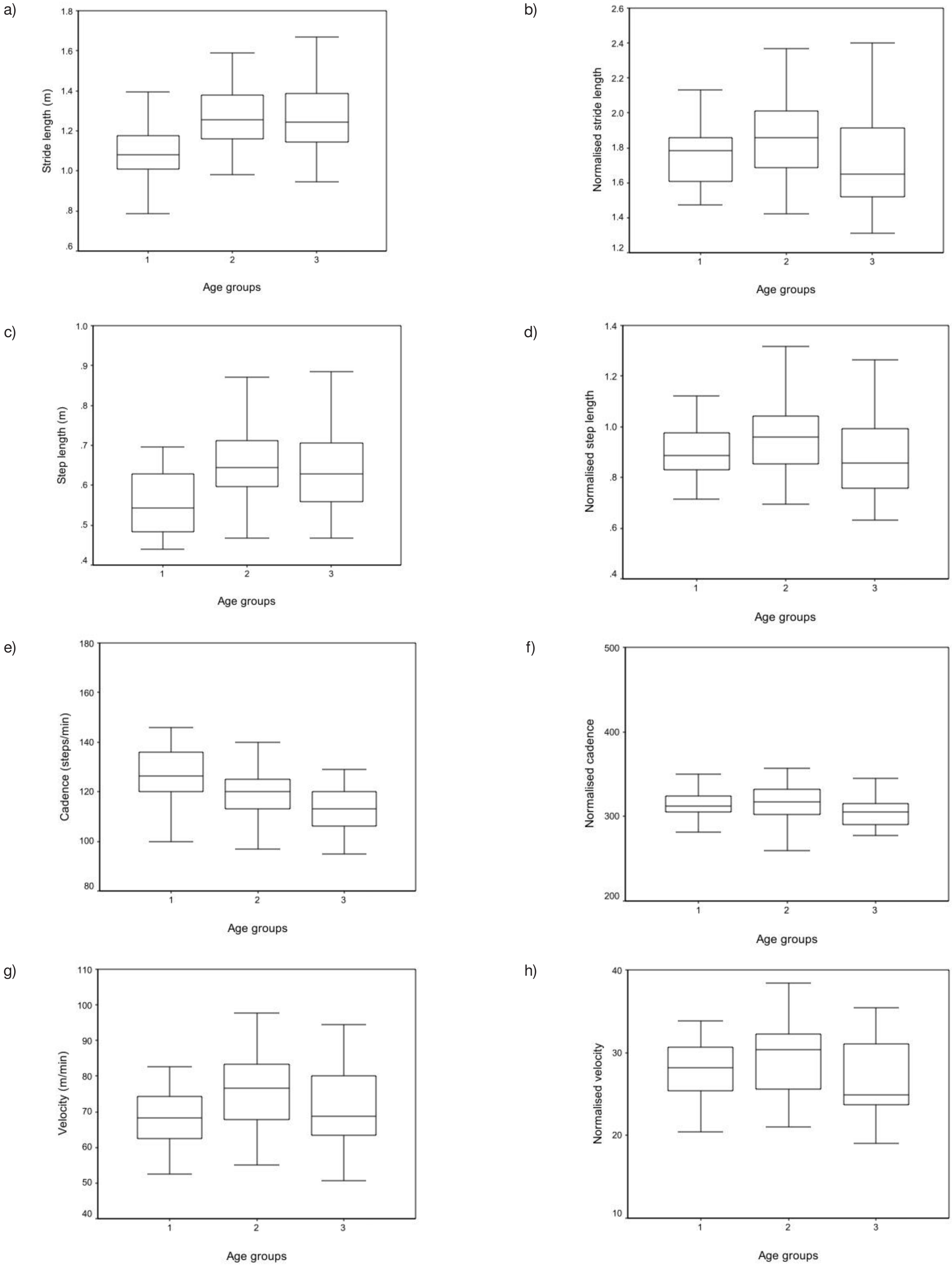
Discussion

There is consensus in the international literature that by four years of age children already exhibit a mature gait kinematic pattern. Several authors [1, 4, 8, 9, 21, 23, 24] have found differences associated with advancing age but have not reported gait kinematic patterns of the population as a whole. Thus, little is known about the possible existence of a universal gait kinematic

Table 2. Gait kinematic parameters of the population (mean ± *SD*)

Gait kinematic parameters	Age groups (years)		
	Group 1 6–7 (*n* = 22)	Group 2 8–9 (*n* = 49)	Group 3 10–11 (*n* = 48)
Step length (m)	0.554 ± 0.08*†	0.656 ± 0.09*	0.644 ± 0.11†
Normalised step length	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.2
Stride length (m)	1.08 ± 0.15*†	1.27 ± 0.15*	1.26 ± 0.17†
Normalised stride length	1.8 ± 0.2	1.8 ± 0.2	1.7 ± 0.3
Cadence (steps/min)	126 ± 11*†	120 ± 11*‡	112 ± 8.5†‡
Normalised cadence	314 ± 22.2	317 ± 27.5	306 ± 19.5
Velocity (m/min)	68 ± 8.3*	76 ± 10.8*‡	70.8 ± 11.4‡
Normalised velocity (NV)	27.9 ± 3.3	29.4 ± 4.3‡	26.5 ± 4.6‡
Stance (%GC)	57.3 ± 3.3	58.3 ± 2.9	58.2 ± 3.7
Swing (%GC)	42.8 ± 3.3	41.7 ± 2.9	41.8 ± 3.7

* Significant difference between Groups 1 and 2, $p < 0.05$; † Significant difference between Groups 1 and 3, $p < 0.05$, ‡ Significant difference between Groups 2 and 3, $p < 0.05$



Figures 1a–h. Interquartile and total range of kinematic gait data shown as box plots of the three age groups (Group 1: 6–7 years; Group 2: 8–9 years; Group 3: 10–11 years)

pattern in children over four years of age, a problem that has already been identified by researchers [2].

No significant differences were found between groups for gender among the analysed gait parameters. In the adopted experimental design, gender was not a modifying factor of gait pattern. These findings agree with the results from previous research [8] and were in accordance with our original hypothesis.

Our results were similar to those in previous studies for step length, normalised step length, stride length, normalised stride length, cadence, normalised cadence, stance and swing of children older than 6 years of age [4, 9, 21, 23]. However, differences among the applied methodological procedures and the specificity of normalisation strategies make it difficult to accurately compare results.

One interesting point is that when comparing our findings with those by Dusing and Thorpe [4], who used an electronic system more sophisticated than ours to register children's gait, it was found that similar values were recorded for walking step length, cadence and velocity. This finding suggests that the data collection procedures adopted in the present study provide satisfactory validity and objectivity in the multi-variable measurement of gait in children with the added advantage of using a less costly measurement method. The application of such an inexpensive technique, particularly with respect to technological resources, could be widely implemented among different Brazilian socioeconomic groups. Indeed, as this method was performed outside a laboratory setting, it can encourage the spread of instrumented gait analysis systems to schools, sport clubs and clinics. Therefore, the accessibility of this method can enables a larger study of a more diverse population so as to start composing a normative database for gait in Brazilian children.

Assuming the probability that a healthy child at approximately four years of age reaches a mature gait kinematic pattern [21], one can assume that the observed differences in gait during the years of remaining growth result from increased body dimensions [25]. In fact, these differences tend to disappear when kinematic variables are normalised for anthropometric variables [20]. In our study, it was expected that the groups would exhibit differences between themselves through non-normalised gait variables due to physical growth. This aspect was confirmed, where the differences observed between groups were in non-normalised step, stride length, cadence and velocity parameters.

In the case of velocity, although there is lack of consensus in the literature, our results were congruent with other studies [8, 21], where most state that children older than 6 years show age-related differences in this parameter. Dusing and Thorpe [4], although they did not test for the significance of differences between various age groups, noted that the velocity of walking increased with advancing age. In contrast, Moreno-Hernandez et al. [8] reported that velocity showed a tendency to decrease with age. In the present study, we observed variability in the walking velocity of children between 6 and 11 years old, where Group 2 (8–9 years) showed a greater magnitude of this spatiotemporal gait parameter than younger (Group 1) and older (Group 3) children. From these findings, we speculate that children between 6 and 11 years old may not yet have reached mature gait kinematic patterns but are progressing towards achieving a mature pattern. This may underline a period of transition towards mature gait patterns in children. Thus, the variability observed in velocity may stem from the fact that this walking parameter is determined by the behaviour of other associated kinematic variables [26, 27]. Although children at this stage may have realised individual kinematic characteristics, they may still not be able to coordinate them to the same level as adults.

Our data suggest that the differences between Groups 1 and 2 for step and stride length are associated with anthropometric differences, as the leg length discrepancy was greater between Groups 1 and 2 than between Groups 2 and 3. Thus, the impact of normalisation on this relationship tended to be less important when comparing Groups 2 and 3.

The fact that no significant differences were found between the groups for the normalised variables of step length, stride length and cadence corroborate the assumption that the differences in body dimensions, namely, height and/or leg length, determine variations in these parameters over time [28]. Moreover, our findings suggest that step and stride length are more sensitive than cadence to variations in body size in walking children.

As was mentioned previously, Moreno-Hernandez et al. [8] found significant differences between age groups for the normalised variables of gait in children. However, these researchers [8] did not identify which pairs of variables were different and, unlike the present study, children aged 12–13 years old were included. Perhaps for this reason it is difficult to compare their results with our findings.

Unlike other non-dimensional variables, normalised velocity was significantly different between Groups 2 and 3. Contrary to our original hypothesis, this finding suggests that differences in body size are not sufficient to explain the differences in velocity of locomotion between children aged 8–9 and 10–11 years. In our understanding, this finding suggests that the walking speed of a child might be related to motor proficiency and, consecutively, to the coordination of kinematic variables beyond the isolated behaviour of the specific kinematic characteristics examined in this study. However, further research is necessary to corroborate or refute this proposition.

Our findings concerning normalised velocity disagree with the earlier literature on the subject, which consists of studies suggesting that children older than four have already reached a mature gait kinematic pattern [4, 9, 21, 23]. This divergence might be explained by the fact that, in these prior studies, statistical comparisons of differences among normalised variables of gait between different age groups were not made and that different normalisation strategies were used [28].

Conclusions

In the present study, gait kinematic behaviour was described in 119 Brazilian children aged 6 to 11 years using a low-cost method, which researchers and clinicians can now use to assess and diagnose gait dysfunction. The results of this study suggest that gender was not a significant modifying factor for gait among the examined children. Moreover, it was found that anthropometric differences determined the kinematic behaviour of most of the analysed variables. Velocity of locomotion was the only kinematic parameter for which a difference was noted between age groups even after normalisation of the data. In contrast to prior literature, these findings suggest the presence of an immature gait kinematic pattern in children between 6 to 11 years old.

We believe that this study is a step towards constructing a normative database on the locomotion of Brazilian children. Additional research that includes children from other age groups and different socio-cultural groups within Brazil are needed to ensure that this database is precise. We also suggest studying the differences between our results and those reported previously in the literature to determine whether these differences are a result of problems of internal validity, such as problems with the adopted methods, or of external validity, such as the inability to extrapolate the findings to other populations with different sociocultural characteristics.

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