Heliyon 9 (2023) e17541

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Accelerometric analysis of trunk acceleration during gait analysis in children between 6 and 11 years old: A cross-sectional study

Jesús García-Liñeira [a], Raquel Leirós-Rodríguez [b,*], Vicente Romo-Pérez [a], Jose L. García-Soidán [a]

[a] *Faculty of Education and Sport Sciences, University of Vigo, Campus a Xunqueira, s/n, 36005, Pontevedra, Spain*

[b] *SALBIS Research Group, Faculty of Health Sciences, Nursing and Physical Therapy Department, University of León, Ave. Astorga, 15, 24401, Ponferrada, Spain*

ARTICLE INFO

Keywords:
Accelerometer
Biomechanical phenomena
Child development
Postural balance
Sex characteristics

ABSTRACT

Background: Gait analysis in children with accelerometers is of special interest in daily clinical practice, as it eliminates possible biases related to the assessor and is not very sensitivity of visual analysis. The sensitivity of data collection by these instruments makes it possible to evaluate the efficiency of body movements during gait and to better understand the degree of motor development in childhood, assessing progress within normal developmental parameters or detecting possible deficits.

Research question: What are the accelerations of the center of mass during normal gait in children aged 6–11 years?

Methods: Descriptive cross-sectional study conducted with a total of 283 school children (girls = 142). The analyzed variables were the mean and maximum values obtained in each of the three body axes and their root mean square during normal gait 10 m out, turn and 10 m back over firm ground in a straight line three times.

Results: The accelerometric data obtained showed similar values between sexes in each of the age sub-groups analyzed. Except for the medial-lateral axis in children aged 10–11 years where differences between sexes were detected (being significantly lower in girls). A reduction in medial-lateral axis average values over the years was also identified in both sexes. The regression models generated for the average accelerometric values showed significant values only in the average value of the medial-lateral axis. However, the maximum values were significant in all cases.

Significance: The preferred motor strategies of boys and girls during gait include developing mainly control and adjustment movements in the frontal plane (hence the high magnitudes recorded there). Flexion-extension movements are the most reduced over the six years of age analyzed, particularly in girls. Conversely, rotational movements are the most constant in speed in both sexes and all age subgroups.

1. Background

Gait analysis is of special interest in pediatrics to identify the underlying causes of abnormalities in normal development [1].

---

[*] Corresponding author.
E-mail address: rleir@unileon.es (R. Leirós-Rodríguez).

https://doi.org/10.1016/j.heliyon.2023.e17541
Received 14 October 2022; Received in revised form 20 June 2023; Accepted 20 June 2023

Considering that visual analysis involves important biases related to the assessor and is not very sensitive, the use of instruments applicable in daily clinical practice is of special interest [2]. In this line, accelerometers allow the "normal" movement of the child as they are small and lightweight devices [3]. These devices record basic gait parameters that are sensitive and valid for the identification of motor control disturbances [4]. In fact, the variability of upper trunk oscillations has been identified as a reflection of gait stability [5].

Gait velocity is a key clinical parameter but has no diagnostic sensitivity about the postural control subsystems causing the gait disturbance [6,7]. Developmentally related mechanisms for refining postural control performance appear to be linked to how children use the different sensory stimuli available to produce appropriate muscle activation [8,9]. Age is a highly influential factor in postural control because of the maturation of the central nervous system and accumulated movement experience [10]. Both of these factors enhance the weighting processes involved in postural control [11]. Although postural control is present from the first months of life, maturation and refinement processes occur especially between the ages of 6 and 10 years [12]. These maturational changes are fundamentally characterized by the optimization of the coordination of head and trunk movements [13,14], and by the improvement in the control and management of the sensory information that feeds this system (vision, proprioception and vestibular) [15–17]. All this coincides, in the same period, with the development of other important maturation phenomena in the central nervous system and the acquisition of other complex motor skills [18].

It has been defined that at 12 years of age, postural control reaches maturity at a physiological level [19,20]. In addition, it has also been identified that this maturity is reached earlier in girls than in boys [9,21]. Subsequently, males appear to have slightly better postural stability [20,22]. It has recently been identified that girls are less dependent on somesthetic and visual information for the maintenance of postural control and, consequently, girls would preferentially use inputs from the vestibular system (or, at least, more than their male counterparts) [9,23].

Based on previous results from studies of postural control in infancy and our current understanding of the sensitivity of accelerometers, they allow continuous monitoring of the stability of the center of mass during movement. The information obtained on postural and gait patterns allows us to observe the development of dynamic balance in infancy and to detect early deficits in its development. Therefore, the present investigation had the objective of analyzing trunk acceleration during gait under normal conditions in children aged 6–11 years. At the same time, as a secondary objective, we aimed to provide normative values of the acceleration of the center of mass during this test in the entire age range mentioned.

2. Methods

2.1. Study design and participants

This descriptive cross-sectional study was conducted in several public schools involving a total of 283 children, 142 of whom were girls. Participants had to meet the inclusion criteria of being between 6 and 11 years old, typically developing, able to walk independently and without aids, and able to understand and comply with the experimental indications. Excluded from the study were children who had undergone previous surgeries, had musculoskeletal injuries at the time of the analysis, used body prostheses, or whose legal guardians had not given informed consent for participation in the study.

2.2. Measuring instruments and variables analyzed

Firstly, the anthropometric analysis of height and weight was carried out using a measuring rod and a Seca scale (SECA, Germany). With the anthropometric data, the Body Mass Index (Kg/m^2) was calculated.

The kinematic analysis instrument used was the Actigraph G3TX + triaxial accelerometer (Actigraph, USA). Body accelerations were recorded in the three body axes: medial-lateral (ML), vertical (VT) and anterior-posterior (AP). From these three measurements, a fourth accelerometric variable was calculated: the Root Mean Square (RMS).

> The accelerometer was configured so that measurements were taken at a frequency of 50 Hz, in fractions of 1 s, and prior to use it was calibrated in static [7].

2.2.1. Procedure

Prior to the measurements, a meeting was held with the parents of the participants in all the schools where the measurements were taken to inform them about the procedure and the objectives of the study and to request their informed consent. The gait measurement was carried out in the school sports facilities of the schools themselves. The place was perfectly acclimatized and known to the subjects analyzed. Before the measurements, the subjects were informed of the procedures to be followed in a manner adapted to their ages and to resolve any doubts they might have. Measurements were taken barefoot and with excess clothing removed.

The accelerometer was attached with an elastic belt and was secured with hypoallergenic adhesive tape to the waist of each subject at the level of the L4 vertebra to ensure that the device would not move independently of the subject's trunk, during the tests. The test consisted of walking 10 m out, turn when passing the mark located on the floor making a 180° turn naturally and 10 m back over firm ground in a straight line three times (the results obtained in the three repetitions were averaged). Between the three repetitions of the test, 30-s rests were taken in order to avoid the onset of muscle fatigue [24]. The instruction given to the participants was to walk at a normal pace, as they usually do (no faster, no slower).

2.3. Statistical analysis

The analysis included first extracting the raw data with the specialized accelerometer software, and then the data analyzed were the four accelerometric variables mentioned above, the average value and the maximum value recorded were calculated. The sample was divided into age subgroups: group 1 (G1), 6–7 years; group 2 (G2), 8–9 years; and group 3 (G3), 10–11 years.

Firstly, a descriptive analysis of the variables studied was carried out using measures of central tendency (mean and standard deviation). The Kolmogorov-Smirnov test was applied to verify the normal distribution of the data analyzed. Subsequently, means were compared between sexes in each of the groups analyzed using the Student's t-test and Cohen's d was calculated. Similarly, means were compared between age subgroups with ANOVA and Bonferroni adjustment and effect size estimation with the partial eta squared statistic.

A logistic regression model (logit) was also applied to analyze the evolution of accelerations occurring during walking over the years (0 = 6–7 years; 1 = 8–9 years; 2 = 10–11 years). This model was adjusted with the anthropometric values of the body mass index and included the calculation of the Odds Ratio (OR) and its confidence interval.

Statistical analysis was performed with the specialized software Stata 15 (Stata Corp., College Station, USA) and in all tests performed the level of statistical significance was set at 5% ($p < 0.05$).

3. Results

Data from a total of 283 children (142 were girls), aged 6–11 years (8.7 ± 1.7 years), were analyzed. Anthropometric analysis data from the sample showed homogeneity between sexes in each age subgroup, with no statistical differences (Table 1). Significant increases in height, weight and BMI with increasing age were observed in the whole sample ($p < 0.05$; $0.04 < \eta_p^2 > 0.75$).

The accelerometric data obtained showed similar values between sexes in each of the age sub-groups analyzed (Table 2). Except for the ML axis in G3 where differences between sexes were detected (being significantly lower in girls) ($p = 0.03$; $d = 0.26$). A reduction in ML axis average values over the years was also identified in both sexes: in boys between groups G1 and G3 ($p = 0.004$; $\eta_p^2 = 0.9$) and between G3 girls and the other two groups ($0.0001 < p > 0.03$; $\eta_p^2 = 0.3$).

The analysis of the maximum acceleration values in all axes and their RMS decreased the older the age analyzed (Table 3). For the variables analyzed, it was perceived that the highest magnitude values occurred in the VT axis and the RMS and the lowest magnitude values in the AP axis. Peak accelerations decreased significantly with age on the VT axis when analyzing the subgroup of G1 girls separately from the other two age groups ($p = 0.005$; $\eta_p^2 = 0.9$) and on the ML ($p = 0.003$; $\eta_p^2 = 0.05$) and RMS ($p = 0.002$; $\eta_p^2 = 0.07$) axes when analyzing G1 girls with G3. Differences in ML axis peak accelerations were identified between both sexes ($p = 0.002$; $d = 0.35$).

The regression models generated for the average accelerometric values (Table 4) showed significant values only in the average value of the ML axis (OR = 0.92; $p < 0.001$). However, the maximum values were significant in all cases ($0.98 < OR > 0.99$; $p < 0.008$ for all four models).

4. Discussion

The aim of this study was to analyze trunk acceleration during walking under normal conditions in boys and girls aged 6–11 years. The results obtained indicate that postural control improves significantly over the age range studied. Especially at the age of 10 years

Table 1
Sample characteristics (mean ± standard deviation).

Age group	N	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
ALL (n = 283)					
G1	88	6.6 ± 0.5	121.8 ± 6.2[aa, bb]	26.1 ± 6[aa, bb]	17.4 ± 2.6[a,b]
G2	71	8.4 ± 0.5	132 ± 6.6[aa,c]	33 ± 7.6[aa,c]	18.8 ± 3.3[a]
G3	124	10.5 ± 0.5	146.9 ± 7.5[bb,c]	40 ± 9.8[bb,c]	18.6 ± 3.3[b]
All	283	8.7 ± 1.7	134.9 ± 12.4	33.9 ± 10.2	18.3 ± 3.1
BOYS (n = 141)					
G1	42	6.5 ± 0.5	121.3 ± 5.3[d,e]	25.4 ± 5[d,e]	17.1 ± 2.4[e]
G2	39	8.5 ± 0.5	132.6 ± 5.3[d,f]	33.2 ± 6.8[d,f]	18.8 ± 3.2
G3	60	10.5 ± 0.5	145.3 ± 6.4[e,f]	40 ± 9.6[e,f]	18.8 ± 3.6[e]
All	141	8.7 ± 1.7	134.7 ± 11.7	33.8 ± 9.8	18.3 ± 3.3
GIRLS (n = 142)					
G1	46	6.7 ± 0.5	122.2 ± 7 [gg,h]	26.7 ± 6.8 [g,h]	17.6 ± 2.8
G2	32	8.4 ± 0.5	131.1 ± 7.8 [gg, ii]	32.6 ± 8.5 [g,i]	18.8 ± 3.4
G3	64	10.4 ± 0.5	146.3 ± 8.4 [h, ii]	40.1 ± 10.1 [h,i]	18.4 ± 3.1
All	142	8.8 ± 1.7	135.1 ± 13.2	34.1 ± 10.5	18.2 ± 3

G1: 6–7 years; G2: 8–9 years; G3: 10–11 years; BMI: Body Mass Index.
ANOVA results all participants: G1 vs. G2 [a]$p < 0.01$; [aa]$p < 0.001$; G1 vs. G3: [b]$p < 0.01$; [bb]$p < 0.001$; G2 vs. G3: [c]$p < 0.001$.
ANOVA results boys subgroup: G1 vs. G2: [d]$p < 0.0001$; G1 vs. G3: [e]$p < 0.0001$; G2 vs. G3: [f]$p < 0.0001$.
ANOVA results girls subgroup G1 vs. G2: [g]$p < 0.05$; [gg]$p < 0.0001$; G1 vs. G3: [h]$p < 0.0001$; G2 vs. G3: [i]$p < 0.01$; [ii]$p < 0.0001$.

Table 2
Gait accelerometric mean values by sex and age groups.

Variable	G1		G2		G3	
	Boys (n = 42)	Girls (n = 46)	Boys (n = 39)	Girls (n = 32)	Boys (n = 60)	Girls (n = 64)
		Average mean values of vertical axis				
Mean ± standard deviation	40.3 ± 15.9	42.3 ± 10.5	38.6 ± 13.3	38.4 ± 13.6	39.5 ± 17.2	40.5 ± 13.1
Minimum	13.7	20	11.1	12.9	3.8	15.2
Maximum	79.2	65.4	62.4	70.5	90.5	73
p25	26.8	33.6	28.9	31.8	25.9	31.1
p50 (median)	38.6	43.8	38.9	37.9	37.9	39.6
p75	47.2	48.2	47.6	45.7	49.2	47.5
Iqr	20.5	14.6	18.7	14	23.3	16.5
Kurtosis	2.9	2.7	2.3	2.8	3	2.8
Skewness	0.7	0.3	−0.3	0.1	0.5	0.4
		Average mean values of medio-lateral axis				
Mean ± standard deviation	25.7 ± 7.9[a]	24.2 ± 8.3[b]	23.2 ± 9.1	21.4 ± 7.9[c]	19.6 ± 7.9[*,a]	16.7 ± 7.2[*,b,c]
Minimum	8.5	5.3	9.3	9.3	7.3	5.8
Maximum	48.4	40.9	42.3	37.2	39.7	44.8
p25	22.2	17.9	14.7	14.5	14.4	12.2
p50 (median)	26.2	22.8	21.4	21.3	18.4	15.6
p75	30.4	29.5	32.2	28.4	24.2	19.2
Iqr	8.2	11.7	17.5	13.9	9.9	7
Kurtosis	3.6	2.3	2	2.1	2.6	5.2
Skewness	0.1	0.2	0.3	0.2	0.6	1.3
		Average mean values of antero-posterior axis				
Mean ± standard deviation	27.5 ± 8.4	30.4 ± 5.2	28.2 ± 7.3	30.8 ± 8.3	28.9 ± 9.8	30.8 ± 8
Minimum	10.2	23	11.8	10.9	12.4	16.3
Maximum	56.9	44.6	43.4	44	54.2	61.8
p25	21.4	25.4	23.2	24.3	21.1	26
p50 (median)	27.2	30.4	26.9	33.1	27.3	29.2
p75	31.9	33.7	33.8	37	35.6	33.8
Iqr	10.5	8.3	10.7	12.7	14.5	7.8
Kurtosis	5.1	2.61	2.7	2.41	2.7	5.6
Skewness	0.9	0.5	0.1	−0.2	0.6	1.3
		Average mean values of Root Mean Square				
Mean ± S. D.	55.9 ± 17.2	58.3 ± 10.3	54.2 ± 13.8	54.6 ± 14.4	53.7 ± 18.5	54.4 ± 14
Minimum	23.7	35	24.3	22.7	22.5	31.8
Maximum	97.2	79.6	77.5	85.1	100.1	87.7
p25	46	49.1	47.7	42.1	39.1	45.5
p50 (median)	54.9	59.4	54.1	54.9	53.4	52.2
p75	66.6	65.2	64	65.9	66.9	59.9
Iqr	20.7	16.1	16.3	23.8	27.9	14.4
Kurtosis	2.8	2.7	2.8	2.55	2.4	2.7
Skewness	0.4	−0.1	−0.4	0.02	0.3	0.6

t-test between sex in intra-group: *$p < 0.05$.
ANOVA results boys subgroup: G1 vs. G3: [a]$p < 0.01$.
ANOVA results girls subgroup: G1 vs. G3: [b]$p < 0.001$; G2 vs. G3: [c]$p < 0.05$.

the accelerations obtained were significantly reduced compared to the results obtained in the 6- and 7-year-old participants. The reduction in accelerations recorded is indicative of better postural control and greater dynamic stability of the children during walking [7]. and is consistent with previous research in different population groups [25–27].

This reduction was significant in the mean value of the ML axis and the maximum values of the three axes and their RMS. In other words, optimization of trunk acceleration during gait occurs in all three axes of movement, but especially in the sagittal plane. Consequently, the movements that undergo the greatest refinement during the maturation of motor control during gait are the flexion-extension movements of the center of mass area (i.e. of the thoracolumbar spine and pelvis). This sophistication in trunk movements allows control of aspects of gait such as speed and body control, an element that is influenced by the age of maturation of children, who over the years required fewer compensatory movements of the trunk to maintain balance [5].

However, it should be noted that accelerations on the ML axis were significantly lower in girls. And this difference increased with the age of the participants. A plausible explanation for this phenomenon would suggest that trunk acceleration during gait matures earlier in girls as early as six years of age and continues to improve until at least 11 years of age. In addition to being earlier, this improvement is greater compared to boys of the same age group. Consequently, the anticipatory movements required to maintain balance during gait evolve as a function of sex (previous in girls) and age [20,21]. In the VT axis, the highest accelerations were detected in all age subgroups. That is, the most abrupt movements, with less constant velocity, occurred in the frontal plane (lateral

Table 3
Gait accelerometric maximum values by sex and age groups (mean ± standard deviation).

Variable	G1		G2		G3	
	Boys (n = 42)	Girls (n = 46)	Boys (n = 39)	Girls (n = 32)	Boys (n = 60)	Girls (n = 64)
Average maximum values of vertical axis						
Mean ± standard deviation	76.2 ± 28.5	80.8 ± 24.2^{a,b}	69.5 ± 23.1	65.4 ± 21.1^{a}	67.5 ± 26.5	67.1 ± 19.7^{b}
Minimum	32	43	21	31	14	34
Maximum	159.3	178	135.3	133.3	145.3	130.3
p25	56.7	61	54.7	50.5	46.2	53
p50 (median)	67.8	77	67.7	62.3	62.8	64.7
p75	92.3	89.3	81.7	74	85.8	77.3
Iqr	35.7	28.3	27	23.5	39.7	24.3
Kurtosis	3.1	7	3.9	4.7	3.7	4.3
Skewness	0.7	1.5	0.4	1	0.8	1
Average maximum values of medio-lateral axis						
Mean ± standard deviation	66.5 ± 14.2	64.6 ± 15.2^{b}	64.9 ± 16.3	60.6 ± 18.3	63.7 ± 16.3*	55 ± 14.4^{*,b}
Minimum	43	20.3	35.7	33.3	33.3	21.7
Maximum	115.7	106	101.3	99.7	113.7	89.3
p25	58	55.3	51	46.8	52.2	46
p50 (median)	64.5	61.3	65	57.2	62.5	54.2
p75	75.7	76.7	75.7	73.3	75.7	62.2
Iqr	17.7	21.3	24.7	26.5	23.5	16.2
Kurtosis	4.9	4.1	2.4	2.3	3.1	2.9
Skewness	0.9	0.2	0.2	0.5	0.3	0.2
Average maximum values of antero-posterior axis						
Mean ± standard deviation	57.5 ± 17.6	61.3 ± 13.4	60.4 ± 21.8	58.3 ± 16.6	56 ± 22.4	54.9 ± 14
Minimum	26	35	24.7	56.5	27	34.7
Maximum	106.3	92	146.3	166.5	159	113
p25	47	54.7	43.7	42.8	42.8	45.7
p50 (median)	53.8	58.5	58	61.7	52	52.5
p75	68.7	66.3	72	72.5	65.8	60.7
Iqr	21.7	11.7	28.3	29.7	23	15
Kurtosis	3.5	2.7	7.3	2.2	8.9	6.5
Skewness	0.8	0.4	1.5	−0.1	1.9	1.5
Average maximum values of Root Mean Square						
Mean ± standard deviation	118.2 ± 29.6	121.5 ± 25.9^{b}	114.3 ± 29.7	108.2 ± 26.1	110.5 ± 31.7	104.1 ± 21.9^{b}
Minimum	64.2	60.7	60.7	56.5	61.6	68.2
Maximum	197	212.4	208.7	166.5	234	176
p25	95.2	100.9	98	88.1	90	87.8
p50 (median)	114.9	118.4	110.4	106	105.4	100.5
p75	138.8	136	130.2	130.2	132.5	113.8
Iqr	43.6	35.1	32.2	42.1	42.5	26
Kurtosis	2.8	5	4.1	2.3	5.4	3.6
Skewness	0.5	0.8	0.6	0.1	1.1	0.9

t-test between sex in intra-group: $^{*}p < 0.001$.
ANOVA results girls subgroup: G1 vs. G2: $^{a}p < 0.01$; G1 vs. G3: $^{b}p < 0.01$.

trunk flexions). This phenomenon had previously been identified as a preferential strategy for the recovery of verticality in girls over 8 years of age in monopodal balance on an unstable Surface [9]. In contrast, the smallest accelerations were detected in the AP axis in both sexes, indicating that the rotational movements of the center of mass and the flex and hip extension are controlled and less accelerated from the early stages of childhood, responding to normal adult gait patterns that have been previously studied in the literature [28].

The secondary objective was to provide the normative values of center of mass acceleration during the test over the age range mentioned above. The data obtained confirm that the values in the ML axis are those that undergo the greatest changes in the magnitude of accelerations during walking and tend to reduce over the years. Thus, for the accelerometric analysis of trunk acceleration in the pediatric population, it could be considered to carry out this 10-m round trip gait test and the subsequent calculation of the average value of the accelerations in the ML axis and the maximum values of the three axes. In this way, a specific and individualized diagnosis of the needs of each child could be obtained for the treatment of motor control during walking and improvement of dynamic stability. All this thanks to the early identification of alterations in trunk acceleration, an aspect that has been demonstrated and presented differences in the comparative analysis between populations with typical development and those with pathologies with balance disturbances [25].

The study achieves to combine the use of accelerometry and gait test, which represent a valid, reliable, minimally invasive methodology that can be used comfortably in a multitude of situations for the quantification of compensatory movements to maintain balance during gait [4,5,24]. The authors recognize that the combined use of other kinematic analysis instruments could provide even more reliable and valid information in this regard, which may be an added limitation of the study not to specifically analyze other associated gait parameters that may provide a greater amount of information. Moreover, further investigations with larger sample sizes

Table 4
Models of logistic regression for age group, adjust by Body Mass Index.

	OR	SE	P > |z|	95% CI
Mean value in vertical axis	1.001	0.008	0.9	0.985–1.017
Body Mass Index	1.1**	0.04	0.01	1.022–1.18
Constant	0.96	0.816		−0.644–2.557
Mean value in medio-lateral axis	0.92***	0.013	0.0001	0.895–0.947
Body Mass Index	1.12**	0.041	0.003	1.039–1.202
Constant	−0.62	0.723		−2.037–0.796
Mean value in antero-posterior axis	1.01	0.014	0.3	0.985–1.04
Body Mass Index	1.1**	0.039	0.009	1.024–1.178
Constant	1.28	0.790		−0.267–2.831
Mean value in Root Mean Square	0.99	0.007	0.3	0.978–1.007
Body Mass Index	1.09**	0.039	0.01	1.017–1.172
Constant	0.38	0.836		−1.258–2.019
Maximum value in vertical axis	0.99**	0.005	0.006	0.978–0.996
Body Mass Index	1.08*	0.039	0.03	1.005–1.159
Constant	−0.34	0.805		−1.922–1.233
Maximum value in medio-lateral axis	0.98***	0.007	0.001	0.964–0.991
Body Mass Index	1.12**	0.041	0.002	1.042–1.204
Constant	−0.18	0.739		−1.631–1.267
Maximum value in antero-posterior axis	0.99**	0.006	0.008	0.977–1.001
Body Mass Index	1.1**	0.04	0.009	1.024–1.179
Constant	0.29	0.749		−1.179–1.757
Maximum value in Root Mean Square	0.99**	0.004	0.002	0.979–0.995
Body Mass Index	1.09**	0.04	0.01	1.0199–1.175
Constant	−0.59	0.82		−2.194–1.022

OR: odds ratio; SE: standard error; 95% CI: 95% confidence interval.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

and with specific subgroups of children with developmental impairments (such as cerebral palsy, visual and/or vestibular system impairments …) should be carried out in order to define more fully and with greater generalizability the trunk acceleration patterns detected. The analysis of gait with accelerometry in a double-task situation or on different surfaces, stable or unstable, is recommended as a line of future research. At the same time, the main strength of this research is that, in addition to specifying in detail the capacity of the postural control system of children during walking, it has made it possible to describe some key factors for the early identification of alterations in the development of normal walking, therapeutic intervention and the prevention of falls in the school population.

5. Conclusions

The gait test analyzed revealed the preferred motor strategies of boys and girls: both develop mainly control and adjustment movements in the frontal plane (hence the high magnitudes recorded there). Flexion-extension movements are the most reduced over the six years of age analyzed, particularly in girls. Conversely, rotational movements are the most constant in speed in both sexes and all age subgroups.

Therefore, interventions for the prevention and treatment of gait disturbances should include activities that preferably involve, encourage and train lateral flexion movements of the body segment of the center of mass (dorsal-lumbar and pelvic area). In addition, the percentiles provided will allow the design of interventions specific to the demands and needs of each child.

Ethics statement

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Faculty of Sport Science of the University of Vigo (code: 3-0406-14). All participants provided informed consent to participate in the study by one of their legal guardians prior to their participation in the research.

Author contributions

J.G.-L., R.L.-R., V.R.-P. and J.L.G-S. conceptualized and designed the study, drafted the initial manuscript, designed the data collection instruments, collected data, carried out the initial analyses, and critically reviewed the manuscript for important intellectual content. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Data availability statement

The data presented in this study are available on request from the corresponding author.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Not applicable.

List of abbreviations

ML:	medial-lateral
VT	vertical
AP	anterior-posterior
RMS	Root Mean Square
OR	Odds Ratio

References

[1] T.A. Wren, C.A. Tucker, S.A. Rethlefsen, G.E. Gorton III, S. Õunpuu, Clinical efficacy of instrumented gait analysis: systematic review 2020 update, Gait Posture 80 (2020) 274–279.

[2] Y. Ma, K. Mithraratne, N.C. Wilson, X. Wang, Y. Ma, Y. Zhang Y, The validity and reliability of a kinect v2-based gait analysis system for children with cerebral palsy, Sensors 19 (2019) 1660.

[3] M. Brandes, W. Zijlstra, S. Heikens, R. van Lummel, D. Rosenbaum, Accelerometry based assessment of gait parameters in children, Gait Posture 24 (2006) 482–486.

[4] D. Jarchi, J. Pope, T.K. Lee, L. Tamjidi, A. Mirzaei, S. Sanei, A review on accelerometry-based gait analysis and emerging clinical applications, IEEE Rev. Biomed. Eng. 11 (2018) 177–194.

[5] M. Iosa, T. Marro, S. Paolucci, D. Morelli, Stability and harmony of gait in children with cerebral palsy, Res. Dev. Disabil. 33 (2012) 129–135.

[6] C.A. Fukuchi, R.K. Fukuchi, M. Duarte, Effects of walking speed on gait biomechanics in healthy participants: a systematic review and meta-analysis, Syst. Rev. 8 (2019) 1–11.

[7] J.L. García-Soidán, R. Leirós-Rodríguez, V. Romo-Pérez, J. García-Liñeira, Accelerometric assessment of postural balance in children: a systematic review, Diagnostics 11 (2021) 8.

[8] M.A. Schmuckler, A. Tang, Multisensory factors in postural control: varieties of visual and haptic effects, Gait Posture 71 (2019) 87–91.

[9] J. García-Liñeira, R. Leiros-Rodríguez, V. Romo-Perez, J.L. García-Soidan, Sex differences in postural control under unstable conditions in schoolchildren with accelerometric assessment, Gait Posture 87 (2021) 81–86.

[10] L. Assländer, R.J. Peterka, Sensory reweighting dynamics in human postural control, J. Neurophysiol. 111 (2014) 1852–1864.

[11] A. Busquets, S. Aranda-Garcia, B. Ferrer-Uris, M. Marina, R. Angulo-Barroso, Age and gymnastic experience effects on sensory reweighting processes during quiet stand, Gait Posture 63 (2018) 177–183.

[12] N. Kirshenbaum, C. Riach, J. Starkes, Non-linear development of postural control and strategy use in young children: a longitudinal study, Exp. Brain Res. 140 (2001) 420–431.

[13] C. Rival, H. Ceyte, I. Olivier, Developmental changes of static standing balance in children, Neurosci. Lett. 376 (2005) 133–136.

[14] G.L. Girolami, T. Shiratori, A.S. Aruin, Anticipatory postural adjustments in children with typical motor development, Exp. Brain Res. 205 (2010) 153–165.

[15] V. Hatzitaki, V. Zlsi, I. Kollias, E. Kioumourtzoglou, Perceptual-motor contributions to static and dynamic balance control in children, J. Mot. Behav. 34 (2002) 161–170.

[16] P.P. Perrin, C. Jeandel, C.A. Perrin, M.C. Bene, Influence of visual control, conduction, and central integration on static and dynamic balance in healthy older adults, Gerontol. 43 (1997) 223–231.

[17] P. Perrin, C. Perrin, Sensory afferences and motor control of equilibrium using static and dynamic posture tests, Ann. Otolaryngol. Chir. Cervicofac. 113 (1996) 133–146.

[18] C. Tanaka, Y. Hikihara, K. Ohkawara, S. Tanaka, Locomotive and non-locomotive activity as determined by triaxial accelerometry and physical fitness in Japanese preschool children, Pediatr. Exerc. Sci. 24 (2012) 420–434.

[19] A.B. Zipori, L. Colpa, A.M. Wong, S.L. Cushing, K.A. Gordon, Postural stability and visual impairment: assessing balance in children with strabismus and amblyopia, PLoS One 13 (2018), e0205857.

[20] R. Steindl, K. Kunz, A. Schrott-Fischer, A.W. Scholtz, Effect of age and sex on maturation of sensory systems and balance control, Dev. Med. Child Neurol. 48 (2006) 477–482.

[21] A. Shumway-Cook, M.H. Woollacott, The growth of stability: postural control from a developmental perspective, J. Mot. Behav. 17 (1985) 131–147.

[22] L. Nolan, A. Grigorenko, A. Thorstensson, Balance control: sex and age differences in 9-to 16-year-olds, Dev. Med. Child Neurol. 47 (2005) 449–454.

[23] J. García-Liñeira, R. Leirós-Rodríguez, J.L. Chinchilla-Minguet, J.L. García-Soidán, Influence of visual information and sex on postural control in children aged 6–12 years assessed with accelerometric technology, Diagnostics 11 (2021) 637.

[24] J. García-Liñeira, J.L. García-Soidán, V. Romo-Pérez, R. Leirós-Rodríguez, Reliability of accelerometric assessment of balance in children aged 6–12 years, BMC Pediatr. 20 (2020) 161–168.

[25] B. Hsue, F. Miller, F. Su, The dynamic balance of the children with cerebral palsy and typical developing during gait: Part II: instantaneous velocity and acceleration of COM and COP and their relationship, Gait Posture 29 (2009) 471–476.
[26] H. Reimann, T. Fettrow, J.J. Jeka, Strategies for the control of balance during locomotion, Kinesiol. Rev. 7 (2018) 18–25.
[27] R. Leirós-Rodríguez, V. Romo-Pérez, J.L. García-Soidán, J. García-Liñeira, Percentiles and reference values for the accelerometric assessment of static balance in women aged 50-80 years, Sensors 20 (2020) 940.
[28] W. Zijlstra, A.L. Hof, Assessment of spatio-temporal gait parameters from trunk accelerations during human walking, Gait & posture 18 2 (2003) 1–10.