Original Article (short paper)

Reliability of plantar pressure and postural control measures of children from 4 to 12 years: analysis by baropodometry

Karina Correia Bonalumi Bittar[1], Simone Saldanha Ignacio de Oliveira[2], Maria Cristina Buta Michel[1], Sérgio Pollizio Terçarolli[3], Camile Ludovico Zamboti[1], Christiane de Souza Guerino Macedo[1]

[1]Universidade Estadual de Londrina, Londrina, PR, Brasil; [2]Universidade Federal Fluminense, Faculdade de Odontologia, Niterói, RJ, Brasil; [3]Centro Universitário Fundação Hermínio Ometto, Araras, SP, Brasil

Abstract - Aim: Baropodometry is used to map pressure areas and plantar pressure oscillation, however, children's evaluation reliability is not established. To establish the intra-rater and inter-rater reliability of baropodometry for analysis of plantar support and postural control (stabilometry) of children. **Materials and Methods**: Reliability study. The sample consisted of 112 healthy children of both sexes; aged 4 to 12 years old. For the baropodometer analysis, children were positioned in orthostatic position, bipodal support, with parallel and bare feet during four rounds of 15-second evaluations, executed by two independent evaluators. In order to establish the reliability of the results at different age ranges, participants were divided into two groups: children ages 7 years and younger (n = 44) and children aged 8 to 12 years old (n = 68). The variables analyzed were pressure area and maximum plantar pressure, area, and amplitude of oscillation of the center of pressure. **Results**: Reliability was rated from good to excellent for the intra- and inter-evaluators (ICC 0.81-0.86 and ICC 0.87-0.95, respectively) on plantar pressure variables, and poor to moderate for the center of pressure oscillations (ICC 0.33-0.55; ICC 0.47-0.57, intra and inter-evaluators, respectively). **Conclusion**: Excellent baropodometry reliability was observed when analyzing children's plantar pressure at different age groups, and a single evaluation established reliable results. However, the stabilometry analysis with a baropodometer has poor reliability, and therefore, it should not be used for children aged 4 to 12 for postural control.

Keywords: reliability, plantar pressure, baropodometry, postural balance.

Introduction

In childhood, muscle imbalance and musculoskeletal disorders may lead to asymmetric characteristics of plantar pressure. The foot in contact with the ground controls the distribution of plantar pressure, postural control, thrust, shock absorption, weight pressure, and adjusts the posture in the upright position[1]. However, high plantar pressure peaks may be associated with tissue damage and trigger contact area changes, with consequent impairment of postural control and balance[2]. It is believed that the imbalance of plantar pressure can lead to functional overload, dysfunction, degeneration, and pathologies[3], which highlights the importance of early diagnosis of plantar pressure and pressure area to detect possible biomechanical changes that may trigger further injury.

In this sense, baropodometry is widely used in clinical practice to map the plantar pressure area through graphical records. By recording the plantar impression and the ground reaction forces during the standing position, it is possible to determine the percentage of weight pressured by each region of the foot, the symmetric and asymmetric relationship between them[4], as well as the displacements and pressure center oscillations[5]. Therefore, baropodometry is capable of providing objective data measurements for evaluation and directing physical therapy treatment, especially in cases associated with orthopedic injuries of the lower limbs and neurological disorders, such as cerebral palsy[6,7].

In addition to evaluating plantar pressure, the baropodometer enables analysis of postural oscillations (stabilometry), an indirect method of describing postural control and reflecting the body's ability to adjust and maintain balance[8]. Thus, the same instrument can measure the plantar pressure variables and can be used as an indirect means of assessing postural control[9], facilitating, and making evaluations in clinical practice viable.

Baropodometry, to assess plantar pressure in children and adolescents is often used in clinical practice, but the metric properties of baropodometer measurements in healthy children have not been observed. For good clinical practice, it is essential to have measuring instruments that have adequate metric properties with precedents for investigating their reliability[10,11]. Thus, it is necessary to establish the intra-evaluator and inter-evaluator reliability of baropodometry for analysis of plantar pressure and postural control (stabilometry) of children aged 4 to 12 years old, to design a reliable evaluation, interpretation and intervention protocols.

In this sense, this study hypothesizes that the evaluation of plantar pressure and postural control oscillations by baropodometry is reliable for healthy children aged 4 to 12 years old. Therefore, the objective was to verify the intra-evaluator and inter-evaluator reliability when analyzing children's plantar pressure and oscillations of postural control by baropodometry.

Materials and Methods

This is a reliability study on the motor and biomechanical control, focusing on the analysis of children aged 4 to 12 years old plantar pressure and postural control. It was approved by the Institution's Research Ethics Committee (Opinion No. 3.209.251) and developed by two independent evaluators.

The convenience sample consisted of 112 healthy children, of both sexes, aged 4 to 12 years old. Exclusion criteria were children with special needs, a history of lower limb fractures and those unable to perform the requested tests.

Initially, the research procedures were explained to parents and guardians, before they signed the consent form and followed the data collection. Next, the sample characterization data (age, gender, weight, and height) were collected.

The baropodometer (BAROSCAN®, Londrina, Paraná, Brazil) evaluation was performed in a school environment, with children in uniform, barefoot, and without socks. Each child stood open-eyed on the baropodometer marking, feet aligned 10 centimeters apart between the heels and 10-degree hip abduction, arms along the body, staring at a fixed point in the eye height, at a distance of 3.80 meters from the child[12].

Familiarization with the equipment and orientation of the test position was developed until the child was safe and able to perform it. Subsequently, four evaluations were performed on the baropodometer, with a permanence time of 15 seconds each, and up to one-minute interval between them, by two independent evaluators (an evaluator did not have access to the data collected by the other evaluator). Three runs (with an interval of one minute between data collections), were performed by the first evaluator (for intra-evaluator reliability analysis), and a fourth run was developed by a second evaluator (for inter-evaluator reliability analysis), with an interval of one minute between data collections, also. The evaluators had previous experience with evaluating plantar support using baropodometry and were trained for the research protocol to be developed.

In order to establish baropodometry reliability, the lower limb with the highest plantar pressure (right or left), anterior or posterior plantar pressure, maximum right and left plantar pressure (in cm^2), the surface area of the plantar pressure on the right and left foot were analyzed. For the analysis of postural control oscillations (stabilometry), the pressure center area (A-CoP) and the amplitude of the pressure center oscillation in the x and y axes were considered. The analysis of the intraclass correlation coefficient was performed with the total sample, children from 4 to 12 years old, and in two different groups, according to the children's variation age (children up to 7 years old and children over 8 years old). The children were subdivided according to age, because during the collections, children under 7 years of age moved more and they found it more difficult to stand, without moving, on the baropodometry platform. All collections were performed in a single day, with a one-minute interval between them. The evaluations took place in a single day for the parents or guardians to come to the collection site only once, otherwise, the sample size could be compromised.

Statistical analysis used the Statistical Package for Social Sciences (SPSS®, Chicago, Illinois, USA.) 21.0 program. Due to the children's large age differences, the reliability of the results was established for the total sample (all children from 4 to 12 years old) and by ages (from 4 to 7 years old and from 8 to 12 years old). To analyze the reliability of the measurements, the Intraclass Correlation Coefficient (ICC) was used (ICC 1,3 for intra-rater and ICC 2,1 for inter-rater), the measures 1, 2 and 3 were from the first rater and was used for the intra-rater analysis and measure 4 of other raters with measure 1 was used to perform inter-rater analysis. Values below 0.49 considered poor, 0.5 to 0.75 moderate, 0.75 to 0.90 good and above 0.90 excellent reliability[13].

To complement the error interpretation of values of baropodometry was included the Standard Error of Measurement (SEM) and minimal detectable change (MDC). The Standard Error of Measurement (SEM) was calculated to establish the absolute reliability, using the following equation: $SEM=SD\sqrt{(1-ICC)}$, in which SD is the standard deviation[14]. MDC can be defined as the minimal change that falls outside the measurement error in the result of an instrument used to measure a clinical characteristic and was calculated using the formula: $1{:}96x\ SEM\ x\ \sqrt{2}$[15].

Results

The characterization data of the evaluated children are shown in Table 1. After evaluating 112 children, it was observed that most were female, and they presented most plantar pressure on the left side and higher area of plantar pressure on the left side, with predominantly bilateral calcaneal pressure (Table 2).

Values of plantar pressure and stabilometry were presented in Table 2 with the total sample (n=112) and separated into two groups by age: 7 years old and lower (n=44) and 8 years old and above (n=68).

Reliability of intra-evaluator and inter-evaluator analysis in the total sample analysis children present good to excellent intra-evaluator and inter-evaluator analysis for the area of plantar pressure (APP) and in plantar pressure for both sides. Values of stabilometry vary from poor to moderate in intra-evaluator and inter-evaluator analysis (Table 3).

In children with age equal or, less than seven years intra-evaluator reliability was excellent for the plantar pressure variables and poor for the stabilometry analyzed in the baropodometer. Inter-evaluator reliability was good to excellent for plantar pressure variables and poor to moderate for stabilometry analysis (Table 4). And, children with eight years or more, intra-evaluator reliability was excellent for the plantar pressure variables and poor to moderate for stabilometry analysis. Inter-evaluators reliability was good to excellent for plantar pressure variables and poor to moderate for stabilometry analysis (Table 5).

SEM in unit and percentage and MDC in unit and percentage have similar values in the total sample (Table 3) and distributed by groups (Table 4 and Table 5). SEM vary from 0.12 to 5.31 and 0.14 to 123.42 and in percentage 22.75 to 114.18 and 22.88 to 123.42 for intra-evaluator and inter-evaluators analysis respectively. MDC vary from 0.37 to 14.74 and 0.43 to 10.96, in percentage 19.97 to 243.53 and 22.79 to 128.57 in intra-evaluator and inter-evaluator analysis, respectively.

Table 1 - Characterization data of the total sample and by age.

Variables	Total Sample (n=112)	7 years old and lower (n=44)	8 years old and above (n=68)
Age (years)	8.03±2.21	5.73±1.14	9.51±1.26
Weight (kg)	30.45±9.21	22.48±5.53	35.60±7.22
Height (m)	1.28±0.16	1.14±0.10	1.38±0.11
Female gender (%)	61 (55%)	25 (57%)	36 (53%)

Data expressed as mean ± SD.

Table 2 - Plantar pressure measures in plantar pressure and stabilometry in children with 4 to 12 years old.

	4 to 12 years (n=112)				4 to 7 years (n=44)				8 to 12 years (n=68)			
Measures	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Higher PS Right	37 (33%)	41 (37%)	37(33%)	41 (37%)	18 (41%)	20 (45%)	20 (45%)	17 (38%)	19 (28%)	21 (31%)	17 (25%)	24 (35%)
Left	75 (67%)	71 (63%)	75(67%)	71 (63%)	26 (59%)	24 (55%)	24 (55%)	27 (62%)	49 (72%)	47 (69%)	51 (75%)	44 (65%)
PSRF Anterior	5 (4%)	5 (4%)	8 (7%)	7(6%)	2 (5%)	2 (5%)	5 (11%)	3 (7%)	3 (4%)	3 (4%)	3 (4%)	4 (6%)
Posterior	107 96%)	107 96%)	104 (93%)	105 (94%)	42 (95%)	42 (95%)	39 (89%)	41 (93%)	65 (96%)	65 (96%)	65 (96%)	64 (94%)
PSLF Anterior	4 (3%)	3 (3%)	1 (0.87)	3 (3%)	2 (5%)	2 (5%)	1 (2%)	1 (2%)	1 (1%)	1 (1%)	1 (1%)	2 (3%)
Posterior	108 97%)	109 97%)	111 (99.2%)	109 (97%)	42 (95%)	42 (95%)	43 (98%)	43 (98%)	67 (99%)	67 (99%)	67 (99%)	66 (97%)
PSRF máx.	1.04 (0.48)	1.05 (0.50)	1.04 (0.51)	1.03 (0.45)	1.10 (0.50)	1.11 (0.54)	1.09 (0.50)	1.07 (0.48)	1.00 (0.47)	1.00 (0.47)	1.01 (0.51)	1.00 (0.44)
PSLF máx.	1.25 (0.53)	1.23 (0.52)	1.21 (0.49)	1.20 (0.49)	1.18 (0.51)	1.15 (0.48)	1.13 (0.46)	1.15 (0.47)	1.29 (0.54)	1.28 (0.54)	1.26 (0.50)	1.24 (0.50)
APP right foot	53.15 (13.0)	53.8 (13.20)	54.51 (13.40)	55.16 (13.60)	48.56 (12.05)	49.61 (13.06)	50.31 (13.02)	50.50 (12.97)	56.12 (12.90)	56.65 (12.64)	57.23 (13.14)	58.17 (13.26)
APP left foot	54.44 (14.10)	54.75 (14.13)	55.48 (14.41)	55.78 (14.41)	49.89 (13.26)	50.21 (12.37)	51.14 (12.90)	51.90 (13.37)	57.38 (14.08)	57.69 (14.50)	58.29 (14.72)	58.29 (14.60)
COP (area total)	0.97 (1.16)	1.00 (1.16)	0.99 (1.06)	1.25 (1.58)	1.05 (1.14)	1.24 (1.56)	1.24 (1.22)	1.68 (2.16)	0.91 (1.18)	0.84 (0.79)	0.84 (0.92)	0.97 (0.98)
COP on x axis	0.90 (0.55)	0.92 (0.56)	0.96 (0.55)	1.03 (0.68)	0.93 (0.55)	0.97 (0.57)	1.08 (0.51)	1.13 (0.77)	0.88 (0.56)	0.88 (0.55)	0.88 (0.57)	0.94 (0.61)
COP on y axis	1.10 (0.65)	1.12 (0.59)	1.12 (0.84)	1.16 (0.80)	1.13 (0.68)	1.19 (0.72)	1.16 (0.70)	1.33 (1.07)	1.08 (0.64)	1.08 (0.50)	1.10 (0.92)	1.05 (0.54)

Measures 1: measure 1/evaluator 1. Measure 2: measure 2/evaluator 1. Measure 3: measure 3/evaluator 1. Measure 4: measure 1/evaluator 2. Data presented as number (%) and mean (SD). Higher PS: Higher plantar pressure; PSRF: Plantar pressure right foot; PSLF: Plantar pressure left foot; Máx: maximum. APP: Area plantar of pressure. COP: Center of pressure oscillation.

Table 3 - Intra and inter-evaluators reliability results for plantar pressure and stabilometry in children aged 4 to 12 years.

	Intra-evaluator					Inter-evaluators				
	ICC (CI 95%)	**SEM (units)**	**SEM (%)**	**MDC (units)**	**MDC (%)**	**ICC (CI 95%)**	**SEM (units)**	**SEM (%)**	**MDC (units)**	**MDC (%)**
PSRF máx.	0.91 (0.88 – 0.94)	0.15	47.6	0.41	39.58	0.87 (0.82 – 0.91)	0.16	44.92	0.46	43.68
PSLF máx.	0.93 (0.91 – 0.95)	0.13	41.70	0.37	30.60	0.87 (0.81 – 0.91)	0.18	41.63	0.50	40.83
APP right foot	0.93 (0.90 – 0.95)	3.49	24.52	9.68	17.98	0.92 (0.89 – 0.94)	3.76	24.55	10.42	24.65
APP left foot	0.86 (0.82 – 0.90)	5.31	25.89	14.74	26.85	0.95 (0.93 – 0.97)	3.18	25.86	8.83	25.83
COP (area total)	0.46 (0.35 – 0.57)	0.82	114.18	2.29	232.59	0.56 (0.42 – 0.68)	0.90	123.42	2.51	126.4
COP on x axis	0.55 (0.45 – 0.65)	0.37	59.71	1.02	111.03	0.57 (0.43 – 0.68)	0.40	63.73	1.11	66.01
COP on y axis	0.33 (0.21 – 0.45)	0.56	62.27	1.57	141.29	0.47 (0.32 – 0.60)	0.52	64.15	1.46	68.96

Data presented as ICC, CI95% and SEM in units of measurement of each test. ICC: Intra-class correlation coefficient; CI95%: Coefficient Interval 95%. APP: Area plantar of pressure. COP: Center of pressure oscillation. SEM: Standard Error of Measurement. MDC: Minimal detectable change. PSRF: Plantar pressure right foot. PSLF: Plantar pressure left foot. Máx: maximum.

Table 4 - Intra and inter-evaluators reliability results for plantar pressure and stabilometry in children up to 7 years old.

	Intra-evaluator					Inter-evaluators				
	ICC (CI 95%)	**SEM (units)**	**SEM (%)**	**MDC (units)**	**MDC (%)**	**ICC (CI 95%)**	**SEM (units)**	**SEM (%)**	**MDC (units)**	**MDC (%)**
PSRF máx.	0.90 (0.85 – 0.94)	0.16	46.66	0.44	40.90	0.88 (0.77 – 0.92)	0.16	45.16	0.47	44.85
PSLF máx.	0.91 (0.86 – 0.95)	0.14	41.90	0.40	34.84	0.77 (0.61 – 0.86)	0.23	42.06	0.65	40.86
APP right foot	0.90 (0.84 – 0.94)	4.01	25.68	11.14	22.50	0.90 (0.83 – 0.94)	3.95	25.25	10.96	25.68
APP left foot	0.92 (0.87 – 0.95)	3.63	25.47	10.06	19.97	0.93 (0.88 – 0.96)	3.52	26.16	9.76	25.76
COP (area total)	0.52 (0.35 – 0.68)	0.90	111.04	2.5	213.25	0.60 (0.37 – 0.76)	1.04	120.87	2.89	128.57
COP on x axis	0.56 (0.39 – 0.71)	0.36	54.69	0.99	100.57	0.63 (0.42 – 0.78)	0.40	64.07	1.11	68.14
COP on y axis	0.51 (0.33 – 0.67)	0.49	60.34	1.35	117.08	0.48 (0.22 – 0.68)	0.63	71.13	1.74	80.45

Data presented as ICC, CI95% and SEM in units of measurement of each test. ICC: Intra-class correlation coefficient; CI95%: Coefficient Interval 95%. APP: Area plantar of pressure. COP: Center of pressure oscillation. SEM: Standard Error of Measurement. MDC: Minimal detectable change. PSRF: Plantar pressure right foot. PSLF: Plantar pressure left foot. Máx: maximum.

Table 5 - Intra and inter-evaluators reliability results for plantar pressure and stabilometry in children aged 8 to 12 years.

	Intra-evaluator					Inter-evaluators				
	ICC (CI 95%)	**SEM (units)**	**SEM (%)**	**MDC (units)**	**MDC (%)**	**ICC (CI 95%)**	**SEM (units)**	**SEM (%)**	**MDC (units)**	**MDC (%)**
PSRF máx.	0.92 (0.88 – 0.95)	0.13	48.12	0.37	37.76	0.88 (0.81 – 0.92)	0.15	45.50	0.43	44.00
PSLF máx.	0.94 (0.91 – 0.96)	0.12	41.25	0.35	28.00	0.92 (0.88 – 0.95)	0.14	41.10	0.40	40.32
APP right foot	0.94 (0.91 – 0.96)	3.15	22.75	8.75	15.44	0.92 (0.87 – 0.95)	3.69	22.88	10.25	22.79
APP left foot	0.95 (0.93 – 0.97)	3.22	24.97	8.94	15.48	0.96 (0.94 – 0.97)	2.86	24.79	7.94	25.04
COP (area total)	0.38 (0.23 – 0.53)	0.75	111.58	2.10	243.53	0.53 (0.33 – 0.68)	0.74	114.89	2.05	101.03
COP on x axis	0.55 (0.41 – 0.67)	0.37	63.63	1.04	118.32	0.51 (0.31 – 0.67)	0.40	64.28	1.13	64.89
COP on y axis	0.21 (0.06 – 0.37)	0.61	63.19	1.69	155.68	0.47 (0.26 – 0.64)	0.42	55.39	1.19	51.42

Data presented as ICC. CI95% and SEM in units of measurement of each test. ICC: Intra-class correlation coefficient; CI95%: Coefficient Interval 95%. APP: Area plantar of pressure. COP: Center of pressure oscillation. COP: Center of pressure oscillation SEM: Standard Error of Measurement. MDC: Minimal detectable change. PSRF: Plantar pressure right foot.
PSLF: Plantar pressure left foot. Máx: maximum.

Discussion

The present study observed excellent reliability of baropodometry results when analyzing children from 4 to 12 years old plantar pressure, but there was poor reliability regarding the stabilometry variables and postural control oscillations. It is noteworthy that this is the first study for intra-evaluator and inter-evaluators reliability on plantar pressure and postural control variables established by baropodometry in healthy children aged 4 to 12 years old.

The intra- and inter-evaluator reliability was good to excellent for all bipodal plantar pressure variables when children aged 4 to 12 years old were evaluated (Table 3), as well as when divided by ages 4 to 7 and 8 to 12 years old (Tables 4 and 5). In this context, Alves et al.[16] presented a similar result to the one demonstrated by this study in healthy young individuals, but only with an intraevaluator analysis, without standardization of foot positioning and eye direction, which makes it difficult to perform the tests with the same reproducibility, different from the present study. Also, previous studies have investigated

the reliability of plantar pressure measurements using other instruments[17], but in baropodometry, this evidence is limited and established only for young individuals.

Present study results for postural oscillation through the oscillation of the body's pressure center (CoP) did not show acceptable reliability (Tables 3, 4, and 5). The study by Alves et al.[16] also obtained poor reliability (ICC of 0.31) in CoP analysis in healthy young subjects. Therefore, the results of the present study did not show adequate reliability on children's stabilometry analyzed in the baropodometer, as it was found to be weak to moderate for intra-evaluator and inter-evaluators reliability.

Also, the dispersion of values must be observed to verify the real measure. The variation between the two analyses cannot be greater than the typical error of the measure. Although, SEM in percentage has demonstrated a higher score in the error of measurement, values of SEM in units were small compared with the data obtained in the assessments. Also, the error of measurement in units can be analyzed with minimal detectable change which may provide better clinical applicability.

In addition, the present study results indicate that children perform greater weight discharge on the left lower limb, unlike the literature results that demonstrated greater plantar pressure in the right foot in different groups[1], from 3 to 6 years old[18]. Still, Fernández et al.[19] demonstrated development associated with sessions directed to postural balance obtained greater pressure in the dominant limb, mostly right lower limb. Therefore, different from what the literature points out, children evaluated in this study with a greater variation in age group present higher weight discharge in the mostly non-dominant left lower limb. This reinforces the use of baropodometer evaluation to distinguish the presence of postural asymmetries and pressure distribution observed in early childhood in order to prevent future postural and biomechanical changes[1].

Among the different foot area pressures, greater posterior pressure was found in the calcaneal region, regardless of age, which may indicate anteroposterior postural balance. However, postural balance is composed of different variables, therefore, baropodometry analysis should be used for clinical and specific purposes and may not be related to balance[19].

The present study results agree with the current literature in different populations, indicating adequate baropodometer reliability in children from 4 to 12 years old. In addition, the assessment of plantar support through the baropodometry can be strongly indicated (as it has excellent reliability), which does not occur with the analysis of postural control, since the CoP established poor reliability. For limitations of this study, the sample is cited as being of convenience and the impossibility of checking reliability on different days (for the parents or guardians to come to the collection site only once, otherwise the sample size could be reduced). Still, the validity of baropodometry results could not be verified, therefore, it is suggested that future studies investigate the validity of baropodometry with a gold standard instrument.

In conclusion, children's plantar area evaluation by baropodometry has excellent reliability, that is, a single evaluation is enough to establish reliable results. Moreover, baropodometry can be performed by different evaluators, since our results indicated high inter-evaluator reliability. However, the stabilometry analysis with a baropodometer has poor reliability, and therefore, it should not be used for children aged 4 to 12 for postural control.

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Corresponding author

Christiane de Souza Guerino Macedo
Hospital Universitário da UEL, Centro de Ciências da Saúde, Departamento de Fisioterapia, Av. Robert Koch, 60, Vila Operária. CEP: 86038-350. Londrina, Paraná, Brasil.
Email: chmacedouel@yahoo.com.br

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