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Acute effects of a walking activity on plantar pressure in children with obesity

Efeitos agudos de uma atividade de caminhada na pressão plantar de crianças com obesidade

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Abstract – Children with obesity present greater foot loads during walking when compared to eutrophic ones. However, the acute effects of a moderate walking on the distribution of plantar pressure in children with obesity are still incipient in the literature. Our aim was to verify the acute effects of six-minute walk test on plantar pressure in obese and eutrophic children. A pressure platform was used to record plantar pressure during walking for 62 children (37 girls), aged 7-10 years old, before and after the six-minute walk test. Children were divided into an obese group - OB (n = 20), and an eutrophic group - EU (n = 42). Peak plantar pressure (PPP), maximum force (MF), and contact area (CA) were assessed in three trials during walking at a comfortable speed. The analyses were performed in five plantar regions: rearfoot, midfoot, forefoot, hallux, and toes. For the PPP was higher under the midfoot region of the OB group after walking. In the comparison between groups, PPP, MF, and CA were higher for the OB group for most regions. We concluded that, after a moderate walking activity, children with obesity experience an increase in plantar loads, especially under the midfoot, which can bring greater discomfort and risk of injuries.

Key words: Body mass; Child; Foot load; Walk test.

Resumo – *Crianças com obesidade apresentam maiores cargas plantares durante o caminhar quando comparadas às eutróficas. No entanto, ainda não se conhece os efeitos agudos de uma atividade moderada de caminhar sobre a distribuição da pressão plantar em crianças com excesso de massa corporal. Nosso objetivo foi verificar o efeito agudo do teste de caminhada 6 minutos na pressão plantar de crianças obesas e eutróficas. Uma plataforma de pressão foi utilizada para registro da pressão plantar durante o andar de 62 crianças (37 meninas), com idade entre 7 e 10 anos, antes e após o teste de caminhada de seis minutos. As crianças foram divididas em um grupo com obesidade – OB (n = 20) e um grupo eutrófico – EU (n = 42). Pico de pressão plantar (PPP), força máxima (FM), área de contato (AC) foram avaliados em três tentativas durante o andar em velocidade confortável. A análise foi realizada em cinco regiões plantares: retro pé, médio pé, ante pé, hálux e dedos. O PPP foi maior sob a região do médio pé no grupo OB após a caminhada. Na comparação entre os grupos, PPP, FM e AC foram maiores para o grupo OB para a maioria das regiões. Concluímos que, após uma atividade de caminhada moderada, crianças com obesidade sofrem um aumento das cargas plantares, especialmente no médio pé, o que pode trazer maior desconforto e risco de lesões.*

Palavras-chave: *Criança; Carga plantar; Massa corporal; Teste de caminhada.*

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INTRODUCTION

Obesity in childhood and adolescence is a worldwide public health problem[1]. In addition to metabolic problems such as diabetes[2], cardiovascular disease and increased blood pressure[3], obesity may be associated with orthopedic problems in children and adolescents due to overload on musculoskeletal structures[4,5]. Previous studies have shown plantar pressure, foot structures, and foot mechanics are different between obese and non-obese children[6], and adolescents[7], with the obese ones presenting greater foot loads during walking and running[8-10].

Heavier children present higher plantar pressure peaks and larger foot contact area, especially under the midfoot region, when walking at different speeds, as well as during jogging and running[8,10]. Song-Hua et al.[9], also found that peak pressure is higher during jogging than during walking and running under most plantar regions of obese children's feet. These factors can increase the risk of injury and cause pain and discomfort in childhood[10], during daily activities, physical activity and sports[11].

Walking activities are common in daily life and a type of exercise often recommended for people with overweight and obesity[12]. A study carried out with normal weight and overweight adults analyzed plantar loads and plantar flexion strength of the ankle after the six-minute walk test (6MWT) and showed that even moderate intensity activities can alter some variables associated with foot function[13]. The 6MWT involves participants walking as far and as fast as possible for six minutes in an indoor environment and it is commonly used to measure endurance walking and represent a test of submaximal physical capacity[14]. The 6MWT shows good reproducibility and validity, and has been validated for children[15]. It also can be recommended for use in clinical practice with children and adolescents with obesity[16].

To our knowledge, studies investigating the acute effect of physical activities with submaximal intensity on plantar pressure distribution in children with obesity are still incipient in the literature. Higher foot loads in children with obesity may imply greater discomfort and pain in certain regions of the foot and may even contribute to abandonment of possible regular physical activity practices. Therefore, the purpose of our study was to verify the acute effects of a six-minute walk test on plantar pressure in obese and eutrophic children before and after a walking activity. Our hypothesis was that children with obesity would present higher values for plantar pressure related outcomes after the walking activity.

METHODS

Study characterization and participants

A total of 100 children from two public elementary schools were eligible to participate in this study. The recruitment occurred from August to November 2019. Age (7-10 years) and body mass index (BMI) were used as inclusion criteria. The BMI ranges for obese boys and girls, were: 7 years (≥ 20.63 / ≥ 20.51 kg / m^2); 8 years (≥ 21.60 / ≥ 21.57 kg / m^2); 9 years (≥ 22.77 / ≥ 22.81 kg / m^2); 10 years (≥ 24.00 / ≥ 24.11 kg / m^2), and for eutrophic boys and girls, were: 7 years (≤ 17.92 / ≤ 17.75 kg / m^2); 8 years (≤ 18.44 / ≤ 18.35 kg / m^2); 9 years

(≤ 19.10 / ≤ 19.07 kg / m^2); 10 years (≤ 19,84 / ≤ 19.86 kg / m^2), according[17]. Based on information provided by parents and guardians, subjects with hypertension, hyperlipidemia, diabetes, cardiovascular problems, or that, for some reason, were unable to carry out the proposed tests were excluded. Thus, 62 children (37 girls) were analyzed in this cross-sectional study. The remaining 38 children were excluded due to: BMI greater or less than the specified range (20), health problems reported by family members (10) or were not authorized by parents and guardians (8).

Participants were divided in two groups: obesity group - OB (n = 20) and eutrophic group - EU (n = 42). Our study was in accordance with the guidelines contained in the declaration of Helsinki. This study was approved by the Ethics Committee of the of the Faculty of Health, local University (protocol 2.599.767/2018). Verbal assent from participants and written informed consent from their parents were obtained.

Measures and procedures

The anthropometric evaluation was obtained with standardized techniques[18]. Body mass was measured with participants barefoot and recorded with a calibrated electronic flat scale (Tec-Silver, São Paulo, Brazil)**.** Height was recorded using a portable stadiometer (Welmy, São Paulo, Brazil). BMI was calculated as weight (kg) divided by squared height (m^2).

The plantar pressure was measured using an EMED AT-4 platform (Novel GmbH, Munich, Germany; 50 Hz; 4 sensors/cm^2; 415 x 255 mm) with the child walking on a walkway before and after a 6MWT performance. The platform was positioned on a 3.7 m dense foam walkway designed to provide a flat surface evaluation.

Peak plantar pressure - PPP, maximum force - MF normalized by body mass, and contact area - CA for plantar regions were assessed using EMED/R Database Light 23.3.43 software. The MF was normalized by body mass. For analyses the foot was divided into 5 anatomical regions: rearfoot, midfoot, forefoot, hallux and lesser toes[19]. Moreover, the foot length was collected during walking, and the dynamic arch index (AI) was calculated from the ratio of the walking contact area of midfoot to the total contact area excluding toes, with a higher ratio indicating a flatter foot (< 0.21 high arch, 0.21–0.28 normal arch, and > 0.28 low arch)[20]. Plantar pressure outcomes of left and right feet were averaged since no significant differences were found between data obtained from the right and left limbs[21].

The gait speed was self-selected for three trials, collected before and after 6MWT. The choice of the self-selected speed was to ensure the child's most natural locomotion activity, in addition to being able to compare with studies carried out with these speeds[22,23]. The gait speed was calculated based on the time, recorded with a stopwatch (seconds), needed to walk the 4 meters distance demarcated with cones, performed during the measurement of plantar distribution.

For the realization the 6MWT, the participants, wearing sport shoes, were instructed to walk "comfortably, as fast as you can, for 6 minutes, steadily, without running or jogging" on a 20 m walkway[24]. They were informed of the time that after every minute, moment which the distance was also recorded. The 6MWT and all other measurements were performed at schools during class time. In an individual way, the children were sent to an appropriate space for carrying out the tests.

Initial heart rate was recorded 30 seconds before the 6MWT and final heart rate was recorded immediately after the end using beats per minute (Polar, MS 400, Finland). The subjective perception of effort (SPE) defined by Borg scale[25], was asked at every minute in the 6MWT.

Statistical analysis

Statistical analyses were performed using the SPSS software version 27.0 for Windows (IBM Corporation, Atmonk, New York, USA). Initially, the normality of the outcome measures was checked using the Shapiro-Wilk test and the values were presented as mean and standard deviation. The assumption of homogeneity was verified by Levene's test of equality of variances.

A mixed analysis of variance (ANOVA) with repeated measures was used to verify intragroup and between groups differences for the two assessment periods: before and after the 6MWT. Between groups differences were detected by the pairwise method and the Bonferroni Post-Hoc correction. The level of significance was set at $p < .05$. Cohen's d specifications were utilized to calculate the effect sizes (ES), considering the classification values <0.2 (ordinary, worthless); 0.2-0.5 (small); 0.5-0.8 (moderate); >0.8 (large).

Experimental designer

Below in Figure 1 are the procedures and phases that were performed in this study.

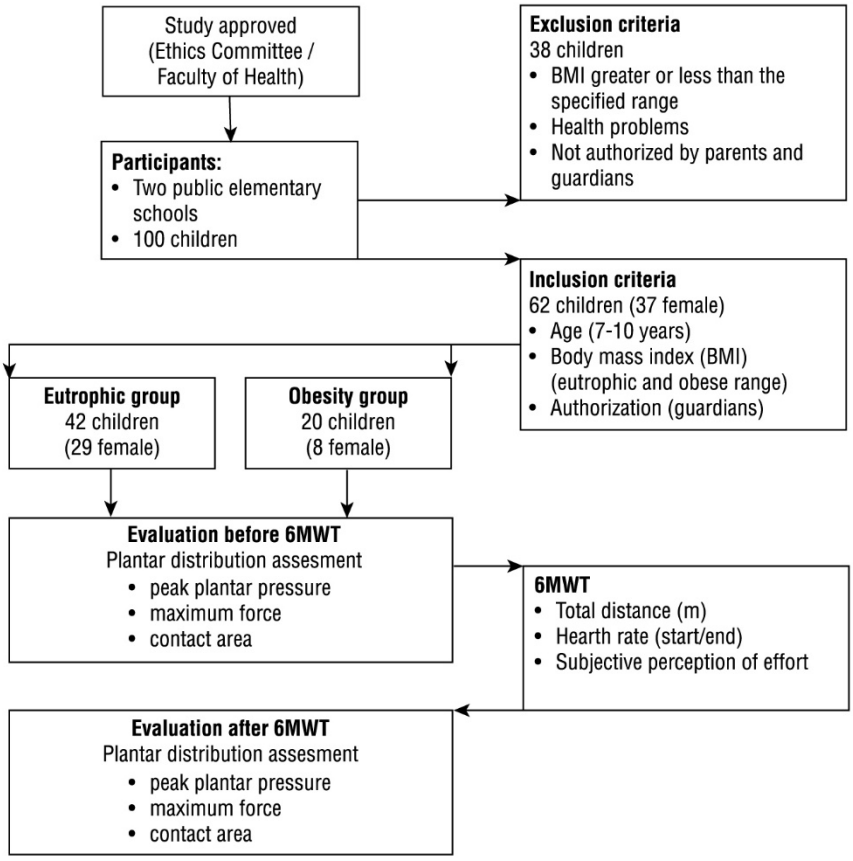

Figure 1. Methodological scheme of the procedures performed in the study; *: Variables analyzed by the EMED platform.

RESULTS

Descriptive statistics were used to anthropometric characteristics and data from 6MWT performance (Table 1). As expected, the body mass was different between groups showing that the OB group had significantly higher weight compared to the EU group ($p < .001$). Similar results were observed for BMI ($p < 0.001$) and AI ($p < 0.001$) comparing the OB and EU groups. There were no differences between groups for age, height, the distance covered during the 6MWT, average speed 6MWT, heart rate, average to subjective perception of effort and subjective perception of effort after 6th minute ($p > .05$).

Table 1. Anthropometric characteristics and data for total 6MWT distance, heart rate, and subjective perception of effort presented as mean (±SD).

	Eutrophic Group	Obesity Group	p-*value*	ES
	(n = 42)	(n = 20)		
Gender (male\female)	13\29	12\08		
Age (years)	8.8 ± 0.9	8.4 ± 1.1	.119	0.40
Body mass (kg)	29.8 ± 5.6	47.8 ± 12.0	**< .001**	1.92
Height (m)	1.34 ± 0.09	1.40 ± 0.09	.215	0.67
Body mass index (kg/m2)	16.2 ± 1.4	24.7 ± 3.2	**< .001**	3.47
Dynamic arch index - AI	0.22 ± 0.02	0.27 ± 0.03	**< .001**	1.96
6MWT distance (m)	407.4 ± 32.3	394.6 ± 27.5	.131	0.43
Average speed 6MWT (m/s)	1.12 ± 0.08	1.10 ± 0.13	.078	0.19
Average SPE	8.8 ± 1.7	8.9 ± 1.4	.695	0.06
SPE after 6th minute	10.3 ± 2.1	10.5 ± 2.5	.281	0.09

6MWT: six-minute walk test; SPE: Subjective perception of effort; ES: effect size; n: number of participants; Significant p-values are bold.

The Table 2 presents the main results of our study. It shows the effect of the 6MWT performance on plantar distribution variables in OB and EU groups. Results from the mixed ANOVA with repeated measures showed no effect of time x group interaction for PPP in any of the 5 plantar regions ($p > .05$). However, a significant effect of the group was observed under the midfoot [$F(1,60) = 56.582$, $p < .001$], both in the moments before [$F(1,60) = 50.885$, $p < .001$] and after the 6MWT [$F(1,60) = 44.942$, $p < .001$].

A significant effect of the group was also observed under the forefoot [$F(1,60) = 40.496$, $p < .001$], both in the moments before [$F(1,60) = 28.668$, $p < .001$] and after the 6MWT [$F(1,60) = 39.781$, $p < .001$]. The post hoc analysis indicated that for EU group there was a significant increase in the PPP under the rearfoot comparing the pre and post 6MWT moments ($p = .044$, ES = 0.28).

Table 2. Peak plantar pressure (PPP), maximum force (MF), and contact area (CA) for rearfoot, midfoot, forefoot, hallux, and lesser toes regions for each group before and after 6MWT are presented as mean (±SD).

	Eutrophic Group					Obesity Group					Mixed Anova		
	(n = 42)		*p*	Δ%	ES	(n = 20)		*p*	Δ%	ES	*p*-	*p*-	*p*-
	Pre	Post				Pre	Post				time	group	int.
PPP (kPa)													
PPP rearfoot	274.9 ± 100.0	306.2 ± 119.8	**.044**	11.38	0.28	339.9 ± 84.3	332.3 ± 110.9	.731	2.23	0.08	.381	.081	.152
PPP midfoot	84.9 ± 25.7	89.0 ± 34.7	.316	4.82	0.13	139.7 ± 33.1*	152.8 ± 35.7+	**.029**	9.37	0.38	**.019**	**< .001**	.212

BM: body mass; superscript symbols indicate between-group significant differences at * pre and + post 6MWT; p-values significant are bold; ES: effect sizes; n: number of participants; Int: interaction.

Table 2. Continued...

	Eutrophic Group (n = 42)		*p*	Δ%	ES	Obesity Group (n = 20)		*p*	Δ%	ES	Mixed Anova *p*- time	*p*- group	*p*- int.
	Pre	Post				Pre	Post						
PPP forefoot	244.0 ± 74.6	247.7 ± 81.3	.722	1.51	0.05	368.1 ± 104.8*	392.4 ± 90.8+	.116	1.10	0.25	.135	**< .001**	.272
PPP hallux	310.8 ± 139.6	320.7 ± 148.1	.527	3.16	0.07	336.5 ± 232.2	337.3 ± 212.8	.961	0.32	0.00	.689	.637	.749
PPP lesser toes	125.4 ± 45.8	125.5 ± 87.5	.751	0.07	0.00	135.8 ± 66.5	126.8 ± 60.5	.531	8.62	0.20	.738	.209	.487
MF (normalized by BM)													
MF rearfoot	82.2 ± 11.1	89.0 ± 18.7	**.003**	8.27	0.44	79.0 ± 8.7	80.2 ± 12.0	.730	1.39	0.10	**.045**	.268	.144
MF midfoot	20.0 ± 8.8	21.5 ± 10.7	.176	7.50	0.15	31.0 ± 12.0*	33.7 ± 11.6+	.105	8.70	0.23	.037	**< .001**	.567
MF forefoot	87.9 ± 10.3	92.0 ± 12.0	**.004**	4.66	0.37	91.1 ± 7.5	98.8 ± 7.1	.420	8.45	1.05	**.020**	.410	.298
MF hallux	29.2 ± 9.4	30.5 ± 8.9	.414	4.79	0.15	19.6 ± 9.6*	21.4 ± 11.7+	.432	9.18	0.17	.268	**< .001**	.855
MF lesser toes	11.1 ± 9.7	9.1 ± 4.7	.098	18.01	0.26	7.2 ± 3.8	6.4 ± 6.4	.617	11.11	0.25	.177	**.027**	.591
CA (cm^2)													
CA rearfoot	22.7 ± 3.2	23.3 ± 3.5	**.027**	2.64	0.18	27.0 ± 4.3*	27.1 ± 4.4+	.930	0.37	0.02	.180	**< .001**	.231
CA midfoot	16.7 ± 5.3	17.3 ± 6.3	.297	3.59	0.10	25.2 ± 5.3*	26.0 ± 5.0+	.316	3.17	0.16	.158	**< .001**	.816
CA forefoot	34.8 ± 4.5	35.6 ± 7.5	.358	2.29	0.13	41.9 ± 5.8*	42.4 ± 4.9+	.669	1.19	0.09	.382	**< .001**	.864
CA hallux	7.8 ± 1.1	7.9 ± 1.1	.525	1.28	0.09	8.3 ± 1.6	8.0 ± 1.8	.199	3.61	0.18	.483	.308	.157
CA lesser toes	6.0 ± 1.4	5.8 ± 1.7	.832	3.33	0.13	6.5 ± 2.2	6.1 ± 2.4	.285	6.15	0.17	.317	.400	.446

BM: body mass; superscript symbols indicate between-group significant differences at * pre and + post 6MWT; p-values significant are bold; ES: effect sizes; n: number of participants; Int: interaction.

On the other hand, the OB group registered a significant increase under the midfoot region comparing the pre- and post-walking test moments (p = .029, ES = 0.38). There were no significant effects of PPP in the other regions of the foot (p > .05), for both groups, either before (p > .05) or after 6MWT (p > .05).

Regarding the MF, results of the mixed ANOVA showed that there was no effect of time x group interaction for the 5 plantar regions (p > .05). Nevertheless, under the midfoot a significant effect of group was observed [F(1,60) = 18.696, p < .001], indicating that MF was significantly different between groups before [F(1,60) = 16.531, p < .001] and after the walk test [F(1,60) = 16.538, p < .001]. A significant effect of group was also observed under the hallux [F(1,60) = 16.910, p < .001], both in the moments before [F(1,60) = 2.588, p < .001] and after the 6MWT [F(1,60) = 2.696, p < .001]. Under the lesser toes the same tendency was recorded for the group effect [F(1,60) = 5.158, p = .027], however, only in the moment after the 6MWT [F(1,60) = 5.785, p = .019). The post hoc analysis indicated that for EU group there was a significant increase in MF comparing the pre and post 6MWT moments under the rearfoot (p = .003, ES = 0.44) and the forefoot (p = .004, ES = 0.37). There were no significant effects of MF under other regions of the foot (p > .05), for both groups, either before (p > .05) or after 6MWT (p > .05).

For the CA, the results of mixed ANOVA showed that there was no effect of time x group interaction for the 5 plantar regions (p > .05). Although, significant effect of the group was observed under the rearfoot [F(1,60) = 17.063, p < .001], before [F(1,60) = 19.731, p < .001] and after the 6MWT [F(1,60) = 13.028, p = .001]. A significant effect of the group was also seen for the CA under the midfoot [F(1,60) = 34.530, p < .001], before [F(1,60) = 34.139, p < .001] and after the 6MWT [F(1,60) = 29.039, p < .001]. For the forefoot was also registered a significant effect of the group [F(1,60) = 22.742, p < .001], showing both before [F(1,60) = 27.445, p < .001] and after the walk test [F(1,60) = 12.769, p = .001).

In addition, the post hoc analysis indicated that for EU group there was a significant increase in the CA under the rearfoot comparing the pre- and post-moments (p = .027,

ES = 0.18). There were no significant effects of the CA under the other regions of the foot (p > .05), for both groups, either before (p > .05) or after 6MWT (p > .05).

Finally, for the heart rate before and after 6MWT moments the results of mixed ANOVA showed that there was no time x group effect (p > .05). Just as it was not observed any effect of the group for the heart rate (p > .05) and gait speed (p > .05) (Table 3). The post hoc analysis indicated that for EU group there was a significant increase in the heart rate comparing before and after walk test (p < .001, ES = 2.19), as observed in OB group (p < .001, ES = 2.19). This significant increase was also observed in gait speed, but only for the EU group (p = .032, ES = 0.35). However, the average gait speed for OB group did not change significantly after the 6MWT (p > .05).

Table 3. Heart rate and gait speed pre and post 6MWT for each group presented as mean (±SD).

	Eutrophic Group					Obesity Group					Mixed ANOVA		
	(n = 42)			Δ%	ES	(n = 20)			Δ%	ES	p-	p-	p-
	Pre	Post	p			Pre	Post	p			time	group	Int.
Heart rate (beats/min)	96.8 ± 11.8	123.5 ± 12.6	**<.001**	27.5	2.19	102.0 ± 12.2	129.4 ± 15.3	**<.001**	26.86	1.98	**<.001**	.094	.779
Gait speed (m/s)	1.01 ± 0.12	1.05 ± 0.11	**.032**	3.96	0.35	1.01 ± 0.15	1.00 ± 0.13	.854	0.99	0.07	.278	.358	.167

p-values significant are bold; ES: Effect sizes; n: number of participants; Int.: interaction.

DISCUSSION

Our study aimed to compare the acute effect of a walking activity on the plantar pressure in obese and eutrophic children, before and after 6MWT. Our data showed that after the 6MWT, OB group registered higher values for PPP under midfoot region. The higher values of plantar pressure in this region may be associated with greater loads under the medial arch measured in children during barefoot gait with self-selected speed[10], and higher fatigue rates after exercise as previously reported by other study with children and adults[21].

In our study, the midfoot region also presented differences between groups before and after the performance of the 6MWT. However, in similar studies that did not carry out any intervention before the evaluation, the data show that higher peak on plantar pressure were also observed in children with obesity during running when compared to normal weight children[8], showing that these differences seem to be associated with biomechanical adaptations on foot children[10]. Greater loads were also observed in most regions of the feet in overweight children[8], which agree with the results of previous studies analyzing plantar pressure during fast walking in overweight children[26].

The distribution of plantar pressure was also assessed in obese children after a three-year follow-up, indicating that with increasing of age, obese children present increase on the lateral forefoot loads in contrast to normal weight children[27]. Recently, a review study addressed the impact of overweight and obesity on plantar pressure in children and adolescents, showing that obese children had increased maximum force, a higher contact area, and decreased sensitivity of the whole foot and midfoot region[28].

The results of higher maximum force values under the plantar regions in children with obesity in comparison to normal weight ones were similar to those of other studies conducted with children and adults. The MF in our study was influenced by the 6MWT in the eutrophic group under the regions of the

rearfoot and forefoot. Such differences can possibly be explained by the fact that the walking test activity worked as a form of warm-up, thus increasing loads under the plantar regions with more contact with the ground. Furthermore, this warm-up may have resulted in a speed increase during the post 6MWT assessment[8,26].

Data from contact area of children aged 1 to 12 years showed that, the older the child, the greater the contact area. Moreover, results showed that children with obesity presented larger contact area than the normal-weight ones for rearfoot, midfoot and forefoot regions[10,11], which was also found in our study. In addition, the significant difference in the AI found between the groups showing higher values for the OB group, which often associates high values with the characteristic of flat feet, corroborates with our findings, and can be related to the larger records contact area for OB group.

Regarding the results for total distance during the 6MWT, all groups in this study walked less when compared to reference values for healthy children of the same age[15]. Same result was observed for SPE. For the variable of heart rate results may be explained by the fact that verbal incentive was not used during the performance of the 6MWT. It has been showed that standard words of encouragement such as: "keep going", "you are doing good" or "everything is going well", given by the same person at set times of the test can result in greater distances during the 6MWT[29], even though reproducibility for tests with and without encouragement is similar[16]. Although the association between BMI status and physical performance to Brazilian children has shown an increase in the odd of overweight and obese children presenting low physical performance[30], our data showed no significant difference at all in the performance of the walking test when we compared obese and normal weight children.

As a potential limitation of our study, we highlight that children's physical activity levels were not verified, as well as the time for obesity status. We also did not describe foot size and the body mass within groups. These factors may in turn affect the interpretation and generalization of the results of our study.

CONCLUSION

In summary, the peak plantar pressure increases under the midfoot region of children with obesity after a moderate walking activity. Moreover, the contact area under all region was larger in children with obesity both before and after the 6MWT compared to normal weight children. Furthermore, the possible increase on foot load after a walking may result in risk for musculoskeletal problems if obesity status persists. As a suggestion for further studies, it would be interesting to verify whether there is an association of the highest peak of plantar pressure in the midfoot region with biomechanical changes in the foot of children with obesity, which may result in pain and discomfort during physical activities.

COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

Ethical approval was obtained from the local Human Research Ethics Committee – University of Brasilia and the protocol (no. 2.599.767/2018) was written in accordance with the standards set by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interests to declare.

Author Contributions

Conceived and designed the experiments: FAPC, ACD. Performed the experiments: FAPC, RJS, PRM, ACD. Analyzed the data: FAPC, RJS, PRM, ACD. Contributed reagents/materials/analysis tools: FAPC, RJS, PRM, ACD. Wrote the paper: FAPC, RJS, PRM, ACD.

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