

Is bodyweight affecting plantar pressure distribution in children?

An observational study

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Abstract

The aim of this study is twofold: firstly, to investigate the plantar pressure distribution differences in children coming from 4 different weight categories and secondly to analyze the presence of sex-related plantar pressure distribution differences.

Overall, 416 children, aged 7 to 12 years old were randomly selected from 6 different local schools, and voluntarily participated in the study. Two hundred twenty six of them were men, while 190 were women (mean age: 9.93 ± 1.02 years; height: 1.39 ± 0.8 m; body mass: 37.76 ± 10.34 kg; BMI: 19.24 ± 4.02 kg/m²). Based on the body mass index (BMI) the sample was grouped in the following categories: underweight (UW); normal weight (NW); overweight (OW), and obese (OB). Besides, the plantar load distribution parameters (total plantar load distribution and load distribution in forefoot and rearfoot) were assessed employing freeMed Maxi; Sensor Medica device. Shapiro-Wilk test was used to test the data distribution. Between-groups comparisons were conducted using Mann-Whitney *U* test, or using Kruskal-Wallis test associated with pairwise comparisons.

There were significant differences in load distribution between weight categories, with (OW) and (NW) being significantly different with (O), $P = .03$ and $P = .04$, respectively. No significant differences were found on load distribution on the rearfoot and forefoot between categories. The sex effect, particularly among boys, revealed a different pattern of load distribution among (O) compared with other categories. This effect was not detected among women. Different profile of load distribution on the rearfoot and forefoot between boys and girls was found, with girls bearing significantly more weight in the right rearfoot compared with boys ($P = .001$).

It can be concluded that the weight status of the children can affect the plantar load distribution, with obese category being different from (NW) and (OW). Additionally, the sex plays a role when it comes to the load distribution in different regions of the foot. Moreover, since the young age, due to growth and development process, is accompanied with anatomical foot changes which might be affected from numerous factors, assessing plantar pressure distribution in young children results to be a quite complicated matter.

Abbreviations: BMI = body mass index, LF = left foot, NW = normal weight, OB = obese, OW = overweight, RF = right foot, UW = underweight.

Keywords: children, foot, obesity, plantar pressure

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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1. Introduction

Considering that the foot is the most inferior part of the body, it serves as a base of support as well as propulsion for movement during activities of daily living.^[1,2] Indeed, there is a general agreement that proper biomechanics of the foot is responsible for preserving the symmetrical distribution of plantar pressure, and consequently to maintain proper body posture.^[1] Furthermore, several researchers have reported that pressure distribution in the human foot varies considerably by participant's posture and health condition of the foot.^[3] As previously reported by Zulkifli and Loh^[3] independently of assessment methods, under identical conditions, the pressure range of healthy foot differs from the unhealthy one. Nevertheless, the lower foot sensitivity among unhealthy populations has been acknowledged as a causing factor of high-pressure foot distribution.^[4] In addition, it has been shown that several individual characteristics such as age, poor fitness status, illness may be influencing factors which alter plantar pressure distribution, which may lead to various deformities.^[1,3] In this regard, studies have shown that overweight and obese children are exposed to a higher risk of gait patterns deficiency,^[5] unstable posture,^[6] exposure to higher forces/impacts to the lower limbs,^[7] lower limbs malalignment,^[8] and diminished bone mineral density, which has been previously

related to increased incidence of overuse injuries and bone fractures.^[9] Consequently, in this regard, studies have urged the necessity to analyze foot plantar pressure as a precaution for postural disorders, particularly in the feet.^[10,11] Besides the above-mentioned health issues, a massive increase of pediatric obesity has been reported worldwide in the last decade,^[12] which has been linked with several health problems,^[13] and has become an essential topic for public health.^[14] Furthermore, it has been proven that excessive body weight has a direct effect on children's musculoskeletal system development,^[15] a problem that disturbs and changes their speed, step length, and stability compared with normal weight counterparts.^[16–18] In addition, the related literature regarding the effect of obesity on foot structure has highlighted that overweight among preschool children is correlated with anatomical changes and differences in the distribution of plantar pressure,^[18–21] and consequently the increased loading could lead to an increased risk of developing pathologies and injuries.^[22]

According to prior findings on children, it was hypothesized that some differences might exist between obese and normal-weighted children in terms of plantar distribution in static standing. Therefore, the purpose of this study is twofold: firstly, to investigate the plantar pressure distribution differences in children coming from 4 different weight categories (underweight, normal weight, overweight, and obese) and secondly to evaluate the presence of sex-related plantar pressure distribution differences, if any.

2. Material and methods

2.1. Participants

Four hundred and sixteen children (416) from 6 different local elementary schools in Palermo, Italy, aged 7 to 12 years old were randomly selected to be enrolled in the current study; 226 of them were men, while 190 were women (mean age: 9.93 ± 1.02 years; body height: 1.39 ± 0.8 m; body mass: 37.76 ± 10.34 kg; BMI: 19.24 ± 4.02 kg/m²). Prior to the recruitment of children, verbal assent was obtained and written informed consent was signed by the parents/guardians of the children, which was approved by the local Ethical Committee of the University of Palermo (ID 2020-UNPACLE-0045262). The following exclusion criteria were adopted for the study: physical injuries; neurologic diseases; intellectual disability. Furthermore, the current study was conducted in compliance with the declaration of Helsinki.

2.2. Study design and measurements

Participants' body mass (kg) was assessed by means of a scale to the nearest 100 g (Seca 709, Hamburg, Germany), while for obtaining the body height (cm) a wall stadiometer with the nearest to 1 mm was used (Seca 220, Hamburg, Germany). Furthermore, in order to calculate the BMI of children we used the formula as presented by Cole et al^[23] determining as weight in kilograms divided by height in meter squared. Furthermore, according to cut off points reported by Cole et al^[23] children were arranged in 4 different categories such as underweight, normal weight, overweight, and obese. Each participant underwent a postural instrumental assessment comprising a static baropodometry in order to acquire feet characteristics in terms of plantar pressure percentage. For the baropodometric test, each child was positioned in an orthostatic position on the platform (freeMed Maxi; Sensor Medica; Guidonia Montecelio, Roma, Italia) for 5

Table 1

Total number and percentage of participants in all categories.

	Female	Male	Total number
Underweight	19 59.38%	13 40.63%	32 100%
Normal weight	109 45.80%	129 54.20%	238 100%
Overweight	41 46.59%	47 53.41%	88 100%
Obese	21 36.21	37 63.79%	58 100%

seconds, gazing forward, barefoot with feet placed side-by-side and arms held along the trunk. The sampling frequency was set at 50 Hz. The parameters considered were: total plantar pressure (%); rearfoot plantar pressure (%); forefoot plantar pressure (%). Furthermore, in the baropodometric test, plantar pressure in physiological condition should be divided into 50% on the right foot and 50% on the left foot, and again, the plantar pressure percentage for each foot should be normally distributed for 60% on the rearfoot and for 40% on the forefoot. The study has been carried out and adopted following the STROBE checklist.

2.3. Statistical analysis

Data were expressed as mean and standard deviation. To test the data distribution, the Shapiro-Wilk test was performed. Between-groups comparisons were conducted using Mann-Whitney U test, or using Kruskal-Wallis test associated with pairwise comparisons. Statistical significance was set at $P < .05$. All statistical analyses were performed by using Statistical Package for Social Sciences software version 21.0 (SPSS Inc., Chicago, IL).

3. Results

The sample was divided into 4 categories as follows: underweight (UW), normal weight (NW), overweight (OW), and obese (OB) (Table 1). The plantar pressure distribution data are presented as mean and SD for both feet, left foot (LF) and right foot (R), in all weight categories (Fig. 1).

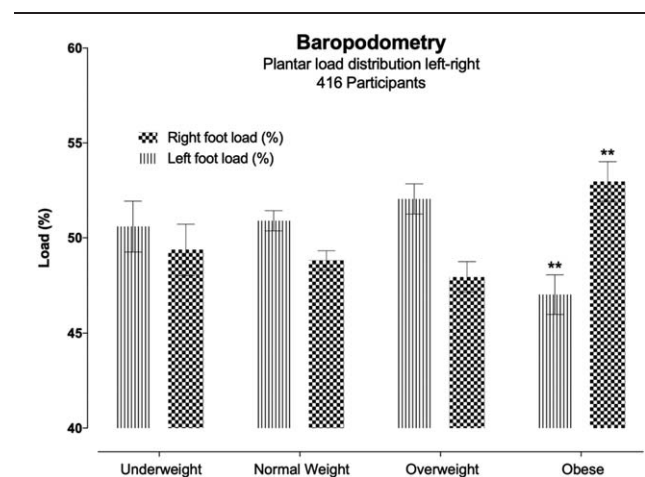


Figure 1. Plantar load distribution in left and right foot among UW, NW, OW, and OB in both sexes. **Significant difference at ($P < .05$). NW = normal weight, OB = obese, OW = overweight, UW = underweight.

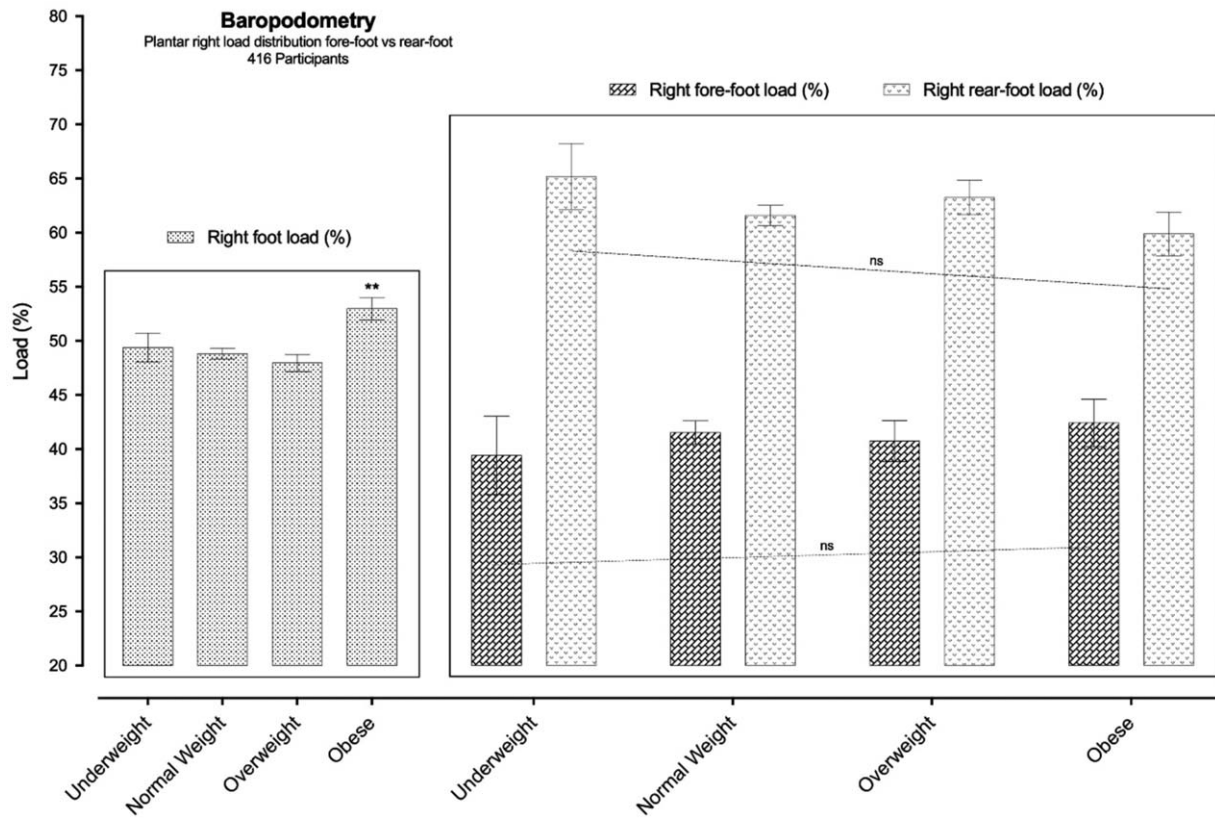


Figure 2. Plantar load distribution only in right foot and load distribution of fore-foot and rear-foot of the right foot among all categories. **Significant difference at ($P < .05$).

An effect of weight category was observed in load distribution in both feet, with obese category being significantly different from overweight and normal weight category $P = .03$ and $P = .04$, respectively. Since the plantar pressure among obese children was significantly higher on the right foot compared with other categories, the distribution of the pressure in foot regions was analyzed only for the right foot.

Additionally, the comparison of load distribution in foot regions of the right foot (forefoot and rearfoot) indicated no significant differences between weight categories ($P > .05$) (Fig. 2). Nevertheless, a higher load distribution percentage on the rearfoot was observed across all categories.

In overall sample, there were no significant differences between legs in total load distribution when stratified based on sex (left $P = .376$; right $P = .373$). A sex effect on load distribution pattern was detected in obese children ($P < .05$), but not in other categories, particularly among boys, while among girls this effect was not found.

Different trending profile on load distribution was detected between boys and girls, with girls loading significantly more weight in the right rearfoot and less weight in the forefoot compared with boys ($P = .001$) (Figs. 3 and 4).

4. Discussion

The main findings of the current study show that there is an effect of weight category in plantar pressure distribution, with obese children being significantly different from other categories (NW

and OW). Furthermore, it has been found that obese children bear more weight in their right foot compared with the left one, which was not the case with the other categories. In overall sample there were no significant differences in load distribution in foot regions (forefoot and rearfoot). In this regard, when the sample was stratified based on sex, significant differences were

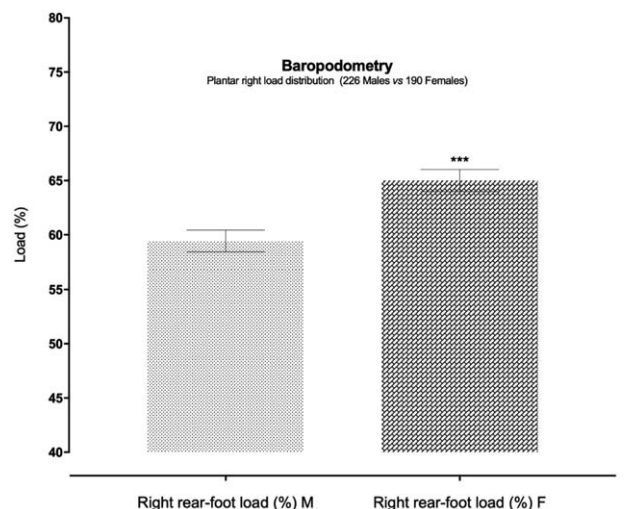


Figure 3. Plantar load distribution in rear-foot between boys and girls. ***Significant difference at ($P < .001$).

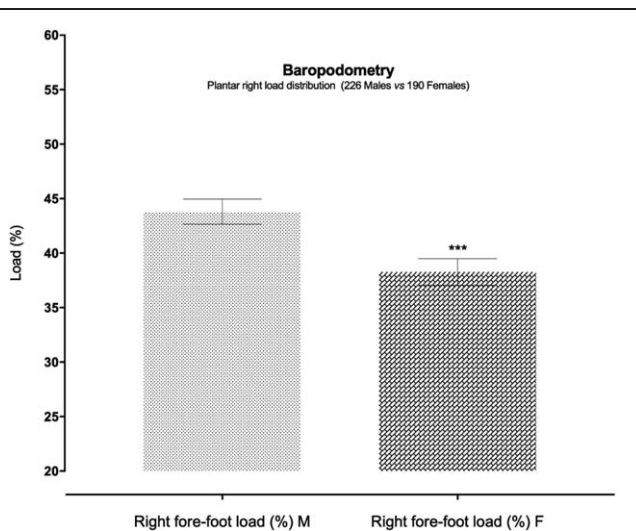


Figure 4. Plantar load distribution in fore-foot between boys and girls. ***Significant difference at ($P < .001$).

detected with boys bearing more weight in forefoot, compared with girls loading more pressure in the rearfoot. In the literature different factors which have an impact in plantar pressure distribution have been widely investigated, among which body mass has been considered as one of the external factors which may have an effect in children,^[24–26] which is in line with the present findings.

The results of the present study are in agreement with the previous research where it was reported that obese children experience higher plantar pressure distribution when compared with non-obese counterpart.^[27] Consequently, excessive weight has been shown to have a negative impact on foot morphology^[22] and foot sensitivity, which has a crucial role on postural tasks involving balance.^[28] However, it is still unclear if the foot adapts to the extensive weight throughout the years.^[29] In addition, previous studies related to plantar pressure distribution and functional gait analysis have reported a negative effect of obesity on load distribution.^[30,31] Furthermore, when comparing plantar pressure distribution between legs, independent of their body mass, former investigations did not reveal any significant differences.^[30,32] However, in contrast to those findings, our data demonstrated that obese children do differ from other categories, with bearing more weight in their right foot. Hence, taking into consideration the current findings, we were keen to understand if there was an effect of weight category in load distribution in foot regions (fore and rearfoot) of the same leg. In this context, the results of our study showed that there were no significant differences in load distribution in fore and rearfoot between 4 categories. Although, the differences across categories were not statistically significant, we found that all weight categories were associated with substantial plantar pressure on the rearfoot. These findings are consistent with those of da Rocha et al^[27] confirming that, independently of weight category, rearfoot was the foot region with highest pressure distribution. Furthermore, depending on the internal and external factors, the pattern of weight distribution in different regions of the foot has been investigated and, generally, it has been reported that certain factors,^[33,34] and specifically among children with postural deformities,^[35] and different diseases,^[36] as well as postural

specificity^[37] might determine the region of the foot which is loaded with greater plantar pressure distribution. Indeed, previous studies have reported an age effect in plantar pressure distribution in different foot regions among healthy children.^[33] In fact, studies have highlighted that differences in plantar pressure are evident in children until the age of 11 years, and afterwards these discrepancies disappear.^[34] However, Phethean and Nester,^[30] suggested that important sex specific changes may be hidden by merging data from both sexes (boys and girls). Hence, in the current study no leg differences between sexes in plantar load distribution were detected. Our study is in good agreement with data presented by Pomarino and Pomarino^[33] where no significant differences between legs in both sexes were reported.

Since there were no differences between legs in both sexes, deeper analyses were conducted to investigate the eventual sex differences in pressure distribution in foot regions. Although, as reported earlier, differences in plantar pressure for both legs between boys and girls were not found, when sex effect was included in analysis for foot regions our results revealed a clear distinction between sexes. Interestingly, our results provide compelling evidence that girls bear significantly more weight in rearfoot compared with boys, whereas boys bear more weight in forefoot. In contrast to our results, other studies reported that obese children, depending on the age, bear more weight under the midfoot and forefoot.^[19,21] However, the data presented in the existing literature are mainly focused on dynamic plantar pressure distribution.^[34,38] In this regard, it is of importance mentioning that data regarding the sex effect on static plantar pressure among children is scarce. Additionally, when the data were analyzed by dividing children based on weight category and sex, it was detected that obese boys distribute their body mass on the floor completely in a different pattern compared with girls. As a result of increased body mass, plantar pressure distribution in forefoot region is affected by obesity,^[38] which could be seen as a compensation strategy adapted by obese children to handle the excessive weight.^[39] There is a general agreement when taking into consideration all the findings from the present and previous studies which have found that boys and girls distribute the load differently from one another. Unfortunately, it is not the same case when conferring about specific regions of the foot in which is distributed more weight, neither in healthy normal weighted children nor in obese children with different disorders/disabilities or even between sexes itself.^[27,30,34] However, some limitations are worth noting. Although our hypotheses were supported statistically, a straight forward comparison with other studies was difficult due to alterations in methodology, participants' age, technology used, etc. Notably, our results provide compelling evidence regarding the use of Sensor medica/baropodometric assessment as a suitable device to be applied in pediatric population. This study, therefore, suggests that this device appears to be effective in detecting plantar pressure issues, and consequently possible postural disorders and/or similar related conditions among children.

5. Conclusion

Based on the results, it can be concluded that weight category influences plantar load distribution, with obese category being different from other categories. Furthermore, across all categories, rearfoot was the foot region with higher pressure distribution. In addition, sex has an effect on plantar load

distribution in obese boy participants, but not in other categories. Moreover, girls distribute significantly higher load on the rearfoot compared with boys. Hence, we strongly suggest to the research community on coming up with a standardized protocol on assessing plantar pressure distribution in both static and dynamic conditions.

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Author contributions

Kaltrina Feka, Valerio Giustino and Jessica Brusa conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Rosanna Cannata, Antonino Bianco and Angelo Iovane:

Analyzed and interpreted the data; Wrote the paper and contributed in the participants' recruitment.

Antonio Palma, Giuseppe Messina and Masar Gjaka. Finalised the manuscript. Contributed on experimental design, wrote the final discussion.

All Authors approved the final version of the paper.

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