DOI: 10.37190/ABB-02437-2024-03

# Correlation between body composition variables and plantar pressure and pain level

Svitlana Dikhtyarenko[1*], Pedro Forte[2], Dulce Esteves[3]

[1]PhD Student, University of Beira Interior, Covilhã, Portugal; Research Center in Sports, Health and Human Development, Covilhã, Portugal

[2]PhD, Coordinating Professor of the Higher Educational Sciences Institute, Porto, Portugal; Research Center in Sports, Health and Human Development, Covilhã, Portugal; Research Center for Active Living and Wellbeing (Livewell), Bragança, Portugal

[3]PhD, Associate Professor and Researcher Sports Science Department, Vice-president of Faculty of Human Social Sciences University of Beira Interior, Covilhã, Portugal; Research Center in Sports, Health and Human Development, Covilhã, Portugal

*Corresponding author: Svitlana Dikhtyarenko, University of Beira Interior, Covilhã, Portugal; Sports, Health and Human Development, Covilhã, Portugal, e-mail address: lana1705@hotmail.com

Submitted: 17th April 2024

Accepted: 2nd October 2024

## Abstract

From a current perspective, it is understood that body posture is influenced by individual asymmetries, cultural context, habitual body patterns, etiological factors and psychosocial factors allocated to the individual. Clarifying the musculoskeletal cause that originated the postural alteration is considered the clinical challenge in the treatment of pain or discomfort. Recent studies have shown the influence of changes in body weight on the distribution of plantar pressure and foot pain, emphasizing the importance of understanding these relationships. Integrating body composition with plantar pressure analysis presents an opportunity to explore gender differences and their associations with plantar pressure distribution. There is currently a lack of research integrating body composition, plantar pressure distribution and gender comparison to elucidate the complex interaction between these variables. Therefore, the main objective of this investigation is to evaluate body composition through BIA (bioimpedance) and the distribution of plantar pressure in the subjects' feet through pressure platform analysis with a specific focus on comparisons between the sexes and the associations between these variables. The study employed an observational cross-sectional design. A total of 77 participants (n=77) aged between 18 and 91 years were assessed, the majority of whom were female (n=53, 68.83%), while 24 participants (n=24, 31.17%) were male. The average age of the participants was 60.717 years for males and 54.33 years for females. Baropodometry and bioimpedance tests were carried out. Significant differences with a medium effect were recorded only for the three indicators, while the rest of the values showed a large effect. Significant negative correlations were found between age and height ($p < 0.05$) and positive correlations between age and other factors such as BMI, fat mass, lean mass and various foot-related metrics. The results of this study showed that plantar pressure characteristics differ according to gender and are related to body composition and pain level.



**Keywords:** Baropodometry, Bioimpedance, pain levels

## Introduction

The assessment of body composition and plantar pressure distribution is crucial in understanding the physiological and biomechanical aspects of human health [2]. Typically, the body composition is easier to assess by Bioimpedance analysis (BIA) due the non-invasive assessment of body composition, including body water, muscular and fat mass, visceral fat, and metabolic rate [21]. BIA provides a comprehensive estimation of fat mass, fat-free mass, and body fluids, offering valuable insights for disease prognosis [21]. Moreover, BIA has been shown to yield comparable results to dual-energy X-ray absorptiometry, making it a reliable method for body composition assessment [21]. The evolution of BIA research has highlighted its diverse applications, ranging from the estimation of physiological function to the assessment of body composition, emphasizing its significance in clinical research [21].

In parallel, the analysis of plantar pressure distribution has gained attention for its role in understanding postural control, foot biomechanics, and the impact of body weight on foot health [29]. Studies have demonstrated the influence of body weight changes on plantar pressure distribution and foot pain, emphasizing the importance of understanding these relationships [23]. Furthermore, the use of plantar pressure analysis has extended to various clinical conditions, such as diabetic toe deformity and patellofemoral pain syndrome, highlighting its clinical significance in assessing musculoskeletal disorders [30].

The differences in plantar pressure distribution between sexes have been a subject of interest in various studies, reported inconsistent findings in the literature regarding plantar pressure values and loading patterns between genders [11]. On the other hand, Yamamoto and others [40] indicated that women have significantly higher peak pressure on specific areas of the foot compared to men, as detected by a newly developed plantar pressure sensor [40]. However, Hawrylak & Gronowska [16] found no significant differences in plantar pressure distribution between female Olympic-style weightlifters and a control group. Furthermore, the influence of factors such as weight, age, anatomical foot structure, and joint range of motion on plantar pressure distribution has been highlighted [27]. Additionally, Dowling et al. [12] studied the impact of obesity on plantar pressure distributions in children, indicating significantly higher forces and pressures in obese children compared to non-obese counterparts [12]. Moreover, investigated foot pressure distribution in individuals with mild hallux valgus and found it to be a significant variable affecting plantar pressure distribution [35]. Similarly, Gawronska & Lorkowski [13] identified hammer toe deformity as a significant variable affecting an increase in plantar pressure distribution [13].

The literature presents varying findings on the differences in plantar pressure distribution between sexes, with some studies indicating significant differences while others report no significant disparities [11]. Factors such as obesity, foot deformities, and anatomical foot structure have also been identified as influential in plantar pressure distribution [13]. The integration of body composition with plantar pressure analysis presents an opportunity to explore sex differences and their associations with plantar pressure distribution. This comprehensive approach can provide valuable insights into the interplay between body composition, foot biomechanics, and sex-specific differences. For this reason, associative studies can offer a comprehensive understanding of the relationships between variables, providing a holistic view of the relationships between body composition, plantar pressure, and sex-specific differences.

Regarding the above-mentioned information, there is a lack of research that integrates body composition, plantar pressure distribution, and sex comparisons to elucidate the complex interplay between these variables. So, this research aims to assess body composition using BIA and plantar pressure distribution in subjects' feet through pressure plate analysis, with a specific focus on sex comparisons and the associations between these variables. It was hypothesised that plantar pressure characteristics differ by sex, and it is related with body composition and pain level.



## Methods

### Study design

The study employed an observational cross-sectional design. A convenience sample was recruited to analyse differences between men and women in anthropometrics, body composition, plantar pressure distribution, and pain levels. Without intervention, researchers observed and recorded data at a single time point, allowing comparisons between sexes and exploring correlations among the measured variables. This type of design allowed a snapshot view of the differences and associations present within the sample. The sampling method was convenience sampling, and the research was conducted between April and October 2023.

## Sample

The population of the present study consisted of 77 (n=77) participants of both sexes. The majority of study participants were female, comprising 68.83% (n=53), while 31.17% of the sample were male (n=24). The mean age of participants was 60.717 years in males and 54.333 years in females.

All participants underwent a physical assessment protocol, which involved obtaining the following data: height, weight, amount of fat mass, amount of lean mass, amount of body water, basal metabolic rate, and shoe size. Data were collected using the LAICA PS5006 bioimpedance scale and height with a portable stadiometer. The shoe size was recorded as self-reported values.

The inclusion criteria in this study were: participants had to be at least eighteen years old and physically fit. The exclusion criteria included: (*i*) severe orthopedic problems (prosthesis placement, recent orthopedic surgeries); (*ii*) neurological issues (diseases requiring daily analgesic intake); (*iii*) cardiopulmonary diseases (pacemaker, use of oxygen cylinders), and (*iv*) pregnant women.

All participants voluntarily took part, signing the Informed Consent Form. The project was submitted to the Ethics Committee for Research with Human Subjects at the University of Beira Interior (Covilhã) and was approved under Opinion No. CE-UBI-Pj-2023-030.

## Plantar pressure distribution

Baropodometry has been widely used in assessing treatment results, whether conservative or surgical in various conditions [14], musculoskeletal pain, dyslexia, fibromyalgia, and multiple sclerosis, and other clinical settings [39] and gait analysis [10] have been done with this technique. However, caution is advised in interpreting baropodometry findings in clinical practice and scientific research [1]. The reliability of baropodometry in evaluating plantar load distribution has been demonstrated, making it a valuable instrument in determining plantar pressure, postural control, and plantar pressure distribution in various conditions [4].

The baropodometry assessment involved the use of the 'Kinefis Podia' baropodometer, equipped with 4 mats, an HD Logitech camera, and a Hama tripod, with technical specifications including a frequency of 800Hz, maximum pressure of

1500N/$cm^2$, 1600 sensor count, XY resolution of 2.5dpi, Z resolution of 8 bits, and calibration validity [31]. The protocol included static and dynamic measurements, with the first stage capturing images in a static position [7]. The duration of the assessment ranged from 8 to 15 minutes, and the data were analyzed using Motux Studio software, version 1.9.69.0 [9]. For the gait analysis, the parameters evaluated for the distribution of forces and pressures exerted on the feet in standing position were: (*i*) the lateral load percentage (Lateral Load %) refers to the total load borne by the left or right foot that is distributed laterally. This parameter gives insight into how weight is distributed across the foot; (*ii*) the maximal pressure (Maximal Pressure KPa) represents the maximum pressure experienced by foot, typically measured in kilopascals (essential for assessing peak pressure points and potential areas of high stress on the foot); (*iii*) The Area (Area $cm^2$) denotes the surface area of the foot in square centimeters (the contact area of the foot for analyzing pressure distribution and load-bearing); (*iv*) the podal axis (Podal Axis °) refers to the angle of the foot's axis concerning the ground (provides information on foot orientation and alignment); (*v*) the I-C (mm) stands for the distance between the first metatarsophalangeal joint and C-D the distance between the fifth metatarsophalangeal joint on the right foot to the center of pressure (evaluating the position of the center of pressure relative to the foot's anatomical landmarks).

These parameters are typically obtained through pressure-sensitive insoles, force plates, or other specialized equipment used in gait analysis. By analysing these metrics, researchers and clinicians can gain valuable insights into foot biomechanics, weight distribution, and pressure patterns during walking or running activities.

**Pain level**

The participants were evaluated with the Numeric Pain Rating Scale (NRS Pain), which was presented orally and with a physical instrument. In a self-assessment action regarding pain, they reported the level of pain or discomfort experienced in their day-to-day activities. The Numeric Pain Rating Scale (NRS Pain) is a widely used tool for assessing pain intensity in various clinical settings [5], [22], [24], [28]. The NRS Pain has been shown to have excellent psychometric properties, making it a reliable and valid measure of pain intensity [26]. It has also been found to be sensitive to changes in pain intensity over time, demonstrating its responsiveness in capturing fluctuations in pain levels [30]. Additionally, the NRS Pain is easy to administer and has high compliance rates, making it a practical choice for assessing pain in diverse patient populations [19].

Furthermore, the NRS Pain has been compared to other pain rating scales, such as the Visual Analogue Scale (VAS) and Verbal Rating Scale (VRS) and has been found to perform favourably in terms of scaling equivalence and administration [17]. This scale ranges from 0 to 10, allows for quick and straightforward interpretation of pain intensity, enabling efficient communication between patients and healthcare providers [32].

**Statistical Analysis**

Descriptive statistics were presented with means, standard deviations, minimum and maximum values. Exploratory analyses were made using the Kolmogorov-Smirnov and Levene to assess the distributions normality and homogeneity, respectively. The comparisons between groups (sex) and the statistical significances were assessed by T-Test. The effect sizes were interpreted as Cohen's d $< 0.2$ assumed as small effect sizes; Cohen's d $\approx 0.2$ to 0.5 were considered as moderate effect sizes; Cohen's d $\approx 0.5$ to 0.8 were medium effect sizes and Cohen's d $> 0.8$ as large effect sizes. The Pearson's ($r_p$) correlation tests were used to check associations between variables.  A representative correlations heatmap was created with software. All the analysis were made using JASP v. 0.18.1 (University of Amsterdam, Amsterdam, Netherlands). The significance of the analysis was defined as 5% for every tests.

# Results

The results are presented in three parts descriptives, groups comparisons and associations between variables. The descriptive data (means, standard deviations, minimum and maximum) regarding the comparisons between sexes, was presented in table 1.

**Table 1**. Descriptive analysis and comparisons of anthropometrics and body composition, pain level and foot pressure distribution by sex and total sample.

| | Females | | | | Males | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Mean | ±Std Deviation | Minimum | Maximum | Mean | ±Std Deviation | Minimum | Maximum | Mean | ±Std Deviation | Minimum | Maximum |
| Age [years] | 60.717 | 19.508 | 18 | 91 | 54.333 | 16.053 | 28 | 88 | 58.727 | 18.634 | 18 | 91 |
| Height [cm] | 160.283 | 7.231 | 142 | 172 | 175.667 | 8.122 | 162 | 193 | 165.078 | 10.353 | 142 | 193 |
| M1_Weight [Kg] | 67.509 | 11.608 | 42.4 | 100 | 80.117 | 13.147 | 59.5 | 120 | 71.439 | 13.381 | 42.4 | 120 |
| M1_BMI [Kg/M²] | 26.271 | 4.549 | 20.31 | 39.39 | 25.806 | 3.131 | 21.36 | 35.06 | 26.126 | 4.144 | 20.31 | 39.39 |
| M1_Fat Mass [%] | 29.46 | 6.828 | 18.4 | 45.7 | 27.337 | 7.365 | 15.1 | 43.2 | 28.799 | 7.021 | 15.1 | 45.7 |
| M1_$H_2O$ % | 49.885 | 4.909 | 37.1 | 58.6 | 52.408 | 4.819 | 42.6 | 60.4 | 50.671 | 4.99 | 37.1 | 60.4 |
| M1_Lean Mass [%] | 27.715 | 4.64 | 16.4 | 36.4 | 31.733 | 3.751 | 23.2 | 36.9 | 28.968 | 4.743 | 16.4 | 36.9 |
| M1_Basal Metabolism [Kcal] | 1252.151 | 126.487 | 1027 | 1588 | 1561.625 | 215.733 | 1133 | 2039 | 1348.61 | 214.124 | 1027 | 2039 |
| Shoe N.º | 37.462 | 1.525 | 32.5 | 41 | 42.438 | 2.092 | 39 | 46.5 | 39.013 | 2.88 | 32.5 | 46.5 |
| Pain Level | 6.679 | 2.208 | 2 | 10 | 6.5 | 2.766 | 2 | 10 | 6.623 | 2.363 | 2 | 10 |
| M1_LF_Lateral Load [%] | 48.508 | 5.317 | 34.6 | 59.4 | 47.092 | 3.343 | 40.7 | 53.1 | 48.066 | 4.813 | 34.6 | 59.4 |
| M1_LF_Maximal Pressure [Kpa] | 234.219 | 19.666 | 161.4 | 248.1 | 240.925 | 11.572 | 194.8 | 248.1 | 236.309 | 17.746 | 161.4 | 248.1 |
| M1_LF_Area [cm²] | 118.34 | 20.314 | 70 | 166 | 147.417 | 24.94 | 94 | 198 | 127.403 | 25.58 | 70 | 198 |
| M1_LF_Podal Axis [°] | 6.879 | 5.253 | -1.3 | 22.3 | 10.758 | 11.523 | 2 | 60.3 | 8.088 | 7.895 | -1.3 | 60.3 |
| M1_LF_I-C [mm] | 99.025 | 22.48 | 59 | 171.5 | 116.508 | 19.543 | 71.5 | 149.4 | 104.474 | 22.974 | 59 | 171.5 |
| M1_RF_lateral Lead [%] | 51.492 | 5.317 | 40.6 | 65.4 | 52.908 | 3.343 | 46.9 | 59.3 | 51.934 | 4.813 | 40.6 | 65.4 |
| M1_RF_Maximal Pressure [KPa] | 238.551 | 12.656 | 196 | 248.1 | 240.575 | 8.836 | 219 | 248.1 | 239.182 | 11.581 | 196 | 248.1 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M1_RF_Area [cm²] | 122.226 | 21.742 | 80 | 171 | 155.708 | 25.686 | 99 | 199 | 132.662 | 27.691 | 80 | 199 |
| M1_RF_Podal Axis [°] | 9.419 | 4.508 | 0.4 | 21.9 | 10.192 | 5.007 | 3 | 24.8 | 9.66 | 4.65 | 0.4 | 24.8 |
| M1_RF_C-D [mm] | 92.857 | 19.294 | 51.7 | 144.6 | 103.017 | 12.987 | 63.8 | 126.8 | 96.023 | 18.116 | 51.7 | 144.6 |

Legend: M1 (Evaluation); BMI (Body Mass Index); $H_2O$ % (percentage of body water); LF (Left Foot); I-C (Distance between left foot COP and body COP); RF (Right Foot); C-D (Distance between right foot COP and body COP)

Regarding the comparisons between sexes. The significant differences with medium effect were noted for: $H_2O$ % [t = -2.101; p = 0.039; d = -0.517], Left Foot Podal Axis [t = -2.038; p = 0.045; d = -0.501] and Right Foot C-D [t = -2.346; p = 0.022; d = -0.577]; significant differences with large effect between groups were noted for: Height [t = -8.32; p < 0.001; d = -2.047], BMI [t = -4.234; p < .001; d = -1.042], Lean Mass [t = -3.723; p < .001; d = -0.916], Basal Metabolism [t = -7.898; p < .001; d = -1.943], Shoe N.º [t = -11.765; p < .001; d = -2.895], Left Foot Area [t = -5.412; p < .001; d = -1.332], Left Foot I-C [t = -3.287; p = 0.002; d = -0.809], Right Foot Area [t = -5.911; p < .001; d = -1.454]. The table 2 presents the groups comparisons for all assessed variables.

**Table 2**. Significant associations between anthropometrics, body composition and foot pressure distribution between sex groups.

| | | | | 95% CI for Cohen's d | |
|---|---|---|---|---|---|
| Variables | t | P | Cohen's d | Lower | Upper |
| Age | 1.401 | 0.165 | 0.345 | -0.142 | 0.829 |
| Height | -8.32 | < .001 | -2.047 | -2.625 | -1.46 |
| M1_Weight | -4.234 | < .001 | -1.042 | -1.549 | -0.529 |
| M1_BMI | 0.454 | 0.651 | 0.112 | -0.371 | 0.594 |
| M1_Fat Mass (%) | 1.233 | 0.221 | 0.303 | -0.182 | 0.787 |
| M1_$H_2O$ % | -2.101 | 0.039 | -0.517 | -1.004 | -0.026 |
| M1_Lean Mass (%)) | -3.723 | < .001 | -0.916 | -1.417 | -0.409 |
| M1_Basal Metabolism | -7.898 | < .001 | -1.943 | -2.512 | -1.365 |
| Shoe N.º | -11.765 | < .001 | -2.895 | -3.557 | -2.221 |
| Pain Level I | 0.304 | 0.762 | 0.075 | -0.408 | 0.557 |
| M1_LF_Lateral Load [%] | 1.199 | 0.234 | 0.295 | -0.19 | 0.779 |
| M1_LF_Maximal Pressure [Kpa] | -1.55 | 0.125 | -0.381 | -0.866 | 0.106 |
| M1_LF_Area [cm²] | -5.412 | < .001 | -1.332 | -1.855 | -0.801 |
| M1_LF_Podal Axis [°] | -2.038 | 0.045 | -0.501 | -0.989 | -0.011 |
| M1_LF_I-C [mm] | -3.287 | 0.002 | -0.809 | -1.305 | -0.307 |
| M1_RF_lateral Load [%] | -1.199 | 0.234 | -0.295 | -0.779 | 0.19 |
| M1_RF_Maximal Pressure [KPa] | -0.708 | 0.481 | -0.174 | -0.657 | 0.309 |
| M1_RF_Area [cm²] | -5.911 | < .001 | -1.454 | -1.986 | -0.915 |
| M1_RF_Podal Axis [°] | -0.673 | 0.503 | -0.166 | -0.648 | 0.318 |
| M1_RF_C-D [mm] | -2.346 | 0.022 | -0.577 | -1.066 | -0.084 |

The correlations between body composition, pain level, plantar pressure distribution variables are presented in table 3. Significant negative correlations were found between Age and Height ($p < 0.05$), indicating that as age increases, height tends to decrease within the sample. Conversely, positive correlations were noted between Age and other factors such as Body Mass Index (BMI), Fat Mass, Lean Mass, and various foot-related metrics. The Height exhibited strong positive correlations with several parameters including Weight, Basal Metabolism, Shoe Number, and foot-related measurements such as Area and C-D, emphasizing the influence of height on these variables within the study group. Notably, BMI displayed associations with Fat Mass, Lean Mass, Water Percentage ($H_2O$ %), Pain Levels, and various foot-related measurements, indicating its interconnectedness with multiple physiological and foot-related factors. Other notable correlations were observed between metrics such as Fat Mass and Water Percentage, Lean Mass, and Shoe Number, as well as different foot-related measurements including Area, I-C, Podal Axis, and maximal pressures in the left and right foot. The representative heatmap of the correlations between variables was presented in figure 1. In the heatmap, darker purple and brown colours represent higher correlation values.

**Table 3**. Significant associations between anthropometrics, body composition and foot pressure distribution between sex groups.

| Correlations Between Variables | | $r_p$ | p | Correlations Between Variables | | $r_p$ | p | Correlations Between Variables | | $r_p$ | p |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Age [Years] | Height [cm] | -0.40 | 0.00** | M1_BMI [Kg/$m^2$] | M1_Fat Mass [%] | 0.74 | 0.00** | Shoe N.º | M1_LF_I-C [mm] | 0.31 | 0.00* |
| Age [Years] | M1_BMI [Kg/$m^2$] | 0.32 | 0.00* | M1_BMI [Kg/$m^2$] | M1_$H_2O$ [%] | -0.54 | 0.00** | Shoe N.º | M1_RF_Area [$cm^2$] | 0.66 | 0.00** |
| Age [Years] | M1_Fat Mass [%] | 0.28 | 0.00* | M1_BMI [Kg/$m^2$] | M1_Lean Mass [%] | -0.52 | 0.00** | Shoe N.º | M1_RF_C-D [mm] | 0.26 | 0.00* |
| Age [Years] | M1_$H_2O$ [%] | -0.43 | 0.00** | M1_BMI [Kg/$m^2$] | Pain Level I | 0.28 | 0.00* | Pain Level I | M1_LF_Podal Axis [°] | 0.26 | 0.00* |
| Age [Years] | M1_Lean Mass [%] | -0.42 | 0.00** | M1_BMI [Kg/$m^2$] | M1_LF_Area [$cm^2$] | 0.28 | 0.00* | Pain Level I | M1_LF_I-C [mm] | -0.27 | 0.00* |
| Age [Years] | M1_LF_Maximal Pressure [Kpa] | -0.33 | 0.00* | M1_BMI [Kg/$m^2$] | M1_LF_I-C [mm] | 0.22 | 0.00* | Pain Level I | M1_RF_C-D [mm] | -0.29 | 0.00* |
| Age [Years] | M1_RF_Podal Axis [°] | 0.29 | 0.00* | M1_BMI [Kg/$m^2$] | M1_RF_Area [$cm^2$] | 0.32 | 0.00* | M1_LF_Lateral Load [%] | M1_LF_Maximal Pressure [Kpa] | 0.65 | 0.00** |
| Height [cm] | M1_Weight [Kg] | 0.58 | 0.00** | M1_Fat Mass [%] | M1_$H_2O$ [%] | -0.72 | 0.00** | M1_LF_Lateral Load [%] | M1_LF_I-C [mm] | -0.55 | 0.00** |
| Height [cm] | M1_Lean Mass [%] | 0.36 | 0.00* | M1_Fat Mass [%] | M1_Lean Mass [%] | -0.60 | 0.00** | M1_LF_Lateral Load [%] | M1_RF_lateral Lead [%] | -1.00 | 0.00** |
| Height [cm] | M1_Basal Metabolism [Kcal] | 0.72 | 0.00** | M1_Fat Mass [%] | Pain Level I | 0.25 | 0.00* | M1_LF_Lateral Load [%] | M1_RF_Maximal Pressure [KPa] | -0.50 | 0.00** |
| Height [cm] | Shoe N.º | 0.85 | 0.00** | M1_Fat Mass [%] | M1_LF_Maximal Pressure [Kpa] | -0.26 | 0.00* | M1_LF_Lateral Load [%] | M1_RF_Area [$cm^2$] | -0.27 | 0.00* |
| Height [cm] | M1_LF_Area [$cm^2$] | 0.52 | 0.00** | M1_Fat Mass [%] | M1_RF_Area [$cm^2$] | 0.23 | 0.00* | M1_LF_Lateral Load [%] | M1_RF_C-D [mm] | 0.30 | 0.00* |
| Height [cm] | M1_LF_I-C [mm] | 0.39 | 0.00** | M1_$H_2O$ [%] | M1_Lean Mass [%] | 0.77 | 0.00** | M1_LF_Maximal Pressure [Kpa] | M1_LF_Area [$cm^2$] | 0.28 | 0.00* |
| Height [cm] | M1_RF_Area [$cm^2$] | 0.55 | 0.00** | M1_$H_2O$ [%] | Pain Level I | -0.25 | 0.00* | M1_LF_Maximal Pressure [Kpa] | M1_RF_lateral Lead [%] | -0.65 | 0.00** |
| Height [cm] | M1_RF_C-D [mm] | 0.33 | 0.00* | M1_$H_2O$ [%] | M1_LF_Maximal Pressure [Kpa] | 0.44 | 0.00** | M1_LF_Maximal Pressure [Kpa] | M1_RF_Maximal Pressure [KPa] | -0.36 | 0.00* |
| M1_Weight [Kg] | M1_BMI [Kg/$m^2$] | 0.73 | 0.00** | M1_Lean Mass [%] | Shoe N.º | 0.31 | 0.00* | M1_LF_I-C [mm] | M1_RF_Maximal Pressure [KPa] | 0.30 | 0.00* |
| M1_Weight [Kg] | M1_Fat Mass [%] | 0.57 | 0.00** | M1_Lean Mass [%] | Pain Level I | -0.33 | 0.00* | M1_LF_I-C [mm] | M1_RF_Area [$cm^2$] | 0.40 | 0.00** |
| M1_Weight [Kg] | M1_$H_2O$ [%] | -0.32 | 0.00* | M1_Lean Mass [%] | M1_LF_Maximal Pressure [Kpa] | 0.28 | 0.00* | M1_LF_I-C [mm] | M1_RF_C-D [mm] | 0.61 | 0.00** |
| M1_Weight [Kg] | M1_Basal Metabolism [Kcal] | 0.66 | 0.00** | M1_Lean Mass [%] | M1_RF_C-D [mm] | 0.23 | 0.00* | M1_RF_lateral Lead [%] | M1_RF_Maximal Pressure [KPa] | 0.50 | 0.00** |
| M1_Weight [Kg] | Shoe N.º | 0.59 | 0.00** | M1_Basal Metabolism [Kcal] | Shoe N.º | 0.76 | 0.00** | M1_RF_lateral Lead [%] | M1_RF_Area [$cm^2$] | 0.27 | 0.00* |
| M1_Weight [Kg] | M1_LF_Area [$cm^2$] | 0.58 | 0.00** | M1_Basal Metabolism [Kcal] | M1_LF_Area [$cm^2$] | 0.55 | 0.00** | M1_RF_lateral Lead [%] | M1_RF_C-D [mm] | -0.30 | 0.00* |
| M1_Weight [Kg] | M1_LF_I-C [mm] | 0.45 | 0.00** | M1_Basal Metabolism [Kcal] | M1_LF_I-C [mm] | 0.26 | 0.00* | M1_RF_Maximal Pressure [KPa] | M1_RF_Podal Axis [°] | -0.23 | 0.00* |
| M1_Weight [Kg] | M1_RF_Area [$cm^2$] | 0.64 | 0.00** | M1_Basal Metabolism [Kcal] | M1_RF_Area [$cm^2$] | 0.56 | 0.00** | M1_RF_Area [$cm^2$] | M1_RF_Podal Axis [°] | -0.30 | 0.00* |
| M1_Weight [Kg] | M1_RF_C-D [mm] | 0.33 | 0.00* | Shoe N.º | M1_LF_Area [$cm^2$] | 0.65 | 0.00** | M1_LF_I-C [mm] | M1_RF_lateral Lead [%] | 0.55 | 0.00** |

*p<0.05; **p<0.001

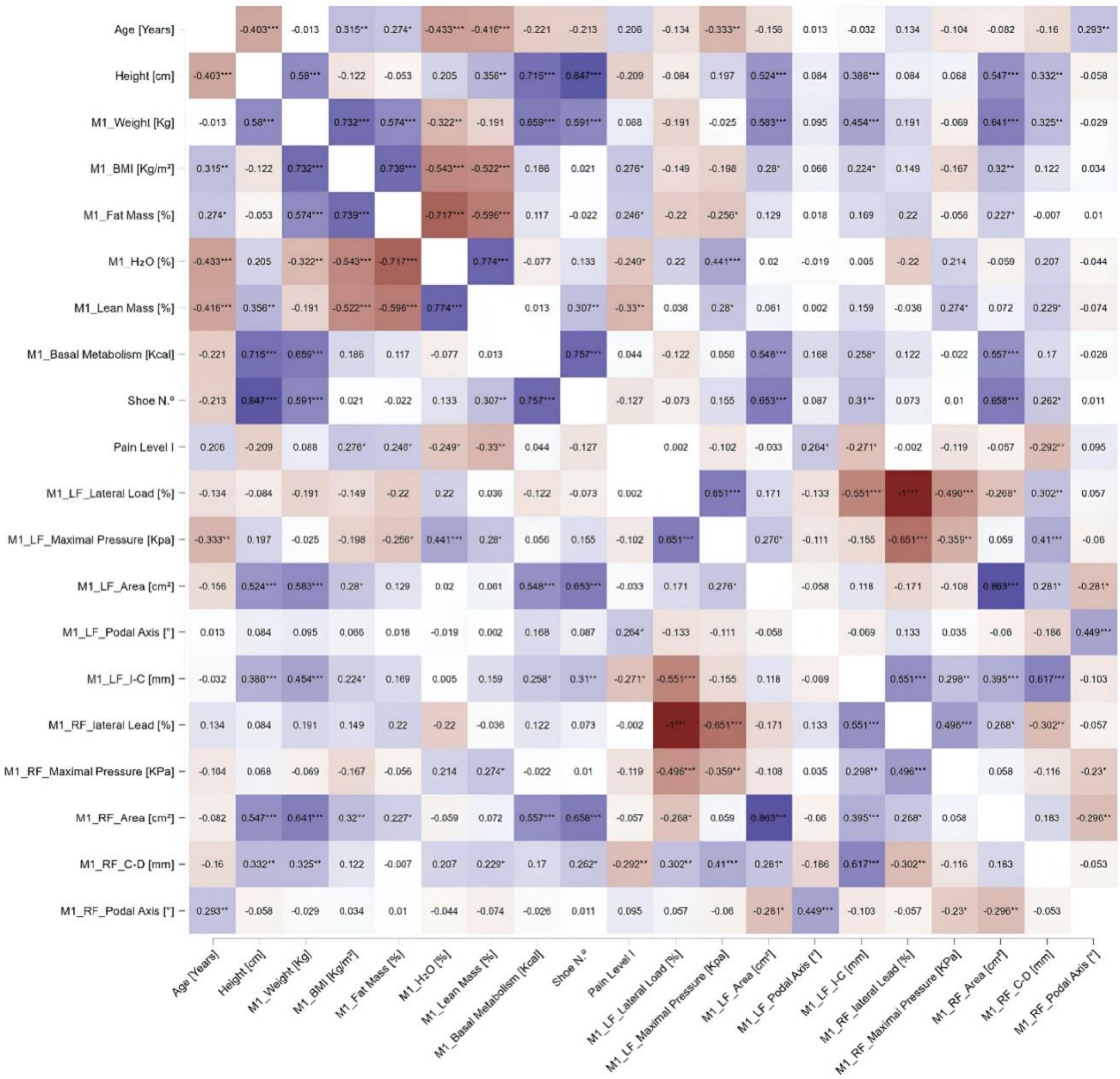


**Figure 1**. Heatmap associations between the evaluated variables.

## Discussion

This study aimed to assess the body composition and plantar pressure distribution in subjects' feet through pressure plate analysis, with a specific focus on sex comparisons and the associations between these variables. It was hypothesised that plantar pressure characteristics differ by sex, and it is related with body composition and pain level. The results confirmed the hypothesis.

The present study revealed significant differences in foot-related and body composition variables between males and females, emphasizing the unique physiological and biomechanical profiles of each sex [18]. These differences, included water percentage, foot dimensions, BMI, lean mass, and basal metabolism. The literature reports that these variables may influence plantar pressure distribution and foot function [6], [16], [36]. The findings also highlighted moderate disparities in water content and foot dimensions between the sexes, potentially contributing to variations in foot biomechanics and plantar pressure distribution [8]. Understanding these differences may be a starting point for developing tailored interventions that account for the unique physiological and biomechanical profiles of males and females [6], [16], [36]. Further research is warranted to comprehensively understand the implications of these differences on foot biomechanics and plantar pressure distribution [8], [16].

Based on comparisons between sexes, this study aimed to assess the intercorrelation between the evaluated variables. The correlations between variables in the provided results demonstrate a complex interplay between various factors and their impact on plantar pressure distribution. The correlations reveal significant associations between age, body mass index (BMI), fat mass, lean mass, water content, and other variables with plantar pressure distribution. For instance, age shows correlations with BMI, fat mass, water content, lean mass, and various aspects of plantar pressure distribution, indicating its influence on foot biomechanics [11]. Additionally, weight exhibits strong correlations with BMI, fat mass, lean mass, basal metabolism, and various aspects of plantar pressure distribution, highlighting its role in foot loading characteristics [33]. Moreover, the results indicate associations between body composition variables such as BMI, fat mass, lean mass, and water content with plantar pressure distribution, emphasizing the influence of body composition on foot biomechanics [20]. The correlations also reveal significant associations between shoe number and various aspects of plantar pressure distribution, suggesting the potential impact of footwear characteristics on foot loading patterns [37]. Furthermore, the results demonstrate correlations between pain levels and plantar pressure distribution, indicating the potential influence of pain on foot biomechanics [25], [34], [38]. Finally, the correlations between plantar pressure distribution variables themselves, such as lateral load, maximal pressure, and area, provide insights into the interrelationships between different aspects of foot loading characteristics [12].

The study has several limitations that warrant consideration for future research. Firstly, the study focused on differences in foot-related and body composition variables between males and females, but it did not explore the impact of these differences on specific foot pathologies or conditions such as osteoarthritis, diabetic neuropathies, or stroke-related foot abnormalities. Second, the study did not address the influence of foot kinematics and muscle performance on plantar pressure distribution, which is crucial for understanding the comprehensive biomechanical factors affecting foot function. Third, the study did not delve into the effects of specific interventions, such as shoe-worn insoles or external fixators, on foot biomechanics and plantar pressure distribution. Four, the study did not consider the potential impact of varying arch height or the mechanical properties of the foot on plantar pressure distribution and foot function. Future studies could investigate firstly, the interplay between foot kinematics, muscle performance, and sex-related differences in foot characteristics to provide a more holistic understanding of plantar pressure distribution and foot biomechanics. Second, could investigate how these differences contribute to the development and progression of such conditions, providing valuable insights for tailored interventions. Third, future research could explore the efficacy of interventions in mitigating the impact of sex-related differences in foot characteristics and body composition on plantar pressure distribution and foot function. Fourth research could explore how alterations in arch height and foot mechanical properties affect plantar pressure distribution, providing insights into potential interventions targeting these factors.

## Conclusion

This study's provide valuable insights into the significant differences in foot-related and body composition variables between males and females and their implications for plantar pressure distribution and foot biomechanics. These findings underscore the importance of considering sex-related differences in foot characteristics and body composition when assessing foot function and plantar pressure distribution. Conversely, positive correlations were noted between Age and other factors such as Body Mass Index (BMI), Fat Mass, Lean Mass, and various foot-related metrics. The Height exhibited strong positive correlations with several parameters including Weight, Basal Metabolism, Shoe Number, and foot-related measurements such as Area and distance C-D, emphasizing the influence of height on these variables within the study group. Notably, BMI displayed associations with Fat Mass, Lean Mass, Water Percentage ($H_2O$ %), Pain Levels, and various foot-related measurements, indicating its interconnectedness with multiple physiological and foot-related factors. Other notable correlations were observed between metrics such as Fat Mass and Water Percentage, Lean Mass, and Shoe Number, as well as different foot-related measurements including Area, distance I-C, Podal Axis, and maximal pressures in the left and right foot. The study emphasizes the need for tailored interventions and further research to comprehensively understand the implications of these differences on foot biomechanics and plantar pressure distribution.

## References


[1] Alves, R., Borel, W.P., Rossi, B.P., Vicente, E.J.D., Chagas, P.S. de C., Felício, D.C., 2018. Test-retest reliability of baropodometry in young asyntomatic individuals during semi static and dynamic analysis. Fisioter. em Mov. 31, e003114. https://doi.org/10.1590/1980-5918.031.AO14

[2] Andréoli, A., Garaci, F., Cafarelli, F.P., Guglielmi, G., 2016. Body Composition in Clinical Practice. Eur. J. Radiol. https://doi.org/10.1016/j.ejrad.2016.02.005

[3] Arnold, J.B., Causby, R., Pod, G.D., Jones, S., 2010. The Impact of Increasing Body Mass on Peak and Mean Plantar Pressure in Asymptomatic Adult Subjects During Walking. Diabet. Foot \& Ankle. https://doi.org/10.3402/dfa.v1i0.5518

[4] Baumfeld, D., Baumfeld, T., Da Rocha, R.L., Macedo, B., Raduan, F., Zambelli, R., Alves Silva, T.A., Nery, C., 2017. Reliability of Baropodometry on the Evaluation of Plantar Load Distribution: A Transversal Study. Biomed Res. Int. 2017. https://doi.org/10.1155/2017/5925137

[5] Brunelli, C., Zecca, E., Martini, C., Campa, T., Fagnoni, E., Bagnasco, M., Lanata, L., Caraceni, A., 2010. Comparison of numerical and verbal rating scales to measure pain exacerbations in patients with chronic cancer pain. Health Qual. Life Outcomes 8, 1–8. https://doi.org/10.1186/1477-7525-8-42/TABLES/4

[6] Caselli, A., Pham, H., Giurini, J.M., Armstrong, D.G., Veves, A., 2002. The Forefoot-to-Rearfoot Plantar Pressure Ratio Is Increased in Severe Diabetic Neuropathy and Can Predict Foot Ulceration. Diabetes Care. https://doi.org/10.2337/diacare.25.6.1066

[7] Castelo, L.D.A., Saad, M., Tamaoki, M.J.S., Dobashi, E.T., Sodré, H., 2022. Correlation between baropodometric parameters and functional evaluation in patients with surgically treated congenital idiopathic clubfoot. J. Pediatr. Orthop. Part B 31, 391–396. https://doi.org/10.1097/BPB.0000000000000937

[8] Cheung, J.T.-M., Zhang, M., Leung, A.K.-L., Fan, Y., 2005. Three-Dimensional Finite Element Analysis of the Foot During Standing—a Material Sensitivity Study. J. Biomech. https://doi.org/10.1016/j.jbiomech.2004.05.035

[9] Choi, S., Ashdown, S. p., 2010. 3D body scan analysis of dimensional change in lower body measurements for active body positions. http://dx.doi.org/10.1177/0040517510377822 81, 81–93. https://doi.org/10.1177/0040517510377822

[10] Cramer, H., Mehling, W.E., Saha, F.J., Dobos, G., Lauche, R., 2018. Postural awareness and its relation to pain: Validation of an innovative instrument measuring awareness of body posture in patients with chronic pain. BMC Musculoskelet. Disord. 19, 1–10. https://doi.org/10.1186/S12891-018-2031-9/TABLES/7

[11] Demirbüken, İ., Özgül, B., Timurtaş, E., Yurdalan, S.U., Cekin, M.D., Polat, M.G., 2019. Gender and Age Impact on Plantar Pressure Distribution in Early adolescence. Acta Orthop. Traumatol. Turc. https://doi.org/10.1016/j.aott.2019.01.006

[12] Dowling, A.M., Steele, J.R., Baur, L.A., 2004. What Are the Effects of Obesity in Children on Plantar Pressure Distributions? Int. J. Obes. https://doi.org/10.1038/sj.ijo.0802729

[13] Gawronska, K., Lorkowski, J., 2021. Evaluating the Symmetry in Plantar Pressure Distribution Under the Toes During Standing in a Postural Pedobarographic Examination. Symmetry (Basel). https://doi.org/10.3390/sym13081476

[14] Gutiérrez-Vilahú, L., Guerra-Balic, M., 2021. Footprint measurement methods for the assessment and classification of foot types in subjects with Down syndrome: a systematic review. J. Orthop. Surg. Res. 16, 1–8. https://doi.org/10.1186/S13018-021-02667-0/TABLES/2

[15] Hawrylak, A., Gronowska, H., 2020. Plantar Pressure Distribution in Female Olympic-Style Weightlifters. Int. J. Environ. Res. Public Health. https://doi.org/10.3390/ijerph17082669

[16] Henriksson, P., Löf, M., Forsum, E., 2015. Glucose Homeostasis Variables in Pregnancy Versus Maternal and Infant Body Composition. Nutrients. https://doi.org/10.3390/nu7075243

[17] Hjermstad, M.J., Fayers, P.M., Haugen, D.F., Caraceni, A., Hanks, G.W., Loge, J.H., Fainsinger, R., Aass, N., Kaasa, S., 2011. Studies comparing numerical rating scales, verbal rating scales, and visual analogue scales for assessment of pain intensity in adults: A systematic literature review. J. Pain Symptom Manage. 41, 1073–1093. https://doi.org/10.1016/j.jpainsymman.2010.08.016

[18] Hooker, S.A., Oswald, L.B., Reid, K.J., Baron, K.G., 2020. Do Physical Activity, Caloric Intake, and Sleep Vary Together Day to Day? Exploration of Intraindividual Variability in 3 Key Health Behaviors. J. Phys. Act. Heal. https://doi.org/10.1123/jpah.2019-0207

[19] Kim, J.M., Kim, M.W., Do, H.J., 2016. Influence of Hyperlipidemia on the Treatment of Supraspinatus Tendinopathy With or Without Tear. Ann. Rehabil. Med. 40, 463–469. https://doi.org/10.5535/ARM.2016.40.3.463

[20] Koller, U., Willegger, M., Windhager, R., Wanivenhaus, A., Trnka, H.J., Schuh, R., 2014. Plantar pressure characteristics in hallux valgus feet. J. Orthop. Res. 32, 1688–1693. https://doi.org/10.1002/JOR.22707

[21] Kuriyan, R., 2018. Body Composition Techniques. Indian J. Med. Res. https://doi.org/10.4103/ijmr.ijmr_1777_18

[22] Li, L., Liu, X., Herr, K., 2007. Postoperative pain intensity assessment: A comparison of four scales in Chinese adults. Pain Med. 8, 223–234. https://doi.org/10.1111/J.1526-4637.2007.00296.X/2/PME_296_F4.JPEG

[23] Lohman, T.G., Hingle, M., Going, S.B., 2013. Body Composition in Children. Pediatr. Exerc. Sci. https://doi.org/10.1123/pes.25.4.573

[24] Michener, L.A., Snyder, A.R., Leggin, B.G., 2011. Responsiveness of the Numeric Pain Rating Scale in Patients With Shoulder Pain and the Effect of Surgical Status. J. Sport Rehabil. 20, 115–128. https://doi.org/10.1123/JSR.20.1.115

[25] Mickle, K.J., Munro, B.J., Lord, S.R., Menz, H.B., Steele, J.R., 2010. Foot Pain, Plantar Pressures, and Falls in Older People: A Prospective Study. J. Am. Geriatr. Soc. 58, 1936–1940. https://doi.org/10.1111/J.1532-5415.2010.03061.X

[26] Miró, J., Castarlenas, E., Huguet, A., 2009. Evidence for the use of a numerical rating scale to assess the intensity of pediatric pain. Eur. J. Pain 13, 1089–1095. https://doi.org/10.1016/J.EJPAIN.2009.07.002

[27] Miura, M., Nagai, K., Tagomori, K., Ikutomo, H., Okamura, K., Okuno, T., Yanamoto, A., Nakagawa, N., Masuhara, K., 2021. Plantar Pressure Distribution During Standing in Female Patients With Hip Osteoarthritis Who Underwent Total Hip Arthroplasty. Phys. Med. Rehabil. - Int. https://doi.org/10.26420/physmedrehabilint.2021.1182

[28] Moisset, X., Attal, N., Ciampi De Andrade, D., 2022. An Emoji-Based Visual Analog Scale Compared With a Numeric Rating Scale for Pain Assessment. JAMA 328, 1980–1980. https://doi.org/10.1001/JAMA.2022.16940

[29] Oosterlinck, M., Hardeman, L.C., der Meij, B.R. van, Veraa, S., der Kolk, J.H. van, Wijnberg, I.D., Pille, F., Back, W., 2013. Pressure Plate Analysis of Toe–heel and Medio-Lateral Hoof Balance at the Walk and Trot in Sound Sport Horses. Vet. J. https://doi.org/10.1016/j.tvjl.2013.09.026

[30] Oosterlinck, M., Royaux, E., Back, W., Pille, F., 2014. A Preliminary Study on Pressure-plate Evaluation of Forelimb Toe–heel and Mediolateral Hoof Balance on a Hard vs. A Soft Surface in Sound Ponies at the Walk and Trot. Equine Vet. J. https://doi.org/10.1111/evj.12210

[30] Pagé, M.G., Katz, J., Stinson, J., Isaac, L., Martin-Pichora, A.L., Campbell, F., 2012. Validation of the numerical rating scale for pain intensity and unpleasantness in pediatric acute postoperative pain: Sensitivity to change over time. J. Pain 13, 359–369. https://doi.org/10.1016/j.jpain.2011.12.010

[31] Palmieri, R.M., Ingersoll, C.D., Stone, M.B., Krause, B.A., 2002. Center-of-Pressure Parameters Used in the Assessment of Postural Control. J. Sport Rehabil. 11, 51–66. https://doi.org/10.1123/JSR.11.1.51

[32] Pieh, C., Neumeier, S., Loew, T., Altmeppen, J., Angerer, M., Busch, V., Lahmann, C., 2014. Effectiveness of a Multimodal Treatment Program for Somatoform Pain Disorder. Pain Pract. 14, E146–E151. https://doi.org/10.1111/PAPR.12144

[33] Pomarino, D., Pomarino, A., 2014. Plantar Static Pressure Distribution in Healthy Individuals: Percentiles for the Evaluation of Forefoot Loading. Foot Ankle Spec. 7, 293–297. https://doi.org/10.1177/1938640014528973/ASSET/IMAGES/LARGE/10.1177_1938640014528973-FIG1.JPEG

[34] Rao, S., Baumhauer, J.F., Nawoczenski, D.A., 2011. Is barefoot regional plantar loading related to self-reported foot pain in patients with midfoot osteoarthritis. Osteoarthr. Cartil. 19, 1019–1025. https://doi.org/10.1016/j.joca.2011.04.006

[35] Taş, S., 2019. Investigation of Foot Pressure Distribution in Asymptomatic İndividuals With Mild Hallux Valgus. Bezmialem Sci. https://doi.org/10.14235/bas.galenos.2019.2906

[36] Tudor-Locke, C., Ainsworth, B.E., Whitt, M.C., Thompson, R.W., Addy, C.L., Jones, D., 2001. The Relationship Between Pedometer-Determined Ambulatory Activity and Body Composition Variables. Int. J. Obes. https://doi.org/10.1038/sj.ijo.0801783

[37] Ullén, F., Forsman, L., Blom, Ö., Karabanov, A., Madison, G., 2008. Intelligence and Variability in a Simple Timing Task Share Neural Substrates in the Prefrontal White Matter. J. Neurosci. 28, 4238–4243. https://doi.org/10.1523/JNEUROSCI.0825-08.2008

[38] Walsh, T.P., Butterworth, P.A., Urquhart, D.M., Cicuttini, F.M., Landorf, K.B., Wluka, A.E., Michael Shanahan, E., Menz, H.B., 2017. Increase in body weight over a two-year period is associated with an increase in midfoot pressure and foot pain. J. Foot Ankle Res. 10, 1–8. https://doi.org/10.1186/S13047-017-0214-5/FIGURES/3

[39] Wong, W.Y., Wong, M.S., Lo, K.H., 2007. Clinical applications of sensors for human posture and movement analysis: A review. Prosthet. Orthot. Int. 31, 62–75.

https://doi.org/10.1080/03093640600983949

[40] Yamamoto, T., Hoshino, Y., Kanzaki, N., Nukuto, K., Yamashita, T., Ibaraki, K., Nagai, K., Nagamune, K., Araki, D., Matsushita, T., Kuroda, R., 2020. Plantar Pressure Sensors Indicate Women to Have a Significantly Higher Peak Pressure on the Hallux, Toes, Forefoot, and Medial of the Foot Compared to Men. https://doi.org/10.21203/rs.3.rs-20441/v3