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The influence of gender and age on foot structure and plantar pressure in asymptomatic adults

Influência de sexo e idade na estrutura do pé e pressão plantar em adultos assintomáticos

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Abstract - The aim of the study was identify the influence of gender and age of healthy adults on the foot structure and the plantar pressure during gait. Sample comprising 608 women and men participants. To identify the structure of the foot, anthropometric measurements of both the total and the truncated length of the foot, the width of the forefoot, and the heights of the back and navicular were taken. Peak pressure and plantar contact area in three foot-masks (forefoot, middle foot, and hindfoot) were considered markers of plantar pressure. The data were analyzed by two-way variance analysis. No significant influence of age on the foot structure dimensions was identified; however, women presented measures equivalent to the five significantly smaller anthropometric markers. As for the peak plantar pressure, both males and females showed statistically similar values, but significant differences were observed for age. As to the plantar contact area, while age did not have significant influence, men showed significantly higher values in the three foot-masks. The findings suggest that gender influences the foot structure and the plantar contact area, while age influences the peak of plantar pressure.

Key words: Adults; Foot; Gait analysis; Pressure.

Resumo - *O objetivo do estudo foi identificar a influência de sexo e idade na estrutura do pé e na pressão plantar durante a marcha de adultos saudáveis. Amostra constituída por 608 participantes de ambos os sexos. Para identificar a estrutura do pé, foram realizadas medidas antropométricas equivalentes ao comprimento total e truncado do pé, à largura do antepé, às alturas do dorso e do navicular. Pico de pressão e área de contato plantar em três máscaras podais (antepé, médio pé e retropé) foram considerados marcadores de pressão plantar. Os dados foram analisados mediante análise de variância two-way. Não foi identificada influência significativa da idade nas dimensões da estrutura do pé; contudo, mulheres apresentaram medidas equivalentes aos cinco marcadores antropométricos significativamente menores. Quanto ao pico de pressão plantar, ambos os sexos apresentaram valores estatisticamente similares, porém diferenças significativas foram observadas com relação à idade. No caso da área de contato plantar, enquanto a idade não demonstrou influência significativa, os homens apresentaram valores significativamente maiores nas três máscaras podais. Os achados sugerem que o sexo exerce influência na estrutura do pé e na área de contato plantar, enquanto o pico de pressão plantar é influenciado pela idade.*

Palavras-chave: *Adultos; Pé; Análise de marcha; Pressão.*

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INTRODUCTION

Differences in plantar pressure related to gender and age have been investigated in previous studies[1,2]. As to age in particular, discordant patterns of plantar pressure were attributed to foot posture[3], body mass[4], and foot structure[5]. Furthermore, plantar pressure measures tend to increase progressively with age[1]. However, these studies focused on comparing young people, adults, and the elderly[5,6], and variations along adulthood have not yet been investigated.

Similarly, the effect of gender on plantar pressure has also been the subject of research. The findings show that men tend to have higher peak plantar pressure on the forefoot and higher plantar contact area on the masks of the forefoot and the hindfoot[7], with differences between the two genders being attributed to the anthropometric dimensions of the feet[8,9].

In addition, studies carried out among different populations reported differences in the foot structure between genders, pointing out that men have longer and taller feet than women[10,11,12]. However, these findings are not consistent in the literature, especially for adults[13].

A better understanding of the influence of gender and age on the foot structure and plantar pressure may provide relevant clinical information to identify musculoskeletal risk factors and foot pathologies. Therefore, we aim to investigate the influence of gender and age on the foot structure and plantar pressure of healthy adults gait. We hypothesize that there are significant differences between both genders and age in foot structure and plantar pressure.

METHODS

The Research Ethics Committee of the State University of Londrina has approved the study under number 3,171,583. After being informed about the nature, objectives, and methodological procedures of the investigation, the participants signed the Free and Informed Consent Term.

Participants

The sample comprised 608 apparently healthy participants (267 women and 341 men), aged 18 to 64, living in Londrina, Paraná, who voluntarily attended the invitation to participate in the study. The exclusion criteria were: (a) presence of pathologies that compromise gait, (b) temporary or permanent lesions of the lower limbs, (c) surgical procedures in the lower limbs, and (d) diagnosis of orthopedic, neurological, or cardiorespiratory pathologies.

Experimental procedure

Before data collection, participants completed a structured questionnaire to gather demographic data. Furthermore, body weight and height were measured to calculate the body mass index (the quotient of body weight in kilograms and height in meters elevated to the square - kg/m^2), and the foot posture index was established[14].

The foot posture index consists of six criteria related to the postural positioning of the foot with the individual in orthostatic and relaxed stance. Based on the investigator's observation, each item receives a score between -2 and +2. The sum of the scores varies from -12 to +12, highly pronated foot ranging 10 to 12, pronate 6 to 9, neutral 0 to 5, supine -1 to -4, and highly supine -5 to -12[14]. The index of foot posture showed acceptable reproducibility for both the final score and the individual items[15].

We used the foot anthropometry technique to measure the structure of the foot, comprising the total length of the foot (distance between the heel and the most distal segment of the foot), truncated length (distance between the heel and the 1st metatarsal-phalangeal joint), forefoot width (distance between the 10th and 50th metatarsus), the height of the back of the foot (height at 50% of the total length of the foot), the height of the navicular (distance from the navicular to the ground), and the height of the navicular normalized by the total length of the foot[16].

The plantar pressure was measured during gait (dynamic plantar pressure) using the FootWork Pro System (AM Cube, France). The equipment has an active surface of 49 x 49cm, thickness of 4mm, 4096 calibrated capacitive sensors, a 7.62 x 7.62mm sensor, frequency of 200Hz, and maximum pressure per sensor of 120N/cm^2. We calibrated the system for each measurement and according to the manufacturer's specifications. The necessary information of the participants was fed into the electronic system.

A three-step start-up protocol[17] was employed. After several attempts to get them acquainted with the measurement protocol, the appropriate starting position for a successful execution of the procedure was drawn on the floor. For the final data collection, the participants remained barefoot and were instructed to walk at a self-steering pace maintaining their usual gait pattern. Three tests were performed with the right foot, which is sufficient to ensure the reliability of the plantar pressure[18]. If the participant showed any of the rejection criteria mentioned below, he would repeat the procedure until reaching the number of treads required. The rejection criteria were: (a) the foot did not fully contact the platform, (b) intentional abnormalities in the gait observed by the researcher, (c) alteration in the gait rhythm to adjust the steps before contacting the platform, (d) unbalance during the gait, or (e) incomplete sequence of steps after contact with the equipment.

Plantar pressure was represented by measurements of the peak plantar pressure and plantar contact area in three plantar regions through the AutoMask function of the FootWork Pro 2.9.1 software: forefoot, midfoot, and hindfoot[19], corresponding, respectively, to 40%, 30%, and 30% of the total foot length (Figure 1). The regional plantar pressure peak was normalized by the overall plantar pressure peak of the foot.

Statistical analysis

The data were submitted to the Kolmogorov-Smirnov normality test. Upon confirmation of the normal distribution of the data, the mean and standard deviation values were calculated. To identify statistical differences between gender and age groups (18 - 34 years, 35 - 54 years, ≥ 55 years) of the foot structure and plantar pressure measures, a two-way analysis of variance was used, accompanied by the Fisher-Bonferroni multiple post-hoc comparison test. The data were analyzed using SPSS software for Windows version 25.0 (SPSS, Inc., Chicago, IL).

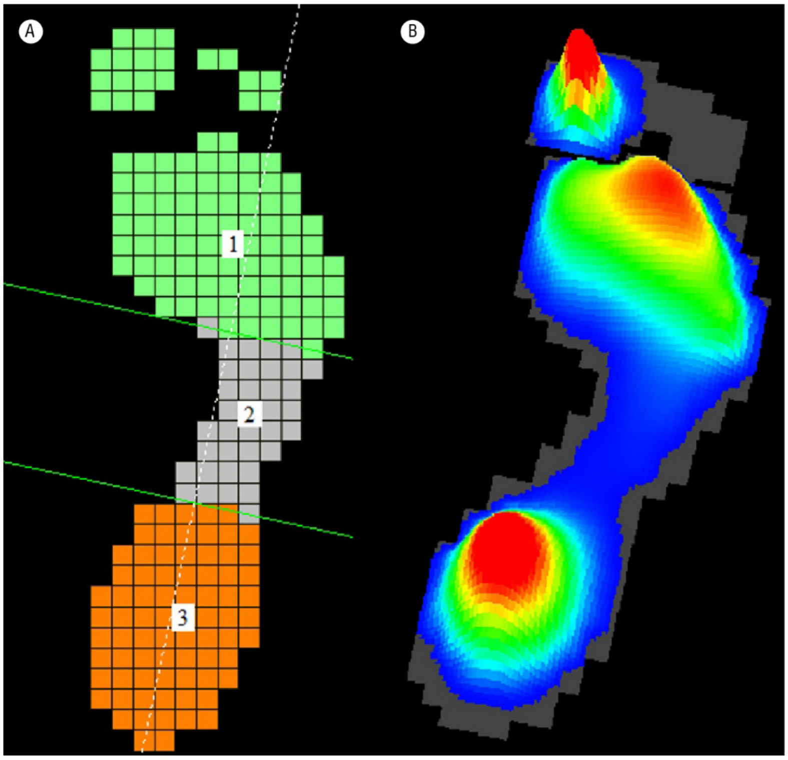

Figure 1. Distribution of plantar pressure. (A) Masking of the three anatomical regions used to identify the peak pressure and the plantar contact area: (1) forefoot; (2) midfoot; (3) hindfoot; (B) Distribution of peak plantar pressure during gait support phase.

RESULTS

Table 1 shows data concerning the anthropometric characteristics of the participants. Regarding the foot posture index, 57.9% of the participants presented a neutral foot, 14.3% a pronated foot, 5.9% an excessively pronated, 18.3% a supine, and 3.5% an excessively supine foot.

Table 1. General characteristics of the participants.

		Age (years)			F Test	
		18 – 34	35 – 54	≥ 55		
		(n = 188)	(n = 316)	(n = 104)	Sex	Age
Height (cm)	♀	164.85 ± 6.31	162.75 ± 7.25	162.62 ± 6.13	362.40	3.351
	♂	176.44 ± 8.09	177.04 ± 7.48	174.06 ± 7.90	p < 0.001	ns
Body weight (kg)	♀	64.10 ± 15.73	67.95 ± 12.54	67.43 ±10.57	137.36	4.750
	♂	79.35 ± 15.64	83.38 ± 14.36	80.99 ± 10.25	p < 0.001	p = 0.009
Body mass index (kg/m2)	♀	23.50 ± 5.01	25.68 ± 4.65	25.54 ±4.12	11.98	10.614
	♂	25.37 ± 4.10	26.49 ± 3.36	26.70 ± 2.94	p = 0.001	p < 0.000

Foot structure

Table 2 provides data regarding the foot structure. As for gender, men showed significantly higher values in five of the anthropometry measurements. However, the normalized navicular height was similar in both genders. As for age, only the forefoot width (F = 3.129; p = 0.042) showed a statistically significant difference.

Table 2. Equivalent measures to the structure of the foot (cm) according to sex and age.

		Age (years)			F Test		
		18 – 34	35 – 54	≥ 55			
		(a)	(b)	(c)	Sex	Age	Post-Hoc
Total length of the foot (cm)	♀	24.30 ± 1.60	24.72 ± 2.02	24.69 ± 1.84	131.85	3.351	a = b < c
	♂	27.89 ± 5.18	27.56 ± 2.39	27.06 ± 1.95	p < 0.001	ns	
Truncated length of the foot (cm)	♀	17.72 ± 1.92	17.95 ± 2.78	17.96 ± 1.73	112.260	1.512	
	♂	20.22 ± 2.11	20.59 ± 2.75	19.85± 1.91	p < 0.001	ns	
Height of the back of the foot (cm)	♀	6.84 ± 0.78	6.79 ± 0.82	6.78 ± 0.70	18.145	0.175	
	♂	7.06 ± 0.91	7.15 ± 1.01	7.25 ± 0.92	p < 0.001	ns	
Forefoot width (cm)	♀	9.12 ± 0.64	9.12 ± 0.54	9.37 ± 0.59	127.900	3.129	
	♂	9.50 ± 0.92	10.08 ± 0.96	10.23 ± 1.49	p < 0.001	p = 0.042	
Height of the navicular (cm)	♀	4.04 ± 0.70	4.14 ± 0.67	3.97 ± 0.56	72.149	1.281	
	♂	4.53 ± 0.86	4.66 ± 0.88	4.76 ± 0.73	p < 0.001	ns	
Height of the navicular normalized (cm)	♀	0.16 ± 0.02	0.16 ± 0.02	0.16 ± 0.02	3.431	0.641	
	♂	0.16 ± 0.03	0.17 ± 0.30	0.17 ± 0.02	ns	ns	

Plantar pressure

Table 3 shows the results of the plantar pressure indicators for the peak pressure and the plantar contact area in the three-foot masks for gender and age. As for the plantar contact area, the three foot-masks showed statistically significant differences between genders. In the foot mask regarding the forefoot, females presented lower values in the three age groups (F = 85.583; p < 0.001). However, the middle foot-masks (F = 18.439; p < 0.001) and the hindfoot-mask (F = 64.419; p < 0.001) showed higher values for males. As for the peak plantar pressure, there were no significant gender differences.

Table 3. Equivalent measures to plantar peak pressure and contact area according to sex and age.

		Age (years)			F Test		
		18 – 34	35 – 54	≥ 55			
		(a)	(b)	(c)	Sex	Age	Post-Hoc
Plantar Peak Pressure (kPa)							
Forefoot	♀	2.05 ± 0.36	2.01 ± 0.34	2.04 ± 0.35	1.520	2.433	
	♂	2.04 ± 0.31	1.95 ± 0.30	2.01 ± 0.33	ns	ns	
Midfoot	♀	0.72 ± 0.56	0.67 ± 0.51	0.92 ± 0.51	0.010	5.845	a = b < c
	♂	0.50 ± 0.47	0.65 ± 0.44	0.73 ± 0.46	ns	p = 0.003	
Hindfoot	♀	1.88 ± 0.40	1.69 ± 0.37	1.68 ± 0.38	0.083	10.005	a > b = c
	♂	1.80 ± 0.33	1.69 ± 0.33	1.73 ± 0.36	ns	p < 0.001	
Plantar Contact Area (cm2)							
Forefoot	♀	55.85 ± 8.92	56.04 ± 9.46	58.59 ± 11.25	85.583	1.881	
	♂	64.35 ± 10.55	65.57 ± 9.72	66.55 ± 10.66	p < 0.001	ns	
Midfoot	♀	10.06± 5.57	11.21 ± 5.02	12.86 ± 4.56	18.439	0.454	
	♂	14.54 ± 5.75	13.22 ± 5.07	12.76 ± 5.17	p < 0.001	ns	
Hindfoot	♀	35.87 ± 6.89	37.26 ± 6.37	38.59 ± 6.19	69.419	0.388	
	♂	43.05± 7.18	42.69 ± 6.12	41.39 ± 6.50	p < 0.001	ns	

Age did not show any significant influence on the plantar contact area measures. However, the plantar pressure peak showed statistically different measures in two of the three analyzed foot-masks. In the case of the medium foot-mask, the highest measurements were identified in age group ≥ 55 ($F = 5.845$; $p = 0.003$), while in the hindfoot-mask age advancement showed significantly lower measurements ($F = 10.005$; $p < 0.001$). In turn, age showed no significant differences in the peak plantar pressure measurements for the forefoot-mask.

DISCUSSION

The study investigated the influence of gender and age on the foot structure and plantar pressure of healthy adults. Our findings suggest that gender influences the structural foot dimensions and plantar contact area, while age seems to influence the peak plantar pressure on the middle, especially the middle and hindfoot.

The structure of the foot has been associated with musculoskeletal pain in the lower limbs[20]. Changes in the foot structure result in repetitive mechanical stress, friction, and changes in the distribution of plantar pressure[3]. Few studies, however, have investigated the potential influence of gender and age on the foot structure, especially in adults. Anthropometric analysis of the foot showed that the foot circumference is higher in older adults than in young adults[21]. Another study examined differences in the foot structure in older men and women, indicating that men tend to have higher anthropometric foot dimensions than women[9].

The current study has shown that male feet are longer, measured by total and truncated length of the foot, higher, measured by the height of the dorsum and the navicular, and wider, measured by the width of the forefoot. Our results are consistent with previous studies, which showed the dimensions of the foot dorsum, length, perimeter, and forefoot width to be smaller in women than in men[13,22].

On the other hand, our results are conflicting with previous studies in which women presented significantly higher foot width, truncated standard length, and smaller foot height measurements compared to men[23,24]. The inconsistency may derive from ethnic and cultural differences, measurement instruments, and the age of participants.

Gender-related differences in plantar pressure have been investigated in several populations in an attempt to point gender out as one of the predisposing factors to musculoskeletal injuries. In fact, studies have shown that indicators associated with plantar pressure are discordant between genders, both in the elderly[6] and adolescents[2], which is in line with the results of this study. However, our study also found that females and males at different ages demonstrate discordant patterns of plantar pressure, thereby offering new conceptions for the area of knowledge.

The plantar peak pressure is defined as the highest pressure value recorded by each sensor during the entire period of the gait support phase[25]. Clinically, high values of peak plantar pressure contribute to the onset of plantar pain and ulceration. Our study showed no gender influence on peak plantar pressure, which corroborates findings from previous studies[26,27].

On the other hand, a study involving adolescents showed that the peak plantar pressure in the hallux was higher in females than in males. Similarly, women showed higher peak plantar pressure in the hallux, toes, forefoot, and medial side of the foot than men. These gender differences may be explained by the female's pelvic position[28] and justify the higher prevalence of hallux valgus in females[29].

Another study did not report significant differences for the contact area and plantar pressure values between males and females[28]. Likewise, the plantar pressure indicators of the peak plantar pressure, contact time, pressure-time integral, and peak pressure instant did not show significant differences; however, the plantar contact area and the force-time integral were significantly higher in males[26].

These inconsistent results are likely related to different experimental conditions, including the equipment used for measuring plantar pressure, pressure platforms or in-shoes systems, gait speed control, foot area considered, and plantar pressure indicators.

The results of this study should only be interpreted after considering the following limitations. Plantar pressure was measured at a self-selected speed; however, gait speed may influence the plantar pressure indicators, so it is to be controlled. The participants were barefoot when measured on the pressure platform, which invalidates inferences when walking with shoes. Additionally, the baropodometry equipment measures only the perpendicular forces acting on the sensors, which offers limited information on gait activities. Finally, the foot structure measurements were obtained by indirect and two-dimensional methods. Hence, they do not reflect the volume dimensions of the feet and offer limited accuracy.

CONCLUSION

The results of the study showed that gender influences the structure of the foot and the plantar contact area, as males showed significantly higher anthropometric dimensions of the foot and plantar contact area than females. Furthermore, age influences the peak plantar pressure during gait, especially for the middle and hindfoot. We recommend that, for the proper prescription of orthoses and therapeutic footwear, the anthropometric gender differences of the feet should be taken into account. Additionally, since peak plantar pressure is associated with pain and discomfort, we suggest special attention to identified age-related differences.

COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

Ethical approval was obtained from the local Human Research Ethics Committee – State University of Londrina and the protocol (no. 3.171.583) 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 experiments: DPG; Performed experiments: FRPGR; Analyzed data: DPG; Contributed with reagents/materials/analysis tools: FRPG, DPG; Wrote the paper: FRPG; DPG.

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