The Effect of Gender on Foot Anthropometrics in Older People

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Context: Some questions remain regarding the anthropometric differences between the feet of young men and women, but the gap is much greater when dealing with older adults. No studies were found concerning these differences in an exclusively older adult population, which makes it difficult to manufacture shoes based on the specific anthropometric measurements of the older adult population and according to gender differences. Objective: To identify differences between the anthropometric foot variables of older men and women. Design: Cross-sectional. Participants: 154 older women (69.0 ± 6.8 y) and 131 older men (69.0 ± 6.5 y). Main Outcome Measures: The foot evaluations comprised the variables of width, perimeter, height, length, 1st and 5th metatarsophalangeal angles, the Arch Index (AI), and the Foot Posture Index (FPI). A data analysis was performed using t test and a post hoc power analysis. Results: Women showed significantly higher values for the width and perimeter of the toes, width of the metatarsal heads, and width of the heel and presented significantly lower values for the height of the dorsal foot after normalization of the data to foot length. The 1st and 5th metatarsophalangeal angles were smaller in the men. There were no differences between men and women with respect to AI and FPI. Conclusions: Overall, the current study shows evidence of differences between some of the anthropometric foot variables of older men and women that must be taken into account for the manufacture of shoes for older adults.

Keywords: aging, anthropometry, feet, elderly

Senescence induces anatomical modifications in all body segments. Postural modifications occur in the feet, and, in the study of Scott et al.,⁠¹ pes planus and pronated feet were more commonly observed in older adults than in a group of young adults. Otsuka et al.⁠² found a high prevalence of pes planus in older men (26.5%) and in older women (25.7%), even though some studies have failed to find an association between age and the height of the arch of the foot when studying a wide age range.⁠³⁴

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Hallux valgus is also observed, and this condition is frequently accompanied by a bony exostosis of the first metatarsal head, which may cause an increase in its height and in the width of the forefoot.\textsuperscript{5,6} Other factors responsible for the increased volume of the forefoot may be related to toe deformities developed over a long period of time or the many nail problems presented by older adults.\textsuperscript{7,8} One study compared the length and width of the feet of 668 older adults and concluded that most of the feet were wider than the shoes available in their size.\textsuperscript{9} Shoe manufacturers use molds of the feet of young adults for their shoe designs, so it is easy to understand why older people have so much difficulty in finding safe, comfortable shoes.

These anatomical changes can occur differently for men and women; differences are observed from childhood.\textsuperscript{10,11} After evaluating the absolute values of the foot measurements of adults, some authors have reported that on average men’s feet have greater length, width, height, and volume than women’s feet.\textsuperscript{12,13} It has also been reported that, for a given height, men had longer and wider feet than women.\textsuperscript{14–16}

Pes planus, generally associated with valgus of the calcaneus and abduction of the forefoot,\textsuperscript{17} presents a strong correlation with ligament laxity and obesity,\textsuperscript{3} which leads to the supposition that women may present flatter and more abducted feet than men. Frey\textsuperscript{18} explained how the structural changes in the female body lead to pronation of the foot: Compared with men, women have narrower shoulders, hips in a more varus position, and knees in a more valgus position, inducing pronation of the rear feet. However, in a survey with 441 individuals 1–80 years of age, the Arch Index (AI) was significantly greater in the males, indicating that males have flatter feet.\textsuperscript{19}

Although some questions remain regarding the anthropometric differences between the feet of young men and women, the gap is much greater in older adults. We could find no studies concerning these differences in an exclusively older adult population, which makes it difficult to manufacture shoes based on the specific anthropometric measurements of the older adult population and according to gender differences. Considering this, we suggested the hypothesis that there are gender-related differences in the foot anthropometrics of older adults. Thus, this study aimed to identify the differences between the anthropometric foot variables of older men and women.

Methods

Design
This was a cross-sectional study.

Participants
The sample was calculated considering the older adult population of the city of São Carlos, São Paulo, Brazil, and the sex quotas in the investigated age groups. In 2000, in the city of São Carlos, approximately 75% of older adults were age 74 years or less, and approximately 25% were age 75 or older.\textsuperscript{20} In the state of São Paulo, approximately 44% of older adults 60–74 years of age were men and approximately
Gender Differences in Foot Anthropometrics

56% were women. Among older adults age 75 or over, approximately 38% were men and 62% women. Thus, data were collected from 167 women and 132 men age 60–74 years and 60 women and 40 men age 75 and over. Those who reported having diabetes or rheumatic disease were excluded, leaving 154 women with a mean age of 68.97 (± 6.80) years and 131 men with a mean age of 69.05 (± 6.49). The women had a mean weight of 64.7 kg (± 11.7), a mean height of 1.53 m (± 0.06), and a mean body-mass index of 27.7 (± 4.7). The men had a mean weight of 72.6 kg (± 13.8), a mean height of 1.65 m (± 0.07), and a mean body-mass index of 26.5 (± 4.4). There was no randomization in the selection of the participants, which was done by convenience, using participants from the data-collection sites most accessible to the researchers.

**Procedures**

The data were collected from the Open University for Older Adults, the Health Care Unit of the Federal University of São Carlos, and 2 basic health units in the city of São Carlos. The supervisors of each site allowed the researchers access to the patients’ charts, and invitations for an interview were made over the phone. The patients who agreed to participate received information about the study and signed a consent form. The Research Ethics Committee of the Federal University of São Carlos, São Paulo, Brazil, approved the study.

During the anthropometric evaluation of the feet, the participants remained barefoot in the standing position with equal weight distribution on both legs. Using direct measurements, the variables of foot length, perimeter, width, and height were measured as described by Manfio and Avila. The foot length was measured using a caliper adjusted to reach the most prominent point of the calcaneal tuberosity region and the tip of the longest toe. The ruler of the caliper was positioned parallel to the longitudinal axis of the foot (midheel to second toe).

The following widths were also measured using the caliper: width of the toes, of the metatarsal heads, and of the heel. The width of the toes is the distance between the most prominent part of the medial region of the tuberosity of the distal phalanx of the first toe and the most prominent lateral region of the middle phalanx of the fifth toe. The width of the metatarsal heads is the distance from the most prominent point of the medial region of the tuberosity of the first metatarsal head to the most prominent point in the lateral region of the tuberosity of the fifth metatarsal head. The width of the heel is the distance between the most prominent points in the medial and lateral regions of the calcaneus.

The following perimeters were measured using a fiberglass tape measure: perimeter of the toes, the metatarsal head, and the instep. The perimeter of the toes is the perimeter of the vertical cross-section of the foot taken along the line through the most prominent part of the medial region of the tuberosity of the distal phalanx in the first toe and through the most prominent lateral region of the middle phalanx of the fifth toe. The perimeter of the metatarsal heads is the perimeter of the vertical cross-section of the foot taken along the line that goes through the most prominent part of the region of the tuberosity of the first and fifth metatarsal heads. The perimeter of the instep is the perimeter of the vertical cross-section of the foot at the most prominent region of the navicular bone.
Heights were measured using a portable height rod, including the height of the first toe, the first metatarsal head, and the dorsal foot. The height of the first toe is the vertical distance from the floor to the upper region of the base of the distal phalange of the first toe. The height of the first metatarsal head is the vertical distance from the floor to the upper region of the first metatarsal head. The height of the dorsal foot is the vertical distance from the floor to the most prominent region of the navicular bone.

The first and the fifth metatarsophalangeal angles were also measured with a toe goniometer. As proposed by Norkin and White, the goniometer was placed on the dorsal face of the foot with its fulcrum centered on the metatarsophalangeal joint. The proximal arm of the instrument was aligned with the first metatarsus, and the distal arm, with the medial line of the proximal phalange. The degree was considered positive when there was valgus of the first toe or varus of the fifth toe and negative when there was varus of the first toe and valgus of the fifth toe.

The same assessor took all the measurements, making certain that the instruments exerted minimal pressure on the skin. Before the evaluation, the instruments were sanitized with 70% alcohol, and the anatomical landmarks of the foot were marked to ensure that the measurements were always taken from the same place.

With the participant remaining in the standing position, the postural assessment of the foot was carried out using the Foot Posture Index (FPI) described by Redmond et al and already validated for use in older adults by Menz and Munteanu. Using this instrument consists of adding up the values given in 6 assessment criteria, scored using whole numbers from –2 to +2, and thus the total score could range from –12 (indicating maximal supination) to +12 (indicating maximal pronation). The criteria are (1) talar head palpation, which scores positive points when the talar head is medially more palpable and negative points when the talar head is laterally more palpable; (2) comparison of the curves above and below the lateral ankle malleolus, in which case, if the infralateral malleolar curvature is more concave than the supra-, it scores positive points, and vice versa; (3) calcaneal frontal-plane position, in which eversion of the calcaneus scores positive points, and inversion, negative points; (4) evaluation of the region of the talonavicular joint, for which a convex curvature scores positive points, and concavity, negative points; (5) height and congruence of the medial longitudinal arch, which scores positive points in the case of a lowered arch with flattening in the central portion and negative points in the inverse case; and (6) alignment of the forefoot on the rear foot (posterior view), which scores positive points when there is abduction of the forefoot on the rear foot and negative points in the inverse.

For the longitudinal arch assessment, we used the AI described by Cavanagh and Rodgers and already validated for older adults. The footprints were taken by the same assessor, using a podograph. The participants were instructed to place one foot next to the podograph and the other one on it, placing the body weight equally on both legs. They were also instructed to remove the foot that was on the podograph first to ensure that the complete weight of the body was never on the foot being evaluated.

The footprints were scanned and converted to images, which were then redrawn using AutoCAD 2005. The first line drawn was the longitudinal axis of the foot, which joins the center of the second toe and the center of the heel. Perpendicular to this line, 2 more lines were drawn, tangent to both the superior and the inferior
Gender Differences in Foot Anthropometrics

edged of the plantar area. Between these 2 lines, another 2 were drawn, dividing the plantar area into 3 parts of equal length (Figure 1). The AI is the ratio of the area of the middle one-third of the footprint to the total area. As suggested by Cavanagh and Rodgers, an AI equal to or less than 0.21 is indicative of a high arch, an AI between 0.21 and 0.26 indicates a normal arch, and an AI equal to or greater than 0.26 indicates a flat or low arch.

Some of the studied anthropometric variables usually depend on foot length and must be adjusted according to this variable to compare individuals with different foot sizes. To identify these variables in the participants, we performed a Pearson correlation that showed significant correlation between foot length and the perimeter, width, and height, which were substituted by the variable $k$, described by Chouquet-Stringer and Bernard as the value of the measurement multiplied by 100 and divided by the foot length, resulting in the percentage ratio of foot length.

Statistical Analyses

The gender-related differences of each variable were evaluated using a 2-sample $t$ test with a significance level of 5%, performed between men’s and women’s absolute values of the first and fifth metatarsophalangeal angles, AI and FPI, and the relative values of the widths, perimeters, and heights (normalized to the foot length). We also performed a post hoc power analysis. A random choice was made between the data of the right and the left feet, and the data from the right feet were selected.
Results

A t test revealed that the women’s feet were proportionally wider than the men’s, whose feet had proportionally larger values for height of the dorsal foot. The first and fifth metatarsophalangeal angles were greater among women, and the AI and FPI did not reveal significant differences between genders (Table 1).

Discussion

Among the limitations of this study, we should point out the use of analog instruments instead of the more precise digital ones. In addition, although the participants with self-reported rheumatism and diabetes had been excluded from this study, other conditions were not investigated; therefore there is no guarantee that the population studied really has healthy feet. In spite of that, the feet evaluated may represent well the older adult population in general, who suffer from several foot problems, and manufacturers must take this into account when fabricating shoes.

Many gender-related differences were observed in this study. The older women had proportionally wider feet than the men, and the latter had proportionally greater height of the dorsal foot. It is important to point out that for the variables for which t test did not show significant differences, there was no sufficient power to detect it. Considering the width of the heel, the difference between genders was only 3 mm, which may lead to questions about the clinical relevance of such finding. In clinical practice, this difference or more than this may not influence the evaluation or the treatment. However, regarding shoe manufacturing, differences as we found in the perimeter of the toes (of 1.3 cm) can be important once the excess of pressure on the toes is a relevant problem related to wearing shoes in older people.

No previous studies were found relating to such gender-related differences in an older adult population—only studies with young or mixed-age populations. These studies present contradicting results, with the exception of Krauss et al., who showed that, for the same shoe size, young women had smaller values for the height of the instep than young men. In contrast, they found that women presented smaller values for the widths of the heel and the forefoot, which opposes our results. Anil et al. also compared foot measurements in the same foot-length category and observed that foot width and perimeter were greater in males than in females. Wunderlich and Cavanagh also normalized the data to the foot length and found some differences when studying the feet of young adults. Women’s feet had smaller values for the height of the first toe and for the perimeter of the instep. Thus, it can be seen that, in youth, the gender-related differences in foot height are the same as in older adults, but the gender-related differences in perimeters and widths, especially of the forefoot, vary with age: Young women have smaller volume in the forefoot than young men, and older women have greater volume in the forefoot than older men. This may be a result of the common foot problems that affect older adults, especially women and in the forefoot region, such as hallux valgus and toe deformities.

The first and fifth metatarsophalangeal angles were significantly greater in women. The presence of hallux valgus can explain the larger values found among the women, because it occurs more frequently in women. Evaluations of joint
<table>
<thead>
<tr>
<th></th>
<th>Women (n = 154)</th>
<th>Men (n = 131)</th>
<th></th>
<th>Post hoc power analysis</th>
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<tbody>
<tr>
<td></td>
<td>Mean ± SD (95% CI)</td>
<td>% of foot length</td>
<td>Mean ± SD (95% CI)</td>
<td>% of foot length</td>
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<tr>
<td>Width of the toes (cm)</td>
<td>9.5 ± 0.6 (9.5–9.7)</td>
<td>40.3</td>
<td>10.1 ± 0.7 (10.0–10.3)</td>
<td>39.1</td>
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<tr>
<td>Width of the metatarsal heads (cm)</td>
<td>9.9 ± 0.6 (9.8–9.9)</td>
<td>41.2</td>
<td>10.5 ± 0.7 (10.4–10.6)</td>
<td>40.6</td>
</tr>
<tr>
<td>Width of the heel (cm)</td>
<td>6.7 ± 0.4 (6.6–6.8)</td>
<td>28.1</td>
<td>7.0 ± 0.4 (6.1–7.1)</td>
<td>27.0</td>
</tr>
<tr>
<td>Perimeter of the toes (cm)</td>
<td>21.8 ± 1.4 (21.6–22.0)</td>
<td>91.4</td>
<td>23.1 ± 1.6 (22.8–23.3)</td>
<td>89.0</td>
</tr>
<tr>
<td>Perimeter of the metatarsal heads (cm)</td>
<td>23.7 ± 1.3 (23.5–23.9)</td>
<td>99.3</td>
<td>25.6 ± 1.4 (25.3–25.8)</td>
<td>98.6</td>
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<tr>
<td>Perimeter of the instep (cm)</td>
<td>23.4 ± 1.2 (23.2–23.6)</td>
<td>97.9</td>
<td>25.6 ± 1.3 (25.4–25.8)</td>
<td>98.7</td>
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<tr>
<td>First metatarsophalangeal angle (°)</td>
<td>12.03 ± 8.40 (10.7–13.4)</td>
<td>10.10 ± 6.56 (9.0–11.2)</td>
<td>.030</td>
<td>.63</td>
</tr>
<tr>
<td>Fifth metatarsophalangeal angle (°)</td>
<td>9.68 ± 6.56 (8.6–10.7)</td>
<td>8.28 ± 4.78 (7.5–9.1)</td>
<td>.039</td>
<td>.56</td>
</tr>
<tr>
<td>Height of the first toe (cm)</td>
<td>2.1 ± 0.3 (2.1–2.2)</td>
<td>8.9</td>
<td>2.3 ± 0.3 (2.3–2.4)</td>
<td>9.1</td>
</tr>
<tr>
<td>Height of the first metatarsal head (cm)</td>
<td>3.1 ± 0.3 (3.1–3.2)</td>
<td>13.1</td>
<td>3.5 ± 0.3 (3.4–3.5)</td>
<td>13.3</td>
</tr>
<tr>
<td>Height of the dorsal foot (cm)</td>
<td>5.8 ± 0.6 (5.7–5.8)</td>
<td>24.1</td>
<td>6.6 ± 0.5 (6.5–6.7)</td>
<td>25.5</td>
</tr>
<tr>
<td>Arch Index</td>
<td>0.234 ± 0.049 (0.226–0.242)</td>
<td></td>
<td>0.226 ± 0.049 (0.217–0.234)</td>
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<tr>
<td>Foot Posture Index</td>
<td>0.90 ± 2.22 (0.55–1.25)</td>
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<td>0.79 ± 2.31 (0.40–1.19)</td>
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CI, confidence interval.
surfaces using a 3-dimensional laser scan suggest that female bones have a greater potential for movement in the direction of adduction, possibly resulting in the first metatarsal of females being more adducted (varus), leading to valgus of the first metatarsophalangeal joint. However, it is important to point out that a diagnosis of hallux valgus does not depend on a single joint angle, as investigated in this study, but also on the angle between the first and the second metatarsals in the transverse plane. The increase in the fifth metatarsophalangeal angle, which may characterize varus of the fifth toe, can also be a consequence of hallux valgus, which would explain the greater values observed in the women.

In the current study, the test did not have sufficient power to evaluate the differences regarding the AI and the FPI (power = 30% and 7%, respectively), and the results of studies on young people are contradictory. In a study with 145 individuals 18–65 years of age, Zifchock et al studied the dorsal height normalized according to foot length and found no difference between men and women with regard to arch height. Hashimoto et al used radiography, a more reliable method, to verify the arch height in young adults and noted that the women had lower arches than the men. In fact, we were expecting this same result, given that men presented a significantly higher dorsal foot and no gender-related differences were found between the perimeters of the instep. Nevertheless, the AI means of older adults were in the normal range (0.21–0.26), and FPI means were slightly above zero—reflecting normal position according to a study that aimed to establish normative FPI reference values. This may indicate that foot posture is not a relevant factor to be considered in the shoe manufacturing process.

Conclusions

The lack of standardization of data-collection methods and approaches for data analysis make it difficult to compare the results of this study with those of other studies. Overall, however, the current study provided evidence of some differences between the anthropometric foot variables of older men and women. They may not have clinical relevance, but they must be taken into account for the manufacture of shoes specifically for older adults.

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References


