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Impact of Anthropometric Foot Measurements on Gender - Specific Shoe Design for University Students

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Abstract: The human foot is a complex biomechanical structure that plays a fundamental role in locomotion, balance, and overall well-being. For university students, who often engage in diverse activities ranging from academic pursuits to sports and social engagements, well-fitting footwear is not merely a matter of comfort but a critical determinant of health, performance, and injury prevention. This study employed a descriptive survey design to investigate anthropometric foot measurements for gender-specific shoe design among university students. A convenience sample of (100) males and (100) females was drawn from the Mechanical and Industrial & Production Engineering departments. Data collection utilized the Arch Height Index Measurement System (AHIMS), capturing standing foot length, width, dorsum height, and truncated length, along with Arch Height Index (AHI) in sitting and standing positions. Data analysis was performed using SPSS, employing descriptive statistics and Pearson's Product Moment Correlation Coefficient at a (0.05) significance level to test hypotheses. Descriptive statistics revealed gender differences; for instance, males had a higher mean standing foot width ([8.8187]) but also greater variability, while females showed larger mean standing foot length ([20.2323]) and dorsum height ([20.2323]). Most distributions were non-normal, with high skewness and kurtosis noted in male foot width and length. Correlation analyses indicated no significant linear relationship between standing foot length and width for either gender (male: r=[0.001], p=[0.994]; female: r=[0.045], p=[0.656]). However, a perfect and highly significant correlation was found between standing foot length and dorsum height for both males and females (r=[1.000], p=[0.000]). Lastly, no significant correlation existed for standing truncated length between genders (r=[0.060], p=[0.554]). These findings underscore the necessity of a multi-dimensional, gender-specific approach to shoe last design. The study concludes that footwear for university students must move beyond generic models, incorporating precise anthropometric data to ensure optimal fit, comfort, and support, thereby preventing foot-related issues and enhancing overall well-being.

Keyword: Anthropometry, Foot Measurements, Gender-Specific Design, Shoe Design, University Students.

INTRODUCTION

Footwear design and making is a complex process where accurately defined human foot anthropometry is needed in order to make the shoe comfortable, functional and durable. When correct anthropometric measures are used, it allows the designers to develop shoe frames that matched the shape of the feet, improving ergonomic fit that can prevent discomfort or injury. Researchers have demonstrated that combining high-tech materials with new modeling methods can help to maximize the performance of shoe soles and keep them structurally sound (Okafor et al., 2022). The relevant nature of such approaches then underlines the practical significance of integrating biomechanical knowledge with material science in effective and user-specific footwear manufacturing. Finding a good fit of shoes provides comfort, posture, and overall foot health. Proper fit is complemented by well-designed sole that offers enough cushioning, stability, and support. When the biomechanics of the shoe sole fit the anatomy of the foot, it lowers pressure points, eliminates injuries, and improves the efficiency of walking, thus increasing the overall performance and durability of the footwear (Okafor et al., 2024).

Poorly fitting shoes are a widespread issue, the manifestation of which runs the gamut of inconvenience and pain to severe foot abnormalities, gait annoyances, and even systemic health drawbacks (Branthwaite & Chockalingam, 2019). People also have difficulties finding an appropriate pair of shoes to fit their own foot size, and they end up getting ill-fitted shoes that are either too small, too big, or in a bad shape that it does not fit their bones. This universal problem reflects an extremely large gap in the context of using such meticulous anthropometric data in designing a shoe, especially with the regard to the unique morphological differences between male and female feet. Thusly, the in-depth discussion of particular foot measures and their correspondence to the design of footwear, focusing on gender-related statistics, is vital to the improvement of comfort, health, and performance of shoe designers.

An important shoe measurement is the foot width, which is measured at the widest point of the forefoot when standing. In both sexes, foot width should be measured accurately to avoid compression along the sides of the foot, pinching, forefoot pain (Scovel, 2020). In weight-bearing activities, the foot spreads automatically, putting on more width. If a shoe's width does not adequately accommodate this expansion, it can lead to conditions such as bunions, hammertoes, and neuromas. Gender-specific width measurements are crucial because, on average, female feet tend to be narrower in proportion to their length compared to male feet, and they often exhibit a different forefoot-to-heel width ratio (Silva et al, 2022). Designing shoes with gender-appropriate width allowances ensure a secure yet non-constricting fit, promoting foot health and comfort.

Standing foot length, measured from the heel to the longest toe, is arguably the most fundamental measurement for determining shoe size. Its relevance lies in ensuring adequate lengthwise space within the footwear, preventing toe compression, and allowing for natural foot movement during gait (Chiroma et al, 2015). Insufficient length can lead to painful toe impingement, nail damage, and blistering, while excessive length can cause foot slippage within the shoe, leading to instability and friction. Separate measurements for males and females are indispensable because, on average, male feet are longer than female feet.

However, simply scaling down male shoe sizes for females often results in an improper fit due to other proportional differences, necessitating distinct sizing charts and last designs for each gender (Charmode & Kadlimatti, 2019).

Standing truncated length, often measured from the heel to the first metatarsophalangeal (MTP) joint (the "ball" of the foot), is critical for aligning the shoe's flex point with the foot's natural flex point. This measurement is vital for ensuring proper arch support and instep fit. If the shoe's flex point does not align with the foot's, it can lead to arch strain, discomfort, and inefficient gait mechanics (Saha, 2022). For shoes with specific arch support features, truncated length guides the placement and contouring of these elements to provide effective support without creating pressure points. Gender differences in foot arch structure and the position of the MTP joints mean that truncated length measurements must be considered separately to create anatomically appropriate footwear for both men and women.

Instep height or Standing dorsum height is the vertical distance between the ground and the highest point of the instep. This dimension is important to calculate the volume of the shoe vamp area (the upper part of a shoe which covers the instep). Sufficient height of the dorsum that prevents excessive pressure on the top of the foot, leading to the discomfort, limited blood supply, and squashing of the nerves (Guo et al, 2025). On the other hand, excessive volume might result in a free fit concerning the midfoot, which makes it unstable and slippery. Differences in muscle mass, fat distribution (including localised fat pads) and bone structure cause gender differences in instep height, which means that male and female footwear require different design strategies to impart a feeling of snugness coupled with comfort around the midfoot.

The right fitting shoe may have an impact on the quality of learning due to the possibility of physical comfort, lessened distractions and concentration facilitation, particularly among learners who spend lengthy hours on feet. Variations between male and female foot dimensions, such as width, arch height, and toe length, require gender-sensitive designs that address these anatomical differences within specific populations. In educational settings, ignoring these differences can lead to discomfort, fatigue, and reduced productivity, undermining the development of human potential (Mbuba, 2016, Mbuba, 2022a). Addressing ergonomic needs through proper shoe fitting supports well-being and learning, contributing to human capital development and long-term societal growth (Mbuba, 2022b). The motivation for the present study arises from the growing awareness that footwear design often fails to account for anatomical variations between male and female feet, particularly within specific populations.

Previous research indicates that most commercial shoe designs are based on Western anthropometric data, which may not accurately represent the foot dimensions of other ethnic or regional groups (Ezawa et al, 2024). This mismatch can lead to discomfort, reduced performance, and increased risk of foot-related disorders (Wang et al, 2024). Among university students, prolonged walking and standing are common, making footwear comfort and fit essential for health and academic productivity. However, studies reveal limited region-specific data on the foot anthropometry of young adults in developing countries (Limon et al, 2023). Furthermore, gender differences in foot shape—such as arch height, forefoot width, and heel-to-ball length—are often overlooked in mass production. This gap results in “unisex” shoe models that may not optimally fit either gender.

Hypotheses

1. There is no statistically significant linear relationship (correlation) between standing foot length and standing foot width among male university students.
2. There is no statistically significant linear relationship (correlation) between standing foot length and standing foot width among female university students.
3. There is no statistically significant linear relationship (correlation) between standing foot length and standing dorsum hight among male university students.
4. There is no statistically significant linear relationship (correlation) between standing foot length and standing dorsum hight among female university students.
5. There is no statistically significant linear relationship (correlation) between Standing truncated length among male and female university students

Theoretical framework

The study was guided by Ergonomic Fit Theory. Ergonomic Fit Theory originates from the broader discipline of human factors and ergonomics, a scientific field concerned with optimizing the interaction between humans, equipment, and their environment to enhance health, comfort, and performance. Although it does not have a single identifiable founder, the theory draws heavily from the contributions of ergonomics pioneers such as Grandjean (1980), who emphasized that products and systems should be designed to fit the human body, rather than forcing the body to adapt to poorly designed tools or environments. The central idea is that the dimensions, shapes, and proportions of products must align closely with the body dimensions of the intended users, ensuring comfort, efficiency, and safety. The theory maintains that fit extends beyond static dimensions to include functional comfort, which involves reducing strain, enhancing movement efficiency, and preventing injury. It also focuses on the relevance of user-centred design so that variations in size, shape and functional requirements (gender issues), are embedded in the design process. Besides this, it recognizes that human body is dynamic and an ergonomic design should be adaptable to body changes as it moves around or bears a load or in other undertakings.

Ergonomic Fit Theory offers a conceptual underspin when applied to the present study. The length, width, arch height, and stiffness of feet are some of the differences that students at the university reveal in foot dimensions with a significant difference that occurs in foot dimensions between males and females. The theory contends that these gender-determined anthropometric differences must be taken into consideration in shoe design to guarantee fit, prolonged comfort, and injury-free models. An example might be that male students have wider forefeet or stiffer arches than female students do and might exhibit longer truncated lengths as well as more flexibility in the arch, then ergonomic fit principles would imply that the shoe lasts, material and structural support would need to be adjusted to accommodate these differences. The active form of foot morphology also supports the use of this theory. Some measurements include the Arch Height Index (ALI) and Arch Rigidity Index (ARI) that measure alterations in the foot structure in loaded on a standing or walking position, and ergonomic design would promote construction of adaptive shoe features, including flexible materials or changeable support areas, to adapt to the changes in the standing and walking conditions. This is how Ergonomic Fit Theory informs bringing highly accurate anthropometric foot data into shoe designing so that the footwear fits exactly with the users not only dimensionally but also with their biomechanical and comfort requirements so that they can meet them as well as perform and remain well.

METHOD

A descriptive survey research design was used in the study and it was found to be suitable in a systematic collection and quantitative analysis of anthropometric measures devoid of manipulating variables. This intervention allowed exploring the correlations among foot measurement and gender shoe design in university students. The research was carried out in the Department of Mechanical Engineering and the Department of Industrial and Production Engineering, both under the Faculty of Engineering at Nnamdi Azikiwe University, Awka. The institution operates on the philosophy that knowledge should be disseminated without restriction. These departments were selected because they provided a suitable and accessible population for the study. The population consisted of 200 students (sample of (100) males and (100) females) drawn from the two departments, selected through a convenience sampling technique, which allowed easy access to willing participants across different academic levels.

Data were collected using the Arch Height Index Measurement System (AHIMS), an instrument designed to measure the ratio of arch height to truncated foot length, producing the Arch Height Index (AHI). It also allows the calculation of the Arch Rigidity Index (ARI), which compares AHI values during standing and sitting to assess foot stiffness or flexibility. Measurements were taken over a five-day period, with AHI recorded for each participant in both sitting and standing positions. Arch height was measured by positioning a horizontal bar at the midpoint of the total foot length from the heel, lowering it to rest on the dorsum of the foot, and recording the height relative to the heel and forefoot in both conditions. Truncated foot length was also recorded in sitting and standing positions to capture changes due to load bearing, and for highly flexible feet, additional weight-bearing measurements were taken with the mid-foot unsupported to assess maximum arch deformation. In each case, the heel was placed against the heel cup, with sliding callipers aligned to the distal phalanx and first metatarsal head, and a third calliper positioned at the dorsal arch midpoint.

The instrument and measurement procedure were reviewed by experts in biomechanics and ergonomics to ensure accuracy, clarity, and alignment with the study’s objectives. Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS), with descriptive statistics such as mean, standard deviation, skewness, and kurtosis used to summarize the measurements. Pearson’s Product Moment Correlation Coefficient was employed to test the hypotheses at the 0.05 level of significance.

RESULTS AND DISCUSSION

Table 1. Descriptive statistics of anthropometric foot measurements for male and female subjects

	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Standing foot width (male)	100	8.8187	7.39559	9.616	.241	94.836	.478
Standing foot width (female)	100	8.0338	1.29430	-.645	.241	2.332	.478
Standing foot length (male)	100	19.3957	6.09696	9.329	.241	91.055	.478
Standing foot length (female)	100	20.2323	8.50822	6.660	.241	44.615	.478
Standing truncated length (male)	100	7.3876	.81479	-5.271	.241	43.198	.478
Standing truncated length (female	100	7.9608	1.54271	5.340	.241	32.505	.478
Standing dorsum height (male)	100	19.3917	6.09682	9.332	.241	91.089	.478
Standing dorsum height (female)	100	20.2323	8.50822	6.660	.241	44.615	.478
Valid N (listwise)	100						

Table 1 presents descriptive statistics for a sample of (100) males and (100) females across several foot measurements. For standing foot width, males have a higher mean of (8.8187) compared to females at (8.0338), although the data for males is highly dispersed with a large standard deviation of (7.39559). Conversely, females show a larger mean standing foot length of (20.2323) compared to males at (19.3957). The standing truncated length mean is also higher for females at (7.9608) than for males at (7.3876). Standing dorsum height shows a similar trend, with females having a mean of (20.2323) against the male mean of (19.3917). Skewness and kurtosis values suggest that most distributions are not normal. For example, male standing foot width has a high positive skewness of (9.616) and a very high kurtosis of (94.836), indicating a distribution with a long right tail and very heavy tails. The standard error for skewness is (0.241) and for kurtosis is (0.478) for all measurements.

Hypothesis 1: There is no statistically significant linear relationship (correlation) between standing foot length and standing foot width among male university students.

Table 2. Pearson correlation between standing foot width and standing foot length for male university students.

		Standing foot width(male)	Standing foot length(male)
Standing foot width(male)	Pearson Correlation	1	.001
	Sig. (2-tailed)		.994
	N	100	100
Standing foot length(male)	Pearson Correlation	.001	1
	Sig. (2-tailed)	.994	
	N	100	100

Table 2 presents the Pearson correlation for a sample of (100) male university students. The Pearson correlation coefficient is (0.001), which indicates a negligible positive linear relationship between standing foot length and standing foot width. The two-tailed significance value (p-value) is (0.994). Since the p-value is greater than the typical significance level of (0.05), the correlation is not statistically significant. Based on this

finding, we fail to reject the null hypothesis, concluding that there is no statistically significant linear relationship between the two variables.
Hypothesis 2: There is no statistically significant linear relationship (correlation) between standing foot length and standing foot width among female university students.

Table 3. Pearson correlation between standing foot width and standing foot length for female university students

		Standing foot width(female)	Standing foot length(female)
Standing foot width(female)	Pearson Correlation	1	.045
	Sig. (2-tailed)		.656
	N	100	100
Standing foot length(female)	Pearson Correlation	.045	1
	Sig. (2-tailed)	.656	
	N	100	100

Table 3 presents the Pearson correlation for a sample of (100) female university students. The Pearson correlation coefficient is (0.045), which suggests a very weak positive linear relationship between standing foot length and standing foot width. The two-tailed significance value (p-value) is (0.656). Since the p-value is greater than the conventional significance level of (0.05), the correlation is not statistically significant. Based on this finding, we fail to reject the null hypothesis. This indicates that there is no statistically significant linear relationship between the two variables for female students in this sample.
Hypothesis 3: There is no statistically significant linear relationship (correlation) between standing foot length and standing dorsum hight among male university students.

Table 4. Pearson correlation between standing foot length and standing dorsum height for male university students

		Standing foot length(male)	Standind dorsum heigth(male)
Standing foot length(male)	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.000
	N	100	100
Standind dorsum heigth(male)	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.000	
	N	100	100

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4 shows a correlation analysis for (100) male university students. The Pearson correlation coefficient between standing foot length and standing dorsum height is (1.000), indicating a perfect positive linear relationship. The two-tailed significance value (p-value) is (0.000), which is well below the significance level of (0.01). This confirms that the correlation is highly statistically significant. Based on these results, the null hypothesis is rejected. This indicates there is a statistically significant linear relationship between standing foot length and standing dorsum height among the male students in this sample.
Hypothesis 4: There is no statistically significant linear relationship (correlation) between standing foot length and standing dorsum hight among female university students.

Table 5. Pearson correlation between standing foot length and standing dorsum height for female university students

		Standing foot length(female)	Standing dorsum heigth(female)
Standing foot length(female)	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.000
	N	100	100
Standing dorsum heigth(female)	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.000	
	N	100	100

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5 presents a correlation analysis for a sample of (100) female university students. The Pearson correlation coefficient between standing foot length and standing dorsum height is (1.000), which indicates a perfect positive linear relationship. The two-tailed significance value (p-value) is (0.000), which is less than the significance level of (0.01). This confirms that the correlation is highly statistically significant. Therefore, the null hypothesis is rejected. This indicates a statistically significant linear relationship exists between standing foot length and standing dorsum height for female students in this sample.

Hypothesis 5: There is no statistically significant linear relationship (correlation) between Standing truncated length among male and female university students.

Table 6. Pearson correlation between standing truncated length among male and female university students

		Standing truncated length(male)	Standing truncated length(female)
Standing truncated length(male)	Pearson Correlation	1	.060
	Sig. (2-tailed)		.554
	N	100	100
Standing truncated length (female)	Pearson Correlation	.060	1
	Sig. (2-tailed)	.554	
	N	100	100

Table 6 shows a correlation analysis for a sample of (100) males and (100) females. The Pearson correlation coefficient is a tiny (0.060), which means there's an extremely weak link between the standing truncated length of male and female students. To find out if this link is a real discovery or just a random fluke, we look at the p-value. In this case, it's (0.554). Since that number is much larger than the typical cutoff of (0.05), we can't really say the relationship is statistically significant. So, we're sticking with our original idea—the null hypothesis-that there is no statistically significant linear relationship between the two groups' measurements

Discussion

The meticulous study of anthropometric foot measurements is paramount for advancing gender-specific shoe design, particularly for university students who require footwear that supports both comfort and performance. The provided correlation analyses offer critical insights into the relationships between various foot dimensions, highlighting the necessity of tailored designs rather than a "unisex" approach. Our findings reveal a negligible linear relationship between standing foot length and standing foot width for both male (Pearson correlation: [0.001], p=[0.994]) and female (Pearson correlation: [0.045], p=[0.656]) university students. This suggests that simply scaling shoe length will not adequately address width variations. In contrast, a study by Charmode and Kadlimatti (2019) on female foot anthropometry, while focusing on correlations with body weight, underscores the complexity of foot dimensions, implying that multiple independent parameters are crucial for accurate sizing. This finding is further supported by the general observation from Chiroma et al, (2015) that mean foot length and width differ significantly between male and female university students, indicating the inherent variability that shoe designers must accommodate.

However, a striking and significant positive linear relationship was observed between standing foot length and standing dorsum height for both male (Pearson correlation: [1.000], p=[0.000]) and female (Pearson correlation: [1.000], p=[0.000]) students. This perfect correlation is highly significant and implies that, for university students, dorsum height is directly proportional to foot length. This finding agreed with the general understanding that foot structure, including height, scales with length, as highlighted by Silva et al, (2022), who noted that men generally have longer and taller feet than women. This strong interdependence means that shoe lasts designed for length must also accurately account for dorsum height to ensure a proper fit over the instep, preventing discomfort or excessive pressure.

Furthermore, the analysis showed no statistically significant linear relationship (Pearson correlation: [0.060], p=[0.554]) between the standing truncated length of male and female students. This lack of inter-gender correlation for this specific measurement reinforces the concept of distinct gender-specific foot morphologies. This aligns with the sentiment expressed by Scovel (2020), emphasizing that shoe brands are moving beyond merely "shrinking and pinking" male designs for women, acknowledging that female feet are structurally different. In a related study, Limon et al, (2023) developed a new shoe sizing system for women based on regression analysis of foot shapes, directly addressing the need for gender-specific grading values for various foot dimensions.

The implications to shoe design are overwhelming. The non-correlation of length and width as well as the ideal correlation of length and height of the dorsum, is a reason to stretch to make shoes as multi-dimensional. Wang et al, (2024) notes that three-dimensional scanning plays a key role in achieving the required anthropometric data that personalized shoe designs demand. This is critical in the prevention of podiatric conditions because an ill-fitting shoe may cause physical discomfort and health risks, which is what Wang et al, (2024) also emphasis. Also, the gender differences which are determined do not imply only stable numbers; Ezawa et al, (2024), discovered that also the foot torsional stiffness is gendered, which would affect the biomechanics and shoe comfortability. Lastly, Gow, (2025) study on the longitudinal bending stiffness of shoes vividly explains how accurate fit which is determined using anthropometric data has a direct coupling on biomechanical performance and injury prevention. These studies, such as by Saha (2022) on foot length and stature, all support the use of data-based, gender-specific decision making in the development of footwear in university students.

CONCLUSION

This survey indicates the great role that anthropometric foot measures play in the formulation of truly gender-specific shoe designs of students in universities. Our findings clearly demonstrate that while foot length and width show no statistically significant linear relationship for either gender, indicating that a simple scaling of length is insufficient, there is a perfect and highly significant positive correlation between standing foot length and standing dorsum height in both males and females. This highlights the necessity of accounting for the three-dimensional nature of the foot, especially the instep region, when designing footwear. Furthermore, the absence of a significant linear relationship in standing truncated length between male and female students reinforces the concept of distinct gender-specific foot morphologies that cannot be addressed by generic designs. These insights collectively advocate for a departure from unisex shoe models towards designs meticulously tailored to the unique anthropometric profiles of male and female feet. Such a data-driven approach is essential for enhancing comfort, preventing foot-related issues, and ultimately improving the overall well-being and performance of university students. Continued research and application of these precise measurements will be key to revolutionizing footwear design.

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