RESEARCH ARTICLE

International Journal of
PHYSICAL EDUCATION, FITNESS AND SPORTS

DOI: 10.54392/ijpefs2432

Foot Dimension among Indian Population: A Pilot Study

Rajib Jana [a], Ayan Maity [a], Rizwan Ahmad [a], Sugata Das Kumar [b], Madhusudan Pal [a, *]

[a] Centre of Excellence, Footwear Design and Development Institute, Noida-201301, India.

[b] Department of Physiology, City College, Affiliated to University of Calcutta, 102/1, Raja Ram Mohan Sarani Road, Kolkata-700009, West Bengal, India.

* Corresponding Author e-mail: madhusudanpal@rediffmail.com

DOI: https://doi.org/10.54392/ijpefs2432

Received: 02-06-2024; Revised: 14-07-2024; Accepted: 22-07-2024; Published: 31-07-2024

Abstract: Foot anthropometry involves measuring the dimensions and shapes of the human foot, crucial for designing footwear that improves athletic performance and reduces the risk of injuries by offering adequate support and matching natural biomechanics. This study aimed to gather foot anthropometric data from both males and females and compare foot dimensions between the two to develop specific footwear. A total of 204 male and female volunteers, with an average age of 28.20 ± 12.95 years, participated in the study, and 15-foot measurements were taken using 3D foot scanner equipment. All data was analyzed using SPSS software version 26. The Mann-Whitney U test was used to compare differences between the right and left feet of males and females. Significant differences were found in various measurements of the left feet, including 'foot length', 'foot width', 'heel circumference', 'toe circumference', 'waist circumference', 'ankle circumference', 'thumb height', 'toe width', 'heel center width', 'lateral malleolus length', 'medial malleolus length', 'Spherion height', and 'instep circumference'; however, no significant difference was observed in 'foot arch height'. This study also showed that all parameters differed significantly between the right and left feet in both males and females. The Kruskal-Wallis ANOVA test revealed no significant difference in 'foot arch height' between males and females, but thumb height did show a significant difference between the left and right feet of females. These precise anthropometric measurements are crucial for ensuring the proper fit of footwear, insights into this variability, allow makers to make footwear that accommodates a wide range of users enhancing control, stability, and response during daily activity. Different activity requires different leg movements and support, and precise foot anthropometry can help customize footwear to meet the unique requirements of each activity.

Keywords: Foot Anthropometry, Indian Adults, Design Sports Footwear, Variation in Left and Right Foot.

1. Introduction

Foot anthropometry is the measuring of both the size and dimensions of the foot. The human foot is the weight-bearing end of a limb and serves as the foundation for bipedal mobility (Igbigbi *et al*., 2018). The human foot is an exceptionally complex mechanical structure that is both flexible and robust, serving as a stable platform to sustain the body's pressure during an erect stance as well as providing propulsive and regulating force during locomotion to accomplish daily activities (Dutta, 2013). Foot structure description is important for a variety of reasons, and foot anthropometric data are invaluable to anatomists, criminologists, forensic scientists, human biologists and physical anthropologists, health and medical sciences, sports science, and the footwear industry (Patel *et al*., 2011; Prasad *et al*., 2014). Anthropometry, as an anthropological method, refers to the measurement and testing of the human body, as well as the correlations between individual measurements (Waterson, 2006). Anthropometric measurement was an essential instrument in the creation of standard sizes. Anthropometric measurements are used in shoe manufacturing to aid with construction operations. When creating shoes and boots, anthropometric measurements of the leg area are taken. Foot anthropometric measures used to design shoes and socks should be representative of a given group, such as children, teenagers, and the elderly (Kok *et al*., 2005).

Footwear designers generally use foot length, foot width, foot height, and ankle circumference to design shoes. These measurements are ergonomic inputs required to create footwear that gives users with comfort and flexibility while they move (Waterson, 2006). However, shoe fit is rarely measured. Differences in foot circumference and footwear can make a considerable difference if the associated widths and heights are not taken into account while shaping the foot. When creating a shoe vamp, it is critical to measure the height of the midfoot (Janisse, 1992). In contrast, the contour of the foot is determined by the fashion of the shoes. To build an ideal platform for shoe design, a mechanism relating foot height to foot length is required (Cheng, 1999). Traditional shoe manufacture, on the other hand, categorizes shoes according to their length and width. It is clear that persons can have the same foot length (McEvoy, 1996; Au,2007) but the morphology of the foot varies, such as wide or narrow, slender or thick, high or low arch. The old one-size-fits-all approach has failed due to the prevalence of foot disorders. Shoes that are custom-made for each individual are vitally important. The most crucial aspect of shoemaking is the final, solid 3D mold of the shoe. The shoe upper is intimately tied to the foot, and its design is determined by a variety of criteria, including foot shape/size, comfort parameters, shoe fashion/style, and construction type (Kok *et al*., 2005).

It has been referred to as the "heart" of shoe production because it primarily dictates the shoe's design, fashion, fit, and comfort (Leng, 2005; Leng, 2006). The leg can be separated into two parts: the back and the front. The back of the foot, which includes the heel, sole, and webbing, is mostly for fit and comfort, but the forefoot, or the toe covering the toe, is primarily for fashion and style. The toe area may have a pointy tip, round toe, square toe, or complicated toe structure. Fashion influences the back as well, thanks to numerous high heels. When the last element of the shoe is completed, the remaining components of the shoe might be made later (upper, outsole, insole, midsole, heel, etc.). Custom toes can still be manufactured using traditional methods, but they are more expensive, time-consuming, and intricate due to the hand-measured dimensions of the foot and the constraints of the final hand-making of shoes. Using the trial-and-error method (McEvoy, 1996; Au, 2007).

Foot and ankle technology is continually advancing, and three-dimensional (3D) scanners are increasingly replacing traditional methods like ink prints and tape measures when it comes to assessing foot and ankle measurements (Kouchi, 1999; Kouchi, 2011). These scanners outperform traditional methods in terms of speed, user-friendliness, and accuracy. They also allow for the measurement of various anthropometric factors, which would be very time-consuming using traditional methods (Lee *et al.,* 2014). The goal of these devices was to update the population's foot and ankle measurements and adjust product design if necessary. This new technology was associated with more accurate measurements than existing methods. Its major characteristics were rapid acquisition, excellent accuracy, user-friendly interfaces, and low cost (Dickerson, 2021). The analysis from the scans enabled the definition of foot shape and size in both adults and children, and it was also significant in demonstrating gender differences in foot size. In addition to accurately mapping the skin surface, these scanners, in combination with specific weight-bearing surfaces, allowed for the characterization of the sole support of the foot. For the first time, large-scale, low-cost automated production of foot orthoses became possible. Nowadays, these scanners are commonly used to create custom-made orthopedic shoes and orthotics that are tailored to the patient's individual foot deformity (Bao, 1994).

For example, it has been shown that certain foot dimensions, such as arch height or foot breadth, are linked to the development of foot diseases such as plantar fasciitis. Foot anthropometry has helped sports medicine researchers better understand the biomechanical aspects that contribute to foot and lower limb injuries in athletes. They have contributed to the development of injury prevention techniques and the identification of potential risk factors for lower extremity injuries, allowing preventive measures to be implemented more effectively. Furthermore, podiatrists and producers of footwear and orthopedic equipment can use foot anthropometric data to enhance product design based on specific patient demands, boosting comfort and performance. In addition, using anthropometric measures in the design of orthopedic devices has been found to enhance walking behaviors and reduce leg pain in patients with knee osteoarthritis (Williams *et al.,* 2001; Rogati, 2019).

Shoes are vital for protecting the feet and preventing injuries. Properly fitted sports shoes help maintain proper biomechanical alignment, reducing the risk of injuries such as sprains, strains, and stress fractures. Footwear designed using precise anthropometric data can provide better shock absorption, protecting athletes from impact-related injuries.

In recent years, there has been a growing demand for appropriate and comfortable footwear and accessories. As a result, foot measurement and the design of related products have become increasingly important. Wearing poorly fitting shoes has been linked to an increased risk of foot disorders such as corns, bunions, pain in the ball or arch of the foot, and flat feet (Irzmańska, 2016). Incorporating foot measurements into shoe design can improve fit and comfort. Shoe size is often determined by matching foot length, width, heel width, ball circumference, sole circumference, heel circumference, and sole height to the shoe (Witana, 2006). Under these circumstances, this study aims to tabulate foot anthropometric data sets of male and female groups of subjects and to compare foot dimensions between male and female subjects for footwear design & development including different sports.

2. Materials &Methods

2.1. Participants

The cross-sectional study was designed to collect foot anthropometric data from male and female participants aged 18 to 40 years. A total of 204 subjects were chosen based on their gender (male and female). The participants according to their gender (male n=108, female n=96) and foot (right and left) of each participant were scanned and they were compared according to these groups as given below-

Table 1. Participants Group -

Group(N=204)	Subgroup
Male (n=108)	Left foot
	Right foot
Female (n=96)	Left foot
	Right foot

This study was carried out at the Footwear Design and Development Institute (FDDI) in India.

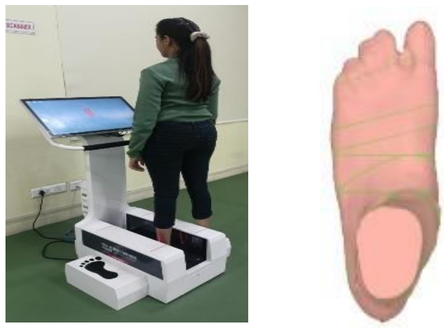
The inclusion criteria for involvement in this study were healthy subjects with no foot deformity and no musculoskeletal disorders in the lower extremities as per acquaintances.

2.2 Instrumentation

In this study, all foot parameters were captured by LSF-350-A 3D foot scanner (Shenzhen 3doe Technology Co., Ltd. China) with high measuring precision and standard error up to <0.5mm.

2.3. Measurement Procedure

Each participant was explained and familiarized with the study design and they signed informed consent before commencement of the study. The subjects were asked to remove their shoe and shocks. Then their height and weight were measured by steel tape and weighing machine. After that, a subject was called for the foot-scanning process. When both feet of the subject were scanned the foot scanner machine generated a report according to the subject foot, where foot condition and all foot anthropometric parameters were observed.



A B

Figure 1- (A) 3D foot scanning of the participant and (B) 3D images of foot.

The foot anthropometric scanning reports have several parameters in this study but only some anthropometric parameters were considered, and these were tabulated below.

2.4. Statistical Analysis

Data were summarized into mean ± SD values. Shapiro-Wilk normality test signified that the parameters were not normality distributed. So, there for the Mann-Whitney U test was done to compare between means of foot wise (male left& right, female left& right), and gender-wise groups. The Kruskal Wallis ANOVA was done to evaluate gender differences (Male &Female) and foot (left and right) for all the parameters. The significant level was considered at 0.05 levels. The statistical software package (SPSS- 26) was applied.

3. Results & Discussion

3.1 Results

The study included 204 subjects, with 108 males and 90 females, who were chosen as a representative sample of the Indian population. The participants were between 18 and 65 years old.

Table 2. Details of foot anthropometric parameters in this study

Parameters(mm)	Definition
Foot length	Distance between the pterion and the tip of the longest toe, measured along the foot axis.
Feet width	It refers to measurement across the widest part of the foot.
Heel circumference	It refers to the circumference or measurement around the heel area of the foot.
Toe circumference	It refers to the measurement of the circumference of the toes and typically taken around the widest part of each toe.
Waist circumference	Distance between the ball and the heel but the measurement was taken at narrowest part of the foot.
Instep circumference	Measurement of the curve of the vertical section of the dorsum foot in the most prominent region of the navicular bone.
Ankle circumference	It refers to the measurement around the ankle, typically taken just above the ankle bone.
Foot arch height	Distance between the ground and the highest point of the arch.
Thumb height	The height or position of big toe.
Toe width	Distance between the medial (inner) and lateral (outer) borders of the toes or the widest part of the forefoot.
Heel center width	The distance between the medial heel point and lateral heel point.
Lateral malleolus length	The vertical distance from the most lateral point of the lateral malleolus to the supporting surface of the foot.
Medial malleolus length	The vertical distance from the most medial point of the medial malleolus to the supporting surface of the foot.
Sphyrion fibulare height	It refers to the measurement taken from the ground to the most prominence point on the lateral malleolus when the individual stands erect with the feet together.
Sphyrion height	It refers to a measurement taken from the ground to the highest point on head when the individual stands erect with the feet together.

Table 3. Mean ± Sd of all foot dimensions with 5th & 95th percentiles values

Parameters (mm)	Mean ± Sd	Percentiles	
		5th	95th
Feet Length	247.59±15.50	224.47	271.58
Feet Width	92.71±6.12	82.84	102.78
Heel Circumference	309.98±20.25	274.61	342.63
Toe Circumference	208.30±17.59	180.17	238.76

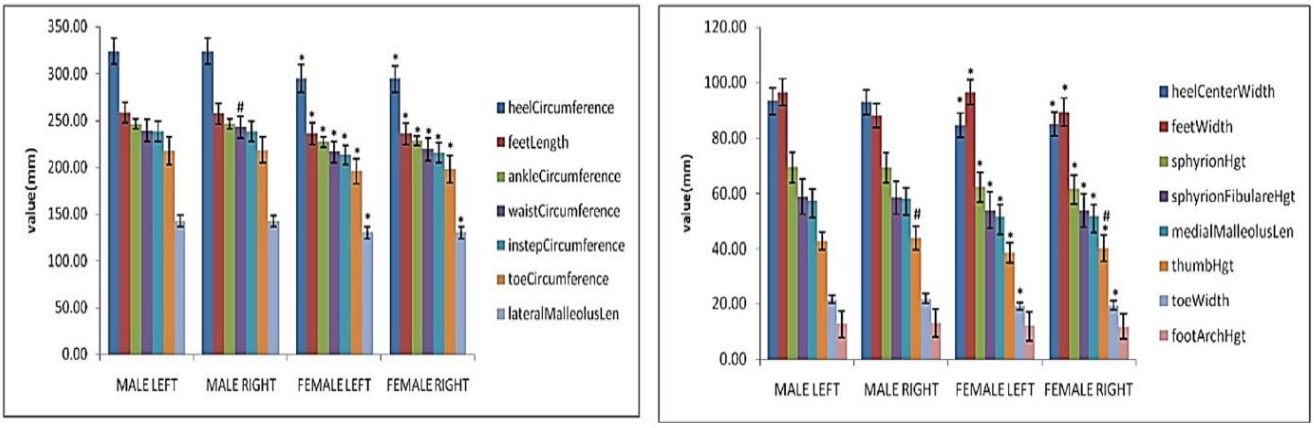
Waist Circumference	230.01±16.54	202.71	256.82
Instep Circumference	226.91±15.79	201.58	252.36
Ankle Circumference	237.66±16.50	211.00	263.70
Foot Arch Height	12.40±4.92	4.76	21.09
Thumb Height	41.43±4.52	34.13	48.94
Toe Width	20.52±2.00	17.56	23.85
Heel Center Width	89.12±6.15	79.17	99.33
Lateral Malleolus Length	136.92±8.57	124.13	150.19
Medial Malleolus Length	54.92±4.99	46.20	63.01
Sphyrion Fibulare Height	56.41±6.59	45.72	67.32
Sphyrion Height	65.76±6.49	55.76	76.00

Table 4. Mean ± SD of all parameters and Mann Whitney u test of foot-wise groups (male left & right, female left & right).

Parameters (mm)	Male left vs Male right [n=108]				Female left vs Female right [n=96]			
	Male left	Male right	Mann Whitney u test	Asymp. Sig.	Female left	Female right	Mann Whitney u test	Asymp. Sig.
	Mean ± Sd	Mean ± Sd			Mean ± Sd	Mean ± Sd		
Feet Length	258.35 ±10.948	257.18 ±10.843	5401.50	0.34 (P>0.05)	236.43 ±11.527	235.86 ±11.288	4498.00	0.77 (P>0.05)
Feet Width	96.38 ±4.816	96.43 ±4.444	5905.50	0.87 (P>0.05)	15.00 ±4.490	89.20 ±4.998	5274.00	0.08 (P>0.05)
Heel Circumference	323.79 ±13.966	323.58 ±13.816	5751.00	0.86 (P>0.05)	294.90 ±14.501	294.20 ±14.293	4493.00	0.76 (P>0.05)
Toe Circumference	217.59 ±14.833	218.82 ±13.626	6163.00	0.47 (P>0.05)	195.94 ±13.332	198.39 ±14.590	4968.00	0.35 (P>0.05)
Waist Circumference	239.08 ±11.966	242.70 ±11.783	6993.00	0.01 (P<0.05)	216.29 ±10.974	219.27 ±12.275	5228.00	0.10 (P>0.05)
Instep Circumference	237.91 ±10.835	237.96 ±10.576	5850.00	0.96 (P>0.05)	213.62 ±10.275	215.41 ±10.799	5015.00	0.29 (P>0.05)

Ankle Circumference	246.07 ±12.352	246.78 ±12.214	6032.00	0.66 (P>0.05)	227.20 ±15.547	228.42 ±14.600	4681.50	0.19 (P>0.05)
Foot Arch Height	12.60 ±4.934	13.20 ±5.024	6280.00	0.32 (P>0.05)	11.90 ±5.113	11.75 ±4.486	4552.00	0.88 (P>0.05)
Thumb Height	42.89 ±3.338	43.83 ±4.321	6821.00	0.03 (P<0.05)	38.38 ±3.616	40.13 ±4.550	5650.00	0.00 (P<0.05)
Toe Width	21.54 ±1.543	21.79 ±1.802	6272.00	0.33 (P>0.05)	19.05 ±1.339	19.42 ±1.609	5160.00	0.15 (P>0.05)
Heel Center Width	93.20 ±4.830	92.89 ±4.502	5666.00	0.71 (P>0.05)	84.53 ±4.316	84.90 ±4.444	4799.00	0.62 (P>0.05)
Lateral Malleolus Length	142.87 ±6.054	142.22 ±5.996	5401.00	0.34 (P>0.05)	130.74 ±6.374	130.43 ±6.243	4498.00	0.77 (P>0.05)
Medial Malleolus Length	57.42 ±4.128	58.05 ±3.888	6456.00	0.17 (P>0.05)	51.62 ±4.124	51.87 ±3.868	4786.00	0.46 (P>0.05)
Sphyrion Fibulare Height	58.79 ±6.349	58.46 ±5.826	5685.00	0.74 (P>0.05)	53.98 ±6.556	53.86 ±5.994	4555.00	0.89 (P>0.05)
Sphyrion Height	69.39 ±5.483	69.22 ±5.409	5616.00	0.63 (P>0.05)	62.16 ±5.211	61.37 ±5.056	4268.00	0.37 (P>0.05)

(p<0.05) shows significant level



C D

Figure 2. (C & D) -Comparison of foot parameters between male and female participants. Mann Whitney u test was performed to find out a significant difference between the left and right foot of male and female participants p< 0.05 "#". To find out the significant difference between the two genders (male left vs female left and male right vs female right) p< 0.05, then "*"

Table 6. Mean ± SD of all parameters and Kruskal-Wallis ANOVA tests between males and females.

Parameters (mm)	Male (n=108)		Female (n=96)		Gender	
	Male left	Male right	Female left	Female right		
	Mean ± Sd	Mean ±Sd	Mean ± Sd	Mean ± Sd	Kruskal-Wallis ANOVA test	Asymptotic sig.
Feet Length	258.35 ± 10.948	257.18 ± 10.843	236.43 ±11.527	235.86 ±11.288	212.34	0.00 (P<0.05)
Feet Width	96.38 ± 4.816	96.43 ± 4.444	87.88 ±4.490	89.20 ± 4.998	183.16	0.00(P<0.05)
Heel Circumference	323.79 ± 13.966	323.58 ± 13.816	294.90 ± 14.501	294.20 ±14.293	221.24	0.00(P<0.05)
Toe Circumference	217.59 ± 14.833	218.82 ± 13.626	195.94 ± 13.332	198.39 ± 14.590	159.84	0.00(P<0.05)
Waist Circumference	239.08 ± 11.966	242.70 ± 11.783	216.29 ± 10.974	219.27 ±12.275	214.30	0.00(P<0.05)
Instep Circumference	237.91 ± 10.835	237.96 ± 10.576	213.62 ± 10.275	215.41 ± 10.799	234.41	0.00(P<0.05)
Ankle Circumference	246.07 ± 12.352	246.78 ± 12.214	227.20 ± 15.547	228.42 ± 14.600	142.21	0.00(P<0.05)
Foot Arch Height	12.60 ± 4.934	13.20 ± 5.024	11.90 ± 5.113	11.75 ± 4.486	5.61	0.13(P>0.05)
Thumb Height	42.89 ± 3.338	43.83 ± 4.321	38.38 ± 3.616	40.13 ±4.550	102.01	0.00(P<0.05)
Toe Width	21.54 ± 1.543	21.79 ± 1.802	19.05 ±1.339	19.42 ± 1.609	165.89	0.00(P<0.05)
Heel Center Width	93.20 ± 4.830	92.89 ± 4.502	84.53 ±4.316	84.90 ± 4.444	197.22	0.00(P<0.05)
Lateral Malleolus Length	142.87 ± 6.054	142.22 ± 5.996	130.74 ± 6.374	130.43 ± 6.243	212.34	0.00(P<0.05)
Medial Malleolus length	57.42 ± 4.128	58.05 ± 3.888	51.62 ± 4.124	51.87 ±3.868	152.86	0.00(P<0.05)
Sphyrion Fibulare Height	58.79 ± 6.349	58.46 ± 5.826	53.98 ± 6.556	53.86 ± 5.994	51.72	0.00(P<0.05)
Sphyrion Height	69.39 ±5.483	69.22 ± 5.409	62.16 ± 5.211	61.37 ± 5.056	149.18	0.00(P<0.05)

(p<0.05) shows significant level

The 5th and 95th percentile values, as well as the mean ± standard deviation of foot dimensions for males and females, are tabulated in Table no 3. Mann Whitney U test was conducted to compare between left and right feet of males and females. In the case of waist circumference and thumb height, there was a significant difference between male left and male right foot. However, there was no significant difference observed in (foot length, foot width, Heel Circumference, Toe Circumference, Instep Circumference, Ankle Circumference, Toe Width, Heel Center Width, foot arch height, Lateral Malleolus Length, Medial Malleolus Length, Sphyrion Fibulare Height, Sphyrion Height) male left and male right foot. All the mentioned parameters data were tabulated in Table no 4 & 5.

Mann Whitney U test was performed to compare between male (left & right) and female (left & right).

In the case of male left and female left foot, the foot arch height has no significant difference but the (foot length, foot width, Heel Circumference, Toe Circumference, Instep Circumference, waist circumference Ankle Circumference, thumb height, Toe Width, Heel Center Width, Lateral Malleolus Length, Medial Malleolus Length, Sphyrion Fibulare Height, Sphyrion Height) have significant difference between male left and Female left foot. It was also observed that all parameters of the male left foot were higher than the female left foot. In the case of male right and female right, all the parameters are significantly difference from each other's. The statistical result was also displaced as a bar diagram which is seen above-

Kruskal-Wallis ANOVA test was conducted to compare the effect of gender (male and female).In foot arch height the Kruskal-Wallis ANOVA test shows that there was no significant difference in gender (male and female), where at $p< 0.05$ level, df=3, 408, but the others parameter were significant difference in (feet length, Feet Width, Heel Circumference, Toe Circumference, Instep Circumference, Ankle Circumference, Toe Width, Heel Center Width, Lateral Malleolus Length, Medial Malleolus Length, Sphyrion Fibulare Height, Sphyrion Height, waist circumference, thumb height) between male and female.

3.2 Discussion

Data-driven segmentation can be applied to any industry and has become a common practice in sectors where customer data is available, such as retail, e-commerce, and consumer goods. In the footwear industry, data-driven segmentation is particularly crucial as it helps identify key customer groups and customize offerings to meet their specific needs and preferences. By analyzing customer demographics, behavior, and psychographics, companies can uncover new product opportunities and tailor their offerings to specific customer segments, resulting in the creation of footwear that offers optimal comfort and safety. Understanding the unique characteristics and needs of each subject segment enables the creation of targeted campaigns that are more likely to resonate with specific groups of people, addressing best-fitted footwear on a larger scale. Additionally, understanding the needs and preferences of gender-specific segments subject can lead to a more personalized experience, resulting in better last development, enhanced customer satisfaction, increased comfort, and reduced risk of injury.

In this study, 15-foot anthropometric parameters were taken from 204 participants. Table 3 illustrates the means, standard deviations, and percentile values (5th and 95th) of the participant's age (28.20 ± 12.95 years). Prior studies conducted in northwest Iran involved measurements of 21-foot dimensions from 580 volunteers. The resulting percentiles can be used to aid local footwear designers. The 5th to 95th percentiles cover 90% of the population. With these dimensions, local manufacturers can create comfortable products for a substantial portion of the population (Hemy *et al.,* 2013; Sen, 2008; Manna *et al.,* 2001).

In this study, it was found that the male right foot generally has higher values in foot width, toe circumference, waist circumference, instep circumference, ankle circumference, foot arch height, thumb height, toe width, and heel center width compared to the left foot. However, the values for foot length, heel circumference, lateral malleolus length, medial malleolus length, and sphyrion height showed no significant difference between the left and right foot. There was a significant difference in several dimensions, including foot length, foot width, heel circumference, toe circumference, waist circumference, ankle circumference, thumb height, toe width, heel center width, lateral malleolus length, medial malleolus length, sphyrion height, and instep circumference between males' left and right feet, but no significant difference in foot arch height was found. It is important to note that another study conducted on the Western Australian population also found a substantial difference in the right and left foot lengths of males (Hemy *et al.,* 2013; Sen, 2008). Additionally, a comparative study of foot dimensions between adult males and females in the Bengalee (Indian) community revealed no significant difference in foot length between the left and right male feet (Manna *et al.,* 2001). Similarly, another research study on young Nigerian adults found no significant variation in foot length between right and left males (Ewunonu *et al.,* 2014).

The research revealed that, in terms of foot width, toe circumference, waist circumference, instep circumference, ankle circumference, thumb height, toe width, heel center width, and sphyrion height, the right foot of women generally has higher measurements than the left foot. However, foot length, heel circumference, lateral malleolus length, and sphyrion fibular height do not show a significant difference between the left and right foot. Additionally, there was a notable difference in thumb height between the left and right feet of women, but not in other parameters. The study also found that there is no substantial bilateral foot asymmetry in females in East Malaysia, as observed among adults of the Iban ethnic group in Sarawak (Moorthy, 2014). Another study reported significant differences in foot breadth between the right and left foot lengths of female Rajbanshi in North Bengal (Krishan, 2008). The data analysis showed significant differences between the left and right feet of males and females. It was found that there were no significant differences in the arch height of the left feet between males and females, but there were significant differences in the length of the feet, toe circumference, waist circumference, instep circumference, ankle circumference, thumb height, toe width, heel center width, and sphyrion height. On the other hand, all the remaining measurements showed significant differences between the right feet of males and females (Xu, 2019). It has been noted in previous studies that most foot measurements did not show significant differences between the left and right feet. However, these studies only considered the size differences in one specific condition, and did not take into account differences in both half-weight-bearing (HWB) and no-weight-bearing (NWB) conditions. Few studies have looked into foot sizes in non-weight-bearing settings, which is important for the development of medical devices such as ankle-foot orthotics and corrective insoles (Barelds, 2018).

In a comparison between males and females, it was observed that males generally have greater foot measurements than females for all parameters. However, it was noted that there was no significant difference in foot arch height between male and female feet, while other parameters showed significant differences. Indian females tend to have smaller foot measurements than Indian males. Further examination of foot length and width revealed significant variations between the two genders (Ozden *et al.,* 2005). Several studies have indicated that the angle of the hallux valgus is correlated with pronation deformity of the first metatarsal and that the pronation of the first metatarsal affects the height of the medial longitudinal arch (Eustace *et al.,* 1993); Kim *et al.,* 2015). Several studies have found differences between male and female feet in terms of foot length, width, and malleolus height measurements (Wunderlich, 2001). A study using 3D scanning techniques scanned the feet of Chinese young adults of both sexes and discovered that foot breadth and instep circumference varied significantly between foot types within the same foot length for both sexes. Neutral shoes only suit a small number of male and female feet, and they frequently induce tension and strain in the foot tissues, resulting in pain and trauma (Bus *et al.,* 2009). To avoid foot abnormalities, gender differences in feet should be considered while designing shoes, including any sports footwear (Menz, 2021). Improperly fitting footwear is a major cause of sports-related injuries. Foot and ankle injuries account for about 20-25% of all sports-related injuries (Srbely, 2010). Studies have shown that nearly 30% of these injuries can be attributed to ill-fitting footwear. Runners, in particular, are at risk, with up to 70% experiencing injuries due to improper footwear. Ankle sprains are the most common, accounting for approximately 45% of all basketball-related injuries (Garet *et al.,* 2013). Soccer players often suffer from foot injuries, such as metatarsal fractures, which can make up to 15% of total soccer injuries. These injuries are often linked to wearing ill-fitting cleats (Steffen, 2010).

There is currently no reliable precise foot anthropometric database available in our country, which is inhibiting the Indian footwear sector from creating shoe designs that enhance comfort and fit. Consequently, it is necessary to conduct a survey to determine the foot size of the Indian population. The findings of this study could be used to improve the design and development of footwear products. Anthropometric data can also be utilized to create custom or semi-custom sports footwear that is tailored to the shape and size of an individual athlete's foot, resulting in better fit and performance. For athletes who require precise foot measurements, these devices must fit well within the sports footwear, providing necessary support without compromising comfort (James, 2014). The measurements represent the foot shapes of individuals, and using these measurements will lead to more comfortable footwear that better fits their feet. These efforts are part of a larger initiative to customize medical and commercial products, such as shoes and orthotic devices, to better match the specific anatomical characteristics of the Indian population and individuals involved in sports. It is expected that researchers will utilize these measurement technologies to provide more accurate and effective foot measurements for improved footwear design and development. Additionally, modern technology will reduce measuring errors, resulting in higher precision. However, this study has some limitations which include a small sample size and not considering all diverse ethnicities of the Indian population. Further study required larger sample size for different age groups and different foot types, different ethnicities, and other anthropometric parameters for better footwear optimization.

4. Conclusions

It is important to ensure that footwear is properly sized to prevent injury and optimize performance. Poorly fitted shoes can lead to discomfort, and foot injuries, and affect gait patterns. Even at the elite level, wearing properly fitting footwear is a pioneer. Due to varying sizing standards among footwear manufacturers, sizes and shapes can differ significantly between models, even within gender-specific footwear. Designers can create a more accurate sizing system by analyzing foot dimensions, better matching the diverse foot shapes and sizes found in the Indian population. This can lead to a more precise fit, reducing discomfort and the risk of foot-related issues. Advanced techniques such as 3D foot scanning provide detailed measurements, enabling the creation of footwear that closely conforms to the natural contours of the foot. An unbiased sizing system that provides information on how specific footwear fits different foot shapes would be very helpful for consumers in selecting the right footwear. The Indian National Footwear Sizing System aims to provide healthy-fitting shoes that adhere to the contours of individuals' feet. Proper fit and comfort are essential for preventing foot related pain, discomfort and disorders. The findings of the present study stated that anthropometric foot dimension varies between left and right foot and male and female differences in foot dimension. These foot dimensions of the study will be utilized as design inputs for designing and developing sports, occupational and safety footwear and related tools; and other foot-related products to enhance user fitment, performance, safety, and comfort. The present study limited to small sample size, detail further study will be required on large sample size, different age group and ethnic population.

References

Au, E. Y. L., & Goonetilleke, R. S. (2007). A qualitative study on the comfort and fit of ladies' dress shoes. *Applied ergonomics*, 38(6), 687-696. [DOI] [PubMed]

Bao, H.P., Soundar, P., & Yang, T. (1994). Integrated approach to design and manufacture of shoe lasts for orthopaedic use. *Computers & industrial engineering*, 26(2), 411-421. [DOI]

Barelds, I., van den Broek, A.G., Huisstede, B.M. (2018). Ankle bracing is effective for primary and secondary prevention of acute ankle injuries in athletes: a systematic review and meta-analyses. *Sports Medicine*, *48*, 2775-2784. [DOI] [PubMed]

Bus, S.A., van Deursen, R.W., Kanade, R.V., Wissink, M., Manning, E.A., van Baal, J.G., & Harding, K.G. (2009). Plantar pressure relief in the diabetic foot using forefoot offloading shoes. *Gait & posture*, 29(4), 618-622. [DOI] [PubMed]

Cheng, F.T., Perng, D.B.A (1999). systematic approach for developing a foot size information system for shoe last design. *International Journal of Industrial Ergonomics*, 25(2), 171-185. [DOI]

Dickerson, L.C., & Queen, R.M. (2021). The Design and Validation of a Low-Cost Foot Measurement System. *Journal of Biomechanical Engineering*, 143(8), 084502. [DOI] [PubMed]

Dutta, S.K., & Dutta, D, (2013). Elementary Orthopedic Biomechanics. *New Central Book Agency*, Kolkata.

Eustace, S., O'byrne, J., Stack, J., & Stephens, M.M. (1993). Radiographic features that enable assessment of first metatarsal rotation: the role of pronation in hallux valgus. *Skeletal radiology*, *22*, 153-156. [DOI] [PubMed]

Ewunonu, E.O., Egwu, A.O., Eleudo, A.N., & Ajoku, K. I. (2014). Bilateral foot asymmetry and sexual dimorphism in young adult Igbo people of South Eastern Nigeria. *European journal of biotechnology and bioscience,* 1(4), 1-5.

Garet, M., Reiman, M.P., Mathers, J., & Sylvain, J. (2013). Nonoperative treatment in lumbar spondylolysis and spondylolisthesis: a systematic review. *Sports Health*, 5(3), 225-232. [DOI] [PubMed]

Hemy, N., Flavel, A., Ishak, N.I., & Franklin, D. (2013). Estimation of stature using anthropometry of feet and footprints in a Western Australian population. *Journal of forensic and legal medicine*, 20(5), 435-441.[DOI] [PubMed]

Igbigbi, P.S., Ominde, B.S., & Adibeli, C.F. (2018). Anthropometric dimensions of hand and foot as predictors of stature: A study of two ethnic groups in Nigeria. *Alexandria journal of medicine*, 54(4), 611-617. [DOI]

Irzmańska, E. (2016). Evaluating the comfort of use of protective footwear: Validation of a method based on microclimate parameters and peripheral blood flow. *Measurement*, 77, 34-39. [DOI]

James, L.P., Kelly, V.G., & Beckman, E.M. (2014). Injury risk management plan for volleyball athletes. *Sports medicine*, *44*, 1185-1195. [DOI] [PubMed]

Janisse, D.J. (1992). The art and science of fitting shoes. Foot and Ankle International, 13(5), 257-262. [DOI] [PubMed]

Kim, Y., Kim, J.S., Young, K.W., Naraghi, R., Cho, H. K., Lee, S.Y. (2015). A new measure of tibial sesamoid position in hallux valgus in relation to the coronal rotation of the first metatarsal in CT scans. *Foot & ankle international*, 36(8), 944-952. [DOI] [PubMed]

Kok, P., Bax, P., Smits, C. (2005). Foot shape dimensions for design criteria of children lasts. *In Seventh symposium on footwear biomechanics,* 27-29.

Kouchi, M., & Mochimaru, M. (2011). Errors in landmarking and the evaluation of the accuracy of traditional and 3D anthropometry. *Applied ergonomics*, *42*(3), 518-527. [DOI] [PubMed]

Kouchi, M., Mochimaru, M., Tsuzuki, K., & Yokoi, T. (1999). Interobserver errors in anthrofometry. *Journal of human ergology,* 28(1-2), 15-24.

Krishan, K. (2008). Estimation of stature from footprint and foot outline dimensions in Gujjars of North India. *Forensic science international*, 175(2-3), 93-101. [DOI] [PubMed]

Lee, Y.C., Lin, G., & Wang, M.J.J. (2014). Comparing 3D foot scanning with conventional measurement methods. *Journal of foot and ankle research*, 7, 1-10. [DOI] [PubMed]

Leng, J., & Du, R. (2005). A deformation method for shoe last customization. *Computer-Aided Design and Applications*, 2(1-4), 11-18.

Leng, J., & Du, R. (2006). A CAD approach for designing customized shoe last. *Computer-aided Design and Applications*, *3*(1-4), 377-384.

Manna, I., Pradhan, D., Ghosh, S., Kar, S. K., & Dhara, P. (2001). A comparative study of foot dimension between adult male and female and evaluation of foot hazards due to using of footwear. *Journal of physiological anthropology and applied human science*, 20(4), 241-246. [DOI] [PubMed]

McEvoy, C. (1996). Comfort is job one. *Sporting Goods Business*, 29, S10.

Menz, H.B., & Bonanno, D.R. (2021). Footwear comfort: a systematic search and narrative synthesis of the literature. *Journal of Foot and Ankle Research*, 14, 1-11. [DOI] [PubMed]

Moorthy, T.N. (2014). Stature estimation from the anthropometric measurements of footprint in Iban ethnics of east Malaysia by regression analysis. *Journal of Forensic Science and Criminology*, 1, 501.

Ozden, H., Balci, Y., Demirüstü, C., Turgut, A., & Ertugrul, M. (2005). Stature and sex estimate using foot and shoe dimensions. *Forensic Science International*, 147(2-3), 181-184.[DOI] [PubMed]

Patel, S.M., Doshi, V., Ruparelia, S., Zalawadia, A., Parekh, D., Rathod, S.P., Parmar, A. (2011). Anthropological Study of the Foot and It's Relationship between Different Parameters and Stature in an Adult Population of Different Areas of Gujarat. National Journal of Integrated Research in Medicine, 2(3), 62-65. [DOI]

Prasad, A., Bhagwat, V.B., Kumar, A., & Joshi, D.S. (2014). Estimation of stature from head length in living adults in Marathwada region of Maharashtra. *International Journal of Recent Scientific Research*, 5(10), 1745-1748.[DOI]

Rogati, G., Leardini, A., Ortolani, M., & Caravaggi, P. (2019). Validation of a novel Kinect-based device for 3D scanning of the foot plantar surface in weight-bearing. *Journal of foot and ankle research*, 12, 1-8. [DOI] [PubMed]

Sen, J., & Ghosh, S. (2008). Estimation of stature from foot length and foot breadth among the Rajbanshi: an indigenous population of North Bengal. *Forensic Science International*, *181*(1-3), 55-e1. [DOI] [PubMed]

Srbely, J. (2010). Chiropractic science: a contemporary neurophysiologic paradigm. *The Journal of the Canadian Chiropractic Association*, 54(3), 144. [PudMed]

Steffen, K., Engebretsen, L. (2010). More data needed on injury risk among young elite athletes. *British journal of sports medicine*, 44(7), 485-489. [DOI] [PubMed]

Waterson, P.R. Sell, (2006). Recurrent themes and developments in the history of the ergonomics society. *Ergonomics,* 49(8), 743-799.[DOI] [PubMed]

Williams Iii, D.S., McClay, I.S., & Hamill, J. (2001). Arch structure and injury patterns in runners. *Clinical biomechanics*, 16(4), 341-347. [DOI] [PubMed]

Witana, C.P., Xiong, S., Zhao, J., & Goonetilleke, R.S. (2006). Foot measurements from three-dimensional scans: A comparison and evaluation of different methods. *International Journal of Industrial Ergonomics*, 36(9), 789-807. [DOI]

Wunderlich, R.E., & Cavanagh, P.R. (2001). Gender differences in adult foot shape: implications for shoe design. *Medicine and science in sports and exercise*, 33(4), 605-611. [DOI] [PubMed]

Xu, M. (2019). Foot type classification for Chinese children and adolescents. *Kinesiology*, 51(1), 127-132.

Acknowledgment

The authors would like to express their sincere gratitude to all the participants for their cooperation during the study. We were also grateful to Suresh Joshi, and Nikita Gaur for their immense support for the completion of this study. We are indebted to and convey our deepest sense of gratitude and sincere appreciation to **Col. Pankaj Sinha**, Managing Director of Centre of Excellence, Footwear Design and Development Institute, Ministry of Commerce, Government of India for his intense cooperation and help in the completion of this study.

Author's Contribution Statement

Rajib Jana - data collection, processing, analysis, and Writing - Original Draft, Writing - Review & Editing. **Ayan Maity -** Data collection and statistical analysis, assisted in Writing - Review & Editing. **Rizwan Ahmad -** was involved in data collection, assisted in data process and Writing - Original Draft, Writing - Review & Editing. **Sugata Das Kumar -** Data interpretation**,** Writing - Review & Editing. **Madhusudan Pal-** conceptualization, experiment design, Writing - Review & Editing overall technical and administrative guidance, and supervision. All authors read and approved the final manuscript.

Funding Information

The study was financially supported by Footwear Design & Development Institute (FDDI), Ministry of Commerce, Government of India.

Ethics Approval Statement

The experimental protocol was screened and approved by the Ethics Committee (Ref. No. HMC/ IEC/ FDDI/ 01) in compliance with the Helsinki Protocol (1964-2013).

Informed Consent

The consent form was signed before the commencement of the study.

Additional Materials

All the data and materials are available with all the authors and can be provided when required.

Conflict of Interest

There are no conflicts of Interest.

Does this article pass screening for similarity?

Yes

About the License