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Morphometric Analysis of Key Foot Dimensions Across Selected Shoe Sizes in Young Indian Adults: A Pilot Study

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Abstract: Foot anthropometric data is important for footwear designing. As shoe sizes increases; foot dimensions influence overall foot morphology. As yet, limited studies explored the progressive changes of foot dimensions across different shoe sizes, particularly implication in footwear design. Present study collected foot anthropometric data from Indian young adults, categorized by shoe sizes and examine the variation across key foot dimensions. One hundred fifty volunteers (N=150; aged 18-25 years) were stratified by self-reported by shoe sizes: UK5 (n=50; age , height and weight were 22.56 ± 6.71 years, 156.49 ± 3.94 cm, 58.46 ± 12.29 kg), UK6 (n=50; age 22.28 ± 6.34 years, height 160.32 ± 4.90 cm, weight 60.22 ± 11.88 kg) and UK7 (n=50; age 20.82 ± 3.83 years, height 165.67 ± 4.34 cm, weight 62.69 ± 11.58 kg). Feet dimensions were obtained using 3D foot scanner, and statistical analysis was performed by SPSS v26. Pearson correlation (r) between Foot sizes and foot dimensions showed significant ($p<0.01$) positive correlation, across most foot dimensions. One Way ANOVA and post hoc ANOVA showed the significant differences ($p<0.05$) in most foot dimensions except arch height and heelpiece total length. In this study major dimensions were increased proportionally with increased shoe sizes (UK 5, 6 and 7); while arch height and heelpiece total length were relatively decreased. These findings provide actionable evidence for footwear last design; however, results should not be generalized for the entire Indian population. Further comprehensive studies are required to develop a robust database of foot dimensions across age groups, genders, and different ethnic backgrounds.

Keywords: Shoe Sizes, Morphometric Study, Foot Anthropometric Dimensions, Footwear Design, Indian Adults.

1. Introduction

Functional anatomical structure of foot very much complex and it is composed of 26 bones, 33 joints, over 100 muscles, tendons and ligaments. the foot and ankle are basic to all upright locomotion performed by the human, constantly adjusting to enable a well-proportioned combination between the body and the environment for successful movement (Jana *et al.,* 2024; Wunderlich and Cavanagh, 2001). Anthropometry is a technique which is used for measuring and analysis of physical property of human body as like height, weight measurement. Same foot anthropometry is used for measuring of various dimension of foot such as feet length, arch height, feet width, toe width, ball girth, waist girth, thumb height etc; and verity shape and types of the human foot as like flat feet, high arch etc. Now Foot anthropometry plays a crucial role in designing ergonomic footwear that ensures proper comfort, balance, reduce injury risk and accommodates population-specific anatomical variations. The accurate foot anthropometric data is especially most required in footwear industry (Manna *et al.,* 2001). Despite global advancements in footwear technology, standardised sizing systems often fail to address the unique foot dimensions of diverse populations, leading to widespread discomfort and musculoskeletal issues (Maity *et al.,* 2024).

Previous study highlighted significant gender-based differences in foot shape, such as variations in arch height and forefoot width, which challenge the use

of unisex sizing standers (Zhang *et al.,* 2013). Additionally, few studies demonstrated anthropometric asymmetry between left and the right feet within individual further complicates sizing standardisation (Telfer *et al.,* 2013). Existing shoe sizing systems assume liner foot dimension scaling, where each half-size increment corresponding with an approximate 4.23 mm increase in foot length (Goonetilleke *et al.,* 2000). However, sever studies have challenged this assumption, arguing that parameters such as ball girth, instep height, and midfoot volume do not always follow a proportional growth pattern. Although various studies have examined foot anthropometry across population, few have investigated how foot dimensions change incrementally across population, few studies investigated that how foot dimension change incrementally across standardised shoe sizes. Hawes and Sovak, (1994a) conducted a broad classification of foot shapes but did not analysis (Hawes and Sovak, 1994a). Few studies surveyed that in maximum cases females have smaller shoe size than males and they have smaller foot dimension, but particularly in terms of arch high relative to foot length (Krauss *et al.,* 2008; Branthwaite *et al.,* 2013; Cheskin, 1987). However, few more research surveyed that foot anthropometry does not follow a liner scaling pattern, leading to inconsistencies in shoe fit across different sizes (Ashizawa *et al.,* 1997; Nigg *et al.,* 2012). Many biomechanical studies have emphasised negative impacts of improper footwear fit on gait efficiency and planter pressure; they have not systematically examined whether these issues stem from non-uniform scaling in shoe size increments (Hawes *et al.,* 1994b; Lee and Wang, 2015). Anthropometric data of Indian population is so limited, which hinders the development of culturally appropriate footwear (Telfer *et al.,* 2013; Goonetilleke *et al.,* 2000). Few studies suggested that proper fitted shoes are very crucial for injury prevention, increase biomechanical efficiencies, enhancing comfort and overall movement stability (Dowling *et al.,* 2001). Ill-fitting footwear that does not match an individual's foot shape can result in excessive planter pressure, foot deformities and musculoskeletal disorders, such as hallux valgus, planter fasciitis and metatarsalgia (Krauss *et al.,* 2008; Hawes *et al.,* 1994b). Despite the significance of accurate foot measurement, most commercial footwear sizing systems primarily consider foot length, mistakenly assuming that other dimensions, such as foot width, instep height, and ball girth scale proportionally with shoe size increments (Hawes, Sovak, 1994a; Hawes *et al.,* 1994b).

Although previous studies have documented variations in foot dimensions by focus descriptive population across India and did not examine how foot measurements scale with standardized shoe sizes; the framework used in footwear manufacturing. In India, footwear manufacturing process depends on western last, which does not accommodate with the foot size of Indian adults, this can lead to serious foot injuries like blister, corn, Bunions etc. Consequently, current sizing systems primarily emphasize foot length while assuming that width, girth, and vertical dimensions scale proportionally. So, present study addresses the research gap and also contributes to the literature by analyzing the scaling of morphological features across three consecutive shoe sizes using high-resolution 3D scanning. Specifically, it investigates linear, circumferential, and vertical foot dimensions for UK sizes 5 to 7 in young Indian adults, identifying parameters that are both size-sensitive and size-invariant, the results serve as a baseline foot anthropometric database for footwear design and related products by providing comfort and stability while minimizing risk of injury. The findings highlight the need for multidimensional sizing systems that incorporate volumetric and shape-sensitive measurements. Such systems have important implications for ergonomic footwear design, the prevention of foot pathologies, and improved biomechanical outcomes. The study hypothesizes that increases in foot size may not correspond linearly with proportional changes in other dimensions, and that non-linear or disproportionate variations may exist. These findings suggest that foot anthropometric parameters do not always scale proportionally across shoe sizes, underscoring the importance of investigating how different dimensions evolve as shoe size increases.

2. Materials &Methods

2.1 Selection of Participants

A total of 150 adult volunteers (N=150, Male= 63 and Female =87) were participated in this study and comprised into three groups based on their shoe sizes: UK5 (n=50; mean age: 22.8± 6.71 years, height: 156.49 ± 3.94 cm, weight: 58.46 ± 12.29 kg), UK6 (n=50; mean age: 22.28 ± 6.34 years, height: 160.32 ± 4.90 cm, weight : 60.22 ± 11.88 kg) and UK7 (n=50,mean age: 20.82 ± 3.83 years, height: 165.67 ± 4.34 cm, weight: 62.69 ± 11.58 kg). All participants were physically healthy, with no history of musculoskeletal disorders, lower limb deformities

factures or vestibular system abnormalities and were of North Indian ethnicity.

2.2 Experimental Design

Participants were briefed about the study objectives and procedures before data collection. Then informed them about written consent paper, subjects were informed of their right to withdraw from the study. Anthropometric measurements of height and weight were recoded using a standard anthropometric rod (R.S. Scientific Works, India) and a calibrated weight were performed with equal weight distribution on both feet and each scan required approximately 5-10 seconds to capture bilateral foot morphology. After complete the process, the measurements were displayed on the screen and recorded in 3d foot scanning system. Information regarding ethnicity, occupational background, and habitual physical activity level was not collected, which is acknowledged as a methodological limitation.

2.3 Instrumentation

Foot anthropometric data were acquired using the LSF-350-A 3D foot scanner (Shenzhen 3DOE Technology Co., Ltd., China), which features a compact, portable, closed-loop optical system with 8-angle full-field scanning capability (Figures 1 a and b). The device is made with an intelligent touch screen for one-click operation and employs non-contract laser technology, ensuring safety for both skin and eyes. The scanner offers very fast acquisition (< 10 seconds per foot) and high precision (±0.5 mm), enabling the extraction of over 65 distinct foot parameters. Environment of the laboratory was maintained at a controlled temperature of 25°C–27°C and relative humidity of 50%-55% throughout the study.

2.4 Studied Anthropometric Parameters

In this study several foot anthropometric parameters were considered, including: foot length, foot width, toe width, heel girth, waist girth, instep girth, ball girth, foot arch, thumb height, heel heart width, heelpiece total length, and heelpiece pump height (mm).

2.5. Ethical clearance

The present study protocol on human use as an experimental subject and the entire principles are outlined by the Declaration of Helsinki Protocol, 1964, and as per approved ethical clearance no HMC/IEC/BU/09 dated 14.08.2025.

2.6. Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Science (SPSS) Statistics software package (IBM SPSS Statistics for Windows, Version 26.0, IBM Corp., Armonk, NY, USA). Normal distribution of data showed data were normally distributed, which was assessed by the Kolmogorov-Smirnov normality test, along with visual histograms and Q-Q plots. The data was summarized as mean ± SD. Pearson Correlation coefficient (r) was applied to find out the relationship between Foot Size and Foot Anthropometric dimension. One-Way ANOVA and Tukey's post hoc ANOVA tests were applied to compare and examine the variation of foot anthropometric parameters among shoe sizes – UK5, UK6 and UK7. The significance level was set at $p<0.05$ levels.

Figures 1 (a and b): Assessment of bilateral foot anthropometric dimensions using a 3D foot scanner (LSF-350-A): (a) participant positioning and (b) digital foot measurement output. scanner.

Table 1. Pearson Correlation analysis of Foot Size and Foot Anthropometric dimension

	FS	FL	FW	BC	HC	WC	IC	FAH	TH	TW	HHW	HTL	HPH
FS	1	.887**	.568**	.464**	.589**	.450**	.513**	-0.081	.197**	.317**	.373**	-0.036	0.014
FL	.887**	1	.652**	.453**	.684**	.452**	.531**	-0.044	.191**	.356**	.468**	-0.057	-0.105
FW	.568**	.652**	1	.826**	.733**	.736**	.767**	-0.001	.423**	.688**	.505**	0.007	-0.036
BC	.464**	.453**	.826**	1	.734**	.852**	.870**	0.068	.555**	.726**	.387**	.133*	.209**
HC	.589**	.684**	.733**	.734**	1	.695**	.788**	0.094	.462**	.536**	.652**	-0.001	-0.096
WC	.450**	.452**	.736**	.852**	.695**	1	.881**	-0.016	.478**	.551**	.420**	.136*	.181**
IC	.513**	.531**	.767**	.870**	.788**	.881**	1	0.001	.497**	.538**	.455**	.122*	.146*
FAH	-0.081	-0.044	-0.001	0.068	0.094	-0.016	0.001	1	-0.019	.160**	-0.018	-0.053	-0.097
TH	.197**	.191**	.423**	.555**	.462**	.478**	.497**	-0.019	1	.463**	.304**	0.086	0.105
TW	.317**	.356**	.688**	.726**	.536**	.551**	.538**	.160**	.463**	1	.227**	-0.001	0.077
HHW	.373**	.468**	.505**	.387**	.652**	.420**	.455**	-0.018	.304**	.227**	1	.142*	-0.112
HTL	-0.036	-0.057	0.007	.133*	-0.001	.136*	.122*	-0.053	0.086	-0.001	.142*	1	.676**
HPH	0.014	-0.105	-0.036	.209**	-0.096	.181**	.146*	-0.097	0.105	0.077	-0.112	.676**	1

** Sign indicated correlation was significant at the 0.01 level (2-tailed).

* Sign indicated correlation was significant at the 0.05 level (2-tailed).

FS = Foot Size (UK 5, UK 6 and UK7), FL = Foot Length, FW = Feet Width, BC = Ball Circumference, HC = Heel Circumference, WC = Waist Circumference, IC = Instep Circumference, FAH = Foot Arch Height, TH = Thumb Height, TW = Toe Width, HHW = Heel Heart Width, HTL = Heelpiece Total Length, HPH = Heel Piece Pump Height.

Table 2. Mean ± SD and Percentage (%) Deviation of Foot anthropometric Dimension across Shoe sizes (UK5, UK6 and UK7) with their comparison by One -Way ANOVA.

Parameters (mm)	Total (N=150)			Percentage (%) deviation b/w UK5 and UK 6	Percentage (%) deviation b/w UK5 and UK7	Percentage (%) deviation b/w UK6 and UK 7	F Score	η²	Significant Level
	UK 5 (n=50)	UK 6 (n=50)	UK 7 (n=50)						
	Mean± SD	Mean± SD	Mean ± SD						
FL	232.42 ± 5.072	241.18 ± 3.414	252.20 ± 3.845	3.77 %	8.51%	4.37%	562.285	**0.884**	**0.00 (p<0.05)**
FW	90.00 ± 5.619	94.67 ± 4.672	98.13 ± 4.043	5.19%	9.04%	3.53%	71.389	**0.493**	**0.00 (p<0.05)**
BC	211.30 ± 12.824	219.96 ± 10.913	225.67 ± 9.642	4.10%	6.80%	2.53%	41.49	**0.361**	**0.00 (p<0.05)**
HC	297.80 ± 14.725	309.48 ± 12.448	321.70 ± 13.046	3.92%	8.02%	3.80%	78.705	**0.517**	**0.00 (p<0.05)**
WC	212.56 ± 13.005	221.99 ± 11.828	227.83 ± 12.326	4.44%	7.18%	2.56%	38.496	**0.344**	**0.00 (p<0.05)**
IC	211.52 ± 12.456	221.47 ± 11.519	228.69 ± 11.196	4.71%	8.12%	3.16%	53.784	**0.422**	**0.00 (p<0.05)**
FAH	13.47 ± 12.958	12.24 ± 9.177	11.29 ± 9.362	**9.12%↓**	**16.15%↓**	**8.39%↓**	0.989	**0.013**	0.37 (p>0.05)
TH	18.25 ± 1.775	18.93 ± 1.709	19.12 ± 1.797	3.71%	4.75%	0.99%	6.687	**0.083**	**0.00 (p<0.05)**
TW	86.04 ± 7.829	89.18 ± 7.644	92.17 ± 6.990	3.64%	7.12%	3.24%	16.616	**0.184**	**0.00 (p<0.05)**
HHW	62.60 ± 5.835	65.85 ± 6.087	68.48 ± 6.009	5.19%	9.39%	3.83%	24.164	**0.247**	**0.00 (p<0.05)**
HTL	33.23 ± 17.554	32.56 ± 17.678	31.71 ± 17.298	**2.02%↓**	**4.59%↓**	**2.69%↓**	0.19	**0.003**	0.82 (p>0.05)
HPH	13.29 ± 5.176	13.41 ± 5.497	13.47 ± 5.145	0.87%	1.37%	0.50%	0.03	**<0.001**	0.97 (p>0.05)

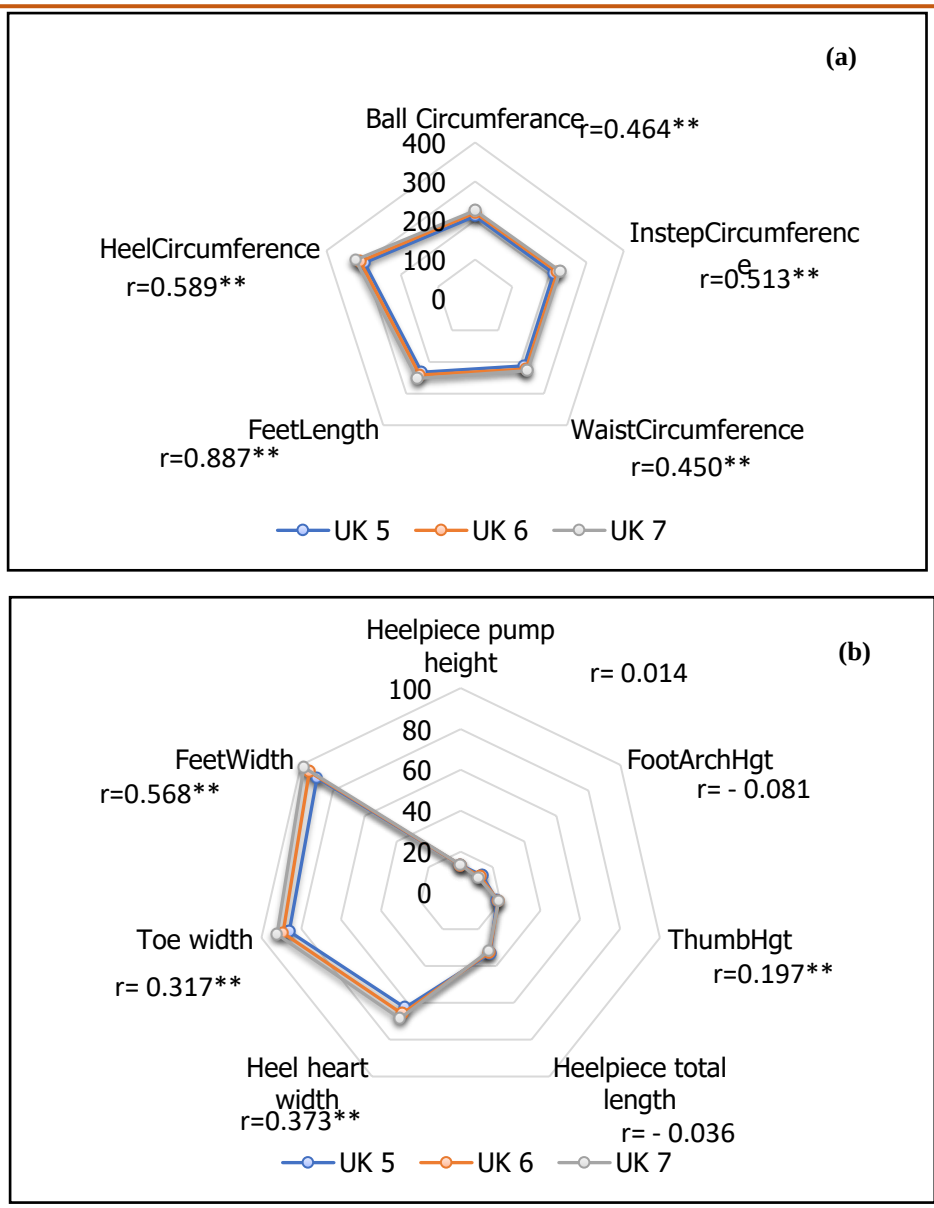
Table 3. Tukey Simultaneous Test to identify differences among shoe sizes (UK5, UK6, and UK7) across foot anthropometric parameters (Post Hoc ANOVA)

Parameters (mm)	(I) UK	(J) UK	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Feet Length	UK5	UK6	-8.757070*	0.591171	**0.00 (p<0.05)**	-10.14959	-7.36455
		UK7	-19.781430*	0.591171	**0.00 (p<0.05)**	-21.17395	-18.38891
	UK6	UK5	8.757070*	0.591171	**0.00 (p<0.05)**	7.36455	10.14959
		UK7	-11.024360*	0.591171	**0.00 (p<0.05)**	-12.41688	-9.63184
	UK7	UK5	19.781430*	0.591171	**0.00 (p<0.05)**	18.38891	21.17395
		UK6	11.024360*	0.591171	**0.00 (p<0.05)**	9.63184	12.41688
Feet Width	UK5	UK6	-4.6735630*	0.6834476	**0.00 (p<0.05)**	-6.283441	-3.063685
		UK7	-8.1365360*	0.6834476	**0.00 (p<0.05)**	-9.746414	-6.526658
	UK6	UK5	4.6735630*	0.6834476	**0.00 (p<0.05)**	3.063685	6.283441
		UK7	-3.4629730*	0.6834476	**0.00 (p<0.05)**	-5.072851	-1.853095
	UK7	UK5	8.1365360*	0.6834476	**0.00 (p<0.05)**	6.526658	9.746414
		UK6	3.4629730*	0.6834476	**0.00 (p<0.05)**	1.853095	5.072851
BALL Girth	UK5	UK6	-8.657590*	1.587817	**0.00 (p<0.05)**	-12.39773	-4.91745
		UK7	-14.363240*	1.587817	**0.00 (p<0.05)**	-18.10338	-10.6231
	UK6	UK5	8.657590*	1.587817	**0.00 (p<0.05)**	4.91745	12.39773
		UK7	-5.705650*	1.587817	**0.00 (p<0.05)**	-9.44579	-1.96551
	UK7	UK5	14.363240*	1.587817	**0.00 (p<0.05)**	10.6231	18.10338
		UK6	5.705650*	1.587817	**0.00 (p<0.05)**	1.96551	9.44579
Heel Circumference	UK5	UK6	-11.678710*	1.904714	**0.00 (p<0.05)**	-16.16531	-7.19211
		UK7	-23.895170*	1.904714	**0.00 (p<0.05)**	-28.38177	-19.40857
	UK6	UK5	11.678710*	1.904714	**0.00 (p<0.05)**	7.19211	16.16531
		UK7	-12.216460*	1.904714	**0.00 (p<0.05)**	-16.70306	-7.72986
	UK7	UK5	23.895170*	1.904714	**0.00 (p<0.05)**	19.40857	28.38177

		UK6	12.216460*	1.904714	**0.00 (p<0.05)**	7.72986	16.70306
Waist Circumference	UK5	UK6	-9.429960*	1.756274	**0.00 (p<0.05)**	-13.56691	-5.29301
		UK7	-15.270400*	1.756274	**0.00 (p<0.05)**	-19.40735	-11.13345
	UK6	UK5	9.429960*	1.756274	**0.00 (p<0.05)**	5.29301	13.56691
		UK7	-5.840440*	1.756274	**0.00 (p<0.05)**	-9.97739	-1.70349
	UK7	UK5	15.270400*	1.756274	**0.00 (p<0.05)**	11.13345	19.40735
		UK6	5.840440*	1.756274	**0.00 (p<0.05)**	1.70349	9.97739
Instep Circumference	UK5	UK6	-9.955150*	1.662825	**0.00 (p<0.05)**	-13.87197	-6.03833
		UK7	-17.173530*	1.662825	**0.00 (p<0.05)**	-21.09035	-13.25671
	UK6	UK5	9.955150*	1.662825	**0.00 (p<0.05)**	6.03833	13.87197
		UK7	-7.218380*	1.662825	**0.00 (p<0.05)**	-11.1352	-3.30156
	UK7	UK5	17.173530*	1.662825	**0.00 (p<0.05)**	13.25671	21.09035
		UK6	7.218380*	1.662825	**0.00 (p<0.05)**	3.30156	11.1352
Foot Arch Height	UK5	UK6	1.2280205	1.55176574	0.70(p>0.05)	-2.4272022	4.8832432
		UK7	2.1760071	1.55176574	0.34(p>0.05)	-1.4792156	5.8312298
	UK6	UK5	-1.2280205	1.55176574	0.70(p>0.05)	-4.8832432	2.4272022
		UK7	0.9479866	1.55176574	0.81 (p>0.05)	-2.7072361	4.6032093
	UK7	UK5	-2.1760071	1.55176574	0.34 (p>0.05)	-5.8312298	1.4792156
		UK6	-0.9479866	1.55176574	0.81(p>0.05)	-4.6032093	2.7072361
Thumb Height	UK5	UK6	-.6779780*	0.2494748	**0.01(p<0.05)**	-1.265622	-0.090334
		UK7	-.8676730*	0.2494748	**0.00(p<0.05)**	-1.455317	-0.280029
	UK6	UK5	.6779780*	0.2494748	**0.01(p<0.05)**	0.090334	1.265622
		UK7	-0.189695	0.2494748	0.72 (p>0.05)	-0.777339	0.397949
	UK7	UK5	.8676730*	0.2494748	**0.00(p<0.05)**	0.280029	1.455317
		UK6	0.189695	0.2494748	0.72(p>0.05)	-0.397949	0.777339
Toe width	UK5	UK6	-3.1345510*	1.0621073	**0.01 (p<0.05)**	-5.636371	-0.632731

		UK7	-6.1221970*	1.0621073	**0.00 (p<0.05)**	-8.624017	-3.620377
	UK6	UK5	3.1345510*	1.0621073	**0.01 (p<0.05)**	0.632731	5.636371
		UK7	-2.9876460*	1.0621073	**0.01(p<0.05)**	-5.489466	-0.485826
	UK7	UK5	6.1221970*	1.0621073	**0.00 (p<0.05)**	3.620377	8.624017
		UK6	2.9876460*	1.0621073	**0.01(p<0.05)**	0.485826	5.489466
Heel heart width	UK5	UK6	-3.2514130*	0.8467676	**0.00 (p<0.05)**	-5.245995	-1.256831
		UK7	-5.8754850*	0.8467676	**0.00 (p<0.05)**	-7.870067	-3.880903
	UK6	UK5	3.2514130*	0.8467676	**0.00 (p<0.05)**	1.256831	5.245995
		UK7	-2.6240720*	0.8467676	**0.00(p<0.05)**	-4.618654	-0.62949
	UK7	UK5	5.8754850*	0.8467676	**0.00 (p<0.05)**	3.880903	7.870067
		UK6	2.6240720*	0.8467676	**0.00 (p<0.05)**	0.62949	4.618654
Heelpiece total length	UK5	UK6	0.67262149	2.480568834	0.96(p>0.05)	-5.17041991	6.51566289
		UK7	1.52546345	2.480568834	0.81(p>0.05)	-4.31757795	7.36850485
	UK6	UK5	-0.67262149	2.480568834	0.96(p>0.05)	-6.51566289	5.17041991
		UK7	0.85284196	2.480568834	0.93(p>0.05)	-4.99019944	6.69588336
	UK7	UK5	-1.52546345	2.480568834	0.81(p>0.05)	-7.36850485	4.31757795
		UK6	-0.85284196	2.480568834	0.93(p>0.05)	-6.69588336	4.99019944
Heelpiece pump height	UK5	UK6	-0.1150584	0.74723294	0.98(p>0.05)	-1.8751841	1.6450673
		UK7	-0.1822745	0.74723294	0.96(p>0.05)	-1.9424002	1.5778512
	UK6	UK5	0.1150584	0.74723294	0.98(p>0.05)	-1.6450673	1.8751841
		UK7	-0.0672161	0.74723294	0.99(p>0.05)	-1.8273418	1.6929096
	UK7	UK5	0.1822745	0.74723294	0.96(p>0.05)	-1.5778512	1.9424002
		UK6	0.0672161	0.74723294	0.99 (p>0.05)	-1.6929096	1.8273418

* The mean difference was significant at the 0.05 level.



Figures 2. a and **b**: Radar chart of Pearson correlation illustrated the variance of foot anthropometric parameters among UK5, UK6, and UK7 shoe sizes. ** sign indicated that the correlation coefficient was significant at the 0.01 level.

A Pearson Correlation analysis test was applied to examine the relationship between Foot Size (UK 5, UK 6 and UK7) and foot anthropometric dimensions. The results showed a fine positive and significant correlation between Foot Size and Foot Length, r = 0.887, Feet Width, r = 0.568, Ball Circumference, r = 0.464, Heel Circumference, r = 0.589, Waist Circumference, r = 0.450, Instep Circumference, r = 0.513, Thump Height, r = 0.197, Toe Width, r = 0.317, Heel Heart Width, r = 0.373, Heel Pump Height, r = 0.014 and also negative correlation between Foot Arch Height, r = - 0.081, Heelpiece Total Length, r = - 0.036 (Table 1).

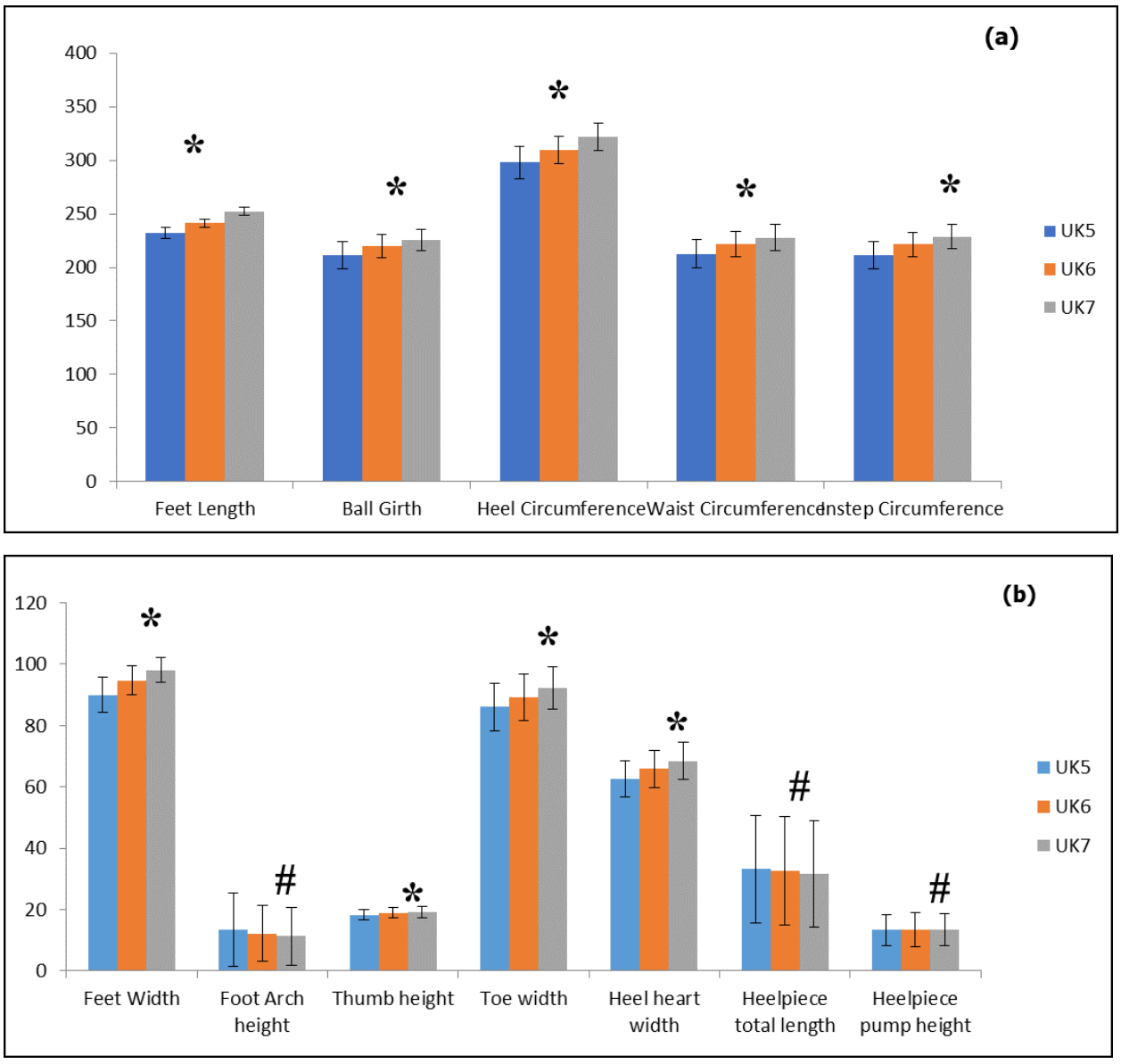
The finding of this study disclosed that increasing variations showed in foot anthropometric dimensions across three shoe sizes categories (UK5, UK6 and UK7). A one-way ANOVA used for assess the statistical differences among group of sizes for each measured parameter (Table 2). Maximum foot dimensions – including Foot length, Foot width, Ball girth, Heel circumference, Waist circumference, Instep circumference, Thumb height, Toe width and Heel heart width – demonstrated statistically significant differences ($p<0.05$; df =2,297) displaying a consistent increase with shoe size.

Highest percentage deviation displayed that the foot length (8.51%), foot width (9.04%), instep circumference (8.12%) and heel heart width (9.39%), these parameters are most sensitive to shoe size increments. Inversely, foot arch height and heel piece total length exhibited a decreasing trend. Foot arch height declined by 9.12% from UK 5 to UK 6 and by

16.15% from UK5 to UK7; however, these changes were not statistically significant ($p = 0.37$). Similarly, heelpiece total length decreased by 2.02% from UK5 to UK6 and by 4.59% from UK5 to UK7, without reaching statistical significance ($P = 0.82$). Heelpiece pump height remained relatively stable across groups, with a minimal deviation of 0.87% between UK5 and UK7 and no significant difference ($p = 0.97$), suggesting that this parameter is not substantially influenced by shoe size.

A one-way ANOVA revealed statistically significant differences in most foot dimensions across different shoe sizes. Foot length showed an exceptionally large effect of shoe size, with values of $F(2,147) = 562.29$, $p < 0.001$, and $\eta^2 = 0.884$. This indicates that nearly 88% of the variance in foot length can be explained by shoe size.

Similarly, we observed large effect sizes for foot width ($\eta^2 = 0.493$), heel circumference ($\eta^2 = 0.517$), instep circumference ($\eta^2 = 0.422$), ball girth ($\eta^2 = 0.361$), waist girth ($\eta^2 = 0.344$), toe width ($\eta^2 = 0.184$), and heel heart width ($\eta^2 = 0.247$). In contrast, foot arch height ($F = 0.99$, $p = 0.37$, $\eta^2 = 0.013$), heel piece total length ($F = 0.19$, $p = 0.82$, $\eta^2 = 0.003$), and heel piece pump height ($F = 0.03$, $p = 0.97$, $\eta^2 < 0.001$) exhibited trivial effect sizes, indicating that these parameters do not change meaningfully with shoe size. These findings demonstrate that while most linear and circumferential foot dimensions increase proportionally with shoe size, certain vertical and posterior dimensions remain relatively unchanged



Figures 3 a and b. Comparison of Foot anthropometric parameters between Foot sizes UK5, UK6 and UK7. The '*' sign indicated statistically significant differences, and the '#' sign indicated no significant difference between Foot Sizes among the studied anthropometric dimensions at the 0.05 level.

Tukey's posthoc ANOVA was used to assess pairwise differences of foot anthropometric parameters across the three-shoe size groups (UK5, UK6 and UK7) (Table 3 and Figures 3 a and b). Statistically significant differences ($p < 0.05$), of the Tukey simultaneous test revealed in the majority of parameters – including foot length, foot width, ball circumference, heel circumference, waist circumference, waist circumference, instep circumference, toe width and heel heart width – across all pairwise comparisons (UK5 vs UK6, UK6 vs UK7 and UK 5 vs UK7). These finding of this study define that shoe size increase consistently and proportionally extension with the foot dimension.

In contrast foot arch height, heelpiece total and heelpiece pump height did not exhibit statistically significant difference ($p > 0.05$) across shoe groups, indicating that these specific parameters remain relatively stable despite changes in shoe size.

3. Results and Discussion

The present study investigated variations in foot anthropometric dimensions across different shoe sizes (UK 5, UK 6, and UK 7) among Indian adults (N = 150). Results of the Pearson correlation coefficient demonstrated a significant positive correlation between foot sizes and most studied foot anthropometric dimensions, except arch height and heel piece total length. One-Way ANOVA and Tukey's post hoc ANOVA results showed a progressive increase in foot anthropometric dimensions across the 3 shoe sizes (UK 5, UK 6 and UK 7), and most parameters were statistically significant at the 0.05 level, except foot arch height, heel piece total length and heel piece pump height. Also, this study strongly indicated that the majority of foot measurements, including foot length, width ball girth, heel circumference, instep circumference, thump height, heel heart width, and heel pump height increased significantly as shoe size increased resulted from statistical analysis. These observations provide valuable insight into the morphological consistency and variability of foot structure across different shoe sizes. All of the parameters from this study critically important for precise sizing in last design.

In this study a Pearson correlation analysis test was applied to determine the relationship between Foot size and Foot anthropometric dimensions. The result table 1 and Radar chart (Figures 2 a and b) display the correlation between Foot size and go through foot anthropometric dimensions using Pearson's correlation coefficient (r). In Fig. 1a and b, Foot Length (r = 0.887), Feet Width (r = 0.568, Ball Circumference (r = 0.464), Heel Circumference (r = 0.589), Waist Circumference (r = 0.450), Instep Circumference, (r = 0.513), Thump Height, (r = 0.197), Toe Width (r = 0.317), Heel Heart Width (r = 0.373), Heel Pump Height (r = 0.014) of several foot anthropometric measurements have strong linear correlation with Foot Size at significantly level ($p< 0.01$). Overall girth of the foot increase with increased Foot Size, as the increase of foot sizes indicates the increase of anthropometric dimension. On the other side foot Heel Pump Height (r = 0.014) shows that weak liner correlation and also negative correlation between Foot Arch Height, (r = - 0.081), Heelpiece Total Length (r = - 0.036). It shows that the increase of foot sizes is non-significantly corelated with Heel pump height, Foot arch height and Heel piece total length.

Stella I. Monye *et. al,* (2023) found that the highest value of correlation coefficients in ball/joint girth and foot waist girth (r = 0.915), foot waist girth and instep girth (r = 0.905) in addition to ball/joint girth and instep girth and weak correlation coefficients displayed in waist height and toe height had the least value (r=0.029) (Monye *et al.,* 2023). While other study has done correlation coefficient between foot length and arch length, that indicated the difference of foot breadth or ball girth are considerably large irrespective of foot length, even though correlation between foot breadth and ball girth was very high, the correlation coefficient results value show r=0.91 for male subjects. Foot breadth may not be able to be substituted for ball girth (Baba, 1974). However, another study conducted correlation on foot morphology of two endogamous group of North India (baniya, jats). Result showed significant correlation between height and foot length in male study group, among females, height showed significant correlation with foot breadth, foot length and foot index (in jats and baniyas female group) (Sharma, 2020). Present study illustrated a sympathetic independent progression through the correlation analysis across major foot dimensions.

One-Way ANOVA test was Applied to compare the differences among shoe sizes (UK 5, UK 6, and UK 7) on studied foot anthropometric dimensions. Results showed the progressive variations in foot anthropometric dimensions across three shoe sizes In most foot anthropometric parameters. UK5, 6, 7 demonstrated the increment pattern across the parameters, including foot length (232.42 ± 5.072,241.18 ± 3.414, 252.20 ± 3.845) with a 3.77% ↑, 8.51% ↑, 4.37% ↑ percentage deviation. Along with

foot width, ball girth, heel circumference, waist circumference, instep circumference, thumb height, toe width, and heel heart width, showed a statistically significant difference (P<0.05, df=2,297) as progressive manner with shoe size increments. Whereas foot arch height (13.47 ± 12.958, 12.24 ± 9.177, 11.29 ± 9.362) and heel piece total length (33.23 ± 17.554, 32.56 ± 17.678, 31.71 ± 17.298) showed non-significant different with reduced pattern. While another study formed shoes size patterns of boys aged 4 to 6 years old , they made the range for Narrow (N1 & N2), Medium (M1,M2,M3 & M4) and Wide(W1,W2 & W3) as per Shoe length (N1 and N2 range 176 to 183 mm, M1 to M4 range 183 to 204 mm and W1 to W3 range 204 to 218 mm) , shoes width (N1 and N2 range 75 to 82 mm, M1 to M4 range 81 to 87 mm and W1 to W3 range 87 to 99 mm) and shoes circumference on Ball girth (N1and N2 range 187 mm, M1 to M4 range 205 mm and W1 to W3 range 223 to 229 mm) (Waluyono *et al.,* 2019). Another study in Malaysia women population of three ethnic groups (Malay, Chinese and Indian) different age categories (20-24, 25 -29, 30 -34, 35 – 39, 40 – 44, 45 – 49, 50 – 54, 55 -60) and created new range and categories of shoe sizes in Malaysian women population. Formed 8 sizes (a, b, c, d, e, ee, eee and eeee) where size increased on Foot length with 5 mm size interval, Foot width or FB with 3mm size interval and Ball girth of 6 mm. This study proposed shoe size 4 to 11. (Shariff *et al.,* 2014). Kim, N. *et al.* (2019) demonstrated sizing system and shapes for the elderly men, study conformed most seven ranges Foot length 235 mm to 265 mm for H sole type and six ranges foot length 240 mm to 265 mm for A sole type conformed Instep circumference 231 to 273 mm and 234 mm to 267 mm included (six ranges) C, D, E, EE, EEE, EEE width range of C-F width range, foot length 235 to 260 mm for V sole type, which conformed 240 mm to 276 mm instep circumference range included Width range D to F. Foot length of Sole type D, 235 mm to 260 mm which conformed 240 mm to 267 mm instep circumference include only five width range D to EEEE (Kim and Do, 2019). All above prior studies highlighted, how shoe sizes increased with the increment of foot dimensions. Few studies conclude how early foot anthropometric changes in adult foot structure and the morphology with functional health outcomes. (injuries, discomfort), also underline the importance of early monitoring of foot anthropometric parameters in overweight children, to overcome the structural and functional foot problems (Wunderlich and Cavanagh, 2001; Mauch *et al.,* 2008).

However, the findings of this pilot study are specific to young Indian adults within a restricted shoe-size range (UK 5–7). Considering India's considerable regional, ethnic, and occupational diversity, these results should not be viewed as representative of the wider Indian adult population. Result of the present study can be serving baseline foot arthrometric database for making Indian Footwear last followed by these shoe sizes. This indigenous approach going to enable a new era of footwear design, where designers can ensure the fitment, comfort and better stability, along with minimizing risk of injuries. This study is essentially limited by small sample size and narrow range of foot size (UK5, UK6 and UK7). In future research efforts should be focused on specific gender, age, community for more comprehensive and robust understanding of foot dimension across diverse population. Specially, to increase the clinical and ergonomical relevance of these anthropometric finding.

4. Conclusion

Present study investigated the variation in majority of liner and circumferential foot dimensions; including feet length, width and different girth measurements, as shoe size increased across the UK5, UK6 and UK7 ranges. In this study Pearson correlation analysis test showed the relationship between Foot size and Foot anthropometric dimensions. Whereas, positive significant correlation (p<0.01) was found in foot sizes with most of the studied parameters except non-significantly corelated with Heel pump height, Foot arch height and Heel piece total length. This finding indicates the progressive effect in overall studied dimensions across shoe size increases. This pattern confirms the proportional scaling of most parameters with increasing foot sizes. The One-Way ANOVA test revealed significant differences in shoe sizes (UK 5, UK 6, and UK 7) among key foot anthropometric dimensions. Specifically, the measurements for UK 5, UK 6, and UK 7 showed a consistent increase across major foot dimensions, with a statistically significant difference (P<0.05, df=2,297) corresponding to the increments in shoe size. In contrast, foot arch height and the total length of the heel piece did not show significant differences; instead, these dimensions decreased as shoe size increased.

Findings of the present study provided an overview of foot dimensions associated with different foot sizes and this outcome serve as a baseline foot anthropometric database for footwear design and related products for Indian populations by providing

comfort and stability while minimizing risk of injury. Present study limited with small sample size also absences of gender, age and ethnicity. Therefor a more detail study is required to enhances a comprehensive, population-specific database of foot dimension to increase the ergonomical performance of footwear in India. In conclusion, this pilot study offers important evidence on foot dimensions among young Indian adults within a restricted shoe size range. Although most measurements increased proportionally with shoe size, the stable arch height and heelpiece length reveal limitations in conventional grading systems. These findings are significant for ergonomic footwear design, but broader conclusions demand larger, regionally stratified studies. Overall, the investigation demonstrates that while most foot dimensions scale with shoe size, arch height and heelpiece total length remain relatively stable. These non-scaling parameters challenge traditional length-based grading systems and underscore the importance of multidimensional footwear design. Future studies incorporating larger, regionally and demographically diverse samples are essential to extend these findings.

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Author's contribution & Statement

Chandan Ram: Data collection, processing, Analysis, Statistical analysis and interpretation, Manuscript preparation and Writing. Ayan Maity: Involved data collection, processing, Review of literature, Editing. Sugata Das Kumar: Data interpretation, Review & Editing. Tushank Jain: Conceptualization, Experimental design and finalization of study protocol, Overall supervision of study, Editing of final manuscript. All authors read and approved the final manuscript.

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Informed Consent

The consent form was signed before commencement of the study.

Ethics Approval

The present study protocol on human use as an experimental subject and the entire principles are outlined by the Declaration of Helsinki Protocol, 1964, and as per approved ethical clearance no HMC/IEC/BU/09 dated 14.08.2025.

Data Availability Statement

All Research data and materials are not publicly archived and is available on request from the corresponding author.

Does this article pass screening for similarity?

Yes

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