Foot Length and Preference: Implication in Footwear Design

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Abstract: *Introduction:* The foot bears great anatomical function and therefore needs to be protected. The design and engineering of footwear for diverse population is subject to accurate anthropometric data provided for the population.

Aims and Objectives: The present study therefore evaluates foot length difference in relation to foot preference and their implication in footwear design.

Methods: A total of 1154 adult Nigerians comprising of 577 males and 577 females were included in the study. Direct linear measurements of the left and right foot length were measured using a metric tape. Foot preference (RT, LF or both) and longer foot (RT, LT or EQ) were also determined. Data were analyzed using SPSS (IBM®Armonk, New York, USA) and Minitab V17 (Minitab® Inc. State College, Pennsylvania) statistical software. Paired-sample t-test was used to evaluate symmetry; student t-test was used to compare sex differences while Chi square analysis was used to evaluate the association of foot preference with sex, side and longer foot. Confidence level was set at 95%; as P-values ≤0.05 were considered significant.

Results: The mean (S.D) of the right and left foot length (RFL and LFL) of male was 270.20±13.25mm and 270.46±12.94mm while female was 248.90±12.07mm and 249.52±11.81mm respectively. The population RFL and LFL was 259.55±16.56mm and 259.99±16.22mm. The paired sample t-test showed significant symmetric differences in RFL and LFL for females (P=0.033) and total population (P=0.011) but not males (P=0.168). Males displayed significantly higher mean values than the females (P<0.001). Results of the Chi-square analysis showed that, when sex was related to foot preference, the right foot was observed to be dominant for both males (88%) and females (87%), while dual-footedness presented least (2.4% males and 1.7% females). However, there was no observed association of sex and the foot preference neither was there any proportionality difference (P>0.05) but there was association between sex and foot-length difference (P<0.01), with more females having a longer left and right foot while more males had relatively equal foot length.

Conclusion: This study suggests the avoidance of assumption of equal foot length; hence, length difference must be considered when constructing footwear for the Nigerian population, most especially for the females, as the study observed bilateral asymmetry in foot length.

Keywords: Foot length, Foot preference, Footwear, Asymmetry, Sex.

INTRODUCTION

Anthropometry has been described as a series of systematized measuring techniques that express quantitatively the dimensions of the human body and skeleton [1]. It is often viewed as a traditional and perhaps the basic tool of biological anthropology. Human anthropometric measurement has become significant in one field or the other. The collaboration of various fields (such as engineering, arts and design, genetics) with physical and forensic anthropology has created expanding need for national database for various anatomical dimensions.

The design of body wears is extensively dependent on the specification of body landmarks, and measurements between them [2]. The understanding of the fact that skeletal development is influenced by a number of factors (such as nutrition, environment, genome, diseases, among others) has created the observed differences in skeletal proportions between different geographical areas [1], thus necessitating the need for the creation of population-specific data which will quantitatively express to which variations such traits exhibit.

For proper fitting of shoes, their design must be complementary to the shape and dimensions of the feet of the target population [3]. Various studies have suggested that improper fitting of the foot to protective wears have resulted in the varying foot deformity (such as hallux valgus, hammer toes, claw toes and corns) observed [4]; especially in adult (older) populations [5].

The main aim of this study is therefore to evaluate foot length difference in relation to foot preference and their implication in footwear design among Nigerians.

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MATERIALS AND METHODS

A total of 1154 adult Nigerians of equally distributed sexes (aged 18-50 years) were randomly selected from various states in Nigeria. Informed consent was taken from each participant and the sample size was determined by proportion, using Cochran formulae for large population (>10,000) or infinite population; $SS = \frac{Z^2 \times p \times q}{d^2}$ [6].

Left and right foot lengths were taken by direct linear measurements using a metric tape (with accuracy of 0.1cm). The right and left foot lengths (RFL and LFL) were defined by the maximum distance from the most anterior or projecting part of the big toe (Acropodian) to the most backward and prominent part of the heel (Pternion), when placed on the surface of the floor. Measurements were taken twice and the average value presented as the foot length. This was used to determine longer foot, as either, RT, LT or equal (EQ). This speculation of longer foot length as an indication of foot dominance is an anthropological perspective worthy of investigation.

Foot preference, right (RT), left (LF) or both was determined using well-structured questionnaire. Generally, foot preference was regarded as the preferred choice of foot in carrying out a specific task. In the context of one foot being used for task manipulation (for example; kicking a ball) and the other for stabilization (lending postural support), the manipulative foot can be referred to as the dominant (preferred) foot while the foot which supports the actions is the non-preferred [7-9].

Selected feet were free of deformity, injury, fracture, amputation or history of any surgical procedures on any of the foot. Ethical clearance was obtained from the University of Port Harcourt Ethical Committee (reference number UPH/R&D/REC/04).

Statistical Analysis

SPSS (IBM®Armonk, New York, USA) and Minitab V17 (Minitab® Inc. State College, Pennsylvania) were the statistical packages used in analyzing the obtained data. Paired-sample t-test was used to evaluate foot symmetry, and student t-test to compare sex differences while Chi-square analysis was used to evaluate the association of foot preference with sex, side and longer foot (foot difference). Confidence level was set at 95%, as P-values ≤0.05 were considered significant.

RESULTS

The values observed from the anthropometric measurements were tabulated and the mean (S.D) values and range (min–max) were determined for the sex (male and female) with side specific differences (left and right) evaluated (Table **1**). Sex differences in foot length were represented in Table **2**. Foot preference [RF=right foot, LF=left foot, BT=both feet] and foot length difference [RF=right foot, LF=left foot, EQ=equal foot]) were presented in Tables **3**-**5**.

Foot Length Symmetry and Sex Difference

In Table **1**, the side differences in foot length were assessed in males, females as well as the general population. The length of the right and left foot of males (M) were relatively equal (t=-1.382; *P*=0.168), although with a slight longer left foot; however, the females (F) and the general population (Gp) exhibited significant longer left foot (F*t=-2.137, *P*=0.033; Gp*t=-2.544, *P*=0.011). Significant positive correlation was observed for the left and right foot of males (r=0.935; *P*<0.001), females (r=0.828; *P*<0.001) and the general population (r=0.939; *P*<0.001). The foot lengths of males were significantly higher when compared to females (RFL* t=20.21, *P*<0.001; LFL* t=20.28, *P*<0.001) (Table **2**).

Foot Preference and Morphometric Foot Length Difference

In Table **3**, foot preference and length difference were assessed for patterns. The distribution of foot preference showed that among males and females, the right foot was preferred with males having right foot dominance (RF) of 88.0% (508) and 87.0% for females (502) while left foot dominance (LF) was 9.5% (55) for males and 11.3% (65) for females. Use of both feet was lower in proportion with 14 males and 10 females. However, the chi-square analysis showed no association between sex and foot preference ($X^2_{df(2)}$ =1.536, *P*=0.464).

The assessment of foot length difference showed that in some individuals both feet may not always be equal as there was variation in the length which was significant when tested for sex association ($X^2_{df(2)}$=44.692, *P*<0.001). 50% (289) of males were observed to be equally footed (EQ) while females had

Table 1: Descriptive Characteristics of the Foot Length, Side Comparison and Inter-Dimensional Correlation

SEX		Foot Length		Pair Sample t-test				Pearson's Correlation		
		RFL [mm]	LFL [mm]	M.D±S.E.D (RFL-LFL) [mm]	t-value	P-Value	Inf.	r	P-Value	Inf.
Male (577)	Mean±S.D	270.20±13.25	270.46±12.94	-0.26±0.19	-1.382	0.168	NS	0.935	<0.001	S
	Min	235.00	240.00							
	Max	310.00	300.00							
Female (577)	Mean±S.D	248.90±12.07	249.52±11.81	-0.62±0.29	-2.137	0.033	S	0.939	<0.001	S
	Min	210.00	210.00							
	Max	300.00	300.00							
Total (1154)	**Mean±S.D**	**259.55±16.56**	**259.99±16.22**	-0.44±0.17	-2.544	0.011	S	0.828	<0.001	S
	Min	**210.00**	**210.00**							
	Max	**310.00**	**300.00**							

Note: RFL=Right foot length; LFL=Left foot length; Min=Minimum; Max=Maximum; S.D=Standard deviation; Inf.=Inference; t-value=t-test calculated value; P-value=Probability value; M.D=Mean difference; S.E.D=Standard error of the difference; r=Pearson's correlation coefficient; S=Significant; NS=Not Significant.

Table 2: Evaluation of Sex Difference in Foot Length

Parameters	Levene's Test for Equality of Variances			t-test for Equality of Means				
	F-Value	P-Value	Inf	M.D±S.E.D	df	t-value	P-Value	Inf
RFL(mm)	12.472	**<0.001**	**EVNA**	19.70±0.97	651.87	**20.21**	**P<0.01**	**S**
LFL(mm)	10.629	**0.001**	**EVNA**	19.31±0.95	648.53	**20.28**	**P<0.01**	**S**

Note: RF=Right foot; LF=Left foot; BT=Both feet; M.D=Mean difference, S.E.D=Standard error of the difference; df=degree of freedom; F-value=Fisher's calculated value; t-value=calculated values; P-value=Probability value; Inf,=Inference; NS=Not Significant; S=Significant.

Table 3: Associations of Sex with Foot Preference, and Longer Foot

		SEX		Total (%)	Chi-Square Tests			Inf.
		Male (%)	Female (%)		df	X^2-Value	P-Value	
Preferred foot	RF	508 (50.3)	502 (49.7)	1010 (87.5)	2	1.536	0.464	NS
	LF	55 (45.8)	65 (54.2)	120 (10.4)				
	BT	14 (58.2)	10 (41.7)	24 (2.1)				
Longer foot	RF	131 (43.2)	172 (56.8) ‡	303 (26.3)	2	44.692	*<0.001*	S
	LF	157 (40.9)	227 (59.1) ‡	384 (33.3)				
	EQ	289 (61.9) ¥	178 (38.1)	467 (40.4)				

Note: RF=Right foot; LF=Left foot; BT=Both feet; df=degree of freedom; X^2-value=Chi-square calculated value; P-value=Probability value; Inf,=Inference; NS=Not Significant; S=Significant.

(Symbols=Z-test of Proportionality; significant difference at, ‡ P<0.01, ¥ P<0.001).

longer left foot (227; 39.3%). For the general population there were more equally foot Nigerians (467; 40.4%) than the left or right foot length (26.3% for RF and 33.3% for LF) (Table **4**).

In testing the association and sex influenced differences in foot preference and foot morphometry (Tables **4** and **5**) Chi-square was employed for association test while ANOVA was used to evaluate mean differences. From the Chi-square analysis summarized in Table **4**, the existence of the distributional difference of the length of the foot was neither sex influenced (*P*>0.05) nor associated with foot preference (*P*>0.05) from the ANOVA. For both

Table 4: Association of Sex with Foot Preference and Longer Foot

Longer Foot	Male Foot Preference^			Total	Female Foot Preference^			Total	Total population foot preference^			Total
	RF	LF	BT		RF	LF	BT		RF	LF	BT	
RF	112 (85.5)	16 (12.2)	3 (2.3)	**131**	153 (89.0)	18 (10.5)	1 (0.6)	**172**	265 (87.5)	34 (11.2)	4 (1.3)	**303**
LF	138 (87.9)	16 (10.2)	3 (1.9)	**157**	199 (87.7)	25 (11.0)	3 (1.3)	**227**	337 (87.8)	41 (10.7)	6 (1.6)	**384**
EQ	258 (89.3)	23 (8.0)	8 (2.8)	**289**	150 (84.3)	22 (12.4)	6 (3.4)	**178**	408 (87.4)	45 (9.6)	14 (3.0)	**467**
Total	**508 (87.9)**	**55 (9.5)**	**14 (2.4)**	**577**	**502 (84.3)**	**65 (11.3)**	**10 (1.7)**	**577**	**1010 (87.5)**	**120 (10.4)**	**24 (2.1)**	**1154**

Note: RF=Right foot; LF=Left foot; BT=Both feet; EQ=Equal foot. **^**P-value for Chi-square >0.05 (No significant association of sex with foot preference and length) (Z-test of Proportionality; No significant difference, P>0.05).

Table 5: Side Difference (Foot Length) and Foot Preference

Foot Preference (Side)	RF (1010)^	LF (120)^	BT (24)^	Total (1154)
RFL (mm)	259.74±16.78	258.79±14.57	255.42±16.35	259.55±16.56
LFL (mm)	260.20±16.43	259.16±14.29	255.63±16.04	259.99±16.22

RF=Right foot; LF=Left foot; BT=Both feet; RFL=Right foot length; LFL=Left foot length. **^**P>0.05 (No difference in foot preference with side length)

males and females, the most preferred foot was the right foot and thus had the most distribution for length difference. From observations, in the entire population, (when the preferred foot was RF, LF or BT), the distribution of the foot morphological difference for right footed was 265 (87.5% RF), 34 (11.2% LF), 4 (1.3 EQ) and for Left footed 337 (87.8% RF), 41 (10.7% LF), and 6 (1.6% EQ). When the population was observed to be both footed, the length difference was 408 (87.4% RF); 45 (9.6% LF), and 14 (3.0% EQ). However, morphometric comparison of the distributional difference using ANOVA did not reveal any significant difference in the preferred foot with side distribution (Table **5**).

DISCUSSION

Asymmetry in corresponding (paired) anatomical structure has always been studied in order to explain various developmental favouritism [10, 11], brain lateralization [12] as well as influences from environmental factors and cultural practices [13]. The findings from such studies have been used to explain various concepts of utilization of the body with preference to size, position, and functionality. Insight into the concept of asymmetry in foot dimensions was made available by Voracek *et al*. [11]; as they stated that such symmetric difference was due to the effect of fetal androgens, which to a large extent appeared to enhance the development of the right side of the body over the left side.

In this study, the relative similarity in the mean values of the left and right foot lengths would have suggested non-asymmetrical differences in the foot lengths; however when tested, the differences in the mean values were significant. Generally, in the studied population, the left foot was on the average longer than the right. However, the difference between the right and left foot of males was insignificant whereas the females (F) and the general population (Gp) exhibited significant longer left foot. It was also suggested that such developmental advantage in men would favour the size of the right foot over the left foot, whereas in women, the pattern on the average would be reversed. However, Baron-Cohen [14] findings regarding sex difference in foot-length asymmetry appeared to be inconsistent.

Sex differences established from morphometric measurement have proven to be very reliable in the identification of dismembered remains. In this study, it was observed that foot length showed, high sex differences as also documented by McFadden and Shubel [15], Manning *et al*. [16], McFadden and Bracht [17] and Voracek and Dressler [18].

When sex was related to foot preference, the right foot was observed to be dominant for both males (88%) and females (87%), while dual-footedness presented least (2.4% in males and 1.7% in females). There was no observed association of sex and the foot preference neither was there any proportionality difference; however, females appeared to be more left-footed than

males while males had a higher proportion of dual-footedness. This finding contradicts the reports of Coren [19] and Voracek *et al*. [18] which implied from a differential mean score, that, men had a weaker tendency to be more right-footed with twice as many men than women being non right-footed.

This study also evaluated longer foot distribution in males and females by subtractive comparison (RF-LF) and observed that there was association between sex and foot-length difference with more females having a longer right foot and left foot. The females dominated the males in the proportion of longer left foot (30% for females and 23% for males) and longer right foot (39% for females and 27% for males). The observed distribution was significantly higher in females. However, a significant higher proportion of males (50%) were more equal footed with more than 1.5 times the population of females (31%). This study also compared the relationship between sex, and foot preference distribution when the right or left foot was considered longer or equal. Statistical analysis did not indicate that foot preference was associated with longer foot in both males and females. But the proportions of females who had longer left and right foot with dominant right foot were higher but not significantly; when compared to males.

In the comparison of side difference (foot length) and foot preference, there was no significant difference in the length of the foot when an individual was right, left or both-footed. This replicates the findings of Manna *et al*. [20]. Though researchers have not really studied the foot length difference in relation to the preferred foot in males and females, there are publication indicating the role of foot difference in sports as well as sports related injuries with documentation of significant association [21, 22].

In foot wear design, there are basically two most important anthropometric specifications required for shoe design and manufacture; the foot length and girth [23, 24]. The mean foot length of both male (270mm) and female (250mm) Nigerians were similar to those reported by Davis [25] for African-Americans (M=276mm, F=251mm), but higher than the Cauca-sians values (M=262mm, F=237mm). The values reported in this study was also higher than the values (FL=220mm) documented by Cheng and Perng [26] for the Japanese population.

By implication, the standard reference chart for shoe size manufactured in UK, EU, US and ASIA may not conform to the size of Nigerian population as marked foot length difference was observed. Since foot length has been regarded as an important parameter for footwear design, it is imperative that appropriate charts be developed, which will accommodate the upper and lower limits of foot dimensions of the Nigerian population.

CONCLUSION

This study observed no relationship between foot preference and foot length; however the difference in the relative length of the left and right foot is an indication that the assumption of equal foot length may not be very accurate; hence, foot length difference must be considered when constructing footwear for the Nigerian population, especially for the females, as the study observed bilateral asymmetry in foot length.

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