Quantitative Comparison Of Foot Anthropometry Under Different Weight Bearing Conditions Amongst Nigerians

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Citation

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Abstract

Knowledge of the change in plantar foot shape under weight bearing can offer implications for the design and construction of a comfortable and functional foot support. This study is aimed at quantitatively analyzing the physical differences that exist in linear measurements of the foot in males and females and across both sex under different weight bearing conditions thus providing data for the design and construction of a comfortable foot support in Nigeria. The linear plantar foot shape dimension of 126 subjects (66 males and 60 females) with normal foot were measured under three weight bearing conditions: non-weight bearing, semi-weight bearing, and full-weight bearing. The data analyzed showed that increased weight bearing increased the foot length and foot breadth. Compared with the non-weight bearing foot shape, the semi-weight bearing condition produced increases in male foot length of 2.55% (6.4mm), female foot length of 1.57% (3.7mm), male foot breath of 3.7% (3.4mm), female foot breadth of 5.03% (4.2mm), while the full-weight bearing condition will produce increase in male foot length of 3.03% (7.4mm), female foot length of 2.33% (5.5mm), male foot breadth of 5.44% (5mm), and female foot breadth of 6.35% (5.3mm). The percentage change in foot length and breadth within and across both sexes is statistically significant ($p<.05$). The findings are useful in considering the change of foot shape in weight bearing during the selection of shoe size and shoe or insole design and construction and to the orthotics during the design of fitting devices for foot support. Also, it can be useful in forensic science.

INTRODUCTION

Quantitative analysis of the foot anthropometry is important to the study of ergonomics, forensic science and anthropology. Hence, the relevance of this research work to the development of these fields of study in Nigeria. Foot anthropometry is the measurement of the size and proportion of the foot. Parameters often measured include foot length and foot breadth.

The human foot, the foundation of bipedal locomotion, is a highly complex multi-bone structure with 26 major bones and more than 30 synovial articulations[12]. The foot gives support to the body in standing, resilient for walking and accommodation to variations of surfaces on which it is placed. The normal foot shows great individual variation in length, and breadth in males and females alike[34].

Shoes and insoles have been designed to protect the foot and facilitate proper functioning of the foot for daily activities. How well the shoes and insoles fit with the planter foot shape is an important determinant for a functional and comfortable foot support. Studies have revealed that sexual dimorphism exist in foot anthropometry with the males have larger foot in size and shape[567].

The foot shapes corresponding to different weight bearing conditions are believed to be unique and can provide a more comprehensive description of the foot-insole interaction when considering foot biomechanics. Hence, the need to understand the foot shape and its change under different weight bearing and to determine which foot shape would best be adopted as the deciding factor in designing the support shape for better fit and comfort[8].

Studies on the anthropometry of foot shape used different protocols and measurement devices. Most approaches directly measure the foot length, breadth, height and girth dimensions using venier caliper, cloth tape flat ruler, etc[9101112]. Others measured from footprint[7131415]. These measurements vary because of inconsistencies in positioning and the orientation of scales.

Anthropometric studies on the foot when weight bearing have revealed that the navicular bone was depressed, on the average, 6.5mm[16], the foot arch prolonged up to 19mm with the second ray and 8mm within the fifth ray[17]. However, Carlsoo and Wetzenstein (1968) differed in their finding that no significant change occurs in foot length and foot height during weight bearing[18]. The difference in results found by these researches may be due to an inconsistency in measuring positions, such that the actual foot joint orientation and amount of load undertaken were different.

Using a surface-mounted electronic arch gauge to monitor the medial arch of the foot during normal walking, Kayano found that the medial arch length changed at different phases of gait[19]. The degree of change in the length of the arch ranged from 3.7 to 9.5mm. Using a similar method, Umeki investigated the factors that influenced the length of the medial arch of the foot in normal adults under different passive motions and loads on the foot. He found that the medial arch was lengthened and the foot was abducted when a vertical load was added to it[20]. Shortening was observed when the first metatarsophalangeal joint was manually dorsi-flexed. The results indicated that the medial arch length would change with weight bearing and foot positioning. The use of skin-mounted measurement techniques may limit the accuracy of measuring the kinematics estimates of motion[22122].

Besides, study analyzing the pressure distribution under static and dynamic casting showed gender differences in the load bearing behaviour of the foot as well as significant correlations of the peak pressures towards body weight and foot contact area[23]. Borches et al. used a commercial light-striping laser digitizer to scan a foot in a non-weight bearing condition and 95% body weight bearing condition[24]. Shape variations observed gave the researches ideas about shape differences between non-weight-bearing foot and weight bearing foot. Also, Bonnie et al. using the impression casting protocol of the foot under three different weight conditions found that increased weight bearing significantly measured the contact area, foot length, foot width and rear foot width, while it decreased average height and arch angle. Compared with the non-weight bearing foot shape, the semi-weight bearing condition would produce increases in foot length of 2.7% ± 1.2%, foot width of 2.9% ± 2.4%. The full weight-bearing condition would produce increases in foot length of 3.4% ± 3.1%, foot width of 6.0% ± 2.1%. These researches using the foot digitizing and impression casting protocol avoids the error caused by skin displacement and tissue distortion[8].

Besides, recently several studies have been conducted on foot and footprints for stature estimation having bearing on personal identification, prediction and forensic anthropometry, and foot biomechanics[25262728293031].

Data on quantitative analysis and description of changes in foot shape under different weight bearing condition in Nigeria are rare. The aim of this study is to provide anthropometric baseline data of the foot shape and changes associated with it under different body weight bearing conditions, which will be useful to the study ergonomics and forensic science in Nigeria.

It is also aimed at providing reference standard to determine which foot shape would best adopted as the deciding factor in shoe selection and designing of shoe for better fit and comfort.

MATERIALS AND METHODS

A total of one hundred and twenty six (126) subjects (66 males and 60 females) between 18years and above were used for this study. The parameters measured from each foot are the foot length and foot breadths at the different weight bearing conditions: non-weight bearing, semi-weight bearing and full-weight bearing.

For this study, the direct measurement technique was employed to investigate the foot shape changes under different weight bearing conditions. The foot dimensions were measured directly using Venier or sliding calipers with the foot placed on a horizontal flat surface at three weight bearing conditions i.e. non-weight bearing (NWB), semi-weight bearing (SWB) and full-weight bearing (FWB).

The foot lengths were measured from the most posterior projection of the heel (akropodion) to the most anterior toe (pternion). The foot breadths were measured as the distance between the medial margin of the head of the first metatarsal and the lateral margin of the head of the fifth metatarsal. The measurements of the foot dimension were taken under the NWB, SWB and FWB[8].

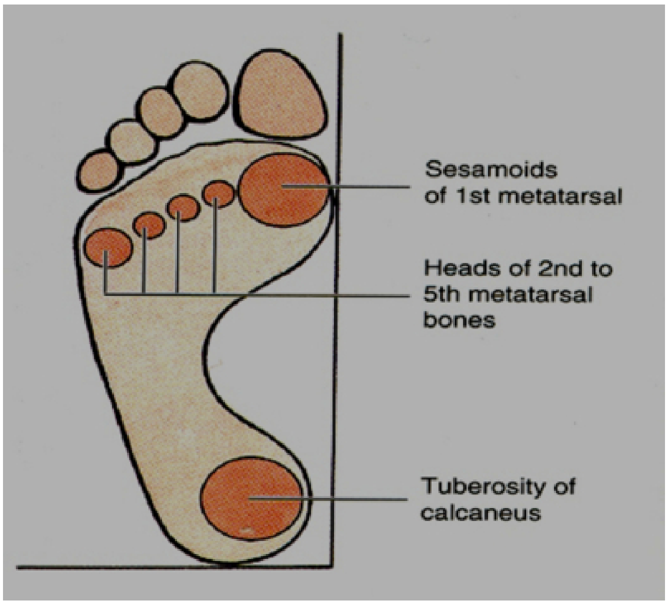
For the non-weight bearing condition, measurements were done with the subject sitting without body weight bearing on the foot measured. The knee and ankle were kept at 90% flexion, and the centres of both heels were separated by the width of the subject's shoulder. The lines of projection of both feet were kept parallel and pointing forward[8].

Measurements for semi-weight bearing were taken with half the body weight placed on the measured foot, with the line of progression of both feet parallel to each other and pointing forward. This was achieved by instructing the subjects to stand upright, with the distance between the two heels centres kept apart at the width of subject's shoulders[8].

For the full-weight bearing (FWB), measurements were taken with the full body weight placed on the foot measured. This was achieved by instructing the subject to stand upright on the measured foot. The foot not measured is flexed up and bore no weight. The line progression of the foot measured pointing forward[8].

Figure 1

Figure 1: Weight bearing areas of the foot



RESULTS

The results of the study are shown in tables below. The age groups and number of individuals in each group for both male and female are represented in table 1.

Figure 2

Table 1: Sample size and age distribution of subjects.

	No of individuals	
Age group	Males	Females
18-20	15	12
21-23	18	24
24-26	15	15
27-29	12	6
30-above	6	3
Total	66	60

Table 2 shows the range of foot length and breadth for males and females at different weight bearing conditions.

Figure 3

Table 2: The range of foot dimensions for male and female at different weight-bearing conditions.

		Males			Females		
Right foot	Foot Dimensions (cms)	NWB	SWB	FWB	NWB	SWB	FWB
	Length	22.9-28.2	23.4-28.3	23.4-28.5	21.6-27.8	22.3-28.1	23.3-28.7
	Breadth	8.4-10.7	8.8-10.70	8.9-11.4	7.2-9.7	7.8-10.0	8.0-10.2
Left foot	Length	22.2-28.2	23.4-28.3	22.7-28.4	22.1-27.9	22.2-28.5	22.3-28.9
	Breadth	8.2-10.4	8.7-10.4	8.8-11.2	7.2-9.6	7.5-9.9	7.7-10.2

Statistical analysis of the collected data showed the following results as given in tables 3 – 9. Student t-test analysis revealed statistically significant difference in foot length and breadth within and across both sexes, ($p<0.05$).

Figure 4

Table 3: Mean right and left dimensions of male population under different weight bearing conditions.

Right foot	Foot Dimensions (cm)	NWB Mean ± SD	SWB Mean ± SD	FWB Mean ± SD
	Length	25.12±0.51	25.81±0.31	25.85±0.29
	Breadth	9.25±0.28	9.57±0.32	9.68±0.31
Left foot	Length	25.08±0.35	25.67±0.21	25.87±0.32
	Breadth	9.13±0.31	9.49±0.24	9.70±0.31

Figure 5

Table 4: Mean right and left foot dimensions of female population under different weight bearing conditions.

Foot Dimensions		NWB	SWB	FWB
Right foot	(cm)	Mean± SD	Mean± SD	Mean± SD
	Length	23.63±1.07	23.99±0.97	24.16±1.09
	Breadth	8.40±0.38	9.77±0.34	9.01±0.39
Left foot	Length	23.49±0.94	23.87±0.87	24.06±1.03
	Breadth	8.29±0.41	8.76±0.36	8.88±0.34

Figure 6

Table 5: The mean foot length and breadth of male and female population.

Foot Dimensions		NWB	SWB± SD	FWB± SD
Female	(cm)	Mean± SD	Mean± SD	Mean± SD
	Mean foot Length	23.56±0.07	23.93±0.06	24.11±0.06
	Mean foot Breadth	8.35±0.05	8.77±0.01	8.88±
Males	Mean foot Length	25.10±0.02	25.74±0.07	25.86±0.01
	Mean foot Breadth	9.19±0.06	9.53±0.07	9.69±0.01

Figure 7

Table 6: Percentage increase of mean right and left foot dimensions in male and female population under different weight bearing conditions

		Males		Females	
		Increase	% increase	Increase	% increase
Right foot	(SWB-NWB)L	0.69	2.75	0.36	1.52
	(FWB-NWB)L	0.73	2.91	0.53	2.24
	(SWB-NWB)b	0.32	3.46	0.37	4.40
	(FWB-NWB)b	0.43	4.65	0.61	7.26
Left foot	(SWB-NWB)L	0.59	2.35	0.38	1.62
	(FWB-NWB)L	0.79	3.15	0.57	2.43
	(SWB-NWB)b	0.36	3.94	0.47	5.67
	(FWB-NWB)b	0.57	6.90	0.59	7.12

Figure 8

Table 7: Percentage increase of mean foot dimensions in males and females population

	Males		Females	
	Increase(cm)	% increase	Increase(cm)	% increase
(SWB-NWB)L	0.64	2.55	0.37	1.57
(FWB-NWB)L	0.74	2.03	0.55	2.33
(SWB-NWB)b	0.34	3.70	0.42	5.03
(FWB-NWB)b	0.50	5.44	0.53	6.35

($p<0.05$).

DISCUSSION

In this study, the changes in the linear measurement of plantar foot shape under the three weight bearing conditions were examine quantitatively using the normal foot of one hundred and twenty-six (126) (66 males and 60 females) Nigerian subjects.

This study revealed that increasing the weight bearing on a tested foot increased the foot length and foot breadth. The result indicates that SWB condition of the foot can cause significant increase from the NWB condition on the measured parameters, while the FWB condition causes a greater increase than SWB condition. However, small increase occurs between SWB and FWB condition. This agrees with previous finding[9].

The foot arch is depressed, and the foot is forced to spread out and forward on weight bearing like a depressed curve plate[32]. The flexible components of the foot can be regarded as a twisted plate with one edge (head of the metatarsals) placed horizontally and in full contact with the supporting surface, while the other edge (calcaneus) is placed vertically. The resulting twist influences both the longitudinal and transverse arches of the foot, leading to the increase in foot length and foot breadth.

Besides, the percentage increase in foot breadth was found to be greater than that of foot length in both sexes. This could be based on the fact that the longitudinal arches have stronger ligamentous support.

From student T-test analysis, statistically significant difference ($p<0.05$) occurs in foot length and breadth of within and across both sexes. The change in foot length of males is statistically greater than that of the females while the change in foot breadth of males is statistically less than that of the females ($p<0.05$).

CONCLUSION AND RECOMMENDATION

The main criterion for a comfortable shoe depends on how well it fits. Therefore, information on how the foot shape change with weight bearing is essential in proper shoe designing for the foot. This quantitative study gives the linear foot shape variables in the three weight bearing conditions. The foot length and foot breadth of male under full-body weight will increase by 2.03% (7.4mm) and 5.44% (5mm) respectively while the foot length and foot breadth of females will increase by 2.33% (5.5mm) and 6.35% (5.3mm) respectively. These findings are useful for both shoe design and the selection of shoe size. As the right foot was significantly longer and wider than the left under the three weight bearing conditions tested, we suggest that the shape of the left and right shoes should not be symmetrical during shoe designing. The length and breadth of the shoe should be 2 to 3mm longer and wider in the right foot for better fit. Besides, this study can be useful be successfully utilized in forensic examination of the foot.

Because this study was carried out right hand dominant subjects, the question of whether side dominance has significant effect on the tested result need further investigation.

CORRSPONDENCE

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References

1. Daniel MT, Fesssler Kevin j Haley and Roshni DL. Sexual dimorphism in foot length proportionate to stature. Annals of Human Biology: 2005; 32(1):44-59.
2. Maslen, BA and Ackland, TR. Radiographic study of skin displacement errors in the foot and ankle during standing. Chin. Biomech. 1994; 9:291-296.
3. Sharrad, WTW. Pediatric, Orthopaedic and Fractures. Vol 1 3rd edn. London: Oxford Blackwell Scientific Publication. 1993. pp 468-471.
4. Snell, Richards. Clinical Anatomy for Medical Students. 6th edn. Philadelphia: Lippincott Williams and Wilkins. 2000. pp 591-595.
5. Jill Ferrari, David A Hopkinson and Alf D. Linney. Size and shape differences between male and female foot bone. J. American Podiatric Medical Association. 2004; 94(5): 434-452.
6. Ashizawa K, Kumakura C, Kusumoto A, and Narasaki S. Relative foot size and shape to general body size in Javanese, Filipinas and Japanese with special reference to habitual foot wear types. Annals of Human Biology. 1997; 24:117-129.
7. Didia BC Omu FT and Obuoforibo AA. The use of foot print contact index II for classification of flat feet in a Nigerian population. Foot and Ankle society. 1987; 8(4): 0192-0211.
8. Bonnie Yuk San Tsung, Ming Shang, Yu Bofan and David Alan Bone. Quantitative comparison of plantar foot shapes under different weight bearing conditions. 2003; 40(6):517-526.
9. Freedman A, Huntington EC, Davis GC, Magee RB, Milstead VM, Kirkpatrick CM. Foot dimensions of soldiers. Third partial report project NT-13 Fortknix: Armoured Medical Research Laboratory. 1946.
10. Liu W, Miller S, Stefanyshyn D, Nigg BM. Accuracy and reliability of a technique for quantifying foot shape, dimensions and structural characteristics ergonomics. 1999; 42(2): 346-348.
11. Rossi WA. The high incidence of mismatched feet in population. Foot ankle 1983; 4:105-112.
12. Rosha E Wunderlich and Peter E. Cavanagh. Gender differences in adult foot. Implications for shoe design. Medical, Science, Sports and Exercise. 2001; 33(4): 605-611.
13. Didia BC and Nyenwe EA. Foot breadth in children. Its relationship to limb dominance and age. Foot and ankle 1988; 8:198-202.
14. Krishan K. Establishing correlation of footprints with body weight - forensic aspects. Forensic Science International, 2008; 179(1):63-69.
15. Krishan K. Individualizing characteristics of footprints in Gujjars of North India – forensic aspects. Forensic Science International. 2007; 169(2-3):137-144.
16. Benninghoff A. Lehrbuch de Anatomic des Menshen. Urban and Schesarezenberg, Berhn- Munchen. 1947.
17. Hohmann G Fusss and Bein. Funfte Erganzte Auflage. Verlag J.E Bergmann. 1951; pp. 34 – 37.
18. Carlsoo S and Wetzenstein N. Change of form of the foot and foot skeleton upon momentary weight bearing. Acta. Orthopaedica Scandinavica. 1968; 39:413-423.
19. Kayano JJ. Dynamic function of medical foot arch. J. Jpn. Orthop. Assoc. 1986; 60:1147-1156.
20. Umeki, Y. Static Results of Medical Foot Arch. Nippon Seikeigeka Gekkai Zassi. 1991; 65(10):891-901.
21. Cheze L, Fregly BJ, Aimnet J. A solidification procedure to facilitate kinematic analysis based on video data system. J. Biomech. 1995; 28:879-884.
22. Reinschmidt C, Van Den Bogert AJ, Nigg BM, Lundberg A, Murphy N. Effect of skin movement on the analysis of skeletal knee motion during running. J. Biomech. 1997; 30:729-732.
23. Hennig, EM and Milani, TL. The tripod support of the foot. An analysis of pressure distribution under static and dynamic loading. Z Orthop Ihre Grenzerb 1993; 13(3):279-84.
24. Borches RF, Bonne DA, Joseph AW Smith DG, Reiber GE. Numerical comparism of 3-d shapes. Potential for application to the insensate foot. J. Prosth. Orthot. 1995; 7(1); 29-34.
25. Krishan K. Estimation of stature from cephalo-facial anthropometry in north Indian population, Forensic Science International, 2008; 181: 52.e1-52.e6..
26. Sen J, Ghosh S. Estimation of stature from foot length and foot breadth among the Rajbanshi: An indigenous population of North Bengal, Forensic Science International. 2008; 181 (1-3):55e1-e6.
27. Krishan K. Determination of stature from foot and its segments in a North Indian population. American Journal of Forensic Medicine and Pathology, 2008; 29(4):297-303.
28. Gulsah Zeybek, Ipek Ergur, Zehra Demiroglu. Stature and gender estimation using foot measurements. , Forensic Sci Int. 2008; 181: 54.e1-54.e5.
29. Kanchan T, Menezes RG, Rohan Moudgil, Ramneet Kaur, M.S. Kotian, Rakesh K. Garg. Stature estimation from foot dimensions. Forensic Sci Int. 2008; 179: 241.e1-241.e5.
30. Krishan K, Sharma A. Estimation of stature from dimensions of hands and feet in a North Indian population. Journal of Forensic and Legal Medicine, 2007; 14(6):327-32.
31. Krishan K. Estimation of stature from footprint and foot outline dimensions in Gujjars of North India. Forensic Science International, 2008; 175(2-3):93-101.
32. MacConail, MA and Basmajian JV. Muscles and Movements: a basis for human Kinestiology. 2nd edn. Baltimore: Willians and Wilkins. 1969; pp. 13 – 15.

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