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Developing a Model for Foot Anthropometric Descriptors for the Design of Prosthesis and Footwear in Nigeria

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ABSTRACT: Foot structure has been known to vary, consequently, there is need for anthropometric data update. The objective of this study is to develop a model of foot anthropometric descriptors for the design of prosthesis and footwear in Nigeria using craft questionnaires structured with Likert's 5-point attitudinal scale which was administered to 100 respondents and the corresponding data analyzed with Kendall's Coefficient of Concordance (KCC) and Principal Component Analysis (PCA). Thirteen judges ranked the 36 foot anthropometric descriptors in descending order of importance. The data revealed footwear safety (0.811), technology enhancement (0.811), footwear fitness (0.810), Joint girth (0.794) and change in lifestyle (0.768) as dominant descriptors based on their factor loadings. This study showed that foot anthropometry is an important science for designing prosthetic and foot wears that can achieve the desired fit and comfort.

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Data on modeling foot Anthropometric descriptors for the design of prosthesis and footwear in Nigeria are rare. This situation has therefore established a yawning crevasse for the development of foot Anthropometry that can serve as baseline for the design of prosthesis and footwear. Foot Anthropometry has shown that foot dimensions vary widely with individuals and the import is that the design of foot wears even prosthesis must consider those variations in order to achieve the desired fitness. Previous studies focused attention more on the estimation of stature (height), prediction of footwear fit as well as gender (sex) from foot dimensions/measurements. The selling point of this research lies in the fact that it will examine a gamut of factors that help to define foot anthropometry with a view to discerning similarities in dissimilarities. Research interest in foot Anthropometry dates back to the 19th century. The works of McConaill (1945); Isman and Inman (1969) examined the mechanism of the human foot; the talocrural and talacalcareal joints to the foot in order to determine the axis of rotation. They are seminal. Feng-Tsung and Der-Naau (1999) also stated that the property of shoe last design significantly impacts the fitness of the shoes produced. An examination of the relationship between the foot dimensions and weight of Turkish university students was carried out by Amil *et al*., (1997). Furthermore, Baba (1975), also conducted a study on foot measurement for shoe construction with reference to the relationship between the foot dimensions. Other studies include quantitative comparison of foot Anthropometry and shape under different weight bearing conditions by Tsung (2003) and Oladipo *et al*., (2008) respectively. Sexual dimorphism in foot dimensions among adult Nigerians was carried out by Bob-Manuel and Didia (2008). Obikili and Didia (2006) also conducted a study on foot dimensions of a young adult Nigerian population. Ozden *et al*., (2005); Jitender (2010); Krishnan *et al*., (2011); Sonali (2012) carried out studies on the estimation of stature (height) from foot measurements. Similarly Ekezie (2013), established the foot Anthropometry of the Igbos in Nigeria, for height reconstruction, while sexual dimorphism and sex estimation from foot Anthropometry were conducted by Danboro and Elukpo (2008) and Reena *et al*., (2012). Furthermore, Nacher *et al*., (2005) described the development of a model for predicting footwear fit on the basis of user data. Ante *et al*., (2006) investigated the relationship between foot Anthropometrical and biomechanical descriptors for Croatian population. Tang and Hui (2011) proposed a fast approach to model foot deformation, while Albert and Ahmed (2012) presented a low cost effective lower limb prosthesis for use in baghdad, Iraq. Recent studies recorded by Hairunnisa *et al*., (2013), Neetu and Khatri (2015) and Tejas *et al*., (2015) were on the estimation of stature from Anthropometric measurements. Mustafa *et al*., (2013) reported a work on modeling and stress

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analysis of a normal foot-ankle and a prosthetic foot-ankle complex. While Kandil *et al*., (2014) investigated the differences in plantar pressure distribution in normal subjects. In addition to the above, Choukou *et al*., (2014) proposed to reduce mechanical stresses resulting from inadequate safety shoe wearing. Samaila *et al*., (2015) measured the anthropometric parameters of foot of adult males and females Ga'anda people, Adamawa Nigeria. It is evident from the foregoing that there is a balance of literature especially in the area of assessment of foot Anthropometric descriptors for Nigerian adult population. Accordingly, the objective of this study is to develop a model of foot anthropometric descriptors for the design of prosthesis and footwear in Nigeria.

MATERIALS AND METHODS

Thirty six scale items were identified through an extensive survey of literature and were used to craft a set of questionnaires that were administered to respondents. Thirteen judges were selected who ranked the first set of questionnaires in descending order of importance and the respondents scores were collated into data matrix having a dimension of 13 by 36. Kendall's Coefficient of Concordance (KCC) denotes the index of consistency in ranking. In order to validate (assess) how consistent the judges were in ranking the scale items, Chi-square (χ^2) was used.

The χ^2- test guided the application of hypothesis.

H_0 : *Judges* ranking are discordant

H_1 : *Judges* ranking are consistent

Decision Rule: (Test of Hypothesis): If $\chi^2_{cal} > \chi^2_{tab}$, we fail to accept the null hypothesis (H_0)

The KCC (W) is given by:

$$W = \frac{S}{\frac{1}{12}K^2\left(N^3 - N\right)} \quad (1)$$

$$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2 \quad (2)$$

Where, $N = Total$ number of variable

$R_j = Column$ sum of ranks , $S = Variance$

Kendall's coefficient of concordance (W), was computed using equation 1

Where, S = 361861.8896, K = Number of judges = 13, N = Number of factors being ranked = 36

Substituting the above values into equation 1:

$$W = \frac{361861.8896}{\frac{13^2}{12}(36^3 - 36)} = \frac{361861.8896}{656409.60} = 0.55$$

To test the significance of the KCC result, Chi-square (χ^2) was used and the equation is given as

$$\chi^2_{cal} = K(N-1)\,W \quad (3)$$

Where; k = 13 judges, W = 0.57 and N = 36

χ^2_{Cal} = 13 (36 – 1) 0.55 = 250.25

RESULT AND DISCUSSION

Result of Kendall's Coefficient of Concordance (KCC): The result of Kendall's Coefficient of Concordance (W) was obtained as 0.55 which is at the threshold of middling. The Chi-square (χ^2) result was also obtained as 250.25. Comparing the calculated chi-square value with that of the tabulated value which is 49.802, the following conclusion was made: Since $\chi^2_{cal} = 250.25 > \chi^2_{tab} = 49.802$, our experimental data do not furnish enough evidence for us to accept H_0. We therefore conclude that the Judges ranking is consistent. Table 1 shows the foot anthropometric descriptors ranked in order of importance by the Judges.

Result of Principal Component Analysis (PCA): From the scree plot figure 1, it can be clearly seen that at eigenvalue of 1, and component number 3, the curvity tends to flatten out, which shows factors reduction from 36 to mere 3.

Factor Interpretation: The varimax rotation, after 21 iterations, extracted three factors F_1, F_2 and F_3 from 36 scale items of foot anthropometric variable. Evidently, from the tableau, F_1, F_2 and F_3 represents the principal factors that help to define foot anthropometry, and hence creatively labeled constitutional miscellanies, Darwinia fitness and ecotype respectively. We shall now interpret the three factors in the accompanying text.

F_1: Constitutional miscellanies: This regime clustered twenty two variables dealing with leg dimension, racial composition and structural build. The variables all wield positive factor loadings suggesting that it is a stocky factor. In this relation, joint girth wields the most influential factor loading of 0.794. This is followed by another three namely:

i. Change in lifestyle (0.768)
ii. Ornament (0.765) and
iii. Community lifestyle (0.757)

Table 1: Merit order sequentiality of 36 variables for foot anthropometric descriptors

S/N	Rj	Variables	S/N	Rj	Variables
1	38	Footwear comfort	**19**	263	Body height
2	51	Footwear safety	**20**	266	The human society
3	56	Footwear Fitness	**21**	266	Stance and gait
4	84	Footwear Functionality	**22**	269	Foot ankle circumference
5	90	Footwear form	**23**	270	Geographical location
6	117	Technology enhancement	**24**	281	Aesthetic limitation
7	123	Satisfaction	**25**	301	Navicular bone
8	172	Race	**26**	311	Foot Length
9	179	Weight bearing condition	**27**	319	Nutrition
10	195	Community Life style	**28**	324	Foot width
11	196	Technical error	**29**	329	Change in lifestyle
12	199	Flexibility	**30**	332	Heredity
13	205	Footwear Price	**31**	336	Ethnic composition
14	209	Foot height	**32**	345	Sexual differences
15	211	Physical appearance	**33**	371	Joint girth
16	230	Climatic factor	**34**	372	Stress and strain
17	233	Individual Lifestyle	**35**	379	Biomechanical factors
18	259	Ornaments	**36**	397	Muscle deformation

The result of the Varimax rotated factor matrix and the influential factor loadings are depicted in Table 2.

Table 2: Result of Varimax Rotated Factor Matrix

S/N	Scale item (Variable) Description	F_1	F_2	F_3
1	Footwear functionality		0.759	
2	Footwear form		0.711	
3	Footwear Fitness		0.810	
4	Footwear Comfort		0.653	
5	Footwear Safety		0.811	
6	Satisfaction		0.657	
7	Individual lifestyle	0.649		
8	Ornaments	0.765		
9	Flexibility		0.684	
10	Technology Enhancement		0.811	
11	Physical Appearance			0.606
12	Footwear Price	0.674		
13	Aesthetic limitation	0.692		
14	Geographical location	0.694		
15	Sexual differences	0.737		
16	Body height	0.750		
17	Change in lifestyle	0.768		
18	Nutrition	0.711		
19	Ethnic composition	0.693		
20	Foot length	0.573		
21	Foot width	0.623		
22	Foot height	0.651		
23	Foot ankle circumference	0.704		
24	Joint girth	0.794		
25	Community life style	0.757		
26	Race	0.725		
27	Climatic factor			0.642
28	The human factor	0.694		
29	Muscle deformation		0.614	
30	Stress and strain		0.560	
31	Heredity	0.757		
32	Stance and gait	0.735		
33	Technical error	0.562		
34	Navicular bone	0.725		
35	Biomechanical factors			0.648
36	Weight bearing condition		0.778	

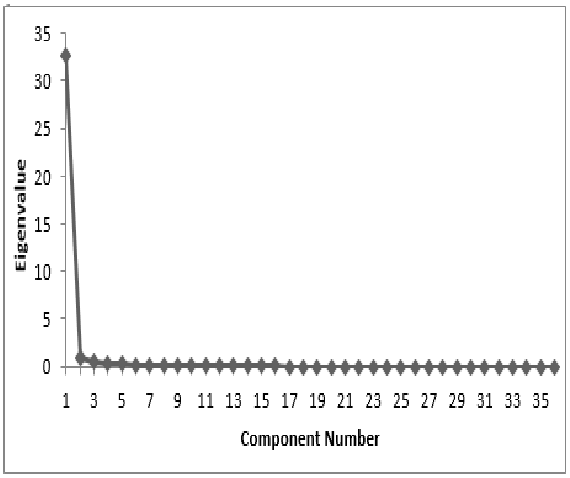

Fig. 1: Scree Plot

Table 3: Factor 1 (F_1) Constitutional Miscellanies.

S/N	Variable description	Factor loading
7	Individual lifestyle	0.649
8	Ornaments	0.765
12	Footwear price	0.674
13	Aesthetic limitation	0.692
14	Geographical location	0.694
15	Sexual differences	0.737
16	Body height	0.750
17	Change in lifestyle	0.768
18	Nutrition	0.711
19	Ethnic composition	0.693
20	Foot length	0.573
21	Foot width	0.623
22	Foot height	0.704
23	Foot ankle circumference	0.704
24	Joint girth	0.794
25	Community life style	0.757
26	Race	0.725
28	The human society	0.694
31	Heredity	0.757
32	Stance and gait	0.735
33	Technical error	0.562
34	Navicular bone	0.725

These factor loadings are substantial suggesting that they bear meaningful, material and significant influence on footwear design and functionality. Clearly, change in lifestyle, be it community or individual, overtime, affect the quality of life of people. Good quality of life improves body stature generally. Sometimes it could lead to increase in body weight and we know that the entire weight of the body is supported on the feet of the individual. In the side of the ornament, though it does not per se affect the foot wear dimensions, it affects actually the aesthetics in terms of colour, fancy, attractiveness and appeal. The remaining variables which include genetic composition, ethnic diversity, and geographical location, all contribute immensely to footwear and prosthetic design. The next cluster, strange things, and creatively labeled Darwinian fitness, is also a sturdy factor.

Table 4: Factor 2 (F_2) - Darwinian fitness

S/N	Variable Description	Factor loading
1	Footwear functionality	0.759
2	Footwear form	0.711
3	Footwear fitness	0.810
4	Footwear comfort	0.653
5	Footwear safety	0.811
6	Satisfaction	0.657
9	Flexibility	0.684
10	Technology enhancement	0.811
29	Muscle deformation	0.614
30	Stress and strain	0.560
36	Weight bearing condition	0.778

Here eleven (11) variables are clustered with two variables footwear safety and technology enhancement wielding the most influential factor loading of (0.811). This is evident from the fact that the safety of footwear is paramount to every user to prevent harm or injury to the foot. Technology enhancement has made possible the manufacture of sustainable and better foot wears, some of which have embedded sensors that can track distance travelled, calories burned and other biometric data. Proper fit comprises: foot Wear fitness (0.810), footwear functionality (0.759), footwear comfort (0.653), satisfaction (0.657), and muscle deformation (0.614). If adequately designed gives footwear Maximum comfort, stability and satisfaction to the user. On the other hand footwear designed inadequately is a misfit; it degrades functionality and results in muscle deformation, thereby affecting the foot dimensions. When the foot is persistently underweight, bearing conditions, the heaviness of the object results in strain and stress on the foot. Finally, flexibility and form of footwear allow the foot to move as naturally as possible. Lack of flexibility (high rigidity) results in high resistance force during gait, thereby putting enormous strain on the ball muscles, causing pain and inflammation which affect the foot structure.
The next factor, a trio, is creatively labeled Ecotype

Table 5: Factor 3 (F_3) – Ecotype

S/N	Variable description	Factor loading
11	Physical appearance	0.606
27	Climatic factor	0.642
35	Biomechanical factors	0.648

In this compilation, three (3) variables are clustered with biomechanical factors, wielding the most influential factor loading of 0.648. This variable which involves muscular activities results in mechanical stresses which alter the physiology of the foot. This is followed by another two variables, namely: (i) Climatic Factor (0.642) and (ii) Physical appearance (0.606)

In the side of climatic factor, footwear designs vary climatically as a result of weather changes, topography and soil and these influence body growth and development with subsequent influence on footwear design and functionality. Furthermore, physical appearance portrays the outward features in terms of the size and shape of the body which have corresponding impact on the design of foot wears. It is evident from this study that so many descriptors tend to influence or should be taken into consideration while designing footwear and prosthesis. On all counts, foot anthropometry is an important science for designing prosthetic and foot wears that can achieve the desired fit and hence comfort. The study therefore has provided a veritable basis for designing foot aids that can engender comfort in walking.

Conclusion: This study has revealed that the Kendall's Coefficient of Concordance and Principal Component Analysis model adopted was successful in ranking the variables and achieving parsimony in factor reduction from thirty-six variables to mere three principal factors creatively labeled constitutional miscellanies, Darwinia fitness and ecotype that influence the design of prosthesis and footwear. In addition, the model provided insight into the merit order sequentiality and the way the variables interplay.

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