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Original Research Article

DISCRIMINANT FUNCTION MODELS FOR DETERMINATION OF SEX USING ANTHROPOMETRIC FOOT DIMENSIONS IN AN ADULT NIGERIAN POPULATION

Ikpa, James Onah *[1], Salawu Ahmed Akinjide [2], Oshodi Olabode Abdulateef [3], Adenuga Omogbolahan Oluyemi [4].

[*1,2,3,4] Department of Anatomy, College Of Medicine University Of Lagos.

ABSTRACT

Background: Sex, age, race and stature are evaluated to determine the identity in forensic investigations. The most important stages in identity determination are stature and sex estimations which are easily done with primary anatomic structures in intact corpses. determination of sex from skeletal or dismembered body remains is one of the most critical aspects of forensic analysis which is crucial to medico-legal investigations.

Aim: This study is aimed at testing the validity of sex classification using anthropometric foot dimensions and discriminant function test in an adult Nigerian population.

Methods: 222 subjects (115 males and 107 females) of Nigerian parentage, aged 18–65 years who volunteered and satisfied the inclusion criteria were involved. Following institutional approval, anthropometric measurements of Foot Length (FL), Foot width (FW), Bimalleolar width (BB), Navicular height (NH), Medial malleolar height (MMH), Lateral malleolar height (LMH), Heel Width (HB) were measured. The data was analyzed for descriptive and inferential statistics using the SPSS statistical package version 25 and Microsoft excel 2016.

Results: Independent t test exhibited statistically significant sex differences ($P < 0.05$) for all the parameters, with the males having consistently higher values than the females. Linear discriminant functions were created for predicting sex.

Conclusion: The prediction models established from this study will be useful in disaster victim identification from mutilated or dismembered human remains to aid medico-legal practice in Nigeria. The normative data developed from this study will be referenced and be used as baseline data for comparing the variations of foot structure of this population and that of other populations.

KEY WORDS: Forensic Sciences, Sex, Identity Determination, Discriminant Function, Foot Anthropometry.

Corresponding Author: Ikpa, James Onah, Department of Anatomy, College Of Medicine University Of Lagos. +2348034598122 **E-Mail:** jamesonahikpa@gmail.com

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INTRODUCTION

Human foot morphology varies considerably due to the combined effects of heredity, lifestyle, and climatic factors [1]. In forensic investigations, sex, age, race and stature are evaluated to determine the identity and ancestry of individuals [2]. The most important stages in identity determination are stature and sex estimations [3]. Determination of sex from skeletal remains is one of the most critical aspects of osteological analysis which is crucial to medico-legal investigations [4]. The present work attempts to test the validity of sex classification using anthropometric foot dimensions and discriminant function test in an adult Nigerian population in Lagos state as a sample for further study. Overtime, researchers have documented studies on sexual differences in foot morphology [5-8].

Although human body appears to be bilaterally symmetric, researchers have noticed the presence of skeletal and morphological asymmetries in human body for long time [9]. The tool used for this vital process is anthropometry; which is the systematic collection and correlation of measurements of the human body, these measurements are carried out in both living and dead state especially in skeletal remains. According to Ozaslan et al., (2003), [10] anthropometric measurements of the body have been developed for various reasons. Anthropometric techniques employed by anthropologists, forensic experts and anatomists have made it possible to use bones obtained from unknown bodies, parts of bodies or skeletal remains to estimate the stature of an individual. Forensic anthropology basically deals with the examination of skeletal remains or body fragments for the purposes of identification [11,12].

This study employed the best statistical model in sex determination being the Discriminant Function Analysis (DFA) designed by Fisher [13,14] in other to estimate sex from hand dimensions among adult Nigerians in Lagos.

METHODS

Ethical approval: Ethical clearance was sought and obtained from the Health Research and Ethics Committee of the College of Medicine of the University of Lagos. Approval No. **CMUL/HREC/11/18/466**

Study Design: The study comprised 222 subjects (115 males and 107 females) of Nigerian parentage randomly selected, who were mainly students the College of Medicine of the University of Lagos, Members of staff College of Medicine of the University of Lagos, Members of staff Lagos University Teaching Hospital, Postgraduate (MSc) students (Anatomy, Physiology and Biochemistry) Aged 18–65 years. All the measurements took place in the anthropology laboratory of the Department of Anatomy, College of Medicine, University of Lagos.

Research Materials: Stadiometer: Alpha 220, SECA™ (Germany) calibrated in centimeters, Large sliding caliper: Rosscraft™ Campbell calibrated in centimeter Anthropometry kit caliper 20 (Rosscraft, Canada) with two straight branches, Vernier caliper: Mitutoyo™ (Japan) calibrated in centimeters. Spreading Calipers calibrated in centimeters. Transparent meter rule calibrated in centimeters.

Informed consent: Informed consent forms were given to all participants while they were briefed on how the research work will go a long way to benefit them and the society at large then, asked to sign the inform consent form, so as to make sure their participation was voluntary.

Measurement protocols: Protocols for direct measurements of stature and weight were adopted from those established by: The International Society for the Advancement of Kinanthropometry ISAK, International Organization for Standardization, ISO [15], Basic Human Body Measurements for Technological Design, Japanese Industrial Standard: [16], Ibeabuchi et al., (2018) [17] and Zeybek et al., (2008) [18]. All anthropometric were taken at a fixed time to eliminate any diurnal variation and by single observer in order to avoid inter-observer bias.

Foot Length (FL), Foot width (FW), Bimalleolar breadth (BB), Navicular height (NH), Medial malleolar height (MMH), Lateral malleolar height (LMH), Heel Breadth (HB) were measured.

RESULTS

Table 1: Descriptive statistics for data used in sex and sex Estimation in right foot.

		Mean±SD	Minimum	Maximum	Standard error
Right Foot length	Male	27.76±1.8	24.10	33.20	0.164
	Female	25.75±1.7	22.40	30.10	0.160
	Combined	26.78±2.0	22.40	33.20	0.133
Foot width	Male	10.20±0.5	8.80	11.70	0.050
	Female	9.03±0.6	7.60	10.50	0.064
	Combined	9.63±0.8	7.60	11.70	0.056
Bi-malleolar width	Male	6.64±0.5	5.30	7.90	0.043
	Female	5.98±0.4	5.10	7.00	0.040
	Combined	6.33±0.6	5.10	7.90	0.037
Navicular height	Male	7.40±0.7	5.80	9.60	0.069
	Female	6.51±0.8	4.10	8.50	0.777
	Combined	6.98±0.9	4.10	9.60	0.059
Medial malleolar height	Male	6.23±0.6	4. 20	8.10	0.060
	Female	5.65±0.8	3.40	7.80	0.081
	Combined	5.94±0.8	3.40	8.10	0.054
lateral malleolar height	Male	5.10±0.6	3.90	8.40	0.060
	Female	4.93±0.7	3.20	8.20	0.083
	Combined	5.02±0.8	3.20	8.40	0.051
Heel width	Male	5.69±0.6	4.30	7.20	0.055
	Female	5.05±3.8	3.80	6.60	0.048
	Combined	5.38±0.6	3.80	7.50	0.042

Table 2: Descriptive statistics for data used in sex Estimation in left foot.

		Mean±SD	Minimum	Maximum	Standard error
Right hand Foot length	Male	27.71.6±1.7	24.2	32.9	0.163
	Female	25.80±1.6	22.30	29.30	0.160
	Combined	26.79±1.9	22.30	32.90	0.130
Foot width	Male	10.24±1.1	8.90	20.60	0.104
	Female	9.79±8.2	7.40	93.00	0.788
	Combined	10.02±5.7	7.40	93.00	0.383
Bi-malleolar width	Male	6.60±0.5	5.30	7.70	0.045
	Female	5.96±0.5	4.80	7.50	0.049
	Combined	6.29±0.6	4.80	7.70	0.040
Navicular height	Male	7.37±0.8	5.60	9.80	0.071
	Female	6.47±0 .8	4.30	8.20	0.076
	Combined	6.93±0.9	4.30	9.80	0.060
Medial malleolar height	Male	6.07±0.7	4.10	8.00	0.061
	Female	5.62±0.8	3.40	7.60	0081
	Combined	5.91±0.8	3.40	8.00	0.054
Lateral malleolar height	Male	5.09±0.7	3.60	8.60	0.063
	Female	4.90±0.9	3.00	8.10	0.086
	Combined	5.00±0.8	3.40	8.10	0.054
Heel width	Male	5.67±0.6	4.20	7.50	0.057
	Female	5.04±0.5	3.70	2.70	0.051
	Combined	**5.37±0.7**	**3.70**	**7.50**	**0.044**

Table 4: Result of test for sexual dimorphism for measured left and right foot dimensions.

	Difference in Mean (Male-Female}	Standard error (difference}	t-value	p-va lue	95%CI
RIGHT					
Foot length	1.999	0.230	8.687	<0.001*	1.55, 2.45
Foot w idth	1.177	0.081	14.587	<0.001*	1.02, 1.34
Bi-malleolar w idth	0.660	0.059	11.108	<0.001*	0.54, 0.78
Navicular height	0.892	0.102	8.765	<0.001*	0.69, 1.09
Medial malleolar height	0.580	0.100	5.793	<0.001*	0.38, 0.78
Lateral malleolar height	0.167	0.102	1.645	0.101	-0.03, 0.37
Heel w idth LEFT	0.641	0.073	8.735	<0.001*	0.50, 0.79
Foot length	1.909	0.227	8.390	<0.001*	1.46, 2.36
Foot w idth	0.453	0.768	0.590	0.556	-1.06, 1.97
Bi-malleolar w idth	0.642	0.067	9.639	<0.001*	0.51, 0.77
Navicular height	0.896	0.104	8.591	<0.001*	0.69, 1.10
Medial malleolar height	0.572	0.101	5.680	<0.001*	0.37, 0.77
Lateral malleolar height	0.193	0.105	1.833	0.068	-0.01, 0.40
Heel width	0.628	0.077	8.199	<0.001*	0.48, 0.78

Sexual dimorphism: An independent two samples t-test was performed to test for the existence of sexual dimorphism. For all dimensions at ($p<0.005$) the results suggested that males have a statistically significantly larger mean than females for any given body dimension, thus supporting the existence of sexualdimorphism (Table 4,). The dimension that displayed the greatest degree of sexual dimorphism was right foot width, male mean 10.204cm and female mean 9.03cm (t =14.587). The dimension that showed the least amount of sexual dimorphism was right lateral malleolar height, male mean 5.10cm female mean 4.93cm (t = 1.645).

Table 5: Tests of Equality of Group Means.

	Wilks' Lambda	F	df1	df2	Sig.
Right foot length	0.745	75.465	1	220	**0.001***
Left foot length	0.758	70.389	1	220	**0.001***
right foot width	0.508	212.756	1	220	**0.001***
Left foot width	0.998	0.348	1	220	0.556
Right bi-malleolar width	0.641	123.377	1	220	**0.001***
Left bi-malleolar width	0.703	92.916	1	220	**0.001***
Right Navicular height	0.741	76.823	1	220	**0.001***
left Navicular height	0.749	73.809	1	220	**0.001***
Right medial malleolar height	0.868	33.557	1	220	0.001*
left medial malleolar height	0.872	32.267	1	220	**0.001***
right lateral malleolar height	0.988	2.706	1	220	**0.101***
left lateral malleolar height	0.985	3.360	1	220	0.068
right heal width	0.742	76.306	1	220	**0.001***
left heel width	0.766	67.222	1	220	**0.001***

Table 6: Tests of equality in population covariance matrices and canonical correlation.

Test Results				
Box's M		541.334		
F	Approx.	4.813		
	df 1	105		
	df2	149193.568		
	Sig.	0.001*		
Eigen values				
Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	1.449 a	100	100	0.769

Table 7: Wilks' lambda test for predictability into group membership.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1	0.408	190.804	14	0.001*

Discriminant function test for sex estimation: Discriminant function analysis (DFA) was carried out using fourteen (14) parameters. In Table 5, the test of equality of means difference of male and female values were carried out, with eleven (11) out of the fourteen (14) entered into the model being significant (P< 0.005). As presented in Table 6, the Box's M test of equality in population, covariance matrices as well as the canonical correlation, provides an index of overall model fit. Significant difference (**p<0.005**) was observed in the Box's M covariance matrix; hence equal group variance cannot be assumed. This suggests a larger discrepancy in the predictor variables. However, the magnitude or the actual effect size of the predictors (being the canonical coefficients) and the outcome becomes the square of the coefficient of the canonical correlation $(0.769)^2$, suggests that the model can only explain 59.13% of the grouping (discriminating) variables (i.e. the sex of the individual). Similarly, Wilks' lambda test for predictability into group membership as presented in Table 9 showed that the predictor variables will make statistically significant predictions (Wilk's lambda = 0. 408, P< 0.005). Standardized and unstandardized coefficients were presented in Table 7, with the unstandardized coefficients used to generate the discriminant function equation. The discriminant function coefficient (unstandardized) indicates the partial contribution of each variable in the discriminant function equation. These values provide information on the relative importance of each variable and are therefore used to assess each individual's variables unique contribution to the discriminant function equation; $DF_{(eqn.)}$ = (-0.726 x RFL) + (0.407x RFW) + (-0.294x RBB) + (-0.011 x RNH) + (0.418 x RMMH) + (0.200 x RLMH) + (1.209 x RHB) + (-0.803 x LFL) + (0.222 x LFW) + (0.970 x LBB) + (1.125 x LNH) + (0.999 x LMMH) + (0.678 x LLMH) + (-0.133 x LHB) - 19.932. Table 9 examined the group centroids (the group mean of the predictor variables), which is a function of group membership or classification. The group centroid also serves as a classification cut off thus a medium of discrimination. As observed, the males have a group mean of 1.156, while the females have a group mean of -1.242. Hence functions at group centroids with a group mean near to a centroid is predicted to belong to that group (i.e. close to 1.156 as male, while -1.242 as female). Once the discriminant functions are determined groups are differentiated, the utility of these functions can be examined via their ability to correctly classify each data point to their a priori groups. Again in Table 10, classification function coefficients also known as linear discriminant functions were presented. Classification functions derived from the linear discriminant functions are used to achieve this purpose. This is expressed as $C_k = C_{k0} + C_{k1}x_1 + C_{k2}x_2 + ... + C_{km}X_m$. Where C_k is the classification score for group k and C is the Coefficient. These coefficients are presented for each parameters according to sex (Table 10). Right Left Foot width, right navicular height as well as the Right bi-malleolar width are the variables with the highest prediction strength for group membership classification, with the least being right lateral malleolar height. According to the classification summary as presented in Table 11, 92.3% of the foot parameters measured were ab initio correctly classified according to sex; however, upon cross validation, 88.7% of the grouped cases therefore accurately classified.

Table 8: Canonical discriminant function coefficient structured, standardized and unstandardized.

	Box'M Structure Matrix coefficients	Standardized canonical discriminant function coefficients	Unstandardized canonicaldiscriminant function coefficients
Var iables (cm)	**Function•**	**Function**	**Function b**
right foot w idth	0.817* **	0.697	0.407
Right bi-malleolar w idth	0.622* **	-0.498	-0.294
Left bi-malleolar w idth	0.540* **	0.583	0.97
Right Navicular height	0.491* *	-0.063	-0.011
right heal w idth	0.489 **	0.535	1.209
Right foot length	0.487 **	-0.36	-0.726
left Navicular height	0.481* *	0.853	1.125
Left foot length	0.470 **	-0.624	-0.803
left heel w idth	0.459 **	-0.099	-0.133
Right medial malleolar height	0.324*	0.313	0.418
left medial malleolar height	0.318*	-0.756	-0.999
left lateral malleolar height	0.103*	0.532	0.678
right lateral malleolar height	0.092*	0.109	0.2
Left foot w idth	0.033*	0.127	0.222
(Constant)			-19.932

Variables that are making; ***strong predictions; **average prediction; * poor prediction. "Function - Pooled within-groups correlations between discriminating var iables and standardized canonical discriminant functions; bFunction - Coefficients used for computing group membership value

Table 9: Functions at group centroids.

Sex	Function
Male	1.156
Female	-1.242

[a] Unstandardized canonical discriminant functions evaluated at group means

Table 10: Classification function coefficients.

	sex	
MEASUR ED PARAMETERS	**MALE**	**FEMALE**
Right foot length	1.165	0.189
Left foot length	4.846	5.551
right foot width	16.586	14.261
Left foot width	-0.021	0.006
Right bi-malleolar width	24.160	21.260
Left bi-malleolar width	-9.687	-7.945
Right Navicular height	23.659	20.959
left Navicular height	-20.824	-18.897
Right medial malleolar height	-0.424	-0.104
left medial malleolar height	6.684	5.682
right lateral malleolar height	-9.562	-7.166
left lateral malleolar height	7.509	5.884
right heal width	1.346	0.866
left heel width	4.794	4.260
(Constant)	-259.207	-211.505
Fisher's linear discr iminant functions		

Table 11: Classification Results[a,c] (Classification Summary)

Prediction (%)		**Sex**	**Predicted Group Membership**		**Total**
			Male	**Female**	
Original	Count	Male	101	14	115
		Female	12	95	107
	%	Male	87.8	12.2	100.0
		Female	11.2	88.8	100.0
Cross-validatedb	Count	Male	98	17	115
		Female	17	90	107
	%	Male	85.2	14.8	100.0
		Female	15.9	84.1	100.0

a. 92.3% of original grouped cases correctly classified
b. Cross validation is done only for those cases in the analysis. In cross validation,each case is classified by the functions derived from all cases other than that case
c. 88.7% of cross-validated grouped cases correctly classified.

DISCUSSION

The results confirmed the presence of statistically significant sexual dimorphism between the males and females in this sample with males being significantly larger for all measurements. When means of stature, foot length and foot width measurements were compared with other studies, differences were found among the communities [19-21]. The significant sexual dimorphism observed in this study provided support for the creation of models for sex estimation and sex specific models for stature estimation. The most sexually dimorphic of the dimensions tested was right foot width (male mean 10.204cm and female mean 9.03cm; t =14.587). Across similar studies of different ancestries, it is evident that that males have statistically significantly larger means than females for any given body dimension [18,22,23]. Thus, supporting the existence of sexual dimorphism in this study with right foot width displaying the greatest degree of sexual dimorphism in both male (mean 10.204cm) and female (mean 9.03cm) with t =14.587. The dimension that showed the least amount of sexual dimorphism was right lateral malleolar height, male mean 5.10cm male mean 4.93cm (t = 1.645). right foot width was consistently the most dimorphic foot dimension. Danborno & Elukpo (2008) [23] found that right foot length to be the most sexually dimorphic measurement in their analysis of foot measurements for sex estimation in a northen Nigerian population while Zeybek et al. (2008) [18], found left navicular height (LNH) to be the most sexually dimorphic parameter in their study of stature and sex estimation using foot measurements in a Turkish population.

Each dimension was assessed for its ability to predict sex using discriminant function analysis (DFA). To provide accurate and reliable models for the estimation of sex, classification accuracies of over 90% with sex biases of <5% are desirable [25,26]. Discriminant function analysis (DFA) as used in this study evaluated the predictability of the model of which 92.3% of the measured parameters were correctly classified. This is relatively high although can be used with caution considering other sex discriminating parameters that may be available aside foot parameters. However, the strength of any DFA model lies in its ability to classify over 80% of the measured parameters into group membership; with a better prediction for male (87.8%) compared to the females (85.2.0%). Previous studies by Eshak et al. (2011) [27] also reported sexual dimorphism in bone lengths among many Nationalities. Numan et al.

(2013) [28] reported to have observed no sex difference in the Hand Length of Igbos, Hausas as well as the Yorubas. Sen et al., (2011) [29] reported that both left foot length and right foot width were the most accurate single variables for predicting sex (82.3%), whereas Krishan et al., (2008) [30] found that it was left foot width (88.5%). However, with the advancement in modern technology, DNA analysis is employed in sex determination which has greatly simplified forensic investigations. Owing to the high cost of DNA technology, anthropometry therefore remains a cheaper and easily available alternative in forensic investigations especially in developing countries.

CONCLUSION

With DFA established as a better tool for sex categorization, this study showed that 92.3% of the variables were successfully grouped according to sex suggesting a high predictive power. Sex can be estimated among Nigerians in this population using foot dimensions whenever the need arises and the equations generated for the DFA is representative of the entire measured variables therefore; unstandardized discriminant function coefficients here can be used to generate equations depending on the available parameter upon examination.

Conflicts of Interests: None

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