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# DETERMINATION OF SEX FROM FOOTPRINT DIMENSIONS AMONG NUPE ETHNIC GROUP IN MINNA NIGER STATE

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## ABSTRACT

Determination of personal identity is a basic and pivotal step in forensic investigations and medico legal practices. In anthropological cases, forensic identification is generally carried out through examination of the body or the remains for prints from the body. Thus, the footprint becomes an invaluable index of identification particularly when the whole body is very badly mutilated. This study was carried out to determine the relationship between footprint dimensions and sex among individuals of Nupe ethnic group of Niger State. Sample size of four hundred and twenty one (421) subjects, two hundred and eighty three (283) males and one hundred and thirty eight (138) females were used in this study. The footprints were gotten by placing the volunteers' foot on the ink pad and it was then transferred on an A4 paper, where the footprint dimensions were later measured with a meter rule. The results of this study show that sex differences were highly significant using toe lengths and breadth ($P \leq 0.01$) but the footprint indices shows no statistical significance. Footprint dimension is sexually dimorphic. Footprint dimensions can be used to determine sex in addition to or in absence of skeletons such as long bones and skull. It can be applied in forensics for medico legal cases, shoe designing, fashion design and industrial design to optimize products.

**KEYWORDS:-** Footprint Dimension, Sexual Dimorphism, Nupe Ethnic Group.

## INTRODUCTION

Personal identification is a basic and pivotal step in forensic investigations and medico legal practices. In anthropological cases, forensic identification is generally carried out through examination of the body or the remains for prints from the body. Thus, the footprint becomes an invaluable index of identification particularly when the whole body is very badly mutilated.(1)

The construction of a biological profile by implementing standards specific to a particular population is a very fundamental and significant step in identification. The high likelihood of recovering a fleshed feet from crime scenes or from victims of mass disaster makes footprint an additional source of evidence needed for forensic investigations.(2)

The use of footprint in personal identification is an emerging technique in biometrics.(3) At crime scenes, footprints are often recovered from several different surfaces like the floor, table top, the wall among others.(4) Foot print dimensions evaluate morphological features such as foot width, foot length, shape and size.(5)

Only a limited number of studies have made attempts to use footprint dimensions in sex determination. This study aimed to determine the relationship between footprint dimensions and sex. The data presented in this study is of immense value to forensic anthropology researchers and medico-legal investigators in the determination of the sex of a person.

## OBJECTIVES

1. To determine the relationship between sex and footprint dimensions.
2. To establish uniqueness of foot dimensions.
3. To establish the footprint dimensions of Nupe ethnic group.

## MATERIALS AND METHOD

### Study population

The study was conducted in two different local government areas in Niger State for duration of two weeks. Niger state; located in north-central Nigeria, had been projected to have a population estimate of 3,954,772 by 2016 according to the 2006 national population census, with the Nupe tribe making up to

1,759,874 of the total number. (6)

**SAMPLE SIZE**

Fischer's formulae was used to determine sample size

$$SS= \frac{Z^2xpxq}{d^2}$$

being a large population (>10,000). It states thus:

**INCLUSION CRITERIA**

All subjects had to be Nupe indigenes, ditto for both parents till the second generation.

All subjects had to fall within the age range of 15 to 65 years. All subjects were verified to have a healthy foot without any form of deformity or open injury.

**EXCLUSION CRITERIA**

Non indigenes of Niger state, subjects that were not in the age group and subjects with open foot injury or deformity were all excluded.

**ETHICAL APPROVAL**

Ethical approval was received from the ethical review committee of the Department of Anatomy, University of Ilorin, Ilorin, Kwara state, Nigeria. The protocols for conducting a field research work were strictly adhered to.

**DATA COLLECTION METHODS**

The foam pad was filled with oil-less ink to form an ink pad before commencing the collection of samples. Participants were provided with water to wash their feet for hygiene purposes and a towel was provided to dry the feet. They were then asked to stand on an ink pad (that had previously been soaked in endorsing ink) applying minimal pressure. From the ink pad, they were asked to step on two A4 papers that had been set aside on a smooth, hard and clean surface (a plank) to get the footprint sample. From the footprint sample, the following parameters were measured with the aid of a scientific ruler:

i. Toe length; the distance between the tip of the toe to the pternion. The toe length for the five toes were measured and labelled T1 to T5.

ii. Breadth at ball (BAB): maximum breadth between the medial margin of the head of the metatarsal print and lateral margin of fifth metatarsal print.

iii. Breadth at heel (BAH): the widest part of the heel.

iv. Heel-ball index: BAH /BAB x 100.

v. Footprint index: Maximum footprint breadth/maximum footprint length x 100.

vi. Base line: perpendicular to the heel at the rear

***Fig. 1: Stepping on the Ink***

***Fig. 2: Stepping on the A4 Paper***


***Fig 3: Measuring the Footprint***

edge of footprint.

## STATISTICAL ANALYSIS

In this current study, footprints dimensions were studied in 421 subjects. The data collected was analyzed using SPSS software (IBM R Version 23.0; SPSS, Inc., Chicago, IL). The SPSS was used for the descriptive statistics and discriminant function analysis (DFA).

DFA was used to estimate sex; it is achieved by accurate categorization. The confidence level was set at 95% and P<0.05 was taken to be significant.

## RESULTS

## PRESENTATION OF RESULTS

The footprint dimensions obtained from Nupe ethnic group in Niger state were analyzed for sex determination. The variables were presented as categorical variable which were described as frequency (percentages) and continuous variables as mean (±S.D) in tables and graphs.

Majority of the study population were males; 281 (67%), while the rest were females; 140 (33%). The mean age group of males was 19.76±6.58yrs while that of females was 21.22±7.75 yrs.Toe length, foot breadth and base length showed significantly higher mean values in males compared to females and these differences were found to be statistically significant (p value ≤ 0.01), while there were no significant differences in the footprint index and heel-ball index p between both sexes.

Table 2 shows a statistically significant difference (p≤0.01) in the right and left fifth toe length and base length of both males and females, which is an indication of asymmetry. It can also be inferred from this table that there is an indication of asymmetry in the right and left breadth at heel and heel-ball index in only males as there was a statistically significant difference (p≤0.01).

| Variable | Sex | Mean(±S.D) and Test of mean difference | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Right Side | M.D | T-value | P-value | Left Side | M.D | T-value | P-value |
| T1 (cm) | Male | 25.02±1.25 | 1.711 | 13.795 | 0.000 | 25.17±1.26 | 1.830 | 14.583 | 0.000 |
| | Female | 23.31±1.09 | | | | 23.34±1.11 | | | |
| T2 (cm) | Male | 24.6±1.28 | 1.735 | 13.448 | 0.000 | 24.69±1.31 | 1.776 | 13.462 | 0.000 |
| | Female | 22.86±1.17 | | | | 22.91±1.19 | | | |
| T3 (cm) | Male | 23.63±1.23 | 1.615 | 12.865 | 0.000 | 23.68±1.27 | 1.651 | 12.882 | 0.000 |
| | Female | 22.01±1.18 | | | | 22.03±1.16 | | | |
| T4 (cm) | Male | 22.44±1.18 | 1.483 | 12.395 | 0.000 | 22.46±1.18 | 1.543 | 12.787 | 0.000 |
| | Female | 20.96±1.11 | | | | 20.92±1.14 | | | |
| T5 (cm) | Male | 21.04±1.24 | 1.418 | 11.753 | 0.000 | 20.95±1.12 | 1.443 | 12.647 | 0.000 |
| | Female | 19.63±1.00 | | | | 19.51±1.08 | | | |
| BAB (cm) | Male | 9.49±0.61 | 0.754 | 12.166 | 0.000 | 9.45±0.61 | 0.676 | 10.820 | 0.000 |
| | Female | 8.73±0.58 | | | | 8.78±0.59 | | | |
| BAH (cm) | Male | 5.58±0.70 | 0.365 | 5.038 | 0.000 | 5.41±0.66 | 0.263 | 3.890 | 0.000 |
| | Female | 5.21±0.70 | | | | 5.14±0.64 | | | |
| FPI | Male | 36.31±2.27 | -0.092 | -0.386 | 0.700 | 36.46±2.20 | -0.102 | -0.426 | 0.670 |
| | Female | 36.4±2.37 | | | | 36.56±2.55 | | | |
| HBI | Male | 58.6±7.59 | -1.403 | -1.831 | 0.068 | 57.33±6.74 | -1.613 | -2.256 | 0.025 |
| | Female | 60.01±7.04 | | | | 58.95±7.24 | | | |
| BL (cm) | Male | 4.52±0.48 | 0.149 | 3.028 | 0.003 | 4.41±0.52 | 0.118 | 2.325 | 0.021 |
| | Female | 4.37±0.46 | | | | 4.29±0.44 | | | |

***Table 1: The Descriptive Characteristics of the Footprint Dimensions and Indices for Males and Females and Test of Mean Difference***

| Paired Sample | | Paired Sample Test (Male) | | | | | Paired Sample Test (Female) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M.D (±S.D) | t-value | P-value | *R* | P-value | M.D (±S.D) | t-value | P-value | *r* | P-value |
| Pair 1 | RT1 | -0.14±1.42 | -1.689 | 0.092 | 0.364 | <0.001 | -0.02±0.51 | -0.547 | 0.586 | 0.892 | <0.001 |
| | LT1 | | | | | | | | | | |
| Pair 2 | RT2 | -0.09±1.42 | -1.073 | 0.284 | 0.403 | <0.001 | -0.05±0.51 | -1.170 | 0.244 | 0.909 | <0.001 |
| | LT2 | | | | | | | | | | |
| Pair 3 | RT3 | -0.05±1.39 | -0.611 | 0.541 | 0.388 | <0.001 | -0.01±0.35 | -0.485 | 0.628 | 0.956 | <0.001 |
| | LT3 | | | | | | | | | | |
| Pair 4 | RT4 | -0.02±0.41 | -0.773 | 0.440 | 0.940 | <0.001 | 0.04±0.37 | 1.339 | 0.183 | 0.947 | <0.001 |
| | LT4 | | | | | | | | | | |
| Pair 5 | RT5 | 0.09±0.71 | 2.090 | 0.038 | 0.825 | <0.001 | 0.11±0.54 | 2.495 | 0.014 | 0.868 | <0.001 |
| | LT5 | | | | | | | | | | |
| Pair 6 | RBAB | 0.04±0.49 | 1.230 | 0.220 | 0.678 | <0.001 | -0.04±0.44 | -1.120 | 0.265 | 0.718 | <0.001 |
| | LBAB | | | | | | | | | | |
| Pair 7 | RBAH | 0.17±0.52 | 5.511 | 0.000 | 0.708 | <0.001 | 0.07±0.52 | 1.581 | 0.116 | 0.697 | <0.001 |
| | LBAH | | | | | | | | | | |
| Pair 8 | RFPI | -0.15±1.83 | -1.368 | 0.173 | 0.665 | <0.001 | -0.16±1.86 | -1.014 | 0.312 | 0.716 | <0.001 |
| | LFPI | | | | | | | | | | |
| Pair 9 | RHBI | 1.27±6.39 | 3.338 | 0.001 | 0.609 | <0.001 | 1.06±6.78 | 1.854 | 0.066 | 0.550 | <0.001 |
| | LHBI | | | | | | | | | | |
| Pair 10 | RBL | 0.11±0.45 | 4.160 | 0.000 | 0.596 | <0.001 | 0.08±0.41 | 2.348 | 0.020 | 0.578 | <0.001 |
| | LBL | | | | | | | | | | |

*Table 2: The Test of Side Differences and Correlations of Parameters for Males And Female*

| Variable | | Wilks' Lambda Test of Equality of Group Mean | | | | |
|---|---|---|---|---|---|---|
| | Wilks' Lambda (Right) | F | Sig. | Wilks' Lambda (Left) | F | Sig. |
| T1 (cm) | 0.688 | 190.309 | <0.001 | 0.663 | 212.667 | <0.001 |
| T2 (cm) | 0.699 | 180.850 | <0.001 | 0.698 | 181.232 | <0.001 |
| T3 (cm) | 0.717 | 165.506 | <0.002 | 0.716 | 165.954 | <0.001 |
| T4 (cm) | 0.732 | 153.640 | <0.003 | 0.719 | 163.507 | <0.001 |
| T5 (cm) | 0.752 | 138.135 | <0.004 | 0.724 | 159.940 | <0.001 |
| BAB (cm) | 0.739 | 148.021 | <0.005 | 0.782 | 117.069 | <0.001 |
| BAH (cm) | 0.943 | 25.386 | <0.006 | 0.965 | 15.133 | <0.001 |
| FPI | 1.000 | 0.149 | 0.700 | 1.000 | 0.182 | 0.670 |
| HBI | 0.992 | 3.352 | 0.068 | 0.988 | 5.091 | 0.025 |
| BL (cm) | 0.979 | 9.168 | 0.003 | 0.987 | 5.407 | 0.021 |

*Table 3: Wilks' Lambda Unidimensional Test for Equality of Means*

| Wilks' Lambda | Canonical Correlation Analysis | | | | |
|---|---|---|---|---|---|
| Right Side | | Lambda (Λ) | Eigenvalue[a] | $r_c$ | $Rc^2$ |
| Lambda (Λ)<br>Chi-square<br>DF<br>p-value | 0.621<br>197.061<br>10<br><0.001 | F1 | 0.61 | 0.615 | 37.82% |
| Left Side<br>Lambda (Λ)<br>Chi-square<br>DF<br>p-value | 0.587<br>220.308<br>10<br><0.001 | F1 | 0.703 | 0.642 | 41.22% |

*Table 4: Wilks' Lambda test for predictability into group membership and Canonical correlation analysis.*

***Note:***

***a.*** *First 1 canonical discriminant functions were used in the analysis.*

$r_c$ *Canonical correlation*

$R_c^2$ *Prediction model accuracy*

Table 4 displays a strong percentage contribution of the variables to the prediction model. It revealed a 37.8% and 41.2% effect for the right and left sides respectively in either the male or the female group. This is suggested by the overall model acceptability ($r_c$) of $0.615^2$ and $0.642^2$ for the right and left sides respectively.

| Variables | Right Side | | | Variables | Left Side | | |
|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | | F1 | F2 | F3 |
| RT1 (cm) | 0.863 | 0.184 | 0.153 | LT1 (cm) | 0.85 | 0.799 | 0.658 |
| RT2 (cm) | 0.841 | 0.43 | 0.345 | LT2 (cm) | 0.785 | -0.185 | -0.145 |
| RT3 (cm) | 0.805 | 0.244 | 0.201 | LT3 (cm) | 0.751 | -0.074 | -0.059 |
| RT4 (cm) | 0.776 | -0.58 | -0.502 | LT4 (cm) | 0.745 | -0.022 | -0.019 |
| RBAB (cm) | 0.761 | 0.557 | 0.93 | LT5 (cm) | 0.737 | 0.458 | 0.415 |
| RT5 (cm) | 0.735 | 0.299 | 0.257 | LBAB (cm) | 0.631 | 0.042 | 0.07 |
| RBAH (cm) | 0.315 | 0.279 | 0.399 | LBAH (cm) | 0.227 | 0.614 | 0.938 |
| RBL (cm) | 0.189 | -0.169 | -0.357 | LBL (cm) | 0.136 | -0.248 | -0.506 |
| RHBI | -0.115 | -0.24 | -0.032 | LHBI | -0.132 | -0.502 | -0.073 |
| RFPI | -0.024 | -0.242 | -0.105 | LFPI | -0.025 | -0.09 | -0.039 |
| Intercept/constant | - | - | -14.376 | Intercept/constant | - | - | -17.196 |

***Table 5: Variable Prediction and Discriminant Function Coefficients***

***Note***

*F1 Factors correlations.*

*F2 Standardized canonical discriminant function coefficients.*

*F3 Unstandardized canonical discriminant function coefficients.*

In table 5, the foot dimensions with significantly high predictor capability for sex grouping were RT1 (0.863), LT1 (0.85), RT2 (0.841), LT2 (0.785), RT3 (0.805), LT3 (0.751), RT4 (0.776) LT4 (0.745), RT5 (0.735), LT5 (0.737), RBAB (0.761), LBAB (0.631), RBAH (0.315), LBAH (0.227), RBL (0.189) AND LBL (0.136) while RHBI, LHBI, RFPI and LFPI had prediction coefficient less than -0.1.

| Class | Fc (Right) | Fc (Left) |
|---|---|---|
| **Female** | 0.55 | 0.59 |
| **Male** | -1.104 | -1.185 |

***Table 6: Class Prediction Using Centroids***

Table 6 shows the sex-specific resultant group mean (centroid) value of the predictor variables. The prediction model used in this study produced a centroid mean of -1.104 and -1.185 on the right and left foot respectively for male; while female produced a mean of 0.55 and 0.59 on the right and left foot respectively.

| Variables | Right | | Left | |
|---|---|---|---|---|
| | Male | Female | Male | Female |
| **T1 (cm)** | 25.468 | 25.215 | 18.046 | 16.877 |
| **T2 (cm)** | 18.539 | 17.968 | 28.568 | 28.826 |
| **T3 (cm)** | -5.931 | -6.263 | -31.573 | -31.468 |
| **T4 (cm)** | -7.224 | -6.394 | 33.818 | 33.852 |
| **T5 (cm)** | 1.893 | 1.469 | -23.175 | -23.911 |
| **BAB (cm)** | 15.121 | 13.584 | 119.901 | 119.776 |
| **BAH (cm)** | -90.561 | -91.22 | -242.897 | -244.562 |
| **FPI** | 15.567 | 15.741 | 12.085 | 12.154 |
| **HBI** | 8.096 | 8.15 | 22.346 | 22.475 |
| **BL (cm)** | 6.437 | 7.027 | 11.118 | 12.016 |
| **(Constant)** | -769.347 | -746.733 | -1138.484 | -1109.187 |

***Table 7: Classification Function Coefficients (CFC) in the Model for the right and Left Footprints.***

Table 7 shows the Linear Discriminant Function Coefficients illustrating the prediction of sex using the centroids of the predictor variables.

Categorization of sex based on the discriminant model was illustrated as;

**Male:**

(Right foot dimension);-769.347+25.468+18.539 -5.931 - 7.224 +1.893 +15.121 -90.561 +15.567 +8.096 + 6.437 +

(Left foot dimension); -1138.484 +18.046+28.568-31.573+33.818-23.175+119.901-242.897+12.085+22.346 +11.118

**Female:**

(Right foot dimensions); -746.733 +25.215 +17.968 - 6.263 -6.394 +1.469 +13.584 -91.22 +15.741 +8.15+7.027+

(Left foot dimensions); -1109.187 +16.877+28.826-31.468+33.852-23.911+119.776- 244.562+ 12.154+22.475+12.016

## .DISCUSSION

Prints as means of personal identification is one of the most accessible methods in forensic anthropology, (7) and examples of such prints are finger prints and footprints. Determination of sex from recovered footprints at crime scenes can help forensic investigators narrow down the pool of possible suspects (8).

The results from this study are consistent with the several related studies conducted on different populations (10,11,12).

Moreover, results from this study also showed a notable significant difference in all the toe lengths (T1 to T5) of males and females with males having longer toe length. This corresponds to a similar study conducted on a population of Haryanvi Jats and North Indian mixed of both sexes, which show significant differences in the toe length of the subjects (9). Variation in toe length across the population inferred that foot dimension varies across respective individuals and sex group.

It was also observed that there was a significant difference in the BAB and BAH lengths of males and females, with males having the larger BAB and BAH length. The differences in Breadth at ball (BAB) and Breadth at heel (BAH) length affirmed the uniqueness of footprint dimension in specific individuals as reported in previously conducted studies.( 8) There was no significant difference in the mean difference in FPI and HBI across the sex groups. This is in accordance with a research carried out by Tanuj et al.

| Classification | Predicted Group Membership [a, c] | | | % Correct classification |
|---|---|---|---|---|
| | Sex | Male | Female | |
| Right | | | | |
| Original | Male (%) | 246 (87.5) | 35 (12.5) | 81.2% |
| | Female (%) | 44 (31.4) | 96 (68.6) | |
| Cross-validated[b] | Male (%) | 244 (86.8) | 26 (13.2) | 79.3% |
| | Female (%) | 50 (35.7) | 90 (64.3) | |
| Left | | | | |
| Original | Male (%) | 255 (90.7) | 26 (9.3) | 83.60% |
| | Female (%) | 43 (30.7) | 97 (69.3) | |
| Cross-validated[b] | Male (%) | 255 (90.7) | 26 (9.3) | 82.90% |
| | Female (%) | 46 (32.9) | 94 (67.1) | |

***Table 8: Initial Classification and Classification After Cross-Validation***

**Note:**

*a. Percentage of original grouped cases correctly classified.*

*b. Cross validation of each case in the analysis which involved classification based on the functions drawn from all cases apart from that case.*

*c. Percentage of cross-validated grouped cases correctly classified.*

Table 8 revealed a classification accuracy of 79.3 % (1.9% error difference) and 82.90 % (0.7% error difference) for the right and left foot respectively from the use of footprint dimensions

(8) which recorded that the differences in HBI and FPI were not statistically significant ( 8).

In the present study, right and left foot dimensions (length and breadth) showed statistically significant difference amongst both male and female as $P \leq 0.01$. This is consistent with the studies done by Singla et al. (13) in 2015 and Atal et al (14). in 2017.

Results from this study showed that model of foot anthropometric parameters can be used to effectively predict the sex of an individual, Wilks' Lambda test for predictability into group membership and Canonical correlation analysis showed an overall model acceptability ($r_c$) of $0.615^2$ and $0.642^2$ for right and left side respectively, which illustrated a percentage contribution by the variables in the model of 37.8% and 41.2% effect in either of the different sex groups. This is against the study carried out by Derya, 2010 (1) which showed an overall model acceptability ($r_c$) of $0.439^2$ and $0.499^2$ for right and left side respectively, suggesting that Canonical correlation analysis shows higher success for classifying the male group than the female group (1).

This study also showed the accuracy of using footprint dimensions, the right foot only achieved a 79.3 % accurate classification, while the left foot produced an 82.90 % accurate classification (with a 0.7% error difference). This is in accordance with a research carried out on a Ghanaian population which stated the degree of accuracy to be 69.8% and 80.3% in right and left foot respectively, indicating that the left foot provides more accuracy.(15) However, this is in contrast with the research carried out on a Western Australian population in 2013, which shows that the accuracy of 89.5% and 82.4% was recorded; indicating that the right foot provides higher accuracy (16).

## CONCLUSION

Footprint measurements are reliable in determination of sex in forensic investigations. Footprint length, footprint breadth, BAB, BAH and base length are higher in males than in females hence sexual dimorphism is evidenced in footprint dimensions. Footprint index appeared to be statistically insignificant and therefore cannot be used in the determination of sex. The uniqueness of footprint dimensions can be established by breadth at ball and breadth at heel dimensions.

## RECOMMENDATION

It is strongly recommended that the use of footprint dimension as a determinant for sex membership should be further investigated to corroborate the findings of this research and a similar research be carried out among other ethnic groups.

## CONTRIBUTIONS TO KNOWLEDGE

The present study has provided an insight into the relevance of footprint dimensions in sex determination. Therefore the results from this study can be used by Nigerian law enforcement agencies when handling cases of personal identification and scientific criminal detection.

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