Stature and sex estimate using foot and shoe dimensions

Hilmi Ozden*a,*, Yasemin Balci*b, Canan Demirüstü*c, Akin Turgutd, Mehmet Ertugrul*d

*aMedical Faculty, Department of Anatomy, Osmangazi University, Eskisehir 26480, Turkey
*bMedical Faculty, Department of Forensic Medicine, Osmangazi University, Eskisehir 26480, Turkey
*cMedical Faculty, Department of Biostatistics, Osmangazi University, Eskisehir 26480, Turkey
*dMedical Faculty, Department of Orthopedics, Osmangazi University, Eskisehir 26480, Turkey

Available online 5 November 2004

Abstract

The aim of the study was to develop a formula to estimate the stature and sex of an individual using foot and shoe dimensions. To this aim the stature, right and left shoe sizes, and maximum and minimum feet length and width measurements of a target group of 569 individuals were taken. The group was composed of 294 males and 275 females. The highest correlation coefficient was found in length measurements. A notable difference between males and females existed with regard to both right and left foot and shoe length and width averages and shoe sizes (p < 0.001). Among the group, a significant correlation was found in regard to stature and right shoe length (r = 0.591, p < 0.001), with the correlation between stature and right foot length and stature and right foot length being 0.579 (p < 0.001); as for the female group, there was a significant correlation between stature and right foot length and stature and right shoe length (r = 0.460, p < 0.001). Thus the regression formula obtained are as follows: for the right side: sex = 69.169 + 0.173 (maximum foot length)/0.368 (maximum foot width)/0.820 (shoe length) + 0.224 (shoe width)/1.280 (shoe number). For the left side: sex = 69.551 + 0.276 (maximum foot length)/0.504 (maximum foot width)/0.739 (shoe length) + 0.344 (shoe width)/1.360 (shoe number). In application of the formula, if sex is lower than 0.50, the shoe belongs to a male, if higher, then to female. The formula which was obtained in regression analysis in order to estimate the stature when the measurements of shoe and foot were known.

For the right side, stature = 47.93 + 1.083 (maximum foot length) + 0.788 (shoe length) + 1.813 (shoe number) (SEE:31.410).
For the left side: stature = 47.33 + 1.139 (maximum foot length) + 0.593 (shoe length) + 1.924 (shoe number) (SEE:31.607).

It was understood that foot and shoe sizes are a criteria to estimate the stature of a person that there was a strong relationship between foot and shoe length and width and that these can be used to aid estimation. It was found that in sex estimate, foot and shoe lengths are better in helping the estimate than width measurements, and that the use of shoe measurements rather than bare foot measurements are better to obtain meaningful results.

© 2004 Elsevier Ireland Ltd. All rights reserved.

Keywords: Foot; Shoe; Dimensions; Stature estimate; Sex determination; Turks

1. Introduction

In forensic sciences to determine one’s sex and to estimate how tall one is quite important during the identity defining stage. The identity of the victim or the suspect that is tried to be defined will be searched in a 50% reduced population within the determination of one’s sex. Beside the body appearance, some parts of a skeleton and bones, private/personal clothes and other belongings, and the other numerous data can be made use of to determine one’s sex in fatal or harmless incidents [1–3].

Anatomical and mathematical methods were used with the purpose of estimating how tall the person is that his/her
corpse or some parts of his/her corpse found. In this study, it will be researched whether the person is male or female and how tall he/she is by the help of his/her foot and shoe size.

2. Materials and methods

2.1. Materials

Harpender anthropometry sets, balance and apparatus to measure stature. In this research, randomly, some measurements were done on the orthopedically healthy adult patients who were applied to Osmangazi University, Medical Faculty, Eskisehir, Turkey. The stature, right and left feet and maximum shoe length and width of 294 males and 275 females over 19 years old within the sample group were measured.

2.2. Methods

In this research, randomly, some measurements were done on the orthopedically healthy adult patients who were applied to Osmangazi University, Medical Faculty, Eskisehir, Turkey. The stature, right and left feet and maximum shoe length and width of 294 males and 275 females over 19 years old within the sample group were measured.

2.2.1. Measurements

Stature, body weight, height, length and width of right and left foot-shoe were obtained. All subjects were barefoot during measurements. Foot length is defined as the direct maximum distance from the rear of the heel to the tip of the longest (first or second) toe. Foot width is the distance between the surfaces of the first and fifth metatarsal boneheads. Shoe length and width are defined as the direct maximum distance [3–6]. Harpender anthropometry sets are used in the foot and shoe measurements. Balance is used in body weight and apparatus to measure stature is used in stature measurements.

Both for male and female, the footwear was recorded as boots (44 pairs), high-heeled boots (29 pairs), heeled shoes (102 pairs), low-cut shoes (119 pairs), timberland (23 pairs), narrow sole (1 pair), rubber sole shoes (148 pairs), sandals (24 pairs), slippers (48 pairs) and sabot slippers (6 pairs), sport shoes (33 pairs), and half boots (3 pairs), whereas any standardization as done because there is a possibility of facing with any kind of shoes on the spot (16 pairs).

Statistical significant of the difference between the data and the mean was evaluated with Student’s t-test by computing the correlation coefficient of Pearson’s and regression analysis, logistic regression analysis and Spearman’s correlation coefficients and cut-off values calculated for male and female.

3. Results

The majority of the model groups were from the central Turkey area (27.83%), with the average age of the males as 32.70 ± 12.55, and the females 32.23 ± 12.71 (Table 1).

It was found that a correlation between stature and other variables as regards the sex. Cut-off values were calculated for each sex (Table 2).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Average ± S.D.</th>
<th>Minimum–maximum</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>32.70 ± 12.55</td>
<td>19.00–77.00</td>
<td>0.44ns</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.58 ± 11.58</td>
<td>37.50–108.00</td>
<td>11.95 ***</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>174.39 ± 7.21</td>
<td>153.00–197.00</td>
<td>23.61 ***</td>
</tr>
<tr>
<td>Shoe size (number)</td>
<td>41.80 ± 1.34</td>
<td>37.00–46.00</td>
<td>40.95 ***</td>
</tr>
<tr>
<td>Left foot width (cm)</td>
<td>8.23 ± 1.18</td>
<td>4.00–10.00</td>
<td>13.32 ***</td>
</tr>
<tr>
<td>Left foot length (cm)</td>
<td>26.30 ± 1.36</td>
<td>20.50–26.80</td>
<td>26.59 ***</td>
</tr>
<tr>
<td>Right foot width (cm)</td>
<td>8.24 ± 1.18</td>
<td>4.00–10.20</td>
<td>12.84 ***</td>
</tr>
<tr>
<td>Right foot length (cm)</td>
<td>26.30 ± 1.36</td>
<td>20.50–26.50</td>
<td>26.84 ***</td>
</tr>
</tbody>
</table>

ns: non significant.

*** p < 0.001.

Table 2

Correlation between stature and other variables

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Male regression coefficient (r)</th>
<th>Female regression coefficient (r)</th>
<th>Cut-off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right foot length</td>
<td>0.579***</td>
<td>0.500***</td>
<td>24.50</td>
</tr>
<tr>
<td>Left foot length</td>
<td>0.614***</td>
<td>0.490***</td>
<td>24.60</td>
</tr>
<tr>
<td>Right foot width</td>
<td>0.161***</td>
<td>0.101***</td>
<td>9.30</td>
</tr>
<tr>
<td>Left foot width</td>
<td>0.165***</td>
<td>0.086***</td>
<td>9.20</td>
</tr>
<tr>
<td>Right shoe length</td>
<td>0.591***</td>
<td>0.460***</td>
<td>27.20</td>
</tr>
<tr>
<td>Left shoe length</td>
<td>0.605***</td>
<td>0.455***</td>
<td>26.90</td>
</tr>
<tr>
<td>Right shoe width</td>
<td>0.208**</td>
<td>0.139*</td>
<td>9.70</td>
</tr>
<tr>
<td>Left shoe width</td>
<td>0.210***</td>
<td>0.153***</td>
<td>10.20</td>
</tr>
</tbody>
</table>

ns: non significant.

* p < 0.05.

** p < 0.01.

*** p < 0.001.
The formula which was obtained in regression analysis in order to estimate stature according to sex when measurements of the right and left shoe and foot were known (Table 3).

In terms of sex, a significant difference was found between male and female in relation to foot and shoe length and width along with shoe size. There was no notable difference in the work taken between male and females’ ages ($p > 0.05$) (Table 1).

A significant correlation was found between sex and measurements of shoe and foot (Table 4).

The formula which was obtained in logistic regression analysis in order to estimate the sex when the measurements of shoe and foot were known:

3.1. For the right side

Sex = 69.169 + 0.173 (maximum foot length) − 0.368 (maximum foot width) − 0.820 (shoe length) + 0.224 (shoe width) − 1.280 (shoe number).

3.2. For the left side

Sex = 69.551 + 0.276 (maximum foot length) − 0.504 (maximum foot width) − 0.739 (shoe length) + 0.344 (shoe width) − 1.360 (shoe number).

In every two formulae, if sex is lower than 0.50, the shoe belongs to a male, if higher, then to female.

Table 4
Correlation between inverse connections

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Regression coefficient ($r$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right foot width and sex</td>
<td>0.552***</td>
</tr>
<tr>
<td>Right shoe width and sex</td>
<td>0.580***</td>
</tr>
<tr>
<td>Right foot length and sex</td>
<td>0.778**</td>
</tr>
<tr>
<td>Right shoe length and sex</td>
<td>0.825**</td>
</tr>
<tr>
<td>Left foot width and sex</td>
<td>0.568***</td>
</tr>
<tr>
<td>Left shoe width and sex</td>
<td>0.579***</td>
</tr>
<tr>
<td>Left foot length and sex</td>
<td>0.769**</td>
</tr>
<tr>
<td>Left shoe length and sex</td>
<td>0.818**</td>
</tr>
</tbody>
</table>

*** $p < 0.001$. The formula which was obtained in regression analysis in order to estimate the stature when the measurements of shoe and foot were known:

3.3. For the right side

Stature = 47.93 + 1.083 (maximum foot length) + 0.788 (shoe length) 1.813 (shoe number). (standard error of estimate: 31.410)

3.4. For the left side

Stature = 47.33 + 1.139 (maximum foot length) + 0.593 (shoe length) 1.924 (shoe number) (SEE: 31.607).

4. Discussion and conclusion

The foot and shoe measurements and heights from a group of 294 Turkish males and 275 Turkish females, with the majority being from the central Anatolian area (female 49.82% and male 50.17%) were appraised. No significant difference was found in either male or female left and right side measurements.

In all male and female measurement results, a significant difference was reported between the maximum right and left foot and shoe length and width averages in relation to the shoe sizes of male and female ($p < 0.01$). Such a difference was not seen in other measurements ($p > 0.05$).

In a study by Jasuja et al. and later by Singh and Phookan, an measurements taken from males of four different ethnic groups in India [7,8]. Works of Giles et al., Robbins and Quamra et al. has been conducted in the area of making height estimations from foot and shoe measurements by means of a statistical method [9–11]. Singh and Phookan saw differences in their studies on the connection between foot measurement and height in relation to ethnic group, with the correlation coefficient between foot length and height in different groups being 0.63 and 0.92, the connection between foot width and height 0.51 and 0.65, proving height estimation by foot length measurement gives better results than height estimation by foot width measurement [8].
This study, the connection between height and foot width in males was shown as right side ($r = 0.161, p < 0.01$), and left side ($r = 0.165, p < 0.01$); in female, the right side as ($r = 0.101, p > 0.05$), and left side ($r = 0.086, p > 0.05$). For this reason, the important relationship between height and foot width for male was seen, whereas it was not seen in female.

In Tokyo, in a study using a total of 533 males and 567 females from three different ethnic groups of the same height, body weight and width were measured, and a linear regression balance was found for different groups and sex measurement averages, differences are pronounced. Female and male from the different ethnic groups, but having the same height, showed a difference in foot lengths. According to the results found by the researchers, morphometric works should be made with attention to the society [3].

Saxena, in a study in Nigeria using 100 male medical students between the ages of 20 and 30, took right foot lengths for calculating height, estimated the formula:

\[
\text{height} = 67.4929 \pm 3.9755 \times \text{right foot length} \quad [12].
\]

Jasuja and Manjula studied height estimations from print averages made with and without shoes [13]. Jasuja et al. for the estimation of height when length measurement were used rather than width measurements, bare foot measurements gave better results than shoe measurements, and less standard deviation extremes were asserted in the given approximations [7].

In our study, better results were achieved in height estimation in terms of foot length measurements than in foot width measurements. The correlations coefficient between male and female foot and shoe length with height was seen to be closer to Singh and Phookan’s correlation coefficient finding, with the differences being 0.579 with 0.614 for male and 0.500 with 0.490 for female [8].

Gordon and Buiistra, for the development of their linear model for height estimation from foot and shoe measurement, showed a strong relationship between the calculation model with foot and shoe length and height [14]. In our study, for males and females, beside left and right foot lengths, other factors of importance may be determined. The same definition can be made for other parameters.

Smith had formed distal and proximal phalanges with metatarsal bones that may prove to be useful, when giving of results of sex differentiation from cranial and pelvic bone examinations is not. With the help of the models gained, it was noticed that determination of one’s sex could be done with an 86–98% accuracy ratio [15]. Because there may be differences between different societies in order to shoe size and people’s feet size, and especially in winter both male and female may wear the same kind of footwear. It was supposed that if any kind of shoes were found on the spot, this study would lead the determination of sex.

References


