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Sex estimation from talus and calcaneus in a Southern Italian sample: application of discriminant functions to the documented skeletal collection of the Museum of Anthropology and Ethnology of Florence

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Abstract. This study evaluates the reliability of discriminant function equations for sex estimation based on measurements of the talus and calcaneus in a Southern Italian population. The analysis was conducted on a documented sample of 52 adult individuals (35 males, 17 females) from the Municipal Cemetery of Siracusa (Sicily), housed at the Museum of Anthropology and Ethnology of Florence. Osteometric data were collected from both sides of the talus and calcaneus. Published equations developed on Northern Italian and Korean populations were tested, and new population-specific discriminant function equations were developed for the sample under study. Both sets produced lower accuracy results compared to those obtained in their respective reference populations. The new equations developed for the Sicilian population yielded the highest classification accuracies (82-88%), outperforming previously published models. These findings emphasize the importance of developing population-specific models in forensic anthropology.

Keywords: forensic anthropology, bioarchaeology, sexual dimorphism, tarsus.

Introduction

The study of skeletal remains in physical anthropology aims to extract as much information as possible about the individual and population under investigation. Central to this process is the construction of a biological profile, which typically includes estimates of sex, age, ancestry, and stature – considered the four fundamental parameters. A correct sex identification is also a crucial starting point for evaluating other parameters of the biological profile, as patterns of variation in age, ancestry, and stature are strongly influenced by the individual's sex (White *et al.*, 2005; Stewart *et al.*, 1979).

Sex determination plays a key role in various applied contexts within physical anthropology (Del Bove *et al.*, 2020; Bidmos and Asala, 2005; Pablos *et al.*, 2013; Rodríguez *et al.*, 2013; Ruff, 2002). In forensic anthropology, it allows the biological profile of unidentified individuals to be refined, aiding legal investigations and contributing to judicial outcomes (Barrio *et al.*, 2006). In bioarchaeological research, sex estimation provides valuable insights into the biological structure and social organization of past populations, informing reconstructions of cultural practices, mortuary behaviour, and demographic patterns (Murail *et al.*, 1999; Rösing *et al.*, 2007; Sparacello *et al.*, 2021; White, 1991). In palaeoanthropology, a correct estimate of sex can inform about the biology of the species and also aspects related to the social sphere, such as structure of the group and mating system (Lockwood *et al.*, 2007; Wood, 1991).

Sex identification is possible due to the presence of sexually dimorphic characteristics. Sexual dimorphism, defined as the differences between the two sexes within the same species, is the phenotypic expression of a complex process at the chromosomal, hormonal, and behavioural levels (Moore, 2013; Stinson, 2012; Nikitovic, 2018). These differences are also reflected in the human skeleton, and the observation of sexually dimorphic traits allows anthropologists to estimate the sex of skeletal remains.

Physiologically, the expression of hormones during growth has a strong influence on the development of dimorphic traits in the skeleton. As a result, the skeletal characteristics used for sex estimation develop with sexual maturity. Consequently, estimating sex in non-adults skeletal remains is challenging, as these traits have not yet fully developed.

Methods for sex classification are generally divided into morphological and metric approaches. Morphological methods rely on visual assessment but are influenced by observer subjectivity and less accurate on fragmented and poorly preserved bones. Metric methods, on the other hand, involve osteometric measurements and statistical analysis to establish discrimination thresholds, providing repeatable, interpretable numerical results that are independent of the operator. However, their accuracy depends on the availability of statistical models built on diverse reference samples, given the variability in sexual dimorphism across populations.

Discriminant Function Analysis (DFA) (Fisher, 1936), is a widely used statistical approach in metric analysis. DFA uses sectioning points to rigidly dichotomize individuals into males and females. DFA results are cross-validated, often using the leave-one-out method. The probability of an individual being classified into a sex is calculated based on statistical models like Bayes' theorem and Mahalanobis distance. Osteometric analysis with DFA is widely used for sex identification due to its objectivity and ease of use. DFA is particularly important for sex estimation in cases of poor skeletal material preservation. DFA is population-specific and accuracy varies with the measures used (Gualdi-Russo, 2007; Šlaus *et al.*, 2003; Bidmos *et al.*, 2004; Kemkes-Grottenhaler *et al.*, 2005). Its efficiency depends on sample size, robustness, and sexual dimorphism of the population (Walker, 2008).

Multivariate methods generally offer higher accuracy (Albanese *et al.*, 2005), but univariate methods are sometimes preferable for fragmented remains or incomplete datasets (Dittrick *et al.*, 1986). Examples of univariate methods include using humeral and femoral head breadths with sectioning points (Stewart, 1979). Recent univariate methods using femoral and tibial epicondylar width, scapular height, and femoral head diameter achieved up to 90% accuracy (Spradley and Jantz, 2011). Multivariate analyses combining measures have reached higher accuracies, such as 94.34% for humerus or radius, 95.7% and 87.9% for talus and calcaneus in Northern Italian and Korean samples, respectively (Gualdi-Russo, 2007; Lee *et al.*, 2012).

Various studies in archaeological and forensic contexts have led to the development of sex estimation techniques based on a wide range of skeletal elements (Krishan *et al.*, 2016). The most frequently used elements are the pelvis, skull, and long bones, as they provide a higher degree of accuracy in sex determination. Morphological analysis of the complete pelvic girdle has shown up to 95% accuracy (Phenice, 1969). In the case of the skull, morphological analysis has yielded 92% accuracy (Williams *et al.*, 2006), while metric approaches have reached 90% (Spradley *et al.*, 2011). Metric analysis of long bones has demonstrated an accuracy of 91% (Spradley *et al.*, 2011).

A study conducted in 2016 comparing metric and morphological analyses to DNA-based sex estimation in FBI cases reported 96% accuracy for the pelvis alone, 92.2% for the skull alone, and 77.8% for long bones alone. Combining skeletal elements improved accuracy further: 91.2% for the skull and long bones, 97.4% for the skull and pelvis, and 97.8% for the complete skeleton (Thomas *et al.*, 2016).

Despite the high levels of accuracy associated with pelvic and cranial analyses, recent research has focused on methods involving other skeletal elements, as the skull and pelvis are frequently found fragmented or incomplete in both archaeological and forensic contexts. This has led to the development of sex estimation techniques based on smaller, more durable bones that are more likely to be preserved (Mastrangelo *et al.*, 2011). Methods have been developed using metacarpals and phalanges (up to 94% accuracy; El Morsi *et al.*, 2013), the talus, cuboid, and cuneiform bones (up to 93.6%; Harris *et al.*, 2012), metatarsals (up to 94.2%; Akhlaghi *et al.*, 2017), the hyoid bone (up to 96%; Urbanová *et al.*, 2013), the patella (up to 85%; Dayal *et al.*, 2005), and the calcaneus (up to 89.4%; Kim *et al.*, 2013).

The talus and calcaneus are important elements for applying metric methods for sex estimation. They are weight-bearing bones, and since body weight is a sexually dimorphic trait, these bones are hypothesized to show sex differences. Steele was the first to employ talus and calcaneus for sex discrimination in 1976, achieving 81% accuracy using only the maximum talus length in a sample from the Terry Collection (Steele, 1976). Using DFA, Steele found talus measurements to be most predictive (83-88% accuracy), while combined talus and calcaneus measures reached the highest accuracy (89%). Subsequent studies focused on DFA from calcaneus (Peckmann *et al.*, 2015a) reaching up to 89.5% accuracy and talus (Peckmann *et al.*, 2015b) reaching up to 86.9% accuracy. However, application of these equations to different populations yielded significantly lower accuracies. Radiographic studies on calcanei have also shown sexual dimorphism. Others studies achieved 84.4% accuracy on Europeans using linear and angular measurements (Riepert *et al.*, 1996); 92.6% accuracy on Egyptians using linear measures from radiographs (Zakaria *et al.*, 2010). A CT-based studies on calcanei on a Turkish population, achieved very high accuracies (up to 100% on original sample, 94% on validation sample) with DFA (Ekizoglu *et al.*, 2017). Additionally, studies on burned remains have shown sexual dimorphism in talus and calcaneus measurements persist despite heat-induced alterations (Gonçalves, 2011; Gonçalves *et al.*, 2013).

In this contribution, we explore the reliability of sex estimation methods when applied to populations different from those on which they were originally developed. Specifically, we evaluate the accuracy of discriminant function equations in predicting sex in a Southern Italian population. The equations tested were originally developed using talus and calcaneus measurements from a Northern Italian population (Gualdi-Russo, 2007) and a Korean population (Lee *et al.*, 2012). Additionally, new discriminant functions were created based on measurements taken from the Southern Italian sample. The aim is to assess the applicability of existing methods to different populations and to improve understanding of sex estimation techniques using bones that are more likely to be preserved in archaeological contexts.

Materials and Methods

Sample composition

The sample used in this study consists of 52 selected individuals from the municipal cemetery of Siracusa (Sicily), housed in the collections of the Museum of Anthropology and Ethnology at the University of Florence (Moggi-Cecchi and Stanyon, 2014). This is a documented collection with known sex and age at death, representing a modern Southern Italian population, with recorded dates of death ranging from the late 1800s to the early months of 1901.

Information on sex and, when available, causes of death were reviewed to exclude individuals with pathological conditions potentially affecting the skeleton. Only individuals who had completed skeletal development were selected. The final sample consisted of 35 males and 17 females, with ages ranging from 19 to 84 years.

Measurements

Osteometric measurements were taken on both the right and left talus and calcaneus, when available. To apply the discriminant function equations developed by Gualdi-Russo (Gualdi-Russo, 2007) and Lee and colleagues (Lee *et al.*, 2012), 8 talus measurements and 3 calcaneus measurements were collected following standard measurements in anthropomety (Martin and Saller, 1914). The measurements and the coding used in this study are reported (Tab. 1).

CODE	MEASUREMENT
T_1	Talus Length
T_1a	Maximum Talus Length
T_2	Talus Width
T_3	Talus Height
T_4	Trochlea Length
T_5	Trochlea Width
T_12	Posterior Articular Facet Width
T_13	Maximum Posterior Articular Facet Width
C_1	Maximum Calcaneus Length
C_2	Calcaneus Width at Midpoint
C_4	Calcaneus Height

Tab. 1. *Measurements used in this study. Measurements from Martin and Saller (1914).*

Application of discriminant function equations

The reference discriminant function equations used in this study were obtained by literature (Gualdi-Russo, 2007; Lee *et al.*, 2012). Gualdi-Russo's equations (GR) were calculated on talus and calcaneus measurements (right and left) of 118 individuals from a Northern Italian population. Lee's equations (L) were developed on left talus measurements of 140 Korean individuals. Both sets of equations used two or more measurements to discriminate sex. For clarity, these equations were coded as shown in (Tab. 2). The equations, which included talus length, were tested with two alternative measures of talus length (T_1 and T_1a), as it is unclear which measurement was used.

EQUATION CODE	MEASUREMENTS USED	REF.
GR_1	T_1L, T_3L	Gualdi-Russo (2007)
GR_1a	T_1aL, T_3L	Gualdi-Russo (2007)
GR_2	T_1R, T_2R	Gualdi-Russo (2007)
GR_2a	T_1aR, T_2R	Gualdi-Russo (2007)
GR_3	T_2R, T_3R, T_1L, T_3L, T_1L, T_2L, T_3L	Gualdi-Russo (2007)
GR_3a	T_2R, T_3R, T_1aL, T_3L, T_3I, T_1aI, T_2I	Gualdi-Russo (2007)
GR_4	T_1L, T_3L, C_1L, C_2L	Gualdi-Russo (2007)
GR_4a	T_1L, T_3L, C_1L, C_2L	Gualdi-Russo (2007)
GR_5	T_1R, T_2R, C_1R	Gualdi-Russo (2007)
GR_5a	T_1aR, T_2R, C_1R	Gualdi-Russo (2007)
GR_6	T_2R, T_1L, C_4R, T_1I, T_2I, T_3I	Gualdi-Russo (2007)
GR_6a	T_2R, T_1aL, C_4R, T_1aI, T_2I, T_3I	Gualdi-Russo (2007)
GR_7	C_1L, C_2L	Gualdi-Russo (2007)
GR_8	C_1R, C_2R, C_4R	Gualdi-Russo (2007)
GR_9	C_2L, C_1R, C_4R, C_2I	Gualdi-Russo (2007)
L_1	T_13L, T_4L	Lee *et al.* (2012)
L_2	T_12L, T_4L	Lee *et al.* (2012)
L_3	T_3L, T_12L	Lee *et al.* (2012)
L_4	T_5L, T_12L	Lee *et al.* (2012)
L_5	T_12L, T_13L	Lee *et al.* (2012)
L_6	T_2L, T_12L	Lee *et al.* (2012)
L_7	T_3L, T_4L, T_12L	Lee *et al.* (2012)
L_8	T_1L, T_2L, T_3L	Lee *et al.* (2012)
L_8a	T_1aL, T_2L, T_3L	Lee *et al.* (2012)

Tab. 2. *Codes of the discriminant function equations tested and the measurements used in each equation. L (left) and R (right) at the end of a measurement code indicate the side from which the measurement was taken.*

Development of new discriminant function equations

New discriminant function equations specific to the analysed sample were also developed. Equations Eq_1 and Eq_2 were developed using the same measures as Gualdi-Russo's GR_8 and GR_9 equations. Equations Eq_3 and Eq_4 were developed using the same measures as Lee's L_4 and L_7 equations. Equations Eq_5 to Eq_10 were developed using measures from equations reported in literature (Peckmann *et al.*, 2015a, b; Ekizoglu *et al.*, 2017). The measures used for each new equation are listed in (Tab. 3).

EQUATION CODE	MEASUREMENTS USED
Eq_1	C_1R, C_2R , C_4R
Eq_2	C_1R, C_4R, C_2L, C_2l
Eq_3	T_5L, T_12L
Eq_4	T_3L, T_4L, T_12L
Eq_5	T_1R, T_2R, T_3R, T_4R, T_5R, T_12R, T_13R
Eq_6	T_1aR, T_2R, T_3R, T_4R, T_5R, T_12R, T_13R
Eq_7	T_1L, T_2L, T_3L, T_4L, T_5L, T_12L, T_13L
Eq_8	T_2R, T_5R, T_12R, T_13R, C_2R
Eq_9	T_2L, T_5L, T_12L, T_13L, C_2L
Eq_10	T_3R, C_4R

Tab. 3. *Codes of the discriminant function equations developed and the measurements used in each equation. L (left) and R (right) at the end of a measurement code indicate the side from which the measurement was taken.*

Statistical Methods

All analyses were performed using R (R Core Team, 2024). To evaluate measurement reproducibility, a random subset of 20 individuals was used for a second set of measurements. Lin's Concordance Correlation Coefficient (Lin, 1989) was calculated for these pairs of measurements to generate a ρ_c value as a repeatability index. This analysis was performed using the epiR package (Stevenson *et al.*, 2025).

For each pair of right and left measurements, an asymmetry index (AI) was calculated as $AI=|R-L| / \min(R, L) \times 100$, where R represents the right measure and L the left measure. Differences between the means of each measurement in male and female samples were evaluated using Welch's t-test.

The obtained measurements were used to discriminate the sex of the 52 individuals through the discriminant function equations. For each equation, a percentage of match was calculated, representing the fraction of individuals correctly identified as male or female. Discriminant function equations, associated statistical parameters, centroids, and sectioning points were obtained using the MASS package (Venables *et al.*, 2002). Each equation was cross-validated on the population itself using the leave-one-out method.

Results

Measurements

Table 4 reports, for each measurement, the ρ_c index obtained from Lin's Concordance Correlation Coefficient calculation and the corresponding confidence interval (Tab. 4). The measures show an overall high repeatability and therefore we used all of them in in subsequent analyses.

The obtained measurements and the asymmetry index (AI) are summarized in (Tab. 5), divided by male and female individuals, and expressed as mean ± standard deviation. The means of the talus and calcaneus measurements were significantly larger in males compared to females ($p < 0.01$).

Regarding the asymmetry indices, no significant differences were found between sexes.

Application of Formulas for Sex Estimation

We applied the discriminant function equations published by Gualdi-Russo (2007) and Lee *et al.* (2012) to our sample.

Table 6 presents the percentages of individuals correctly identified as male or female by each equation, along with the corresponding match rates (Tab. 6). Equations GR_2a and GR_6a yielded the highest (86%) and lowest (17%) match percentages, respectively. Overall, male individuals were more frequently misclassified (average match rate: 51.3%) than females (average: 69.6%) using the GR equations.

A similar trend was observed with the L equations, although the discrepancy was less marked (male average: 77.5%; female average: 80.6%).

MEASUREMENT	ρ_c	LOWER CI 95%	UPPER CI 95%
T_1R	0.98	0.95	0.99
T_1aR	0.96	0.90	0.98
T_2R	0.96	0.91	0.98
T_3R	0.86	0.67	0.94
T_4R	0.93	0.82	0.97
T_5R	0.95	0.89	0.98

T_12R	0.89	0.75	0.96
T_13R	0.99	0.97	0.99
T_1L	0.98	0.96	0.99
T_1aL	0.93	0.83	0.97
T_1R	0.98	0.95	0.99
T_1aR	0.96	0.90	0.98
T_2R	0.96	0.91	0.98
T_3R	0.86	0.67	0.94
T_4R	0.93	0.82	0.97
T_5R	0.95	0.89	0.98
T_12R	0.89	0.75	0.96
T_2L	0.87	0.71	0.94
T_3L	0.90	0.79	0.96
T_4L	0.90	0.77	0.96
T_5L	0.94	0.86	0.98
T_12L	0.78	0.54	0.90
T_13L	0.92	0.82	0.97
C_1R	0.98	0.94	0.99
C_2R	0.95	0.87	0.98
C_4R	0.95	0.89	0.98
C_1L	0.98	0.95	0.99
C_2L	0.94	0.85	0.98
C_4L	0.88	0.74	0.95

Tab. 4. *Lin's Concordance Correlation Coefficient (ρ_c) and confidence interval at 95% obtained for each measurement. Measurements are subdivided into T (Talus) and C (Calcaneus).*

MEASUREMENTS	N	MALES MEAN	sd		N	FEMALES MEAN	sd		M vs F *p*
T_1R	35	52.63	2.69		15	49.27	2.79		**< 0.01**
T_1L	34	52.12	2.53		16	49.25	3.02		**< 0.01**
T_1AI	34	1.88	1.65		15	1.08	1.66		0.13
T_1aR	35	58.17	3.29		15	53.70	2.86		**< 0.01**
T_1aL	34	57.63	2.87		16	53.03	2.97		**< 0.01**
T_1aAI	34	2.11	1.99		15	1.90	1.23		0.663
T_2R	35	40.96	3.17		15	36.63	1.86		**< 0.01**
T_2L	34	40.06	2.23		16	36.38	2.45		**< 0.01**
T_2AI	34	3.17	3.91		15	4.19	4.14		0.424
T_3R	35	29.91	3.08		15	26.70	1.54		**< 0.01**
T_3L	34	28.78	1.88		16	26.13	1.66		**< 0.01**
R_3AI	34	4.59	6.50		15	4.56	3.58		0.982
T_4R	35	33.66	2.45		15	30.80	2.14		**< 0.01**
T_4L	34	32.87	2.21		16	30.00	2.48		**< 0.01**
T_4AI	34	3.80	3.31		15	3.64	3.15		0.868
T_5R	35	31.54	2.22		15	28.50	1.70		**< 0.01**
T_5L	34	30.82	1.56		16	27.97	1.52		**< 0.01**
T_5AI	34	2.97	4.47		15	2.38	2.17		0.536
T_12R	35	32.03	2.06		15	29.13	1.45		**< 0.01**
T_12L	34	32.03	1.99		16	29.13	2.07		**< 0.01**
T_12AI	34	3.79	3.21		15	3.53	4.72		0.852
T_13R	35	21.76	1.37		15	19.97	1.14		**< 0.01**
T_13L	34	21.38	1.50		16	19.91	1.10		**< 0.01**
T_13AI	34	3.15	2.96		15	2.07	2.45		0.194
C_1R	34	77.50	3.87		16	73.34	3.59		**< 0.01**
C_1L	33	77.94	3.72		16	73.69	3.55		**< 0.01**
C_1AI	33	1.90	1.67		16	1.93	1.24		0.957
C_2R	34	40.53	2.41		16	37.28	1.70		**< 0.01**
C_2L	33	40.00	1.94		16	37.47	1.78		**< 0.01**
C_2AI	33	3.36	2.46		16	2.11	2.08		0.0711
C_4R	34	41.85	2.71		16	37.75	2.25		**< 0.01**
C_4L	33	40.77	3.19		16	37.84	2.55		**< 0.01**
C_4AI	33	3.63	4.52		16	3.19	3.13		0.695

Tab. 5. *Mean and standard deviation (in mm) of the measurements and the asymmetry index (AI) for the talus and calcaneus, presented separately for male and female individuals. Statistically significant p-values are shown in bold.*

FORMULA	M%	F%	TOT%
GR_1	32.4%	93.8%	52.0%
GR_1a	79.4%	68.8%	76,0%
GR_2	54.3%	86.7%	64.0%
GR_2a	97.1%	60.0%	86.0%
GR_3	61.7%	6.7%	44.9%
GR_3a	26.5%	26.7%	26.5%
GR_4	36.4%	100%	56.3%
GR_4a	66.7%	80.0%	68.8%
GR_5	52.9%	85.7%	62.5%
GR_5a	91.2%	64.3%	83.3%
GR_6	27.3%	21.4%	25.5%
GR_6a	3.0%	50.0%	17.0%
GR_7	48.5%	100%	65.3%
GR_8	47.1%	100%	64.0%
GR_9	45.5%	100%	63.3%
L_1	76.5%	81.3%	78%
L_2	82.4%	93.8%	84%
L_3	79.4%	81.3%	80%
L_4	82.4%	81.3%	82%
L_5	79.4%	93.8%	82%
L_6	79.4%	81.3%	80%
L_7	88.2%	56.3%	78%
L_8	44.1%	93.8%	60%
L_8a	85.3%	62.5%	78%

Tab. 6. *Percentage of correct identification for each equation tested, for males (M%), females (F%) and the total sample (Tot%).*

Discriminant Function Analysis and new equations

The results of the discriminant function analysis for the newly developed equations are presented, along with the centroids and sectioning points used for sex classification (Tab. 7 and Tab. 8). For each equation, the constant and the unstandardized coefficients associated with each measurement, are reported (Tab. 9).

The accuracies of the equations developed on the analysed population were similar (ranging from 82% to 88%), regardless of the measurements used.

However, they were, on average, higher than those obtained with the GR and L equations. In all cases, the new equations yielded higher identification rates for male individuals compared to females.

	EIGENV.	WILKS' λ	CANONICAL CORRELATION	X^2	d.f.	*p*	C_f	C_m	SECTIONING POINT
Eq_1	0.926	0.584	0.645	22.468	3	< 0.01	-1.207	0.568	-0.639
Eq_2	0.944	0.574	0.653	21.830	4	< 0.01	-1.211	0.587	-0.624
Eq_3	1.087	0.544	0.675	19.647	2	< 0.01	-1.307	0.615	-0.692
Eq_4	0.98	0.570	0.656	13.622	3	< 0.01	-1.241	0.584	-0.657
Eq_5	1.447	0.488	0.715	25.175	7	< 0.01	-1.532	0.657	-0.875
Eq_6	1.280	0.519	0.694	25.950	7	< 0.01	-1.441	0.617	-0.824
Eq_7	1.742	0.427	0.757	25.950	7	< 0.01	-1.655	0.779	-0.876
Eq_8	1.144	0.554	0.668	23.828	5	< 0.01	-1.369	0.564	-0.805
Eq_9	1.194	0.527	0.688	17.609	5	< 0.01	-1.377	0.626	-0.751
Eq_10	0.866	0.621	0.615	22.597	2	< 0.01	-1.191	0.491	-0.7

Tab. 7. *Results of the discriminant function analysis for the newly developed equations, including centroid for females (Cf) and males (Cm) and sectioning points used for sex classification.*

	M ACCURACY (%)	F ACCURACY (%)	TOT ACCURACY (%)	CROSS-VALIDATED ACCURACY (%)
Eq_1	94.1	75	88	88
Eq_2	93.9	75	87.8	83.7
Eq_3	91.2	75	86	86
Eq_4	91.2	62.5	82	82
Eq_5	94.3	80	90	82
Eq_6	91.4	86.7	90	82
Eq_7	94.1	81.3	90	82
Eq_8	91.2	85.7	89.6	83.3
Eq_9	90.9	73.3	85.4	83.3
Eq_10	97.1	71.4	89.6	87.5

Tab. 8. *Accuracy of the newly developed discriminant function equations in classifying males, females and the merged sexes.*

	MEASUREMENTS	UNSTANDARDIZED COEFFICIENTS
Eq_1	C_1R	0.0218
	C_2R	0.231
	C_4R	0.232
	Costant	-20.225378
Eq_2	C_1R	0.0424
	C_4R	0.2176
	C_2L	0.2409
	C_2I	0.1155
	Costant	-21.847058
Eq_3	T_5L	0.4978
	T_12L	0.1738
	Costant	-20.347592
Eq_4	T_3L	0.3465
	T_4L	0.0252
	T_12L	0.2866
	Costant	-19.439848
Eq_5	T_1R	-0.2445
	T_2R	0.0283
	T_3R	0.1532
	T_4R	0.0005
	T_5R	0.3153
	T_12R	0.2705
	T_13R	0.3941
	Costant	-19.472962
Eq_6	T_1aR	-0.0195
	T_2R	0.012
	T_3R	0.0966
	T_4R	-0.0747
	T_5R	0.2603
	T_12R	0.2173
	T_13R	0.3438
	Costant	-21.80785
Eq_7	T_1L	-0.216
	T_2L	0.2068
	T_3L	0.3539
	T_4L	-0.1544
	T_5L	0.4932
	T_12L	0.1683
	T_13L	-0.0876
	Costant	-20.160504

Eq_8	T_2R	-0.0158
	T_5R	0.2346
	T_12R	0.2111
	T_13R	0.2632
	C_2R	0.1063
	Costant	-23.015514
Eq_9	T_2L	0.195
	T_5L	0.4307
	T_12L	0.0808
	T_13L	-0.1355
	C_2L	0.0345
	Costant	-21.561987
Eq_10	T_3R	0.1734
	C_4R	0.2986
	Costant	-17.217905

Tab. 9. *Constant terms and unstandardized coefficients for each measurement included in the newly developed discriminant function equations.*

Discussion

In archaeological and forensic contexts, skeletal remains are rarely complete and are often fragmented in those regions most informative for biological profile reconstruction, such as the skull and pelvis. In contrast, bones like the talus and calcaneus — being smaller and less fragile — tend to better withstand taphonomic processes and are more likely to be preserved than other skeletal elements. Understanding the morphological characteristics of these two bones is thus valuable for identifying unknown skeletal remains and contributing to biological profile construction. Since the seminal work of Steele (1976), several studies have explored the use of the talus and calcaneus for sex estimation, reporting classification accuracies ranging from 87.1% to 96.4%. Among the various methods for sex identification, discriminant function analysis (DFA) is widely employed due to its efficiency and, as a metric approach, for the objectivity and reproducibility of its results. Reported accuracies of DFA using talar and calcaneal measurements range from 83.3% to 96.4%.

This study aims to evaluate the performance of some discriminant function equations for sex estimation based on the talus and calcaneus (Gualdi Russo, 2007; Lee *et al.*, 2012).

In all measurements taken on the talus and calcaneus, sex-linked dimorphism was evident with a high level of significance ($p < 0.01$). Conversely, asymmetry indices did not show significant differences between the sexes ($p > 0.01$). On average, males exhibited larger bone dimensions, which is in agreement with the weight-bearing function of the talus and calcaneus. The lack of non-significant sex-based differences in asymmetry indices is expected, as asymmetry between the right and left limbs is not related to the sex of the individual.

From the application of GR's formulas to the population examined in this paper, average percentages of correct identification of 55.3% emerged. The low accuracy is in agreement with the literature (Gualdi Russo, 2007), highlighting that formulas built on individuals from Northern Italy do not allow for correct sex identification when applied to populations from Southern Italy. The same formulas applied using the maximum talus length (T_1a) provided more accurate results (average 61.1%). However, the identification percentages are much lower than those obtained on the Northern Italian population for which the formulas were developed (average 89.3%). Contrary to the findings in the original study, the discriminant function equations using only calcaneus measurements showed greater efficiency in sex discrimination (64.2%) compared to those from the talus alone (53.6%), and talus and calcaneus together (48.1%). In general, the GR equations were more accurate in identifying females than males, consistent with observations in the original population and the Northern and Southern Italian populations used for cross-validation. This erroneous classification of male individuals compared to females in the Southern Italian population is in agreement with the smaller dimensions of individuals from Southern Italy compared to those from Northern Italy (Gualdi-Russo, 2007; Arcaleni, 2006; Arcaleni, 2012).

From the application of discriminant function equations developed by Lee on a Korean population, it is observed that the average identification percentage obtained on the examined population (80.25%) is slightly lower than that obtained in the original population (81.5%). This degree of accuracy is in line with Lee's work from cross-validation on other populations (Lee *et al.*, 2012). Similarly to the GR formulas, these equations were more accurate in identifying females than males; however, in both the original and the examined populations, this difference was marginal.

The accuracies obtained from the equations developed on the examined population (82%-88%) are higher than those reported in the literature for a Southern Italian sample (76.2%-85%; Introna *et al.*, 1997) and those obtained using the GR and L equations. No differences in discriminatory capacity are observed among equations Eq_1-Eq_2, Eq_3-Eq_4, and Eq_5-Eq_10. Furthermore, accuracy did not differ significantly between equations using only calcaneus measurements (Eq_1 and Eq_2), only talus (Eq_3-Eq_7), or talus and calcaneus combined (Eq_8-Eq_10). Equations Eq_8 and Eq_9 were developed using the same parameters, on the right and left sides respectively; the accuracy obtained is identical. Unlike the results obtained from the GR and L equations, the new equations showed higher accuracy in identifying male individuals.

Overall, all discriminant function equations applied in this work showed higher accuracies when applied to the population on which they were developed. This observation is in agreement with what has already been observed in the literature on works using discriminant function equations (Peckmann *et al.*, 2015a,b).

In the Southern Italian population examined, a higher efficiency in sex estimation was found for equations developed on a Korean population compared to equations developed on a Northern Italian population. This suggests that, in the absence of population-specific equations, the use of formulas developed on populations geographically or genetically close does not always provide the best results. Furthermore, the development of specific equations for the examined population provided reliable results regardless of the bone and measurement combinations used.

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