Shelley L. Smith,[1] *Ph.D.*

Attribution of Foot Bones to Sex and Population Groups*

REFERENCE: Smith SL. Attribution of foot bones to sex and population groups. J Forensic Sci 1997;42(2):186–195.

ABSTRACT: Although cranial and pelvic bones are the preferred skeletal material used by forensic anthropologists to assign unknown individuals to their most probable sex and population (racial) groups, these remains may be unavailable. This paper presents models for classification using metatarsals, proximal pedal phalanges, and the first distal phalanx of the foot. Measurements include lengths and mediolateral and dorsoplantar widths of these foot bones. Four samples of 40 individuals each (black and white males and females) comprise the dataset. Models were developed separately for right and left sides. Three models are provided for each side: a metatarsal model, a proximal phalangeal model, and a combination model involving selected metatarsal and phalangeal measurements. A stepwise discriminant procedure was used for variable selection, with some highly correlated ($r > 0.85$) variables subsequently removed. The metatarsal models correctly assign approximately 77–84% of individuals to their correct sex and population groups; proximal phalangeal models yield correct assignments in 70–72% of cases, and the combination models give correct classifications in 87% of cases. Models exchanging variables selected from one side for corresponding variables on the other show discriminating power ranging from approximately 67–86%. More conservative "jackknife" estimates give correct assignments in 64–82% of cases. When these models are used for classification of sex alone, 86.2–93.7% ("jackknife" range, 84.3–91.2%) of cases are correctly classified; for race alone, 78.6–96.2% ("jackknife" range, 75.5–92.4%).

KEYWORDS: forensic science, forensic anthropology, physical anthropology, human identification, metatarsals, phalanges

Forensic anthropologists are frequently able to determine the sex and population affiliation, or race, of an unknown individual solely from osteological evidence. In doing so, one hopes to have cranial and pelvic material available. However, in the absence of this more reliable material, non-pelvic postcranial bones provide a secondary means of judging probable sex and race. Several models have been developed utilizing a variety of postcranial bones (1).

Footprint or shoeprint lengths are frequently used in a forensic context to estimate stature. Giles and Vallandigham (2) survey previous literature and present new foot length data from U.S. Army databases and new shoeprint (shoe length) data from a sample of male police officers. In a similar vein, Gordon and Buikstra (3) give models to predict stature from foot and combat boot measurements. Less commonly, foot bones themselves are used for height estimation. Byers et al. (4) provide regression equations, derived from a study of the Terry and Maxwell (University of New Mexico) Museum osteological collections, that use metatarsal lengths to estimate stature. They claim that their study is the first to do so..

The potential forensic value of foot bones beyond their use in stature estimation has rarely been examined. An exception is the work of Steele (5), who in 1976 reported that the maximum length of the talus could be used to assign sex correctly to 81% of his Terry Collection sample. In addition, his discriminant function equations attained 79% accuracy using two calcaneal measurements, 83–88% accuracy using different combinations of measurements of the talus, and 89% accuracy using one calcaneal and two talar measurements. Aside from this report, little is known of the potential value of foot bones to distinguish sex or race. Steele's study continues to be a landmark today, and the lead sentence of his article, "To date, few studies have dealt specifically with the problem of structural variations related to sex or race in the bones of the foot" remains true.

The purpose of this paper is to present a series of selected models derived from analyses of metatarsals and pedal phalanges. For cases in which these foot bones are found in association with other bones from an individual, the models can provide additional supporting information relevant to classification. For cases involving only foot bones, the models will help a forensic anthropologist select the most probable sex and race of the individual based on the limited available evidence, provided the measurements selected in one of the models can be determined.

Materials and Methods

Samples

The Terry and Huntington osteological collections of the Smithsonian Museum of Natural History (USNM/NMNH) were sampled for these analyses. Collection dates of Terry individuals range from the 1920s to the 1960s; the Huntington Collection derives from the late 19th and early 20th centuries. Forty individuals of each sex were selected for two racial designations, listed here as "white" and "black." Individuals with complete, or nearly complete, bones of the hands and feet were accepted for inclusion in the sample. (For models derived from analyses of the hand bones, (see (6).). Sampling was not random due to concern with bone condition and presence of bones to be measured. Furthermore, the skeletons in these collections cannot be claimed to be a random sample of the U.S. population of their time. The age ranges of selected individuals are the following: 26–35 years for black males, 21–40 years for black females, 27–50 years for white males, and 22–50 years for white females. Older individuals were accepted for white samples

---

[1] Assistant professor of Anthropology, Department of Sociology and Anthropology, University of Texas at Arlington, Arlington, TX.

*Data collection for this research was funded by a Smithsonian postdoctoral fellowship; portions of this research were presented in a poster session at the 1996 meetings of the American Association of Physical Anthropologists.

Received 27 March 1996; and in revised form 8 May and 12 Aug. 1996; accepted 27 Aug. 1996.

in order to obtain sufficient numbers of individuals; for further details, see (6).

Measurements

A series of length, mediolateral width, and dorsoplantar width measurements were collected from metatarsals (MT) 1 through 5, proximal pedal phalanges (PP) 1 through 5, and the distal hallucal phalanx (DP1). For metatarsals 2–4, one length measurement, interarticular length, was taken. For metatarsals 1 and 5, interarticular and maximum lengths are different; hence two length measurements were taken for these metatarsals. Maximum mediolateral and dorsoplantar base widths were measured for each metatarsal. These widths should be taken at the level of the basal articulations of these bones. Mediolateral and dorsoplantar midshaft widths were measured at the approximate middle of the shaft; on MT 2–4, plantar shaft curvature served as a visual aid. Condyle measurements were taken across the condyles of the metatarsal heads at the point of maximum width. Mediolateral and dorsoplantar maximum widths of the MT heads themselves complete the metatarsal measurements.

Proximal phalangeal measurements include maximum length, interarticular length, maximum mediolateral and dorsoplantar base widths, mediolateral and dorsoplantar midshaft widths (taken at the approximate center of the shaft), and maximum mediolateral and dorsoplantar head widths. For DP1, interarticular and maximum lengths, maximum mediolateral and dorsoplantar base widths, mediolateral and dorsoplantar midshaft widths, and maximum mediolateral and dorsoplantar tuft widths were measured.

Although the measurements used here were devised for my study of these collections, they are generally consistent with previously used techniques for measuring foot bones, where such are described. One standard source is Martin and Saller (7). For those who are interested, I compare my measurements to those listed in this source in the following two paragraphs.

My MT1 interarticular length measurement is similar to Martin's #1, but I used a standard sliding caliper for this (and all other) measurement(s). His lengths for MT2—MT5 (#2) are measured from the middle of the upper border of the proximal joint surface to the highest elevation (apex) of the capitulum. For MT5, the proximal point is presumably at the intersection of the MT4 and cuboid facets, in which case his measure corresponds to mine for interarticular length. For interarticular length of MT2—MT4, my proximal point is taken at the center of the base. This measure *may* be somewhat different from what Martin intended in some cases, but it is consistent with that of other workers, e.g., Byers et al. (4), who follow Martin; my MT5 maximum length is equivalent to the "morphological length" in (4). Martin's #3 corresponds to my MT mediolateral midshaft measurement and his #4 to my MT dorsoplantar midshaft measurement. His #6, base width of MT1, is taken across the proximal epiphysis, which should correspond to my maximum mediolateral base width, because he also describes this as being across the most projecting points. Similarly his #7, height of the MT1 base (straight-line distance from the highest point on the dorsal surface of the base to the top point on the tuberosity of MT1), should correspond to my maximum dorsoplantar base width. His capitulum width of MT1 (#8) corresponds to my maximum mediolateral head width only if his "beiden am meisten seitlich vorragenden" points (most prominent or projecting points on both sides) represent the maximum width. Finally, his #9, height of the MT1 capitulum, will correspond to my maximum dorsoplantar head width as long as the dorsal surface of the capitulum is the most projecting dorsal surface of the head. (Martin does not provide mediolateral and dorsoplantar base and head width measurements for MT2–MT5.)

My interarticular proximal phalanx length corresponds to Martin's #1a (straight-line distance from the center of the trochlea to the center of the joint surface of the base), except that I used sliding rather than spreading calipers. The upper border of the base does not usually prevent placing one caliper point on the center of the base; if it does, and if no shorter distance is obtainable (e.g., as may happen on PP1), then this length would become equivalent to Martin's #1 (straight-line distance from the center of the trochlea to the center of the upper border of the base). Martin's #2 corresponds to my mediolateral midshaft width. Martin's #3 corresponds to my dorsoplantar midshaft width. Martin mentions that #2 and #3 can also be measured on the base and trochlea of the phalanx; these correspond to my maximum mediolateral and dorsoplantar base and head widths. Martin states that measurement #3 (height of the phalangeal corpus) is only measured on the proximal phalanx, but I took this measure on DP1 as well. I also have DP1 measurements corresponding to his 1a and 2.

Because complete or nearly complete sets of selected foot bones were measured, with right and left feet stored separately, identification of side and ray for these bones was relatively straightforward. Middle phalanges and distal phalanges of rays 2–5 were not measured due to their diminutive size and the difficulty of identifying their side and ray position. It is doubtful their inclusion would improve classification success even in cases in which their identification was certain.

In a forensic case in which bones have been scattered, identification of foot bones will present a greater challenge. Metatarsals, the first proximal pedal phalanx (PP1), and the first distal hallucal phalanx (DP1) can be accurately assigned to side and ray even when found unassociated and out of context. Sources such as Bass (8), Steele and Bramblett (9), and White and Folkens (10) are helpful in this regard. Viewed from the plantar aspect, the projection of the base of PP1 will be greater on the side the bone is from; similarly the base of DP1 can be expected to be more developed on the side it is from, and the bone at the base will project down further on the side it is from (i.e., the medial side projects down further) if the articular surface is held straight across, perpendicular to the long axis of the bone. The valgus angle of DP1 and the torsion of this bone are aids to side identification.

Proximal pedal phalanges 2–5 can be expected to form a length series of 2>3>4>5. With the bases aligned in a straight line, the heads of these bones will incline so that the higher end is opposite the side the bone is from (i.e., the slope is upward in the direction of the big toe). As an additional side test for PP2, hold the plantar aspect of the base of the bone flat against a flat surface; the side of the head from which it comes (i.e., the lateral side) will rise off the surface. PP5 is not only comparatively short, but it also is less constricted in its midshaft region. PP3 and PP4 are most difficult to distinguish, and in the absence of one another or other proximal phalanges, it may not be possible to identify them reliably.

Statistical Analyses

Both right and left foot bones were measured for each individual. Models were created separately for right and left feet. This allowed models developed on one side to be tested on the other side (see below). Stepwise discriminant analysis (SPSS/PC+, version 5.0.1) using the Mahalanobis' distance criterion for variable selection was used to select the most useful variables for distinguishing sex and racial groups. (Mahalanobis' distance, symbolized by D^2, measures the "distance" between two groups. To use D^2 as a criterion for variable selection, D^2's are calculated between all possible pairs of groups, and then the variable with the largest D^2 for the two closest groups is chosen (11).). Five types of models were explored: 1) full-foot models including all measured bones, 2) metatarsal models, 3) proximal phalangeal models, 4) models with DP1 added to the proximal phalanges, and 5) combination models including the metatarsals, PP1, and DP1.

The discriminant analysis procedure omits cases with missing data for any variable used. Therefore, a review of such cases was undertaken to minimize the sample size reduction that would otherwise occur. Minimal changes were required for the black samples. For the black male sample, one value for one case was taken from the opposite foot; for the black female sample, one value was substituted from the opposite side for two cases. Because it proved more difficult to construct the white samples, some less than ideal cases were accepted (e.g., with some missing bones, breakage, or local bone conditions not sufficient to result in rejection of the case as pathological). One white male case has an omitted brachydactylous PP1. For white males 15 cases required some substitution with measurements from corresponding opposite foot values (1–4 variables for 8 cases, 8 variables for 4 cases, and 6, 10, and 14 variables for one case each). For white females, 19 cases required substitutions (1–3 variables for 11 cases, 8 variables for 3 cases, and 5, 10, 11, 12, and 16 variables for one case each). In addition, for two of these white female cases, although one value in one case and eight in another were substituted from the opposite side, those opposite sides had excessive missing data elsewhere and were allowed to drop from some analyses.

Three steps were taken to simplify the models. First, to reduce the number of variables, the minimum probability of F-to-enter and the maximum probability of F a variable is allowed to have before removal were both set at $p = 0.05$. The default values of F-to-enter and F-to-remove (which represent the F values associated with the changes in Wilks' lambda accompanying variable addition or removal) are fixed, set at 1.0. That is, F-to-enter must be at least 1.0 for a variable to be entered, or selected, and F-to-remove must be greater than 1.0 to avoid variable removal, or deletion. No default values are set for the *probabilities* of F-to-enter and F-to-remove (11). Setting these probabilities at $p = 0.05$ will simplify the models by reducing the number of variables that can pass these criteria and thus be selected. (The primary method of variable selection was Mahalanobis' D^2; addition of these probabilities provided an extra "statistical hoop.") Second, all models were limited to two functions. Third, choices among highly correlated variables ($r > 0.85$) were made for all models presented here other than the metatarsal models, the latter showing no correlations among selected variables that reached this level.

Two tests of the final models were conducted. First, the models have been applied "in reverse." That is, models developed from right foot bone measurements were used to classify bones from the left foot, and vice versa. A model generated with data from one side should be capable of discriminating well on the other side. Although in a large proportion of white sample cases values from one side have been substituted with those from the other, application "in reverse" does give some indication of ability of the variables to discriminate among the groups when measurement values differ from the original data used to derive the models.

A more conventional test used to give less biased classification estimates is the jackknife. Although this procedure is not available in SPSS/PC+, a macro is available from SPSS that will perform a procedure very similar to a jackknife. This U-method, or leaving-one-out method, provides slightly more conservative estimates than a conventional jackknife. I used this macro (compatible with SPSS version 4.1, CMS) to obtain the "jackknife" figures presented here.

It has become standard to test for equality of group covariance matrices using Box's M test. Of the final six 4-group models, one shows borderline significantly different covariance matrices (left foot PP; $p = 0.0498$). Linear discriminant analysis is fairly robust even when the assumption of equal covariance matrices is violated, and good classification results are a positive sign that this violation is not detrimental (12). The left foot PP model does, however, have the least impressive results of the six.

Results

Of the five types of models initially explored, two were omitted. The full-foot models were judged to be too cumbersome to be of practical value. These models would involve taking 18 (left foot) or 24 (right foot) measurements. I decided to limit presented models to those that would have 15 or fewer variables remaining after highly correlated variables were removed.

The PP + DP1 models were also omitted. The right-sided model would contain 18 variables. The left-sided model would contain only 11 variables, but its 2-function success in classification (based on 12 variables) was the same as that for the left proximal phalanges without DP1 (based on 10 variables), and thus because no advantage appeared to be gained by the addition of DP1, this model was not further pursued.

Three types of models thus remain—the metatarsal, proximal phalangeal, and combination (MT + PP1 + DP1) models—and these models are presented here for both feet (Tables 1–6) along with all-groups scatterplots for the left foot models (Figs. 1–3).

The 4-group classification percentages for models applied "in reverse" are the following:

Left foot MT model used on right foot—79.87%
Right foot MT model used on left foot—79.38%
Left foot PP model used on right foot—67.30%
Right foot PP model used on left foot—74.21%
Left foot MT + PP1 + DP1 model used on right foot—86.16%
Right foot MT + PP1 + DP1 model used on left foot—83.02%

Tables 1–6 give the percentages of correctly classified cases based on two functions. The 3-function success rates are listed in parentheses beside the "jackknife" values because the SPSS macro is not easily modified from the default (3 functions for 4 groups), and therefore the "jackknife" figures are best compared with these rates.

To use Tables 1–6 to assign a sex and race to an unknown case (with "white" or "black" being the presumed choices for race), compute a score for both Function 1 and Function 2 by obtaining the sum of the value for each variable multiplied by its unstandardized coefficient, plus the constant. That is, obtain a function score, F, for each function, where

$$F = m_1c_1 + m_2c_2 \cdots + m_nc_n + C$$

$m_1 \cdots m_n$ are measurements 1 to n for the function variables

$c_1 \cdots c_n$ are the unstandardized coefficients 1 to n for the function variables.

TABLE 1—*Left foot metatarsals.*

	Eigenvalue	% Variance	Canonical Correlation
F1	2.24	68.80	0.83
F2	0.88	26.93	0.68

Centroids	BM	BF	WM	WF
F1	2.32	−0.52	−0.05	−1.76
F2	−0.26	−1.13	1.44	−0.05

Coefficients	Unstand	Str	Unstand	Str
Variable	F1		F2	
LFMT1DPH	−0.0770	0.59	0.5618	0.64
LFMT2IAL	0.0632	0.78	−0.1860	−0.19
LFMT2MLB	0.1123	0.74	0.3464	0.37
LFMT3MLB	0.6292	0.90	−0.0587	0.16
LFMT3DPH	0.1891	0.72	0.4979	0.51
LFMT4DPM	0.5841	0.86	−0.6680	−0.11
LFMT5MLM	0.1383	0.69	0.1304	0.18
LFMT5CON	−0.3867	0.35	0.2462	0.34
Constant	−18.6508		−6.5163	

76.88% Correctly Classified; N = 160
(77.50%, 3 functions; 75.00%, "jackknife")

NOTE—F1 = Function 1, F2 = Function 2; BM = black males; BF = black females; WM = white males; WF = white females; LFMT = left foot metatarsal; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; CON = condyles; Unstand = unstandardized; Str = structure.

TABLE 2—*Right foot metatarsals.*

	Eigenvalue	% Variance	Canonical Correlation
F1	2.37	64.73	0.84
F2	1.22	33.29	0.74

Centroids	BM	BF	WM	WF
F1	2.26	0.39	−0.86	−1.80
F2	0.42	−1.43	1.51	−0.50

Coefficients	Unstand	Str	Unstand	Str
Variable	F1		F2	
RFMT1DPB	0.1097	0.50	0.2297	0.69
RFMT1MLM	0.4442	0.67	−0.1383	0.46
RFMT1DPM	−0.5379	0.39	−0.0842	0.59
RFMT1DPH	−0.2425	0.34	0.6277	0.81
RFMT3IAL	0.1237	0.76	−0.0956	0.16
RFMT3MLB	0.3369	0.65	0.3508	0.57
RFMT4DPM	0.8281	0.87	−0.5104	0.16
RFMT4DPH	−0.0844	0.48	0.5378	0.77
RFMT5CON	−0.4407	0.07	0.0735	0.53
Constant	−12.0200		−17.3356	

83.75% Correctly Classified; N = 160
(85.63%, 3 functions; 80.63%, "jackknife")

NOTE—F1 = Function 1, F2 = Function 2; BM = black males; BF = black females; WM = white males; WF = white females; RFMT = right foot metatarsal; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; CON = condyles; Unstand = unstandardized; Str = structure.

TABLE 3—*Left foot proximal phalanges.*

	Eigenvalue	% Variance	Canonical Correlation
F1	1.35	61.19	0.76
F2	0.78	35.42	0.66

Centroids	BM	BF	WM	WF
F1	1.18	−1.13	1.09	−1.17
F2	1.03	0.65	−1.08	−0.61

Coefficients	Unstand	Str	Unstand	Str
Variable	F1		F2	
LFPP1IAL	−0.1456	0.52	0.3586	0.52
LFPP1MLB	0.2282	0.75	−0.6302	0.20
LFPP1DPB	−0.1746	0.58	0.8903	0.53
LFPP1MLH	0.3193	0.80	0.2637	0.32
LFPP1DPH	0.0553	0.70	−0.6769	0.02
LFPP3MLB	−0.4631	0.61	0.7986	0.37
LFPP3DPB	0.7632	0.83	−0.8961	0.08
LFPP4IAL	0.3598	0.73	−0.1988	0.22
LFPP5MLM	0.6198	0.68	0.1451	0.13
Constant	−17.4099		−5.9605	

69.81% Correctly Classified; N = 159
(71.07%, 3 functions; 64.15%, "jackknife")

NOTE—F1 = Function 1; F2 = Function 2; BM = black males; BF = black females; WM = white males; WF = white females; LFPP = left foot proximal phalanx; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; Unstand = unstandardized; Str = structure.

Using these function scores, a Mahalanobis' distance (D^2) from each group centroid can then be calculated by obtaining the sum of the square of the differences between the function scores for the unknown case and the respective function scores of the centroids for each group. That is,

$$D_i^2 = (X_{i1} - F_1)^2 + (X_{i2} - F_2)^2, \quad \text{where}$$

F_1 = Function 1 score,

F_2 = Function 2 score,

i = group i,

X_{i1} = the centroid for group i on Function 1, and

X_{i2} = the centroid for group i on Function 2.

The case in question can then be assigned to the group from which it has the smallest D^2. (Assign the unknown case to the group i with the smallest D_i^2.)

It is in addition useful to know the posterior probability (the probability a case belongs to a group given its score or D^2) associated with membership in each group, because this provides a sense of how likely the group assignment is. The posterior probability of membership in each group i can be obtained using the following equation (from (13)):

$$P_i = \frac{\exp(-0.5 \times D_i^2)}{\sum_{i=1}^{g} \exp(-0.5 \times D_i^2)}, \quad \text{where}$$

TABLE 4—*Right foot proximal phalanges.*

	Eigenvalue	% Variance		Canonical Correlation
F1	1.62	53.33		0.79
F2	1.13	37.13		0.73
	Centroids			
	BM	BF	WM	WF
F1	1.88	−0.84	0.34	−1.41
F2	−0.76	−0.90	1.72	−0.06
	Coefficients			
	Unstand	Str	Unstand	Str
Variable	F1		F2	
RFPP1IAL	0.0812	0.71	−0.1953	−0.12
RFPP1MLB	−0.0886	0.74	0.0515	0.14
RFPP1DPB	0.2638	0.75	−0.8692	−0.18
RFPP1MLH	0.4223	0.84	0.3606	0.15
RFPP1DPH	−0.2103	0.60	0.9015	0.30
RFPP2IAL	−0.1191	0.68	0.2263	0.01
RFPP2DPB	0.2763	0.73	0.1580	0.15
RFPP3MLB	−0.0609	0.63	−0.8860	−0.05
RFPP3MLM	0.4240	0.62	−0.1382	0.09
RFPP3DPM	0.4083	0.57	0.9790	0.45
RFPP4MLH	−0.1519	0.69	−0.8513	−0.03
RFPP5MXL	0.4186	0.73	−0.2100	0.06
RFPP5MLB	−0.3485	0.58	1.0929	0.23
RFPP5MLM	0.5110	0.59	0.4401	0.37
RFPP5DPM	−0.8019	0.31	0.2817	0.45
Constant	−16.8414		−2.6916	

71.70% Correctly Classified; N = 159
(83.02%, 3 functions; 70.44%, "jackknife")

NOTE—F1 = Function 1; F2 = Function 2; BM = black males; BF = black females; WM = white males; WF = white females; RFPP = right foot proximal phalanx; IAL = interarticular length; MXL = maximum length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; Unstand = unstandardized; Str = structure.

TABLE 5—*Left foot metatarsals, proximal phalanx 1, and distal phalanx 1.*

	Eigenvalue	% Variance		Canonical Correlation
F1	2.58	62.95		0.85
F2	1.34	32.63		0.76
	Centroids			
	BM	BF	WM	WF
F1	2.36	−0.73	0.28	−1.97
F2	−0.51	−1.37	1.74	0.15
	Coefficients			
	Unstand	Str	Unstand	Str
Variable	F1		F2	
LFMT1DPH	0.0230	0.63	0.4333	0.50
LFMT2MLB	0.1142	0.74	0.3554	0.24
LFMT3MLB	0.5332	0.89	−0.2581	0.02
LFMT3DPH	0.2835	0.75	0.4061	0.36
LFMT4IAL	0.0051	0.72	−0.1798	−0.25
LFMT4DPM	0.5938	0.82	−0.4996	−0.21
LFMT4CON	−0.4337	0.48	0.3659	0.25
LFMT5MLM	0.1752	0.70	0.1028	0.07
LFPP1DPB	0.0443	0.66	−0.5112	−0.09
LFDP1IAL	0.0652	0.55	0.1686	0.40
LFDP1DPB	0.2678	0.65	0.4914	0.46
LFDP1DPT	−0.4431	−0.03	−0.0055	0.32
Constant	−18.3162		−4.6656	

87.42% Correctly Classified; N = 159
(86.16%, 3 functions; 79.25%, "jackknife")

NOTE—F1 = Function 1; F2 = Function 2; BM = black males; BF = black females; WM = white males; WF = white females; LFMT = left foot metatarsal; LFPP = left foot proximal phalanx; LFDP = left foot distal phalanx; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; T = tuft; CON = condyles; Unstand = unstandardized; Str = structure.

g = the number of groups and

exp = exponential.

(See (13) for a worked example including D^2 and posterior probability calculations.)

Variable selection for these models was done for the 4-group case; that is, variables that would best assign individuals to both their correct sex and their correct race simultaneously were selected for inclusion in the models. As would be predicted, when used to decide only between male and female or only between "black" and "white," the models perform better (Tables 7–12). The sole exception occurs with the right foot PP model *if* 3 functions are used in 4-group discrimination. In that case, 83.0% of individuals are correctly classified compared with 82.4% of individuals classified by race alone. However, the 3-function "jackknife" of 70.4% is considerably below the 79.9% "jackknife" for race classification accuracy. (The large difference between the 2-function and 3-function percentages is associated with the 9.54% of the variance attributable to the third function in this model. For all other non-"reverse" models here, this figure is below 5%; the highest percentage for a "reverse" model is the 5.17% obtained when the right foot PP variables are applied to the left foot.)

It would further be expected that classification success for sex would exceed that for race. This expectation does not hold for the right foot MT model; classification for race is better by 5% (6.25% based on "jackknife" figures). The slightly better classification success for race of the right foot combination model is likely due to the contribution of the right foot MT as well. This finding is intriguing given that variables selected for a right hand metacarpal model (6) also produce better classification by race than by sex.

For the 4-group analyses, the simplest expectation would be that the first function would separate the sexes, based largely on size differences, and the second function would serve mainly to differentiate groups through shape differences. The actual situation appears somewhat more complex.

One way to see this is to examine what are called the structure coefficients, which are the correlations between the variables and function scores. (These are given in the tables beside the unstandardized coefficients.) The total structure coefficients, or correlations, show the relationships between the variables and functions *across* groups; they therefore indicate patterns of group differentiation (12,13). (SPSS does not provide these total structure coefficients as direct output, but they can be obtained indirectly through saving the discriminant scores as new variables and then correlating them with the original variables.)

In the 4-group left foot metatarsal model, the highest correlations with Function 1 are for MT3MLB (0.90) and MT4DPM (0.86). A comparison with the 2-group MT models shows that while MT3MLB has the third highest correlation (0.83) with the function for sex, MT4DPM has the best correlation (0.68) with the race function. Furthermore, the variables with the two highest correlations with Function 2 in the 4-group model (0.64 for MT1DPH

TABLE 6—*Right foot metatarsals, proximal phalanx 1, and distal phalanx 1.*

	Eigenvalue	% Variance	Canonical Correlation
Fl	2.71	56.13	0.85
F2	1.95	40.44	0.81

Centroids	BM	BF	WM	WF
Fl	2.35	0.56	−1.08	−1.88
F2	0.56	−1.61	1.95	−0.92

	Coefficients			
	Unstand	Str	Unstand	Str
Variable	Fl		F2	
RFMT1DPB	0.0550	0.44	0.2412	0.65
RFMT1MLM	0.4142	0.62	−0.1113	0.47
RFMT1DPM	−0.4587	0.34	−0.1682	0.55
RFMT1DPH	−0.2967	0.27	0.5487	0.76
RFMT2IAL	0.1392	0.74	−0.1059	0.22
RFMT2CON	−0.3256	0.30	0.0970	0.34
RFMT4DPM	1.0446	0.84	−0.3614	0.21
RFMT4DPH	−0.0178	0.41	0.4735	0.73
RFMT5MLM	−0.1302	0.47	0.3034	0.43
RFPP1DPB	0.2759	0.62	−0.4842	0.33
RFPP1MLM	−0.2161	0.42	0.3431	0.62
RFDP1IAL	−0.0256	0.23	0.1231	0.61
RFDP1DPB	0.1927	0.35	0.6085	0.70
RFDP1DPT	−0.3678	−0.17	−0.5226	0.16
Constant	−9.9272		−14.9326	

87.42% Correctly Classified; N = 159
(89.94%, 3 functions; 82.39%, "jackknife")

NOTE—Fl = Function 1; F2 = Function 2; BM = black males; BF = black females; WM = white males; WF = white females; RFMT = right foot metatarsal; RFPP = right foot proximal phalanx; RFDP = right foot distal phalanx; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; T = tuft; CON = condyles; Unstand = unstandardized; Str = structure.

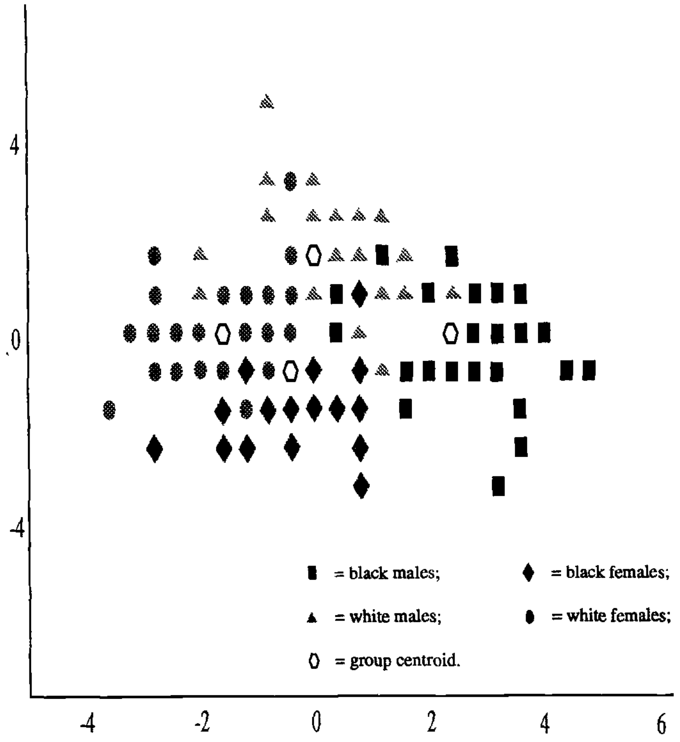

FIG. 1—*Left foot metatarsals.*

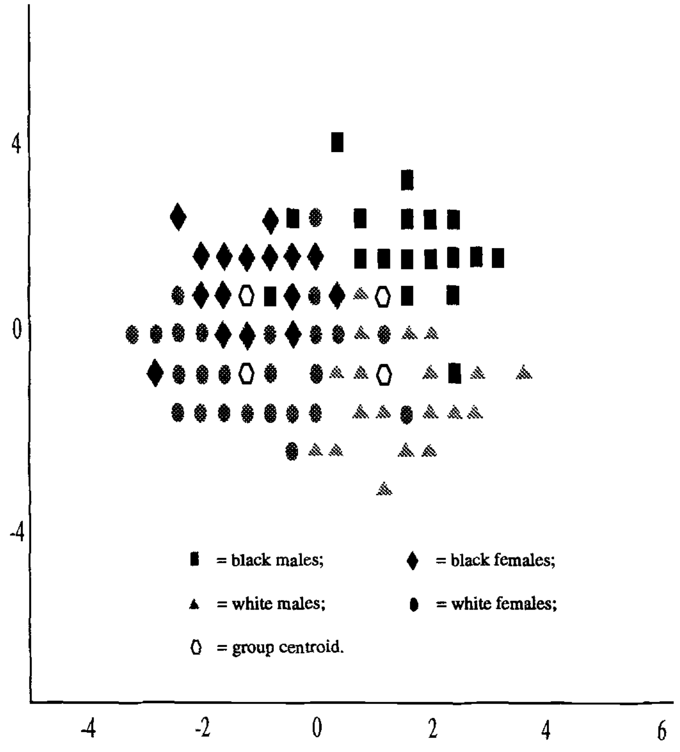

FIG. 2—*Left foot proximal phalanges.*

and 0.51 for MT3DPH) are also those with the two highest correlations with the 2-group function for sex (0.89 for MT3DPH and 0.84 for MT1DPH). An examination of the right foot MT models shows that the variables with the highest correlations with *Function 1* in the 4-group model (0.87 for MT4DPM and 0.76 for MT3IAL) also have the highest correlations with the *race* function in the 2-group model (0.72 for MT4DPM and 0.60 for MT3IAL), while those variables showing the highest correlations with *Function 2* in the 4-group model (0.81 for MT1DPH and 0.77 for MT4DPH) also show the highest correlations with the *sex* function in the 2-group model (0.90 for MT4DPH and 0.87 for MT1DPH). When it is recalled that classification for race is better than that for sex using the right foot metatarsal model, it can be seen that these results are internally consistent. That is, Function 1 does more to separate races than sexes and Function 2 does the opposite. Therefore variables which perform well on the race function in the 2-group model would be expected to have high correlations with Function 1 in the 4-group model, while variables which perform well on the sex function in the 2-group model would be expected to have high correlations with Function 2 in the 4-group model. This is in fact the case (see Tables 2 and 8).

The 4-group left foot proximal phalangeal model presents a straightforward case of size/sex first and shape/race second: The variables with the highest correlations with Function 1 are also the best for sex-only discrimination, and those with the highest

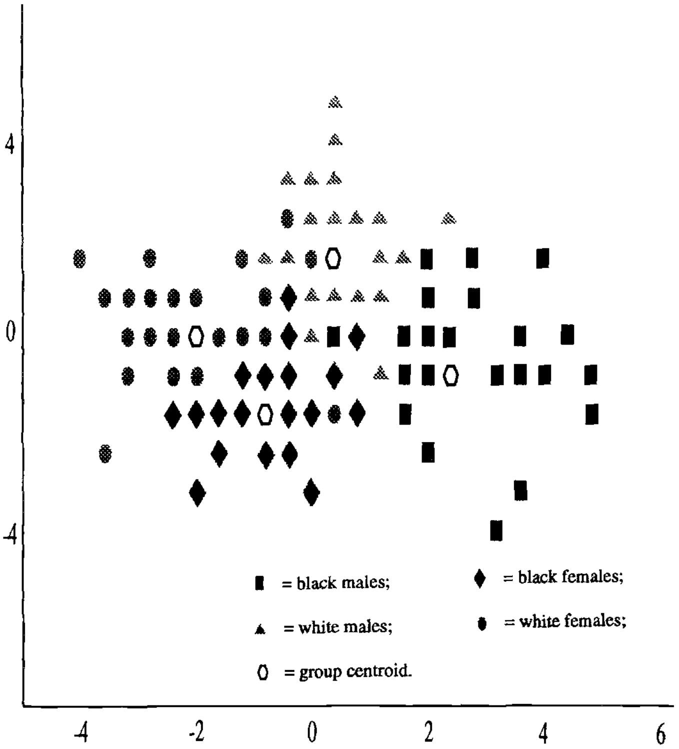

FIG. 3—*Left foot metatarsals, proximal phalanx 1, and distal phalanx 1.*

TABLE 7—*Left foot metatarsals; 2-group analyses.*

Sex		Race	
Eigenvalue	Canonical Correlation	Eigenvalue	Canonical Correlation
1.50	0.77	1.13	0.73
Male Centroid 1.22	Female Centroid −1.22	Black Centroid 1.05	White Centroid −1.05

	Coefficients			
	Sex		Race	
Variable	Unstand	Str	Unstand	Str
LFMT1DPH	0.2988	0.84	−0.5413	−0.06
LFMT2IAL	−0.0764	0.54	0.1710	0.67
LFMT2MLB	0.2885	0.81	−0.3156	0.21
LFMT3MLB	0.4171	0.83	0.3818	0.52
LFMT3DPH	0.4892	0.89	−0.1158	0.17
LFMT4DPM	−0.0129	0.65	0.8239	0.68
LFMT5MLM	0.2075	0.68	0.1067	0.40
LFMT5CON	−0.1204	0.48	−0.4020	0.02
Constant	−17.7980		−5.2804	
	91.25% Correctly Classified; N = 160 (89.38%, "jackknife")		83.13% Correctly Classified; N = 160 (82.50%, "jackknife")	

NOTE—LFMT = left foot metatarsal; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; CON = condyles; Unstand = unstandardized; Str = structure.

TABLE 8—*Right foot metatarsals; 2-group analyses.*

Sex		Race	
Eigenvalue	Canonical Correlation	Eigenvalue	Canonical Correlation
1.39	0.76	1.90	0.81
Male Centroid 1.17	Female Centroid −1.17	Black Centroid 1.37	White Centroid −1.37

	Coefficients			
	Sex		Race	
Variable	Unstand	Str	Unstand	Str
RFMT1DPB	0.2439	0.85	−0.0619	0.14
RFMT1MLM	0.0803	0.74	0.5003	0.42
RFMT1DPM	−0.3076	0.70	−0.4143	0.10
RFMT1DPH	0.4567	0.87	−0.5247	−0.04
RFMT3IAL	−0.0345	0.52	0.1433	0.60
RFMT3MLB	0.4724	0.82	0.1651	0.36
RFMT4DPM	−0.1097	0.59	0.9158	0.72
RFMT4DPH	0.4514	0.90	−0.3156	0.11
RFMT5CON	−0.1260	0.49	−0.4181	−0.16
Constant	−20.6137		−1.0441	
	88.75% Correctly Classified; N = 160 (85.63%, "jackknife")		93.75% Correctly Classified; N = 160 (91.88%, "jackknife")	

NOTE—RFMT = right foot metatarsal; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; CON = condyles; Unstand = unstandardized; Str = structure.

TABLE 9—*Left foot proximal phalanges; 2-group analyses.*

Sex		Race	
Eigenvalue	Canonical Correlation	Eigenvalue	Canonical Correlation
1.34	0.76	0.71	0.64
Male Centroid 1.15	Female Centroid −1.16	Black Centroid 0.83	White Centroid −0.84

	Coefficients			
	Sex		Race	
Variable	Unstand	Str	Unstand	Str
LFPP1IAL	−0.1565	0.51	0.3809	0.53
LFPP1MLB	0.2471	0.74	−0.6661	0.20
LFPP1DPB	−0.2021	0.57	0.8430	0.53
LFPP1MLH	0.3128	0.79	0.2192	0.31
LFPP1DPH	0.0759	0.69	−0.6308	0.03
LFPP3MLB	−0.4882	0.60	0.8398	0.39
LFPP3DPB	0.7951	0.83	−0.7928	0.11
LFPP4IAL	0.3668	0.73	−0.2448	0.21
LFPP5MLM	0.6215	0.68	0.2981	0.20
Constant	−17.3389		−6.1681	
	88.05% Correctly Classified; N = 159 (86.16%, "jackknife")		78.62% Correctly Classified; N = 159 (75.47%, "jackknife")	

NOTE—LFPP = left foot proximal phalanx; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; Unstand = unstandardized; Str = structure.

TABLE 10—*Right foot proximal phalanges; 2-group analyses.*

Sex		Race	
Eigenvalue	Canonical Correlation	Eigenvalue	Canonical Correlation
1.49	0.77	0.95	0.70
Male Centroid 1.21	Female Centroid −1.22	Black Centroid 0.96	White Centroid −0.97

Variable	Coefficients Sex Unstand	Sex Str	Race Unstand	Race Str
RFPP1IAL	−0.0221	0.59	0.2333	0.46
RFPP1MLB	−0.0465	0.73	−0.3457	0.18
RFPP1DPB	−0.1834	0.60	0.9473	0.51
RFPP1MLH	0.5436	0.82	−0.0809	0.27
RFPP1DPH	0.2394	0.68	−0.7076	0.03
RFPP2IAL	−0.0022	0.62	−0.0725	0.35
RFPP2DPB	0.3318	0.72	−0.4683	0.17
RFPP3MLB	−0.4823	0.54	0.9677	0.38
RFPP3MLM	0.3051	0.60	0.4345	0.30
RFPP3DPM	0.8285	0.71	−0.7170	−0.13
RFPP4MLH	−0.5285	0.60	0.2576	0.31
RFPP5MXL	0.2743	0.68	0.1980	0.29
RFPP5MLB	0.2052	0.62	−0.8145	0.10
RFPP5MLM	0.6581	0.69	−0.0461	0.03
RFPP5DPM	−0.5863	0.47	−0.1522	−0.16
Constant	−16.1461		−5.5060	
	86.16% Correctly Classified; N = 159 (84.28%, "jackknife")		82.39% Correctly Classified; N = 159 (79.87%, "jackknife")	

NOTE—RFPP = right foot proximal phalanx; IAL = interarticular length; MXL = maximum length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; Unstand = unstandardized; Str = structure.

TABLE 11—*Left foot metatarsals, proximal phalanx 1, and distal phalanx 1; 2-group analyses.*

Sex		Race	
Eigenvalue	Canonical Correlation	Eigenvalue	Canonical Correlation
2.09	0.82	1.46	0.77
Male Centroid 1.43	Female Centroid −1.45	Black Centroid 1.19	White Centroid −1.21

Variable	Coefficients Sex Unstand	Sex Str	Race Unstand	Race Str
LFMT1DPH	0.2619	0.79	−0.4041	−0.06
LFMT2MLB	0.2844	0.76	−0.3482	0.19
LFMT3MLB	0.2812	0.78	0.4498	0.49
LFMT3DPH	0.4781	0.84	−0.0947	0.15
LFMT4IAL	−0.0992	0.50	0.1559	0.61
LFMT4DPM	0.1904	0.61	0.6761	0.63
LFMT4CON	−0.1439	0.54	−0.5373	0.07
LFMT5MLM	0.2162	0.64	0.1147	0.38
LFPP1DPB	−0.2612	0.53	0.4300	0.44
LFDP1IAL	0.1466	0.67	−0.1386	−0.04
LFDP1DPB	0.5127	0.80	−0.1877	0.01
LFDP1DPT	−0.3653	0.13	−0.2275	−0.30
Constant	−17.4932		−4.3717	
	93.71% Correctly Classified; N = 159 (91.19%, "jackknife")		89.94% Correctly Classified; N = 159 (84.28%, "jackknife")	

NOTE—LFMT = left foot metatarsal; LFPP = left foot proximal phalanx; LFDP = left foot distal phalanx; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; T = tuft; CON = condyles; Unstand = unstandardized; Str = structure.

correlations with Function 2 are the best for race-only discrimination (4-group Function 1, 0.83 for PP3DPB and 0.80 for PP1MLH; 4-group Function 2, 0.53 for PP1DPB and 0.52 for PP1IAL; 2-group for sex, 0.83 for PP3DPB and 0.79 for PP1MLH; 2-group for race, 0.53 for PP1IAL and for PP1DPB). On the right foot, the variables with the first and third highest correlations with Function 1 in the 4-group model (0.84 for PP1MLH and 0.74 for PP1MLB) correlate the best with the sex-only function (0.82 and 0.73, respectively). However, the variable with the best correlation with the race-only function is PP1DPB (0.51), which is also the variable with the second best correlation (0.75) *with Function 1* in the 4-group model.

The combination models show a pattern similar to the metatarsal models, not unexpectedly because metatarsal variables predominate. On the left, MT3MLB has the highest correlation (0.89) with Function 1 in the 4-group model and the fourth highest correlation with the sex-only function (0.78), but MT4DPM, with the second highest correlation with Function 1 in the 4-group case (0.82) has the highest correlation (0.63) with the race-only function. The two highest correlations with Function 2 in the 4-group analysis, 0.50 for MT1DPH and 0.46 for DP1DPB, are also prominent in the sex-only function (3rd highest at 0.79 and 2nd highest at 0.80, respectively). On the right, the variables with the two highest correlations with Function 1 in the 4-group case are also those with the two highest correlations with the race-only function, and the variables with the two highest correlations with Function 2 in the 4-group case are also those with the two highest correlations with the sex-only function (4-group Function 1, 0.84 for MT4DPM and 0.74 for MT2IAL; 4-group Function 2, 0.76 for MT1DPH and 0.73 for MT4DPH; 2-group for sex, 0.84 for MT4DPH and 0.81 for MT1DPH; 2-group for race, 0.69 for MT4DPM and 0.58 for MT2IAL).

Given the complications in interpreting the 4-group models, we can turn to the 2-group analyses to see more easily the kinds of variables likely to be most useful in separating the sexes and different groups of only one sex, keeping in mind that the original variable choices were made for the purpose of distinguishing both sex and race simultaneously and therefore the sole-function models are constrained to work with these selected variables. In all six cases, the variables having the two highest correlations with the functions distinguishing sex alone involve head and base widths. In contrast, the best correlations with race-only functions are midshaft widths and lengths for the metatarsal and combination models and base widths and lengths for the proximal phalangeal models. This suggests, reasonably enough, that joint robusticity is important in male-female separation whereas overall length to width proportional differences are more critical for group differentiation within one sex.

Discussion and Conclusions

If all the bones in one of the combination models or the right foot metatarsal model are present, the use of one of these models will produce the highest probability of correct classification in 4-group discrimination or 2-group discrimination for race. For

TABLE 12—*Right foot metatarsals; proximal phalanx 1, and distal phalanx 1; 2-group analyses.*

Sex		Race	
Eigenvalue	Canonical Correlation	Eigenvalue	Canonical Correlation
2.03	0.82	2.32	0.84
Male Centroid	Female Centroid	Black Centroid	White Centroid
1.41	−1.42	1.50	−1.52

	Coefficients			
	Sex		Race	
Variable	Unstand	Str	Unstand	Str
RFMT1DPB	0.2591	0.79	−0.0959	0.13
RFMT1MLM	0.0304	0.69	0.4806	0.40
RFMT1DPM	−0.3258	0.65	−0.3443	0.09
RFMT1DPH	0.4042	0.81	−0.4975	−0.05
RFMT2IAL	−0.0442	0.51	0.1574	0.58
RFMT2CON	−0.0182	0.44	−0.3709	0.12
RFMT4DPM	0.0619	0.54	1.0407	0.69
RFMT4DPH	0.4325	0.84	−0.2014	0.09
RFMT5MLM	0.2020	0.58	−0.1300	0.30
RFPP1DPB	−0.3296	0.57	0.3778	0.43
RFPP1MLM	0.2282	0.73	−0.2940	0.16
RFDP1IAL	0.1086	0.66	−0.0841	−0.03
RFDP1DPB	0.6224	0.79	−0.0209	0.05
RFDP1DPT	−0.6053	0.09	−0.1765	−0.24
Constant	−18.0987		−1.0899	
	93.71% Correctly Classified; N = 159 (90.57%, "jackknife")		96.23% Correctly Classified; N = 159 (92.45%, "jackknife")	

NOTE—RFMT = right foot metatarsal; RFPP = right foot proximal phalanx; RFDP = right foot distal phalanx; IAL = interarticular length; ML = mediolateral; DP = dorsoplantar; B = base; M = middle; H = head; T = tuft; CON = condyles; Unstand = unstandardized; Str = structure.

discrimination by sex alone, the left foot MT model performs somewhat better than does the right foot MT model.

The left foot combination model, with 12 variables, and the right foot combination model, with 14 variables, have the same percentage of correctly classified cases in the 4-group analyses (87.4%) and in the analyses by sex (93.7%). For classification by race, the right foot combination model performs the best of all the models presented here (96.2%), but the left foot model is less accurate (89.9%).

The metatarsal models show moderate success in 4-group analyses. The left-sided model, using 8 variables, correctly assigns 76.9% of individuals. Using 9 variables, the right MT model yields a somewhat better result (83.8%). These models achieve over 90% correct for sex classification on the left (91.2%) and race classification on the right (93.8%). Sex classification using the right-sided model is also quite good, at 88.8%; race classification using the left-sided model, at 83.1%, is for these data comparable to what was achieved using the right side in the 4-group case.

The proximal phalangeal models are the least impressive of the three forms of models, yet it is surprising they perform as well as they do, particularly in the 2-group analyses. The left-sided model, with 9 variables, gives in the 4-group classification the poorest result reported here (69.8%); the right-sided model uses 15 variables and hardly does better (71.7%). However, in 2-group discrimination the results are sufficiently good (88.0% and 86.2% for sex and 78.6% and 82.4% for race, for left and right, respectively) that in the absence of other evidence they are of some use.

For 4-group models the reported "jackknife" values are directly comparable to the 3-function (default) classification scores rather than the 2-function percentages discussed above. However, with the exception of the right foot PP model, classification success does not change greatly when the models are limited to 2 functions. Thus the "jackknife" values give a fair indication of the bias in estimates that results from using the same data in classification that were used to derive the functions. The 4-group "jackknife" ranges are 79–82% correct for combination, 75–81% for metatarsal, and 64–70% for proximal phalangeal models. The "reverse" models provide an additional test for the 4-group models. These models yield approximately 83–86% correct classification for combination, 79–80% for metatarsal, and 67–74% for proximal phalangeal functions. The "reverse" models perform better in two cases than the original models do (by 3% for left MT model applied to right and by 2.5% for right PP model applied to left). In the other four cases, reductions in classification success range from 1.3% to 4.4%. The "jackknife" values reported for sex and race classification, based on the sole function that can be derived, provide a more direct indication of the bias of the original estimates than the 4-group "jackknives" do. The greatest reduction is 5.66% (left combination model for race); the least is 0.63% (left MT for race).

It is therefore reasonable to expect some reduction in classification success when the models are applied to new unknown cases. It should in addition be recognized that any secular changes that have occurred in foot bone measurements since the time of these collections may affect the applicability of these models. Meadows and Jantz (14) have demonstrated positive allometry with stature for the tibia and fibula among Terry Collection and WWII casualty males. Although the implications for stature prediction are clear, it is less certain how any associated changes in foot proportions would affect classification by race and sex using foot bone data from such osteological collections. Larger, taller females might well be classified as males within their respective groups. Misclassification of females as males should be less of a problem if females are merely taller with similar levels of joint robusticity; but if the latter change as well, then females are especially likely to be misclassified. In simultaneous sex and race classification, proportional changes could result in assignment to an incorrect group (race). For example, if length to width proportional changes in foot bones accompany change in height, a "white" female might be classified as a "black" female, even if a relatively low level of joint robusticity maintains assignment as female.

In addition, this paper has dealt with a simple dichotomous division into "black" and "white" groups. In this research, no data for Hispanics, Asians (including Amerindians), or other groups are given. It should be realized that the predictive power would be less if additional groups were included.

Nevertheless, despite such problems, all these models produce considerable improvements over prior probabilities. Thus in the absence of more preferred osteological remains, the bones of the feet can provide evidence that in some cases should result in a good probability of correct classification by sex or race alone. The probability of assigning both correctly is predictably less, but while less than ideal is at a level that is substantially better than chance. Therefore, the 4-group models may prove useful in cases involving very limited information.

Acknowledgments

The data used in these analyses were collected while I was a postdoctoral fellow at the Smithsonian Natural History Museum.

The support provided by the Smithsonian is gratefully acknowledged. I thank Dr. Richard Potts, Jennifer Clark, Dr. Thomas Plummer, Dr. David Hunt, Robert Mann, and Carol Butler for all their help and kindness during my year's stay in Washington, D.C. In addition, I thank Dr. Michael Domingue for help with the figures, Nancy Rowe for computing aid and advice, and SPSS support staff for statistical aid, and the *Journal of Forensic Sciences* reviewers for helpful comments that improved the manuscript version of this paper.

References

1. Krogman WM, İşcan MY. The human skeleton in forensic medicine. 2nd edition. Springfield (IL): Charles C Thomas, 1986.
2. Giles E, Vallandigham PH. Height estimation from foot and shoeprint length. J Forensic Sci 1991;36:1134–51.
3. Gordon CC, Buikstra JE. Linear models for the prediction of stature from foot and boot dimensions. J Forensic Sci 1992;37:771–82.
4. Byers S, Akoshima K, Curran B. Determination of adult stature from metatarsal length. Am J Phys Anthropol 1989;79:275–9.
5. Steele DG. The estimation of sex on the basis of the talus and calcaneus. Am J Phys Anthropol 1976;45:581–8.
6. Smith SL. Attribution of hand bones to sex and population groups. J Forensic Sci 1996;41:469–77.
7. Martin R, Saller K. Lehrbuch der anthropologie. Volume 1, 3rd edition. Stuttgart: Gustav Fischer, 1957.
8. Bass WM. Human osteology. A laboratory and field manual. 3rd edition. Columbia (MO): Missouri Archaeological Society, 1987.
9. Steele DG, Bramblett CA. The anatomy and biology of the human skeleton. College Station (TX): Texas A & M Press, 1988.
10. White TD, Folkens PA. Human osteology. San Diego: Academic Press, 1991.
11. Norušis MJ. SPSS/PC+ advanced statistics™ 4.0 for the IBM PC/XT/AT and PS/2. Chicago:SPSS, 1990.
12. Klecka WR. Discriminant analysis. Sage university paper series on quantitative applications in the social sciences, 07-019. Beverly Hills (CA): Sage Publications, 1980.
13. DiBennardo R. The use and interpretation of common computer implementations of discriminant function analysis. In: Reichs KJ, editor. Forensic osteology: Advances in the identification of human remains. Springfield (IL): Charles C Thomas, 1986;171–95.
14. Meadows L, Jantz RL. Allometric secular change in the long bones from the 1800s to the present. J Forensic Sci 1995;40:762–7.

Additional information and reprint requests:
Shelley L. Smith, Ph.D.
Department of Sociology and Anthropology
Box 19599
University of Texas at Arlington
Arlington, TX 76019