Trenton W. Holliday,[1] Ph.D. and Anthony B. Falsetti,[2] Ph.D.

A New Method for Discriminating African-American from European-American Skeletons Using Postcranial Osteometrics Reflective of Body Shape

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ABSTRACT: A discriminant function analysis based on seven postcranial measurements for the metric assessment of race is presented. A sample from the Terry Collection (NMNH) was used to create independent functions for African-American males and females, and European-American males and females. The functions were tested using known forensic cases from the Maxwell Museum of Anthropology and the C.A. Pound Human Identification Laboratory.

Based on the Terry Collection sample, correct classification of race for males was 87.0%, and for females 100.0%. For the independent test population, correct classification for males was 81.8%, and for females only 57.1%. The low classification for females is most likely due to sample bias.

KEYWORDS: forensic science, forensic anthropology, body proportions, discriminant functions, race determination

Over the past two decades, there have been relatively few attempts to determine the race of skeletons using discriminant functions derived from postcranial measurements (1–3). Rather, the most commonly used multivariate methods for the determination of race from the skeleton are based solely on craniometrics (4–7). This is due not only to the historically cranio-centric approach taken by many biological anthropologists toward the skeleton, but also because broadly ecogeographically dispersed groups of humans (generally referred to as races) differ from each other in a suite of cranial features. Primary among these differences are those manifest in the midfacial skeleton, which is dominated by the nose (8–10). Given these robust craniofacial differences, multivariate linear and quadratic discriminant functions for determining race based on cranial measurements have generally proved more reliable (as measured in percentage of correctly assigned specimens) than those based on postcranial measures (8).

There are, however, postcranial features that, like their craniofacial counterparts, differ significantly between widespread geographic groups of modern humans. Presumably these characteristics could be used to segregate individuals from different races. In particular, the body form of humans around the world shows variability consistent with "rules" posited for homeothermic animals by Bergmann (11) and Allen (12). Bergmann's rule states that as members of a widespread warm-blooded species inhabit more and more polar regions, their body mass is expected to increase. Similarly, Allen's rule states that as members of a warm-blooded species inhabit warmer and warmer climes, their extremities will increase in length.[1] Thus, the expectation for a widespread homeothermic species, such as *Homo sapiens*, is that in tropical regions, one will find lighter, longer limbed individuals and groups, and that in colder regions, one will tend to find heavier, shorter limbed populations and individuals.

Indeed, adherence to Bergmann's rule is evident among recent humans, whose body mass shows a clinal distribution, such that there is a significant, negative correlation ($r = -0.60$) between mean annual temperature and body mass across a global sample of humans (13). In fact, this pattern is so robust that it can even be detected in smaller, more regional samples of humans (14,15).

Similarly, relative length of the lower limb shows patterning indicative of adherence to Allen's rule, as reflected in relative sitting height indices (sitting height/stature × 100; 16,17). Roberts (16) demonstrated that in a global sample, these indices have a high, negative correlation with mean annual temperature ($r = -0.62$), such that individuals with relatively longer lower limbs tend to be found in tropical regions. Additionally, Eveleth and Tanner (17) showed that there is a marked difference in relative sitting height index values, with Europeans, Native Americans and Asians generally showing higher values (51>), while Australian aborigines and sub-Saharan Africans have generally lower values (<50). This patterning is what one would expect if Allen's rule were mandating shorter limbs in colder climates. While this ecogeographic model is robust, relative sitting height is obviously an anthropometric measure that one cannot take on skeletons. However, relative sitting height can be approximated in skeletal material using skeletal trunk height (see below), and significant differences in relative limb length when scaled to skeletal trunk height are manifest between recent African and European populations (18).

Bi-iliac (pelvic) breadth also exhibits strong ecogeographical patterning (14,19). This follows expectation from Bergmann's rule, since a broader-trunked individual would tend to be heavier (greater body weight). An even higher correlation with climatic variables is seen when bi-iliac breadth is scaled to stature via the relative bi-iliac breadth index (bi-iliac breadth/stature × 100) (16,19). This measure reflects both Bergmann's and Allen's rules, since we expect tropically adapted humans to have among the nar-

[1] Department of Anthropology, Tulane University, New Orleans, Louisiana.
[2] Department of Anthropology and C.A. Pound Human Identification Laboratory, University of Florida, Gainesville, FL.
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rowest bi-iliac breadths (following Bergmann's rule) and relatively greater stature, given longer lower limbs (following Allen's rule).[2]

Importantly, body shape features seem to be largely genetically controlled, and do not show extreme phenotypic plasticity (20–23). As a result, despite the fact that African-Americans and European-Americans share a common, largely temperate, environment (and despite having experienced significant interbreeding), there are nonetheless significant differences in body shape which remain manifest between these two groups (24,25). Specifically, members of each group tend to exhibit body shapes more similar to those of the populations on the continent from which most of their ancestors derive (i.e., either Africa or Europe).

A likely conclusion, therefore, is that if one could take a series of postcranial osteometrics reflective of body shape (particularly those that show ecogeographical patterning), one could then use those measurements to produce a linear discriminant function that could effectively assess the racial affinity of human skeletons. The current paper is just such an attempt—to use body shape features such as limb length, relative body mass, skeletal trunk height and bi-iliac breadth to discern the skeletons of African-Americans from those of European-Americans. Should such a method prove successful, it could be useful either to complement cranially-based methods, or could, in the absence of cranial data, provide an accurate racial assessment for a postcranial skeleton of unknown race.

Materials and Methods

Materials

The linear discriminant functions were created from a sample of African-American (n = 54; 28 F, 26 M) and European-American (n = 56; 28 F, 28 M) skeletons. These skeletons are from the Smithsonian Institution's Terry Collection, and were measured by the first author to the nearest 0.5 mm. Since the sample is from a documented collection, all the individuals used are both chronological, as well as skeletal, adults of known sex and race. The specimens were chosen at random. However, most (over 75%) are primage adults (i.e., <55), since the majority of the vertebral data taken (see below) dictate that the vertebral segments measured be largely free of osteoarthritic changes generally associated with advanced age. This therefore limits the number of specimens that can be used in the analyses; in the future we hope to augment sample size with more recently collected skeletal material.

Linear discriminant functions are designed to effectively differentiate between members of classes in the population from which it was created. It is usually less effective, however, in discriminating between classes for an independent sample. Therefore, once the discriminant function was generated from the Terry Collection data, it was tested on an independent skeletal series. The independent series includes twelve specimens (5 F; 7 M) from the documented collection of the Maxwell Museum of Anthropology at the University of New Mexico and six documented individuals (2 F; 4 M) from the C.A. Pound Human Identification Laboratory at the University of Florida. All specimens were measured by the first author.

Methods

The measurements taken on the skeletal sample are femoral A-P head diameter (FHAP), skeletal trunk height (STH), bi-iliac breadth (BIB), femoral bicondylar length (FL), humeral maximum length (HL), tibial maximum length (TL) and radius maximum length (RL). All but one of the measurements (STH) are standard osteometric dimensions that are easily taken on human skeletal material. BIB was taken by manually articulating the pelvis at the sacro-iliac joints (thereby leaving a gap for the fibrocartilage of the pubic symphysis), then inverting the articulated pelvis on an osteometric board to measure its maximum transverse diameter. STH is defined as the summed dorsal body heights of the thoracic and lumbar vertebrae plus sacral ventral length (18). While not the case for the current data set, in many instances, particularly those involving burials, STH must be predicted, because not all of its components are preserved. In these instances, least-squares regression analyses to predict total column height from the summed height of the preserved elements (based on a complete skeletal series), have been shown to be very accurate, as indicated by their low standard errors of prediction (18).

The variables were chosen *a priori* because they are easily taken and are the best skeletal reflections of the generalized body shape morphocomplexes discussed earlier. The measurements were used in the linear discriminant function analysis, with the cross-validation option, (PROC DISCRIM) procedure in PC-SAS Windows Version 6.12 (26). Separate discriminant functions were generated for males and females. Given the fact that this method requires a relatively complete pelvis, the sexing of individuals prior to the application of this method should not be problematic.

Results

Computation of the Functions

The summary statistics for the Terry Collection sample are found in Table 1. As expected following Bergmann's and Allen's rules, for both sexes, the African-Americans have absolutely longer limb bones, and shorter, narrower trunks than do the European-Americans. The femoral head size of female African- and European-Americans appears virtually identical, while male European-Americans have larger (albeit not statistically significantly larger) femoral heads than their African-American counterparts. Whether these univariate differences translate into multivariate discrimination of European-Americans from African-Americans was determined by the computation of the male and female discriminant functions.

TABLE 1—*Sample size, measurement means, and standard deviations for the Terry Collection sample from which the discriminant functions were derived.*

Measurement		African-Am. Females	Euroam. Females	African-Am. Males	Euroam. Males
N		28	28	26	28
FHAP	$\bar{X}$	42.4	42.5	47.3	48.1
	SD	1.9	2.4	2.6	2.7
STH	$\bar{X}$	455.4	482.5	488.2	502.6
	SD	17.1	26.5	21.3	24.5
BIB	$\bar{X}$	249.9	270.5	251.1	268.9
	SD	17.9	18.3	14.4	16.8
FL	$\bar{X}$	442.3	424.6	468.5	458.0
	SD	25.7	18.5	25.0	28.7
HL	$\bar{X}$	314.4	302.1	335.3	328.4
	SD	14.1	13.6	16.4	20.6
TL	$\bar{X}$	374.3	351.7	400.2	379.1
	SD	23.2	17.5	25.7	27.3
RL	$\bar{X}$	240.7	219.4	262.4	244.5
	SD	11.7	9.4	15.2	17.1

The unstandardized linear discriminant coefficients for the female sample are reported in Table 2. This function is significant, according to the F-test ($F_{7,48} = 24.1$; $p < 0.00001$). With regard to the individual variables' ability to discriminate, with the exception of femoral head diameter (FHAP), which has an individual F-probability of 0.94, all other coefficients are significant at $p < 0.01$. Therefore all other variables contribute to the discrimination of the groups. The classification table for the Terry Collection females is found in Table 3. As is evident in the table, the discriminant function correctly classified 100% of the females used in its computation—none was misassigned to the other group.

The unstandardized discriminant function coefficients for the males are presented in Table 4. As for the females, the function for the Terry Collection males is also significant, according to the F-test ($F_{7,46} = 10.4$; $p < 0.00001$). Among the males, the variables that significantly ($p < 0.05$) contribute to the discrimination of European-Americans from African-Americans are maximum tibial length (TL), maximum radius length (RL), bi-iliac breadth (BIB) and skeletal trunk height (STH). None of the other variables' associated F-probability is significant at $p < 0.05$. The classification table for the Terry Collection males is presented in Table 5. The discriminant function correctly classified 24 of 28, or 85.7%, of European-American males, and 23 of 26, or 88.5% of the African-American males. In total, it correctly classified 47 of 54, or 87% of the male individuals.

TABLE 2—*The unstandardized discriminant function coefficients for computing an individual female's discriminant function score from her measurements.*

	Linear Discriminant Function Coefficients—Females	
Variable	European-American	African-American
Constant	−375.65646	−392.04578
FHAP	2.07883	3.05694
FL	0.13143	−0.04703
TL	−0.14542	−0.00602
HL	0.59330	0.52934
RL	0.86867	1.30027
BIB	−0.17927	−0.33328
STH	0.69568	0.61506

TABLE 3—*Number of cases assigned to each group from each actual group—females.*

Actual Group Membership	Predicted Group		
	European-American	African-American	Total
European-American	28	0	28
African-American	0	28	28
Total	28	28	56

TABLE 4—*The unstandardized discriminant function coefficients for computing an individual male's discriminant function score from his measurements.*

	Linear Discriminant Functions Coefficients—Males	
Variable	European-American	African-American
Constant	−316.30070	−305.04550
FHAP	3.04603	2.92032
FL	0.55650	0.49137
TL	−0.27556	−0.18454
HL	0.02719	−0.02916
RL	−0.05357	0.10140
BIB	0.00280	−0.12155
STH	0.67209	0.67417

TABLE 5—*Number of cases assigned to each group from each actual group—males.*

Actual Group Membership	Predicted Group		
	European-American	African-American	Total
European-American	24	4	28
African-American	3	23	26
Total	27	27	54

TABLE 6—*Linear discriminant functions for race for use with the independent sample.*

	Males	Females
Constant	−11.252	16.38932
FHAP	0.1257	−0.9781
FL	0.0651	0.1784
TL	−0.0910	−0.1394
HL	0.0563	0.0639
RL	−0.1549	−0.4316
BIB	0.1243	0.1535
STH	−0.0020	0.0806

TABLE 7—*Number of cases assigned to each group from each actual group—independent sample females.*

Actual Group Membership	Predicted Group		
	European-American	African-American	Total
European-American	4	3	7
Total	4	3	7

Independent Test of the Functions

One derives a single linear function by subtracting the paired unstandardized coefficients and the constants from each other, producing a single linear function, which is equivalent to Fisher's discriminant function (Table 6). This single function can then be used to test independent samples. The results of the test of the female discriminant function on the independent sample are presented in Table 7. As is evident from Table 7, there were no African-American females in the independent sample. This was due to the paucity of known African-American females in the two forensic samples. The discriminant function derived from the Terry Collection females does not very effectively assign the females from the New Mexico and Florida samples. Only 4 of 7 (57.1%) are correctly assigned as European-Americans. This result is most likely due to the small sample size of the independent female sample, since the discriminant function segregated 100% of the Terry Collection females.

The results of the independent test of the Terry Collection male discriminant function are presented in the form of a classification table in Table 8. As seen in the table, the discriminant function effectively discriminates European-American from African-American males. It correctly assigns 6 of 8, or 75% of the European-Americans, and correctly assigns all three of the African-American males from the independent sample. In sum, 81.8% of the independent male sample was correctly assigned.

It has recently been suggested that the secular trend toward increased stature may affect the results of discriminant function analyses based on essentially 19th-century skeletal samples such as the Terry Collection (7,27). Indeed, our late 20th century test sample shows a general size increase over the Terry Collection for the measurements used here, as indicated by the percentage deviations of their mean values over those of the Terry Collection sample (Table 9). This could, at least in part, be responsible for the poor racial assignment of the test sample European-American females. However, we feel this is unlikely, since a size increase is also evident among the European- and African-American males, and in fact, is in many cases a larger percentage deviation among the African-American males than among the European-American females (Table 9). Thus, despite the fact that the test sample males also exhibited an increase in overall size relative to the Terry Collection males, they were nonetheless much more successfully assigned to their appropriate racial groups.

A related problem involves the fact that the increase in stature has been an allometric change, i.e., there has been a greater increase in tibial length relative to femoral length, as reflected in crural indices (27). Yet the secular trend has resulted in differences in crural indices (27) that are generally smaller than the differences observed between widely dispersed ecogeographical groups (18). As a case in point, in the current study, crural index differences between Terry Collection and test sample individuals of the same race are not significantly different at $p < 0.05$, while the differences between the races within the same time period are. Perhaps more important than brachial and crural indices, however, are limb-trunk proportions, which appear to have exhibited an even a smaller secular trend increase. For example, the TL/STH index in the European-Americans increased from 74.3 in the Terry Collection to 76.3 in the test collection. Not only is this a non-significant difference (two-tailed t-test $p = 0.0928$), it brings them nowhere near the Terry Collection African-American mean of 82.1. This suggests that postcranial discriminant functions that include some measure of trunk height may be better able to discriminate racial groups than those that do not.

TABLE 8—*Number of cases assigned to each group from each actual group—independent sample males.*

Actual Group Membership	Predicted Group		
	European-American	African-American	Total
European-American	6	2	8
African-American	0	3	3
Total	6	5	11

TABLE 9 —*Summary statistics for the independent test sample and percentage deviations from the Terry Collection means.*

Measurement		Euroam. Females	African-Am. Males	Euroam. Males
N		7	3	8
FHAP	$\bar{X}$	42.2	48.2	49.1
	SD	2.0	3.5	4.3
	%deviation	+0.7	+1.9	+2.0
STH	$\bar{X}$	483.6	487.6	520.4
	SD	15.9	22.8	31.6
	%deviation	+0.2	−0.1	+3.4
BIB	$\bar{X}$	267.0	237.7	273.3
	SD	15.8	16.6	12.8
	%deviation	−1.3	−5.6	+1.6
FL	$\bar{X}$	437.9	494.3	472.1
	SD	15.7	17.9	34.9
	%deviation	+3.0	+5.2	+3.0
HL	$\bar{X}$	314.4	356.7	339.8
	SD	13.0	28.4	24.9
	%deviation	+3.9	+6.0	+3.4
TL	$\bar{X}$	373.0	428.7	393.4
	SD	18.8	13.4	29.7
	%deviation	+6.1	+7.1	+3.8
RL	$\bar{X}$	232.0	273.0	249.9
	SD	9.1	8.9	18.5
	%deviation	+5.6	+3.9	+2.2

Applications and Limitations

These functions are best applied when crania are not recovered or do not present enough of the necessary landmarks for accurate measurement. This may be the result of intentional dismemberment and/or natural taphonomic activity (including scavengers). The method as presented requires the preservation of several vertebral elements, and a relatively complete pelvis. In cases where some, but not all vertebrae are preserved, workers should feel free to contact the first author, who will predict STH for them using a regression analysis based on the appropriate reference sample. Finally, this method may be used in combination with the widely available FORDISC 2.0 program (28), which also includes postcranial measurements, to provide further confirmation of the racial affinities of unknown individuals who lack cranial remains.

The most obvious limitation of this analysis is the poor assignment of the female test sample. While this may be due to the secular trend, it is most likely due to the small available sample size of modern female forensic cases ($n = 7$). We invite others to test this method using the functions presented in Table 6, and to report their results to either author, as we are continuing to refine this technique.

Endnotes

1. These morphological changes are said to be adaptively significant in that they alter the surface area: volume ratio (SA:V), and thus affect the ability of the organism to either shed, or conversely, retain heat. Obviously, an enhanced ability to shed excess heat afforded by decreased body mass and/or a larger percentage of total mass in the limbs (which have high surface area) should be adaptive in hotter climes. Whether this adaptive explanation is correct is not of concern for medico-legally significant questions. All that matters for forensic anthropologists is that the empirical pattern is demonstrably robust to allow consistent and accurate discrimina-

tion of groups of different recent evolutionary ancestry (e.g., African-Americans and European-Americans).

2. What is meant here is stature relative to overall size. Stature itself does not tend to exhibit ecogeographical patterning, since Bergmann's and Allen's rules produce conflicting restraints as one moves into colder regions. Bergmann's rule predicts that one will find individuals of greater body mass in these regions, which leads to an expectation of increased stature, while at the same time Allen's rule predicts that limb lengths will be reduced, thus decreasing stature.

References

1. DiBennardo R, Taylor JV. Multiple discriminant function analysis of sex and race in the postcranial skeleton. Am J Phys Anthropol 1983;61:305–14.
2. Schulter-Ellis FP, Hayek LC. Predicting race and sex with an acetabulum-pubis index. Collegium Anthropol 1984;8:155–62.
3. Krogman WM, İşcan MY. The human skeleton in forensic medicine. Springfield, IL: Charles C Thomas 1986.
4. Giles E, Elliot O. Race identification from cranial measurements. J Forensic Sci 1962;7:147–57.
5. Gill GW, Hughes SS, Bennett SM, Gilbert BM. Racial identification from the midfacial skeleton with special reference to American Indians and whites. J Forensic Sci 1988;33:92–9.
6. Byers SN, Churchill SE, Curran B. Identification of Euro-Americans, Afro-Americans, and Amerindians from palatal dimensions. J Forensic Sci 1997;42(1):3–9.
7. Ousley SD, Jantz RL. The forensic data bank: documenting skeletal trends in the United States. In Forensic Osteology: Advances in the Identification of Human Remains. Reichs KJ, editor. Springfield, IL: Charles C Thomas 1998.
8. St. Hoyme LE, İşcan MY. Determination of sex and race: accuracy and assumptions. In: MY İşcan, Kennedy KAR, editors. Reconstruction of life from the skeleton. New York: Liss 1989;53–93.
9. Howells WW. Skull shapes and the map: craniometric analyses in the dispersion of modern *Homo.* Cambridge, MA: Peabody Museum of Archaeology and Ethnology, Harvard University 1989.
10. Franciscus RG, Long JC. Variation in human nasal height and breadth. Am J Phys Anthropol 1991;85:419–27.
11. Bergmann C. Über die Verhältnisse der Warmeokonomie der Thiere zu ihrer Grosse. Göttinger Studien 1847;3:595–708.
12. Allen JA. The influence of physical conditions in the genesis of species. Radical Review 1877;1:108–40.
13. Roberts DF. Body weight, race and climate. Am J Phys Anthrop, n.s., 1953; 11:533–58.
14. Crognier E. Climate and anthropometric variations in Europe and the Mediterranean area. Ann Hum Biol 1981;8:99–107.
15. Endo A, Omoe K, Ishikawa H. Ecological factors affecting body size of Japanese adolescents. Am J Phys Anthropol 1993;91:299–303.
16. Roberts DF. Climate and human variability. 2nd ed. Menlo Park: Cummings, 1978.
17. Eveleth PB, Tanner JM. Worldwide variation in human growth. International Biological Programme 8. Cambridge: Cambridge University Press 1976.
18. Holliday TW. Body proportions in Late Pleistocene Europe and modern human origins. J Hum Evol 1997;32:423–48.
19. Ruff CB. Morphological adaptation to climate in modern and fossil hominids. Yrbk Phys Anthropol 1994;37:65–107.
20. Schultz AH. Fetal growth in man. Am J Phys Anthrop 1923;4:389–99.
21. Schultz AH. Fetal growth of man and other primates. Q Rev Biol 1926;1: 465–521.
22. Stini WA. Adaptive strategies of human populations under nutritional stress. In: Watts ES, Johnston FE, Lasker GW, editors. Biosocial Interactions in Population Adaptations. The Hague: Mouton 1975.
23. Warren MW. Prenatal long bone growth and proportionality in fetal abortus and stillborns (Abstract). Am J Phys Anthrop 1998; Suppl 26:226.
24. Hamill PVV, Johnston FE, Lemeshow S. Body weight, stature and sitting height: White and Negro youths 12–17 years, United States. Department of Health, Education and Welfare Publication, No. (HRA) 74-1608, Vital Health Statistics Series 11, No. 126. Washington: US Government Printing Office, 1973.
25. Martorell R, Malina RM, Castillo FS, Pawson IG. Body proportions in three ethnic groups: children and youths 2–17 years in NHANES II and HHANES. Hum Biol 1988;60:205–22.
26. SAS Institute Inc. SAS System for Windows, Release 6.12. Cary, North Carolina.
27. Meadows L, Jantz RL. Allometric secular change in the long bones from the 1800s to the present. J Forensic Sci 1995;40(5):762–7.
28. Ousley SD, Jantz RL. FORDISC 2.0 Personal Computer Forensic Discriminant Functions. 1996. Knoxville, Tennessee.

Additional information and reprint requests:
Trenton W. Holliday
Department of Anthropology
Tulane University
New Orleans, Louisiana 70118
Tel: (504) 862-3066
Fax: (504) 865-5338