Reports

Multivariate Analysis of an Early Hominid Metacarpal from Swartkrans

Abstract. *Discriminant analysis permits hand bones of living primate genera to be represented as swarms of points in a multidimensional statistical framework within which intergroup relationships, and the affinities of fossil forms, can be examined. The metacarpal of* Paranthropus *from Swartkrans, South Africa, was so located with respect to groups of monkeys, apes, and modern man. The results suggest that the fossil metacarpal may be functionally similar to that of chimpanzees.*

In 1949, Broom and Robinson (*1*) announced the recovery of a complete left first metacarpal (SK 84) from the cave breccias at Swartkrans, South Africa. This bone, attributed to *Paranthropus*, has been described in detail by Napier (*2*), who sees in it a rather confusing combination of pongid and hominid features with the former predominating. Le Gros Clark (*3*) has called attention to possible conformity of the proximal articular surface of the Swartkrans specimen with the corresponding surface of the Olduvai trapezium, associated with a hand whose overall primitiveness has been emphasized (*4*).

Because of the apparent intermediacy in form of SK 84 and the importance of this bone in continuing discussions of early hominid hand function, a new multivariate statistical approach to the fossil has been undertaken. Toward this end, measurements were made on series of 44 adult male and female East African Negro metacarpals from the Galloway Collection of Makerere University, Kampala. Additional materials examined include samples of 14 *Gorilla*, 18 *Pan*, 14 *Pongo*, 5 *Hylobates*, and 10 *Papio* specimens, all fully adult and in good condition, drawn from American, British, and African collections. The 12 measurements taken with a Helios dial caliper and with a specially constructed coordinate caliper are listed in Table 1. The multivariate technique most suitable for deploying the several extant genera in meaningful fashion and thus for providing a framework within which the fossil can be located is that of discriminant analysis. Here the original measurements are used to determine orthogonal axes (discriminant functions), to a possible total of one less than the number of populations represented, upon which each individual can be plotted by means of a single discriminant score. This approach has been widely employed in studies of cranial and dental remains of modern man and has also been applied to advantage in some recent investigations of hominid postcranial fossil materials (*5*).

In the present analysis, the first three functions extracted together account for over 99 percent of all discrimination, and these three only are retained. Each may be described in turn.

Function 1, which accounts for a major portion (61.5 percent) of the total generalized variance, contrasts the modern *Homo sapiens* males and females receiving high mean scores with the orangutans, which show lower, negative, scores (see Fig. 1). Gorillas and chimpanzees are more or less intermediate on this scale. This particular sequence or distribution of centroids does not lend itself immediately to any functional interpretation in terms of overall hand posturing or manipulative ability of the thumb. There is a tendency for the hands of terrestrial genera (*Homo, Gorilla*) to be contrasted with those of the highly arboreal forms (*Hylobates, Pongo*), and *Pan* is properly intermediate, but the ground-living baboons are somewhat out of place in any locomotor spectrum of this kind. Similarly, while "truly" opposable thumbs (*Homo*) receive positive scores, and groups with far less efficiently opposable thumbs (*Pongo*) generally score negatively, any interpretation of this axis as a reflector of pollical capability must remain limited and tentative.

Further interpretation of the significance of the discriminant is best done by reference to the original measurements and the relative contributions that these make to the function. When viewed in "scaled vector" form (Table 1), this first axis is seen to be determined largely by breadth measures of the distal extremity (distal articular

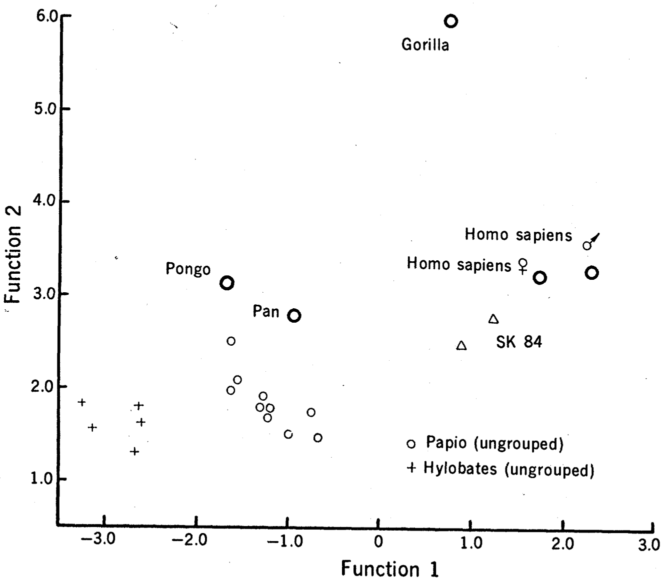

Fig. 1. Distribution of group centroids and ungrouped subjects on the first two discriminant functions (1 and 2), which together account for almost 91 percent of the total discrimination achieved. Two possible positions are indicated for the Swartkrans metacarpal (SK 84); these differ slightly depending on whether the peculiar distal "beak" on the bone is included in one of the measurements (distal articular height) used in the analysis. A third axis, perpendicular to the plane of 1 and 2, places the fossil close to *Pan* and the ungrouped specimens and far from the larger genera (*Gorilla, Homo, Pongo*).

Table 1. The first three discriminant functions in scaled vector form and correlations of the original measurements with the discriminant scores. All measurements were recorded to the nearest 0.1 mm or, where appropriate, to the closest whole degree.

Measurement	Function 1		Function 2		Function 3	
	Scaled vector	Correlations	Scaled vector	Correlations	Scaled vector	Correlations
Maximum length	−6.12	0.11	1.05	0.65	15.20	0.97
Midshaft subtense*	0.36	−0.41	−0.01	0.19	−0.45	0.39
Midshaft angle†	−1.46	−0.48	−0.34	−0.01	2.12	0.07
Proximal articular breadth	−0.16	0.53	−1.25	0.66	−2.27	0.60
Proximal articular substence (medio-lateral)	−0.81	0.14	2.36	0.47	−0.88	0.49
Proximal articular height	−1.59	0.40	0.84	0.74	−0.51	0.68
Proximal articular subtense (dorso-volar)	−1.05	−0.02	3.02	0.79	−1.33	0.32
Transverse breadth at midshaft	0.14	0.64	1.96	0.66	−2.42	0.46
Height at midshaft	1.87	0.50	0.33	0.64	−0.81	0.54
Distal articular breadth	5.76	0.86	−2.81	0.31	−0.99	0.49
Maximum head breadth	3.89	0.65	3.71	0.70	5.13	0.68
Distal articular height	−2.05	0.41	−1.76	0.50	0.20	0.68

* A measure of longitudinal curvature of the shaft. † Computed from the subtense to show curvature in degrees.

breadth and maximum head breadth) and by overall length of the bone. These same breadth dimensions, accompanied by midshaft transverse diameter and breadth of the proximal articular surface, are also highly correlated with the function, although maximum length is not. These correlations of the individual discriminant scores with each of the measurements provide the more useful interpretive index, and results suggest that transverse breadths, most likely related to robusticity of the bone, are closely associated with discrimination. The appreciable negative loadings of midshaft subtense and angle indicate that longitudinal curvature of the metacarpal shaft, or lack thereof in the case of human materials, is also being registered here.

The second discriminant accounts for some 29 percent of the total variance and appears mainly to segregate gorillas, with high scores, from the remaining hominid and pongid representatives, which show rather uniform and lower mean scores. The baboon and gibbon metacarpals occupy the low extreme on this axis, so that these and the gorilla specimens are antipodal. Correlations or loadings of the measurements with this function are greatest for the subtense recording depth of the dorso-volar concavity of the proximal articular surface and also for the height measurement of this surface. The cavity is generally deep and well marked in gorillas, shorter and shallower in orangutans, and intermediate in man; it is not well developed in the baboon specimens examined. Breadth of the proximal articular surface and prominence of the lateral convexity also receive notable loadings (the latter having a high scaled weight as well), so that the function appears primarily to reflect differences in the configuration of the saddle-shaped articulation of the metacarpal base. Various other breadths, of the head and at midshaft, are again associated with the discrimination obtained, but their contribution is not easily understood from the information at hand.

Finally, the third function, responsible for only about 8 percent of discrimination, provides some separation of the several genera along an axis perpendicular to the plane of the discriminant space in which the first two functions lie. Here *Gorilla* and *Pongo* are opposed to *Pan* (and also the gibbons and cercopithecoids) at the lower end of the scale, while *Homo* occupies an approximately central position. This patterning of the group mean scores and also the important role of maximum length as that morphological character which the function is registering suggest that discrimination is here based mainly on size alone: size measured not in terms of relative robusticity or stoutness, as in function 1, but rather in an absolute sense, as with the information conveyed by one dimension (such as length) only.

These three functions together delimit a tridimensional discriminant space or universe within which the group mean vectors, or centroids, can be plotted and the probable group membership of a particular individual examined. So-called classification chi-squares may be computed and used to provide an index of the extent to which a single specimen resembles a particular group, or one centroid resembles another (*6*). In the case of the five original hominid and pongid samples (*7*), the computed chi-squares assign 92 out of 104 specimens (88.5 percent) to the correct group; that is, the chi-square "distances" relating individuals to centroids are lower for the correct group than for any other. Eleven of the 12 "misassignments" are by sex within *Homo*, and if these errors are discounted the measure of discriminant accuracy exceeds 99 percent. Discrimination of the extant genera on the basis of 12 measurements of the metacarpal is thus quite satisfactory, and the major sources of variation between these groups seem at least partially identifiable. The statistical framework developed should provide a useful tool for assessing the affinities of the fossil bone.

In its position on the first and relatively the most important of the three discriminant axes, the fossil is allied with modern man and the gorillas; it recives a score close to the mean of the latter but falling well outside of the expected .05 probability limits of the chimpanzee and orangutan sample distributions computed for function 1 singly. Function 2, when also looked at independently, places the Swartkrans thumb in the midst of several human and pongid distributions and close to many of the baboon and gibbon specimens plotted. But here any gorilla resemblance is strongly ruled out, largely by virtue of metacarpal base characteristics which this axis seems to measure. The third discriminant has the effect of removing the fossil somewhat from the human centroids while associating it with *Pan* alone among the original groups tested.

In terms of chi-squares computed with the use of scores on all three discriminants together, and hence in total morphological pattern as assessed by the 12 measurements taken, SK 84 is excluded with 95 percent probability from membership in any group, including *Homo sapiens*. The closest approach by the fossil to a centroid in the discriminant space occurs in the case of *Pan*, the sample to which assignment is subsequently made and in fact the only group for which membership is not excluded with 99 percent probability. (Chi-squares relating the fossil to the chimpanzee centroid are 8.36 and 10.12 with three degrees of freedom, for distal height measurements including and omitting the beak, respectively.)

This does not, of course, prove that *Paranthropus* at Swartkrans possessed a thumb (or hand) precisely like that of a modern chimpanzee. But a degree of similarity is certainly implied, with respect to measurable morphological structure and presumably in matters of function as well. The chimpanzee metacarpal and thumb are short relative to the other digits, and there is some limitation on movement at the carpometacarpal joint imposed by the surrounding "cuff" of thenar musculature (*8*). Thus, despite the potential for mobility at the well-developed saddle joint, the animal is seldom, if ever, observed to oppose the pulp of the thumb to the pulp surface of one or all of the remaining fingers. A true "precision grip" is not performed, although various imperfect approaches to this grip are possible (*8, 9*). The degree of thenar muscle development, the morphology of the articular capsule itself (whether loose or closely constructed), and the relative lengths of the pollex and other digits are unknown for *Paranthropus*, but in overall length and articular surface configuration, and in other characteristics emphasized in the discriminant analysis, the fossil metacarpal approximates the chimpanzee condition and may thus have fitted a hand with similar functional limitations.

In any case, despite its robust nature and tentative association with specimens of *Homo* on functions 1 and 2, the Swartkrans bone is far from fully modern in its morphology. Further study of such materials, including the judicious application of multivariate statistics, is necessary in order to detail the locomotor and manipulative capabilities of *Paranthropus* and early *Homo*.

G. P. RIGHTMIRE
Department of Anthropology,
State University of New York,
Binghamton 13901

References and Notes

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10. I thank Dr. C. K. Brain for permission to examine the Swartkrans metacarpal and Prof. W. W. Howells for the loan of indispensable measuring equipment. Project support was provided by the Research Foundation of the State University of New York.

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Enrichment of Heavy Metals and Organic Compounds in the Surface Microlayer of Narragansett Bay, Rhode Island

Abstract. *Concentrations of lead, iron, nickel, copper, fatty acids, hydrocarbons, and chlorinated hydrocarbons are enriched from 1.5 to 50 times in the top 100 to 150 micrometers of Narragansett Bay water relative to the bulk water 20 centimeters below the surface. Trace metal enrichment was observed in the particulate and organic fractions but not in the inorganic fraction. If these substances are concentrated in films only a few molecular layers thick on the water surface, the actual enrichment factor in the films may be well over 10^4, resulting in extremely high localized pollutant concentrations in the surface microlayer.*

From a pollution standpoint, the air-sea interface is perhaps one of the most important but most poorly characterized regions of the marine environment. The surface microlayer of the ocean has many unique chemical and physical properties, most of which are little understood. The organic and trace metal chemistry of this microlayer has received scant attention. The few studies of this region (*1*) indicate the presence of a variety of surface-active substances (for example, fatty acids and fatty alcohols) at the interface. These materials often form a coherent film which becomes evident as a result of the localized damping of capillary waves. Even when this film or slick is not visible, the surface microlayer may still be enriched with surface-active compounds. The major source of these compounds in the open ocean is the reservoir of natural marine organic matter in the mixed layer. The process of slick formation is complex, but surfactants are probably concentrated in the surface microlayer by convection currents, rising bubbles, and diffusion. The most surface-active of these materials displace the less active compounds, and eventually the microlayer is enriched with lipoid material and a coherent slick is formed.

Many pollutants may be concentrated and stabilized in this layer after its formation or may in fact be incorporated into it directly. This is especially true for lipophilic pollutants such as chlorinated hydrocarbons (*2*) and petroleum hydrocarbons. Trace metals may also be concentrated in the microlayer. Organic acids, proteinaceous material, and other surface-active organic substances may provide complexing sites for many heavy metals and thus be responsible for the transportation and concentration of these metals at the water surface.

The sources of the various pollutants that can reach and eventually concentrate in the surface microlayer are numerous. They include atmospheric transport, rivers, sewage and industrial effluents, dumping, pumping, and spills. Once concentrated, pollutants are readily accessible to bacteria and other microorganisms as well as phytoplankton and zooplankton at the surface. In this way, pollutants initially in the surface microlayer can enter the food chain and eventually be concentrated in the higher trophic members of the marine community.

Since the chemical nature of the surface microlayer is poorly understood, both in terms of its natural composition as well as in terms of its pollution gradients, it would seem appropriate to characterize more fully this region of the marine environment. This report de-