The Theoretical Foundations
and Development of Skeletal Biology

George J. Armelagos, David S. Carlson, and Dennis P. Van Gerven

Some people think that the philosophy a scientist accepts is not of very much importance; his job is to observe the phenomena. This is a gross oversimplification and it involves the subsidiary hypothesis that all scientists are fully equipped with serendipity. A sensible philosophy controlled by a relevant set of concepts saves so much research time that it can nearly act as a substitute for genius. . . . A scientist can have no more valuable skill than the ability to see whether the problem he is investigating exists and whether the concepts he is using are applicable.

N.W. Pirie 1952

Skeletal analysis has played a significant role in the development of physical anthropology. Indeed, physical anthropology in its preoccupation with qualitative and quantitative evaluations of human skeletal morphology, has an origin as a subdiscipline that is distinct from those of anatomy and anthropology. Interest in morphological analysis was generated, initially, by a concern for explaining variation among extant human populations or racial groups. It received added stimulation during the mid-nineteenth century by efforts to establish the natural position of modern Homo sapiens relative to earlier fossil forms and to the rest of the primate order. Blumenbach's (1795) reliance on his extensive collection of crania to establish his racial classification and Huxley's (1863) use of skeletal remains to interpret the Neanderthal fossil were only the beginnings of the discipline's use of osteological material.

There have been major technical advances in skeletal analysis since Petrus Camper first proposed the facial angle as a comparative measure of facial form in 1792. For example, the development and use of roentgenography, multivariate statistics, high-speed computers, and atomic absorption spectrometers for trace element analysis have greatly influenced skeletal biology. Unfortunately, however, theoretical perspectives have failed to keep pace with the development of new
techniques. Reliance on a descriptive–historical model utilizing racial typologies has proved a major deterrent to other theoretical approaches. The application of a population model that stresses functional interpretation of morphological features can provide an alternative to the descriptive–historical approach as well as a basis for determining the evolution and adaptation of prehistoric populations through time.

In this chapter, we will discuss (a) the impact of racial typology in assessing historical relationships between populations, (b) the rise of anthropometry in interpreting biological relationships, and (c) the development of a functional approach in skeletal biology.

Race, Type, and Historical Reconstructions

Traditionally, human biologists have maintained a conceptional framework characterized by the extensive utilization of historically orientated typological models as explanatory devices. This approach was developed in the late eighteenth and early nineteenth centuries and, although criticized by many physical anthropologists, continues to be used today. Lasker (1970), in a review of the literature, noted that physical anthropologists, despite statements to the contrary, are still largely concerned with historical, rather than processual, problems. Although theoretical aspects are often discussed, physical anthropologists have tended to focus on the description of events rather than on an explanation of the processes that have brought about these events.

Traditional emphasis on description in skeletal biology stems from pre-Darwinian ideals of biological discreteness. Anthropometric data was normally described within a framework that emphasized morphological differences and thus reinforced the ideas that certain human populations (e.g., racial groups) were discrete biological units. Any similarity of morphological features among populations was attributed to the exchange of genes. Even when arranged within a temporal framework, populations tended to be described as a temporal sequence of unique events, each with its own coordinates in space and time and with no obvious connection with its morphologically distinct predecessor or successor. The roots of this orientation are not unique to skeletal analysis. They can be found entrenched in broader scientific and cultural conditions.

With the rise of Christianity a sense of time totally unlike that entertained by the historically shallow primitive or the endless cycles over which Greco–Roman thought brooded in antiquity took possession of the European mind. The Christian saw time, wordly time, as essentially the divine medium in which a great play—the drama of the human Fall and Redemption—was being played out upon the stage of the world... Older pagan notions of eternal recurrent cycles were blasphemous to the Christian mind. "God forbid," protested St. Augustine, "that we should believe this. For Christ died once for our sins, and rising again dies no more" [Eiseley 1961:60].
According to Lynn White, "the axiom of the uniqueness of the Incarnation required a belief that history is a straight line guided by God. . . . No more radical revolution has ever taken place in the world outlook of a larger area [1942:147]."

With the growth of taxonomy as an observational science even Linnaeus, whose system of classification was a bastion of static morphological analysis could not resist the historical implications. In the later editions of *Systema Naturae* Linnaeus, himself, referred to species as "daughters of time [Greene 1959]." This "evolutionary vacillation", notwithstanding, it was not until 1859, 124 years after the first edition of *Systema Naturae*, that the full impact of the descriptive elegance of Linnean taxonomy became apparent. Prior to *The Origin of Species*, the morphological configurations of life forms were believed to represent a static gradation resulting from the single act of creation. In this context, taxonomic categories were conceived of as empirically verifiable, static, morphological units. However, the meaning of Linnean taxa became radically extended when viewed in light of Darwinian evolution. Subspecies, species, genera, and families came to stand, inferentially, as observable effects of prior evolutionary causes.

The extension of meaning from Linnean taxonomy to post-Darwinian phylogeny has been tremendously important to the development of physical anthropology, although not for the reasons traditionally given. Whereas the theoretical concept of evolution became synonymous with gradual dynamic change in organic structure through time, the impact of Darwinian evolution on scientific method remained quite different. Evolutionism, rather than shifting the focus of scientific attention away from an essentially static Linnean taxonomy toward the mechanisms of evolution *via* functionally oriented explanatory models, served to reinforce a broad scientific commitment to accelerated taxonomic description and definition. Thus, taxonomic description, as an inherently static, preevolutionary concept, did not give way to evolutionism after 1859; rather, evolutionism became cast in the form of traditional descriptive historicism.

The mechanisms of evolution have remained essentially theoretical, having broad definitions but little contextual meaning. Logically, this is to be expected. The meaning of the mechanisms of evolution must be derived from the context of specific evolutionary processes. Phylogenetic models, by assuming evolutionary change, beg the question of evolutionary process entirely. Change is asserted, rather than approached directly as an area of empirical analysis. The mechanisms of evolution are invoked to justify that assertion. In this sense, the greatest impact of *The Origin of Species* on physical anthropology has not been the concept of gradual dynamic change in complex organic systems; it has been the methodological entrenchment of taxonomy as a descriptive historical approach.

The historical paradigm is most clearly reflected in the extensive use of cranial material since the beginnings of physical anthropology. The skull is an extremely complex structure the morphology of which often varies widely between even closely related species. Intraspecies variation is extensive, particularly in *Homo sapiens*. Because of this factor, among others, the human skull has been most extensively studied by physical anthropologists seeking to establish taxonomies at
the subspecific level. The human skull has been thought of not only as an indicator of individual identity, which it certainly is, but also as an indicator of racial identity. In his classic treatise *On the Natural Varieties of Mankind* (published initially in 1775) and *Contribution to Natural History* Johann Friedrich Blumenbach relied extensively on the analysis of cranial remains (a total of 82 skulls), to formulate his views on human variation. In 1795, Blumenbach stated,

But it might have been expected that a more careful anatomical investigation of genuine skulls of different nations would throw a good deal of light upon the study of the variety of mankind; because when stripped of the soft parts and changeable parts they exhibit the firm and stable foundation of the head, and can be conveniently handled and examined, and considered under different aspects and compared together. It is clear from a comparison of this kind that from the forms of skulls take all sorts of license in individuals, just as color of skin and other varieties, of the same kind, one running as it were into the other by all sorts of shapes, gradually and insensibly. But that still, in general there is in them a constancy of characteristics which cannot be denied and is indeed remarkable, which has a great deal to do with the racial habit and which answers most accurately to the nations and their peculiar physiognomy [1795/1969:234–235].

There were, however, a number of criticisms of the use of cranial material even in the early post-Darwinian era. In 1896, Rudolf Virchow, an extremely influential scientist, supported the typological concept while being extremely critical of the use of crania for assessing biological affinity. As to the relationship of cranial morphology and racial type, Virchow stated that,

Here we must come to clear understanding as to whether we wish to lay greater weight upon skull form or on pigmentation of eyes and skin with its appurtenance, hair or, expressed otherwise, whether we wish to divide mankind more from the standpoint of the osteologist or from that of the dermatologist, the answer seems to admit of no doubt. The attempt of Anders Retzius to select a few categories of skull type as a basic principle for classifying man—though to be sure he mitigated it by adding in prognathism and orthognathism—has had no thoroughgoing success. Even the corrections which have been undertaken in the course of the years, have not made it possible for even a practiced craniologist to tell for certain without knowing anything of the provenience of the skull to which race, let alone stock, it belonged [1950:191].

Physical anthropologists not only failed to heed Virchow's warnings about the use of similarities in cranial morphology for establishing the history of a population but devoted even greater energy in the late 1800s and early 1900s toward the development and standardization of measurements and indexes that would hopefully give the clearest indication of biological affinity. Hrdlička describes (see Stewart 1947) many attempts to standardize anthropometric technique, for example, meetings were convened in Monaco (1906) and Geneva (1929) to resolve the disagreements over the methods and measurements used by various countries. This concern for standardization underscores the importance of measurement and of craniometry for physical anthropology.

Even when researchers did question the validity of certain anthropometric practices, there was little evidence that it diminished the significance of anthropometry. For example, the cranial index remains one of the most frequently used
measures of racial affinity. Yet, as early as 1910, Franz Boas discussed the instability of the cephalic index and its inappropriate use in racial analysis. The differences in the cephalic index of Jewish and Sicilian immigrants raised in the United States compared with relatives in their homeland suggested the instability of this feature. The change in cephalic index should have indicated the problems that the skeletal biologist faced in using crania for the analysis of the biological relationship between populations. Instead, Boas’s research was attacked on a number of different points. Radosavljevich (1911) argued that Boas failed to demonstrate the instability of the cephalic index because he did not consider evidence for the inheritance of the head form; he made countless mathematical, technical, and methodological errors that invalidate his conclusions; he was uncritical in the collection of data; and his measurements of the cephalic index lacked the necessary scientific exactness. Radosavljevich’s criticisms, however, were largely unsubstantiated. For example, he stated that Boas’s sample of nearly 6,000 was inadequate and that comparisons were invalid since Boas did not measure all individuals in the study. Shapiro (1959:377), in evaluating the impact of Boas’s study on the stability of cranial typology, states that the older concepts of a relative fixity of physical type were shattered. As will be seen in the following, Shapiro’s assessment was not warranted in light of the subsequent history of skeletal studies.

Earnest A. Hooton developed a method of typological analysis that greatly influenced the study of skeletal biology from 1925 until the late 1940s. Like his scientific predecessors, Hooton argued that an individual could be racially typed and that this racial typology would provide information on the biological history of the population. Hooton’s (1930) study, The Indians of Pecos Pueblo, was a key to his methodology, and he used the typology of the Pecos Pueblo population to interpret their racial history. Exemplary of the extent to which the racial-typological approach could be extended, Hooton ascertained a ‘pseudo-Negroid’ type within the Pecos Pueblo population. Hooton was careful and states that an “undiluted” Negro type would be different than the “Full African Negro type” and that there need not necessarily be a biological relationship between these types. Nevertheless, these similarities existed and required an explanation. He reverted to the obvious interpretation by stating that “pseudo-Negroids” could be explained by “earlier invaders who worked their way up Northeast Asia across the Bering Straits down the New World, and carried with them a minor infusion of Negroid blood which had trickled in from the tropical parts of the Old World [Hooton 1930:356].”

During the early 1950s, there were significant changes in the race concept as physical anthropology incorporated the population orientation. One would have expected concomitant shifts in methodology in which population and mechanisms for altering its structure (natural selection, mutation, gene flow and drift) would gradually become the focus of physical anthropological studies. However, just as human biologists maintained their traditional focus on taxonomy following the Darwinian revolution, the development of population biology did not drastically alter the approach of the physical anthropologist (see Weiss and Chakraborty, in the present volume). Instead, the taxonomists incorporated genetic traits into their classificatory systems.
The analysis of skeletal material in the 1950s showed traces of the Hootonian influence. Typological analysis of skeletons utilizing a racial model remained a major perspective of the skeletal biologist. There was, however, a devastating attack on skeletal biology presented by William C. Boyd in *Genetics and the Races of Man* (1950). Boyd, in one of the most influential studies of the period, attempted to develop a genetic perspective for race. He emphasized the importance of using traits of known inheritance, such as blood group, in racial classification. He stated that although bones may have been useful in racial classification during physical anthropology's infancy, there was no longer a necessity to rely on such imprecise material. Specifically, Boyd discussed four major reasons for the unacceptability of skeletal analysis in racial classification: (a) it is difficult to determine skeletal morphology in the living, (b) the skeleton adapts rapidly to its environment, (c) skeletal features are polygenetic and (d) anthropometry and craniopectometry are passé since metric studies were never logically conceived.

It is obvious that Boyd’s obituary of skeletal biology was premature. As Shapiro has noted, anthropologists are still willing to measure skulls at the drop of a hat. Furthermore, it is interesting to note that Boyd’s criticisms of skeletal biology were not theoretical or conceptual but entirely methodological. The basic goals of his research were identical to those of the traditional anthropological approach—the definition and delineation of racial groups. Indeed, even the racial groups defined by Boyd on the basis of blood types were the same as those most often defined by traditional anthropometry. Thus, it is apparent that whereas Boyd’s analysis may have initiated a change in many of the methods of racial analysis, the major questions asked by those methods had not changed; they remained racially and typologically oriented.

Major problems with the genetic approach to the analysis of human racial history were more recently discussed in more detail by Weiss and Maruyama (1976). These authors present the major views in the analysis of racial history and the methodology used to generate this information, which includes the traditional anthropometric approach and the population genetics approach. According to Weiss and Maruyama, the genetic approach to reconstructing racial history is certainly no less ambiguous and problematical than the anthropometric approach. Weiss and Maruyama state that

> Not only is the classification into major races a tenuous pursuit but ... there really may have been no effective separation between populations taken to represent the major races. What then is the meaning of genetic separation times? They really are nothing other than simple transformations of genetic distance, and add no definitive empirical support to any position regarding human evolution [1976:47].

There can be little doubt that human osteology has been and continues to be dominated by an overriding concern for the description of biological differences between populations, the result of which has been an ever-growing number of taxonomic definitions. However, because no attempts have been made to analyze systematically the nature of human variation within human populations, such
definitions have served only to generate a series of broad typological categories in the absence of any understanding of the lower order processes that such categories assume.

The analyses of the racial history of Amerindian populations by such workers as Neumann (1952), Bass (1964), and Long (1966) provide graphic examples of the limitations of this approach. Neumann developed a model to explain the peopling of the New World in which he placed all Amerindian populations within what has been referred to as the "Mongolid subspecies." With a temporal framework, he proposed that all Amerindian populations can be dealt with as "1) earlier phyletically more primitive Paleoamerind, 2) more recent derived or modified Mesoamerind, and 3) most recent immigrant Cenoamerind series [Neumann 1959a:66]."

Beyond the temporal configuration, Neumann classified the Amerindian populations into eight races based on their geography, cultural association, and morphological similarity. By applying both racial and temporal classifications simultaneously, Neumann was able to generate a descriptive typology of interpopulational variation.

Each of Neumann's varietal series of races was defined by a series of qualitative and metric cranial features that he believed ideally separated each race from the other. For instance, Neumann asserted:

In cranial vault form the Lenid variety tends toward exhibiting more elliptical contours, while the Walcolid variety tends toward exhibiting broader ovoid and spherical forms. Development of more medial frontal cresting, greater anterior projection of the zygomatic bones, a more elevated nasal bridge, a somewhat larger face, and greater chin prominence, distinguish the Walcolid from Lenid variety [1959b:72].

In the racial approach, no attempt is made to determine the relationship of one feature to another, or to determine the extent of intrapopulational variation. Anatomical features are defined as racial because they distinguish populations. Such a definition provides no explanation of the traits themselves. Furthermore, once a morphological feature becomes defined as "belonging" to a specific racial type, the only possible explanation of its occurrence in other populations is admixture resulting from migration. Such a view incorrectly portrays human populations as internally static units that only change as a function of gene flow.

Criticism of the racial–typological model has had little impact on its use. Although the use of the preconceived racial types was criticized at the turn of the century (Myers 1905, 1908, for example), they were never taken seriously. However, in 1959, Edward E. Hunt, Jr., a former student of Hooton, presented an extremely critical evaluation of Hooton's methods of typological analysis that had a significant impact on the use of typology in skeletal biology. Hunt saw no genetic reason "why ... 'ancestral' morphological types would persist in an ancestral population more than one might expect by chance [Hunt 1959:81]." Hunt was especially critical of the use of morphological types to establish relationships between populations that were geographically distant.
However, Hunt was willing to accept regional typological analysis in those cases where chronology and cultural affiliation were well established (Hunt 1959:74). Specifically, he was impressed with Neumann’s classification of North American cranial material that, he states, was based on Neumann’s study of over 10,000 skulls. Because Neumann’s study was based on archaeological samples in context, rather than on individual crania, Hunt considered the analysis “ provisionally convincing” (Hunt 1959:74). However, Neumann’s analysis actually utilized only a small number of the total 10,000 crania in the formulation of his classification. Two types, for example, are based on 15 and 18 specimens each.

Other skeletal biologists have attempted to extend the Neumann classification with more elaborate statistical procedures and analysis (e.g., Bass 1964; Long 1966; Wilkinson 1971; Robbins and Neumann 1972). Bass (1964) reanalyzed the biological relationship between the Plains Indian populations originally described by Georg Neumann. Although Bass criticized Neumann for his small sample size and sampling technique and was concerned with the limitations of Neumann’s racial categories, Bass brought no new theoretical insight to the problem.

Similarly, Long (1966), in an attempt to understand cranial changes in American Indian populations within a microevolutionary context, tested Neumann’s methodology and approach. He used a series of discriminant function analyses and rejected much of Neumann’s earlier typology but, at the same time introducing a new Iroquoian type. As an alternative, Long proposed that

All relations discovered in this study can be explained by micro-evolution, occasionally involving genetic drift but more frequently involving the mixing of groups. Multiple discriminant analysis can probably best be used to define major groups based on the degree of “fit” of individuals from closely related cultures. Such groups would be homogeneous for 1) a limited geographic area, 2) a limited time period, and/or 3) a limited cultural or linguistic affiliation [1966:464].

This focus on interpopulational variation does not provide us with any greater understanding of the nature of human variation than Neumann’s original classification. Neumann, Bass, and Long do not consider the relationship of variables used in their analysis. In order to understand microevolutionary change, this information is essential. Although Long notes that some variables were weighted on the basis of their interpopulational variation, he makes no systematic attempt to determine the source or nature of the observed variation.

Hardy and Van Gerven (1976) have shown that Neumann’s (1952) classification of the Indian Knoll variety as Iswamid and the Fort Ancient folk as Muskogid (Robbins and Neumann 1972) did not consider size relationship in their racial assessments. Robbins and Neumann believed that these two groups were racially distinct since 16 of 19 t-tests were significantly different at the 0.05 probability level. Using principal components analysis and analysis of covariation, Hardy and Van Gerven showed that when size was held constant, only four of the variables were significantly different. In this sense, two groups originally thought to be distinct were found to be more closely related after size factors had been removed.
High-speed computers and a series of multivariate statistical packages have recently become available to the physical anthropologist. However, the theoretical and methodological commitment toward the analysis of interpopulational variation has remained. Old measurements and taxonomies continue to be reanalyzed with little new insight gained into the nature of human variation (e.g., Birkby 1966; Crichton 1966; Rightmire 1970a, 1970b).

Multivariate analysis has not eliminated typological thinking. Analyses of skeletal remains that use racial categories in the context of multivariate methodology frequently resort to typological analysis. When we discuss the origins of the “Asian component” of the American Indian, or the “Negro component” of an African population, we are especially prone to slip into typological thinking. The classification of contemporary groups using genetic traits does insure nontypological thinking. Most racial classifications that use genetic features remain typological. In the same way, skeletal biologists remain typological thinkers even though they speak of variation and use multivariate techniques.

Because it shows promise as a way to escape this dilemma, there has been an increased interest in the use of discrete traits, which are thought to represent features under genetic control. Berry and Berry (1967, 1972) and Finnegan and Faust (1974) have suggested that noncontinuous variants of the teeth and bony skeleton can be used to establish biological distances between skeletal populations. There are many problems in defining even the most common discrete traits, in understanding the nature of discontinuous variation, and in understanding the inheritance of these traits. For example, the influence of development upon the appearance of discrete traits may be intimately related to nongenetically determined (canalized) development (Howe and Parsons 1968). Thus, the appearance of discrete skeletal traits may be as much a function of nongenetic factors as genetic factors. For this reason, the use of discrete traits to obtain genetic differences or similarities may not be as useful as many researchers believe.

Anthropometry, Statistics, and Biological Processes

Our inability to break away from historical–descriptive approaches in the light of more sophisticated statistical procedure needs to be examined in more detail. The paradox of typological analysis undertaken with complex procedures, such as multivariate analysis, was noted by Blackith and Reyment (1971). Their discussion of the development of multivariate techniques in life science confirms many of our observations that evolutionary theory had little impact on the development of processual models. Despite the evolutionary concepts of change, adaptation, and variation, the typological approach continued. According to Blackith and Reyment, “this fact in itself is witness to the superficial nature of biology at the classificatory level [1971:5].”
Relatively advanced statistical techniques were developed quite early to describe variation and compare attributes among large samples. Pearson, in 1896, first applied his regression analysis to cranial material in an investigation of the correlation between cranial width and length in different racial groups. Subsequently, Lee (1901), Fawcett (1901–1902), and MacDonnell (1901) also published correlation analyses using craniometric variables.

Correlation analyses of craniometric variables continued throughout the 1920s. In 1924, Pearson and Davin published an analysis that differed significantly from earlier studies and has since become a classic in both anthropology and biostatistics. Using a sample of 1600 ancient Egyptian crania, Pearson and Davin attempted to determine the major factors accounting for particular patterns of correlations in the human skull. In doing so, they delineated two broad types of correlations that can be found in anatomical data: "spurious" and "organic." Spurious correlations generally occur between two variables spanning the same anatomical region, and thus, for this reason alone, a strongly positive correlation is to be expected. Organic correlations, on the other hand, occur between two measures covering different, and often distinct, anatomical regions. More importantly, Pearson and Davin (1924) stressed that it is the pattern of organic correlations that is most likely to reveal meaningful biological relationships. Indeed, as Solow has noted,

although the required calculations were too comprehensive to be carried out at that time, Pearson and Davin predicted the development of the factor analysis technique and its use in the study of the determinants of the growth and development of cranial bones [Solow 1966:16].

Pearson and his co-workers continued to study cranial variation with similar approaches, often focusing upon specific areas of the human skull in the hopes of understanding particular relationships (Woo 1931, 1937; Elderton and Woo 1932; Pearson and Woo 1935).

Early biostatistical analysis of crania tended to focus on the mathematics of a particular statistical procedure rather than on the biological aspects of craniofacial morphology. Often the primary objective of craniological studies was a demonstration and substantiation of statistical procedures on large, multivariate samples. As a result of this overriding concern, very little attempt was made at a biological explanation of observed statistical phenomena, Pearson and Davin's work being the most notable exception. In fact the development of distance measures and related techniques merely reinforced the typological and taxonomic concerns of physical anthropology at this time, especially in relation to the concept of race (Fisher 1936a, 1936b).

Prior to World War II biostatistical research clearly reflected the interest in problems of historical reconstruction and racial origins. For example, Pearson's (1926) "coefficient of racial likeness" (CRL) utilized mean, standard deviation, and sample size to determine a measure that was essentially an additive assessment of the critical ratio. As a consequence, the CRL is biased toward separating samples
when the units of measure are correlated; it emphasizes differences when more kinds of measurements are introduced (Hunt 1959:75).

Although other distance statistics have been developed to overcome the limitations of Pearson’s CRL, the problem of interpreting the meaning of the differences remains. Take, for example, Mahalanobis $D^2$, which, as Hunt (1959) notes, is a more appropriate measure of distance because it can correct for correlation of variables and differences in sample size as well as test the impact of additional variables to the $D^2$ score. There are procedures for measuring the significance of $D^2$ differences between populations. According to Hunt, however, Roberts (1954) has ascertained that differences in $D^2$ depend on the measurements taken.

The role that size and shape play in the distance between populations was investigated by Penrose (1954). Although this represents an attempt at uncovering the “meaning” of biological distance in terms of size and shape it provides interpretation at the broadest level. As Hunt observed,

> When any multivariate distance function is used, similar distances in two comparisons are no guarantee that the pattern or divergence of the separate variables are alike. What we measure, then, is at the heart of using anthropometry for racial studies [1959:76].

Unfortunately, neither the anthropologist nor the biostatistician of the pre-war period understood the biology of the skeleton well enough to question whether the observed differences have biological significance. Both undertook their analyses with the express purpose of establishing racial, typological distinctions between skeletal samples (e.g., Morant 1925, 1935; Stoessiger 1927; Collett 1933; Fawcett 1901–02; Elliot Smith and Wood Jones 1910).

The fact that this orientation has continued until the present is evidenced by a more recent discussion by Weiner and Huizinga:

> Human biologists have a variety of reasons for making comparisons between populations, or rather between appropriate populations samples. The oldest established object of inter-group comparisons still continues to be of interest to many, namely the tracing of historic or prehistoric relationships amongst human populations. These may reflect actual genetic relationships, the derivation of one group from another of two groups from a common ancestry or again a group may be the result of actual mixing between two parental communities [1972:v].

Similarly, Howells, in a symposium on craniofacial growth and development, reflected concern for historical analysis by stating that “my purpose is not the study of growth but of taxonomy, of the variation between existing recent populations in the dry skull, for obvious reasons relating to the study of human evolution [1971:210].”

This is confounded by his observation that, although the primary goal of multivariate craniometrics is to determine racial and taxonomic affiliations, “we do not actually know whether ... variation is of taxonomical, functional or genetic importance, relative to other known or unknown features of the skull [Howells, 1973:3].”
Questions relating to such processual concerns as adaptation, structural-functional relationships, and more general biological phenomena that might explain cranial variation and evolution are rarely considered in the dry skull. Instead, gene flow or admixture are usually implemented to explain cranial variation in both ancient and extant human populations. With some notable exceptions (Bielecki and Wetton 1964; Tattersall 1968; Suzuki 1969), the same research strategy is generally followed even when cranial materials are arranged within a temporal framework and evolutionary mechanisms other than gene flow might be investigated more readily (Jantz 1973; Wiercinski 1966).

Specific criticism of anthropological craniology has recently been provided by craniologists who take a more dynamic approach to the study of the human skull. Horowitz and Osborne for example, stated,

The historical beginnings of anthropometric interest in the dentition and cranial and facial characteristics implanted a conceptual orientation which is seriously in need of re-evaluation in respect to their adaptive significance in human evolution [1971:189].

Only by injecting a notion of process into the theoretical foundation for cranio-metric studies can we consider broad evolutionary problems in both the fossil record and more recent remains. Without this, anthropometric studies will continue to be typologically and historically oriented and will provide no real understanding of human evolution in general.

This criticism of the analysis of cranial material also applies to the use of postcranial remains. Often, postcranial remains were not deemed of sufficient biological interest to be retained. Vast numbers of long bones, vertebral columns, pelvises, etc. were reburied or discarded in the backdirt of excavation. When postcranial material was collected, it was used only to determine the age and sex of the individual (e.g., Dwight 1904–1905; Holtby 1918; Pearson and Sell 1919).

Analysis of Form and Function

Alternatives to the historical-descriptive studies in osteology were available, beginning in the early 1900s. The analysis of form and function from a growth and development perspective could have provided a method for interpreting morphological features.

The theoretical foundation for the dynamic study of form was provided by D'Arcy Thompson's classic work On Growth and Form (1917/1942). Thompson recognized that form, growth, and function are all intimately related. In terms of form as it relates to growth, for example, he stated,

The form of an object is defined when we know its magnitude, actual or relative, in various directions and growth involves the same concepts of magnitude and direction, related to the further concept or "dimension" of time [1971:15].
Similarly, Thompson showed that the degree of dependence of form on function is quite extensive. Mechanical relationships between two or more structures act both to limit and stimulate growth. Form, therefore, is the result of the forces placed on anatomical components and their associated structures throughout ontogeny, or the growth process.

It is clear, I think, that we may account for many ordinary biological processes of development or transformations of form by the existence of trammels or lines of constraint, which limit and determine the action of the expansive forces of growth that would otherwise be uniform and symmetrical [Thompson 1971:287 (emphasis added)].

Thompson's interpretation of form and function utilized a descriptive analysis of structure based on the "statics" of the civil engineer. In this model, the body is viewed as a machine that must accommodate the "stress" and "strains" placed on it in the course of activity.

Thus, Thompson outlined what has become a basis for functional anatomy and biomechanics—that form is linked causally and temporally to function as the latter influences growth. Studies of form and function have also been concerned with broad questions of biological process as they relate to human origins and evolution. The most recent research has emphasized functional interpretation of postcranial remains since this material forms the basis for the comparison of prehistoric populations. There is some question as to the value of the functional interpretation of cranial material. Russell H. Tuttle, for example (1972:viii), suggests that except for certain features of the masticatory apparatus, orbital dimensions, and neurocranium, the skull provides few functional correlates.

Tuttle's interpretation is consistent with the traditional view of craniometrics discussed in the previous section. In fact, Howells (1972) concurred with Tuttle's conclusions, suggesting that functional considerations are of little value in the analysis of human crania. Although Howells (1957) and others (e.g., Landauer 1962) have been concerned with variation of human skull form (Howells 1957, 1968, 1972), these studies have tended to minimize biological causes of variation in form other than direct genetic response. For example, Howells stated that studies of the interrelationships of growth factors, function, and related compensatory factors have offered little to anthropologists dealing with the dry skull, because (a) these are secondary explanations, and (b) the broad range of differences between major populations still faces us. We must still find the various local growth determinants which, combining with one another, produce both the continuing differences in head form between racial types, and the range of variation within such a type [Howells 1957:20].

Thus, Howells has remained concerned with only the validity of specific cranio-metric variables for "taxonomic purposes."

The analysis of crania for taxonomic purpose alone has been rejected by a number of researchers who believe that a functional approach to craniology is possible. Functional craniology, as a holistic approach to the study of the skull, was introduced by Moss and Young (1960). In discussions of functional craniology,
Moss (1968a, 1968b, 1971, 1972; Moss and Young 1960) expanded on several points conceived by van der Klaauw (1945, 1952) and proposed additional concepts for analysis of function in the skull. He extended van der Klaauw's original concept of "functional cranial components" from the consideration of bony elements only to include the soft tissues and spaces within the head. Each "functional component," such as mastication, protection for the brain and housing and structural support for the sense organs, subsumed two additional operational units: a "functional matrix" corresponding to all the soft tissues and spaces necessary for a given function, and a "skeletal unit" including all the skeletal tissues necessary to carry out a given function (Moss 1968a).

Operationally, functional craniology rests on the assumption "that cranial skeletal growth is [a] secondary, compensatory, and mechanically obligatory response to temporally and morphologically prior growth changes in specially related tissues [Moss 1972:481]." In other words, there are significant developmental and environmental processes that affect cranial growth and, consequently, cranial form. In order to understand these processes, we must first understand the functional relationships within the human skull and the degree to which they can affect change in both a phylogenetic and ontogenetic sense. Merely to ascribe variation and the processes that bring about variation to genetic ("racial") differences or simply to suggest that cranial change through time resulted from genetic mutation provides no real explanation of cranial morphology in either modern or fossil hominids. Such explanations, which are so common in traditional craniometric studies, only beg the more important processual questions of how and why variation and change came about.

The approach of functional craniology is clearly appealing to anthropological investigation of craniofacial variation and evolution. Because of its emphasis on the skull as a complex of "functioning" areas, each maintaining a degree of dependence as well as independence from the other, functional craniology provides a framework for viewing processes operating within the skull. In terms of anthropological considerations, investigation of the interaction of functional cranial components will make clearer the meaning and causes of human craniofacial change and variation.

The relatively minor interest, in physical anthropology, in the analysis of postcranial remains can also be attributed to an overriding concern for racial diagnosis. Whereas bones such as the femur were an early subject of description for racial assessment (Parsons 1913-1914, 1914-1915b; Pearson and Bell 1919; Ingalls 1924) and its use has continued through the application of multivariate techniques (Thieme 1957; Thieme and Schull 1957), the racial assessment of postcranial remains never captured the interest of physical anthropologists to the degree that cranial studies had. As a result, the common pattern was to exclude postcranial remains from detailed analysis.

Only when it was realized that information about sex and age could be ascertained from the skeletons were postcranial remains finally retained for further study. Although a methodology for interpreting the functional significance of sexual dimorphism could have been developed, it was not. Physical anthro-
pologists instead created statistical techniques for determining sex without concern for the functional factors that lead to these differences.

Recently, however, there has been an attempt to assess the evolutionary significance of sexual dimorphism. In a series of papers edited by David Frayer (see the *Journal of Human Evolution* Vol. 9, 1980), the importance of sexual dimorphism in making taxonomic decisions, determining phylogenetic relationships and interpreting evolutionary trends was discussed. Yet, as these researchers note, there is much disagreement about the approach and methods that should be used to answer the questions asked (see Armelagos and Van Gerven 1980).

The functional interpretation of postcranial remains received its greatest impetus from comparative studies of primate locomotion. Functional anatomical studies of human and nonhuman primates were carried out by Sir Arthur Keith as early as 1899. These, and subsequent studies, attempted to establish a relationship between certain anatomical and behavioral features. The focus of these studies was a correlation between gross body form and locomotor activity. Even later researchers (Oxnard 1963; Ashton and Oxnard 1964), utilizing a more sophisticated statistical methodology, did not move beyond the descriptive level. Often, intensive multivariate descriptions were developed in the hope that a comprehensive description would uncover the function inherent in the shape (Corruccini 1975; Day 1967; McHenry 1973; Oxnard and Lisowski 1980). In many instances, a single bone was analyzed, and the locomotor potential of the organism was interpreted from that specimen alone. According to Gomberg 1981, a multivariate analysis that merely describes an anatomical structure, or points out correlations between the form of a structure and a broad spectrum classification of behavior, without demonstrating causal relationships between specific forms and specific locomotor or postural behavior is, in the last analysis, still typological in terms of orientation, interpretation and goals.

Thus, we encounter a basic theoretical problem in the application and interpretation of multivariate statistical methods that is clearly similar to the one we discussed previously for the genetic approach. The methods of analysis may have changed, but the basic orientation toward explanation via typologically oriented descriptive models remains essentially unaltered. This certainly does not imply that multivariate statistical procedures have been unfruitful in the analysis of morphological form, or that they do not have great potential for investigating problems relating to form and function. However, such potential can only be realized by the knowledgable and thoughtful application and interpretation of these methods within a conceptual framework that allows for explanation within a nontypological, nonclassificatory framework. Addressing himself to a similar problem within an entirely different context, Einstein, at the beginning of the century, stated,

Even scholars of audacious spirit and fine instinct can be obstructed in the interpretation of the facts by philosophical prejudices. The prejudice—which has be no means died out in the meantime—consists in the faith that facts by themselves can and should yield scientific knowledge without free conceptual construction [as cited in Clark 1971:90].
More recently, Ripley (1967), Grand (1972), Stern and Oxnard (1973), and Morbeck (1975) have been critical of the descriptive nature of earlier functional studies and have suggested alternatives based on an analysis of functional features of the anatomy and behavior with the environment.

Biomechanical analysis utilizing a static approach has been implemented by Preuschoft (1970, 1973) in the analysis of the feet and lower extremities of selected nonhuman primate species, looking primarily at the locomotion capabilities of Dryopithecines and early pleistocene hominids. Lovejoy et al. (1973) and Hieple and Lovejoy (1971) have applied biomechanical analysis to the reconstruction of australopithecine gait.

In addition, biomechanical analysis of motion (Prost 1965a, 1967, 1970; Grand 1972; Jenkins 1971, 1972; Wells 1974, Wells and Tebbets 1975) has developed, which applies kinematic and kinetic analysis to locomotor problems. The methodology for motion analysis was stimulated by Manter (1938), who analyzed the quadrapedal movement of the cat, by the analysis of sport movement (Carlsoo 1967; Hay 1978; Plagenhoef 1971) and by the analysis of the development of prosthetic devices by orthopedists (Eltman 1954; Denham 1959). It is not surprising that the origin and development of the biomechanical analysis came outside the discipline, which continued its philosophical commitment to description and taxonomy rather than explanation and process (Gomberg 1981).

The many difficulties encountered in establishing the relationships between behavior and anatomy in contemporary primates are only compounded when fossil materials are considered. The completeness of the fossils and the amount of environmental reconstruction possible vary, making interpretations difficult. Although methods of taphonomy are becoming quite sophisticated, there are still problems in understanding the relationship between anatomy, behavior and, the environment. For example, the joint complexes for some of the Dryopithecines have been reconstructed, yet there are still difficulties in interpreting the postural capabilities of these forms. A great deal of information is needed to establish the population parameters for the morphology of these joint systems. We are now beginning to interpret the behavior--anatomy--environment interactions in fossil primates, and the development of a methodology for undertaking such studies should place them on a more sound foundation.

The application of the functional approach is beginning to have a major impact on the analysis of the skeletal biology of archaeological populations. It has been used to establish the relationships between populations, to interpret the interrelationship of biology and behavior and to elucidate process in skeletal development.

We have been critical of the use of racial typology in establishing historical relationships. However, there have been a number of attempts to apply a functional approach to the study of the morphology of archaeological populations. Even in the Sudan, where the racial approach (Strouhal 1971) has been the major focus, functional studies have been applied to the interpretation of postmesolithic facial development. Carlson (1976), Carlson and Van Gerven (1977, 1979), and Van Gerven et al. (1977) have used an evolutionary model to interpret the reduction in
facial morphology. They suggest that conversion to an agricultural subsistence pattern was a primary cause of the changes in facial morphology. Working in a very different part of the world, Hylander (1975) has provided a functional model for understanding the craniofacial development of the Eskimo. These studies suggest that in assessing biological affinities, one must understand the extent of the intrapopulation variation before interpreting interpopulation variation. In addition, the function of features must be determined prior to their use to establish the relationship between groups. For example, the extent and function of cranial indexes must be determined before they can be used to establish relationship between groups.

The problems of analyzing fossil hominids have improved somewhat with the increase in the size of samples and better methods for reconstructing the culture and environment of a group. The latter provides a basis for interpreting the functional complexes from a population perspective.

The relationship of changes in morphology to alterations in the subsistence pattern suggests that the biocultural approach can be applied in other areas. For example, Ångel (1969) has demonstrated how changes in the ecology of classical Greece resulted in population changes in stature, morbidity, and mortality. Similarly, Buikstra (1977) has used a regional approach to study prehistoric biocultural changes in the lower Illinois River valley. At the Dickson Mounds (near Lewiston, Illinois), changes in the pattern of pathology were associated with changes in subsistence: Lallo and co-workers found a fourfold increase in iron deficiency anemia, a threefold increase in infectious disease, and a significant increase in mortality with the intensification of maize agriculture (1978).

The study of process in skeletal biology is often overlooked in archaeological samples, although these samples represent a major untapped resource for understanding response to environmental conditions. Problems, such as growth and development (Armelagos et al. 1972; Johnston 1962; Merchant and Ubelaker 1977), and specific conditions, such as osteoporosis (Dewey et al. 1969) and function features of long bones (Lovejoy et al. 1976), can be studied using skeletal material from archaeological populations.

The functional approach provides the skeletal biologist with one of the most important useful concepts. The analysis of the morphology is enhanced by the functional interpretation of adaptive complexes. It is the key to understanding the significance of intrapopulational and interpopulational variation in extant and extinct primate and hominid populations.

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