To the Graduate Council:

I am submitting herewith a thesis written by Terry Stewert Zobeck entitled "An Analysis of the Functional Significance and Sexual Dimorphism of the Neandertal Mastoid Process." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Fred H. Smith, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

AN ANALYSIS OF THE FUNCTIONAL SIGNIFICANCE AND SEXUAL DIMORPHISM OF THE NEANDERTAL MASTOID PROCESS

A Thesis

Presented for the

Master of Arts

Degree

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Terry Stewert Zobeck

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ABSTRACT

This study examines the functional significance and sexual dimorphism of the Neandertal mastoid process. The mastoid process is identified as a part of the Posterior Cranial Complex which includes the nuchal and occipital planes, and a portion of the basicranium as well as the mastoid region of the temporal bone.

In order to draw conclusions regarding the functional significance and sexual dimorphism of the mastoid process, a number of multivariate statistical techniques are applied to a modern human sample; the Larson Site Arikara.

The examination of the morphological features of the Neandertal posterior cranial vault (a relatively long, low and broad cranium, a broad, rugose and horizontally oriented nuchal plane, a large occipitomastoid crest, and a supposedly small and nonprojecting mastoid process) shows that this morphology provides an extensive and optimally oriented area of attachment for the powerful muscles that act to counter-balance and provide force for the utilization of the relatively massive Neandertal dento-facial complex. It is demonstrated that the function of the mastoid process in Neandertals as well as modern hominids, is to provide a point of insertion for the sternocleidomastoid muscle and to provide an additional area of attachment for the nuchal

musculature. It is hypothesized that, in Neandertals, the occipitomastoid crest is developed to a greater extent than in modern hominids in order to provide even more area for the attachment of the increased nuchal muscle mass of Neandertals. This large caudally projecting crest masks the projection of the mastoid process, thus fostering the illustion of a small nonprojecting Neandertal mastoid process.

This study also demonstrates that it is possible, with some reservations, to determine the sex of individual Neandertal crania utilizing the dimensions of the mastoid process. Two methods are presented that produce nearly identical results.

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I. INTRODUCTION

Statement of Purpose

The purpose of this thesis is twofold: (1) to determine certain aspects of the functional significance of the mastoid process in *Homo sapiens neanderthalensis*, and (2) to assess the degree of sexual dimorphism observable in the mastoid process of Neandertals. More specifically, it deals with how the process is related to the surrounding morphology of the temporal and occipital bones, and how this relationship has changed through time. It also attempts to assess the degree of sexual dimorphism in Neandertal mastoid processes and to determine if this dimorphism can be used to aid in sexing individual Neandertal crania.

Statement of the Problem

Many authors have commented upon the morphology of the mastoid region in Neandertals (Alexeyev 1976; Angel 1972; Boule 1911; Guth 1963; Heim 1976; Howells 1973; Hrdlička 1930; Le Gros Clark 1964; Mann and Trinkaus 1973; Riquet 1974; Smith 1976, in press; Suzuki 1970; and Vallois 1969). The characteristics mentioned most often include: a short and nonprojecting mastoid process, a generally roughened and robust lateral surface for muscle attachment, a wide base, a medially oriented process tip, and a marked supra-mastoid ridge. In modern man the process is generally

described as long and projecting, the muscle markings on the lateral surface are more gracile, the base is narrower, the process tip tends to point caudally, and the supramastoid ridge is not as well developed as it is in Neandertals.

In this thesis the mastoid process is considered as one part of a larger functional unit that includes the base of the cranium, the temporal bone, the nuchal plane, and the occipital plane. It is my intention to demonstrate the nature of the structural and functional relationship that exists between the supposed small size of the Neandertal mastoid and the surrounding morphology, especially the nuchal plane.

In Neandertals the nuchal plane is more rugose, broader, and more horizontally oriented than in modern man. The result of this pattern is an extensive and optimally oriented area of attachment for the powerful muscles that act to counterbalance and to provide force for the utilization of the relatively massive Neandertal dento-facial complex. A significant contributing factor to this increased rugosity is the occipitomastoid crest. In Neandertals the crest is larger in every dimension than in modern specimens. It thus projects further caudally than in modern hominids, to the extent that it normally projects further than the tip of the mastoid. This fosters the illusion of a reduced mastoid process in Neandertals when viewing the cranium in <u>norma lateralis.</u> I propose that the occipitomastoid crest provides

additional area of attachment for muscles that in modern man require only the area provided by the nuchal plane and mastoid process, but which in Neandertals (due to the increased size of the musculature) require an increased area. Instead of increasing the breadth of an already broad nuchal plane the same result is achieved by developing a downward projecting crest that provides ample area for muscle attachment.

The posterior neurocranium of Homo sapiens sapiens exhibits a more evenly contoured curve from opisthion to lambda, perhaps due to decreasing demand on the craniofacial (including dental) complex, thus producing a more vertically oriented nuchal plane than in Neandertals. This, along with the reduction of the occipitomastoid crest, results in the distinctly projecting mastoid of Homo sapiens sapiens.

Even though the mastoid processes appear to be vastly reduced in Neandertals, some degree of sexual dimorphism should still be apparent. This should be especially true if the processes are not in fact as reduced as has been thought. I would propose that the degree of sexual dimorphism is no greater in modern man than it is in Neandertals. If this is indeed the case then it may be possible to sex individual Neandertal crania on the basis of the mastoid.

These hypotheses are supported by observations, with some reservations of course, upon the posterior cranial morphology of Neandertals and modern man taken from the

literature as well as my own observations on a modern cranial series and Neandertal specimen casts. Also, these hypotheses are tested by the analysis of a battery of measurements taken on this area in both the modern and Neandertal sample (where appropriate). These data are subjected to multivariate morphometric analyses in an attempt to discern the relationship between the various parts of the posterior cranial functional complex. The guidelines for multivariate analysis set forth by Corruccini (1978) are followed especially with regard to relating the statistical results to the original anatomy. These multivariate techniques and guidelines are discussed in detail in the Methods section.

II. POSTERIOR CRANIAL MORPHOLOGY AND MUSCULATURE IN *HOMO SAPIENS NEANDERTHALENSIS* AND *HOMO SAPIENS SAPIENS*

The Temporal Bone

The temporal bone is a paired bone located on the sides and base of the cranium. It is posterior to the sphenoid, inferior to the parietals and anterior and lateral to the occipital. It is generally divided into three portions:

1. The squamous portion is the broad and flat superior portion.
2. The petrous portion contributes to the formation of the base of the skull, supports the brain, and houses the inner ear.
3. The mastoid process is a cone shaped projection located behind the auditory meatus forming the posterior portion of the temporal (Bass 1971).

The mastoid process contains one or more foramina for the transmission of the mastoid branch of the occipital artery and the mastoid emissary vein. Another feature of the mastoid process is its internal structure which consists of a large number of mucous lined air cells. These cells connect with the tympanic cavity; their exact function is unknown (Bast and Anson 1949; Anson and Donaldson 1967). An interesting fact is that these air cells are more numerous

in Neandertals than in modern hominids. This difference has not been explained satisfactorily.

The Posterior Cranial Complex

Moss and Young (1960:281) make the deceptively simple statement that "the form of the skull is related to its functions." While this seems to be self-evident it is often overlooked. They go on to claim that the skull is composed of a number of functional components that are associated with particular soft tissues. Moss and Young (1960:290) state the relationship between the soft tissue and the bone tissue:

> . . . ontogenetically the form of the osseous skull at any moment accurately reflects the resultant of the functional demands of the protected and supported soft tissues. An identical orientation may be given to phylogenetic considerations.

The primary changes that occur in soft parts (e.g. muscles) produce secondary changes in bone.

Bilsborough (1972) has adopted the notion of functional components in his study of 12 such cranial complexes. He compared three human groups using D^2 analysis: European Neandertals (EN), Middle East Neandertals (MEN), and Upper Paleolithic man (UPM). Two of Bilsborough's complexes are of special interest to the present study: cranial vault (which includes the temporal bone) and basicranium (which includes the nuchal plane). The D^2 values for the two complexes are as follows:

	EN-MEN	EN-UPM	MEN-UPM
Cranial Vault	8.5*	8.9*	5.4*
Basicranium	4.8**	4.5**	1.3

*Significant D^2 value at the .01 level.

**Significant D^2 value at the .001 level.

The values indicate that these complexes have changed considerably through time. European Neandertals are distinctly different from Middle Eastern Neandertals and Upper Paleolithic hominids.

In this thesis I too have adopted a functional component approach. I have termed this component the Posterior Cranial Complex. It includes the mastoid region of the temporal bone, the occipital plane, the nuchal plane, and the foramen magnum area of the basicranium. The changes that occur through time in the orientation and size of the soft tissue of this area, as well as in the soft and bony parts of the rest of the cranium, should certainly affect the form of the posterior cranial complex.

Posterior Cranial Morphology of Neandertals

There is nearly unanimous agreement in the literature on the morphology of this region in Neandertals. Neandertal posterior cranial morphology is characterized by a broad, long, rugose and horizontally oriented nuchal plane; a broad and shallow digrastic sulcus; strongly developed

occipitomastoid crests; and small nonprojecting mastoids with broad bases (Boule 1911; Guth 1963; Heim 1976; Hrdlička 1930; Smith 1976; Suzuki 1970; Vallois 1969; Weidenreich 1940). The feature that attracts the most comment is the small nonprojecting mastoid processes. Vallois (1969:392), commenting upon the general morphological trend as it appears in La Quina Hominid 27, states: ". . . la portion apophysaire proprement dite est extrêmement courte." Hrdlička (1930), in reviewing the fossil specimens available to him at the time, repeatedly states that the mastoid processes of Neandertals are noticably smaller than modern man's. His remarks on the Gibralter/Forbes Quarry cranium are typical: "The mastoid was decidedly smaller than it is in modern crania" (Hrdlička 1930:167). Boule (1911:43), in his classic work, comments on the mastoids of La Chapelle-aux-Saints: ". . . les apophyses mastoides sont très réduites . . . ." Heim (1976:162) also finds that Neandertals have small mastoids; when discussing the fossils of La Ferrassie he writes: ". . . les apophyses mastoides des Néandertaliens sont moins développées que celles des Hommes modernes . . . ." McCown and Keith (1939:264-265) compare the mastoid of the Gibralter cranium to Tabun I's: "It is of small size in both, but is placed more vertically in the Tabun skull than in the Gibralter skull."

At two transitional sites in North Africa, Skhūl and Amud, a change to the modern form can be seen. McCown and

Keith (1939) report that the processes of Skhūl V are modern in size while Skhūl IV's are intermediate. Suzuki (1970:145) reports that the left mastoid process of Amud I ". . . projects downward and slightly forward and is well developed, unlike that of classic Neandertals."

These authors are commenting upon a single specimen or the general trend in Neandertals. Smith (1976:90) however, discussing the series of temporals at Krapina (Yugoslavia), is able to discuss the variation that exists within that sample:

> . . . the general tendency in the Krapina sample is to observe mastoid processes that do not project below the cranial base. This is the configuration seen in the temporal from the Krapina C skull and in the other more complete temporal, Number 39-1. However, there are at least two specimens (and probably others) that exhibit mastoids that project somewhat below the cranial base.

Posterior Cranial Morphology of Modern Man

This region in *Homo sapiens sapiens* is markedly different from the Neandertal pattern. The nuchal plane is shorter, narrower, more gracile and less horizontally oriented than it is in Neandertals. The digastric sulcus is narrow and deep, and the occipitomastoid crest is greatly reduced (in a few of the Arikara crania I examined it is almost unobservable). The mastoid process projects below the cranial base; the muscle markings on the lateral surface are more gracile; and

the supramastoid ridge is usually not as well developed as it is in Neandertals.

The Illusion of Small Mastoids in Neandertals

It would appear then that the mastoid process has developed through time, attaining its largest size in modern man. It may be, however, that this trend is more illusory than real. Riquet (1974) offers an explanation for this illusion. Due to the lower positioning and more horizontal orientation of the cranial base the mastoid tip fails to project below the cranial base. This causes the mastoid to appear small. Heim (1976:163) is more specific, he lists two contributing factors:

1. The external surface of the mastoid forms, with the rest of the mastoid region, a uniform surface that makes it difficult to identify and isolate the mastoid process.
2. The projection of the process is generally masked in adults by the development of the eminence located medially to the process.

This eminence has been termed the occipitomastoid crest (Weidenreich 1940; Stewart 1962). This crest runs, in an oblique manner, anterio-posterially and lies medially to the mastoid process. It is separated from the process by the digastric sulcus. In Neandertals, as discussed above, the

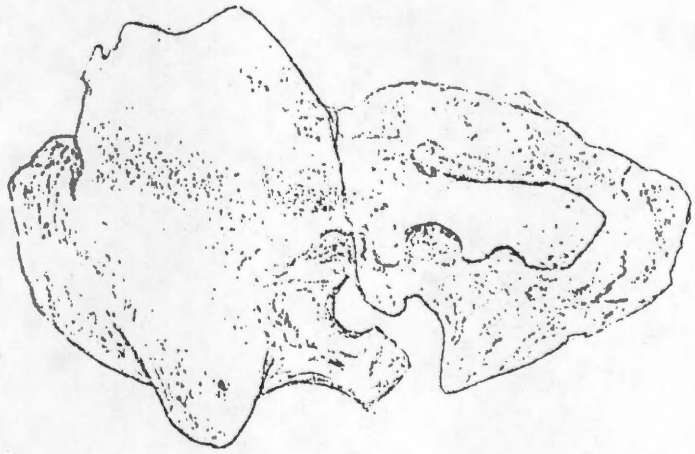
crest is massive; it is a large roughened area that projects caudally (see Figure 1). In most instances it projects considerably further than the mastoid process. For example, Angel (1972:55) states that in the 13 Neandertal cranial casts that he measured the crest projected 1.2mm below the mastoid process, on the average, or 3.0mm if he omitted the three Skhūl male skulls.

Musculature of the Posterior Cranial Complex

There are a number of muscles and muscle groups that have either their point of origin or insertion in this area. The musculature, only as it applies to modern man, is discussed since soft tissue is not preserved in the fossil record. However, there is no reason to believe that the basic arrangement is significantly altered in Neandertals. There are three major muscles in addition to a number of superficial ones that are of importance in any functional interpretation of the mastoid. Their areas of attachment are illustrated in Figures 2 and 3. The major muscles are:

Sternocleidomastoideus

> This muscle arises by a tendinous head from the manubrium sterni and by fleshy fibers from the medial third of the clavicle; it inserts upon the mastoid process behind the ear. The sternocleidomastoids of the two sides, acting together, powerfully flex the head and neck; the muscle of one side laterally flexes the head and neck toward this side and at the same time rotates the face toward the opposite side. (Hollinshead 1969:369-370) (See Figures 2 and 3.)



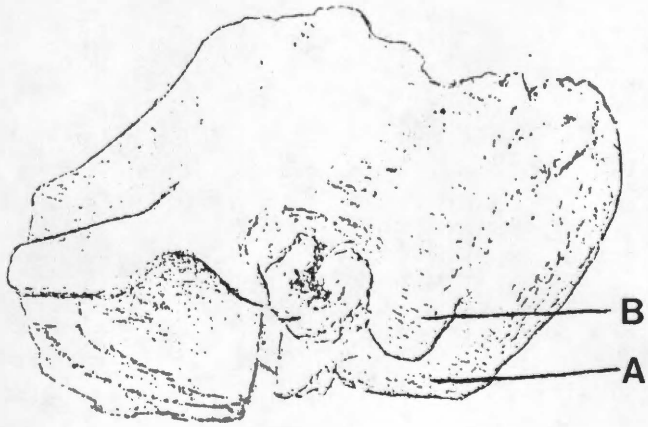


Figure 1. A comparison of two temporals, 38.2/32.14 (top) and 39.1 (bottom), from the Krapina site. Note the large projecting occipitomastoid crest (A) of 39.1 which produces the effect of a small nonprojecting mastoid process (B). The projection of 38.2/38.14 is accentuated by the absence of the occipitomastoid crest area which is not preserved on the specimen. The difference in projection is still distinctive however, based on metrics. Drawings by M. O. Smith.

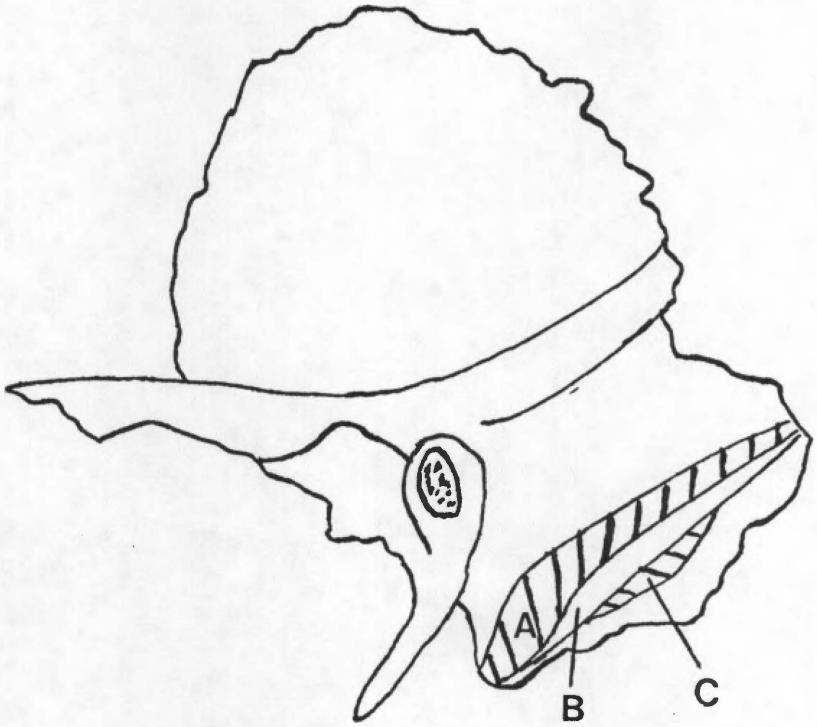


Figure 2. Left temporal bone showing the areas of muscle attachment. The muscles are: (A) m. sternocleidomastoideus, (B) m. splenius capitis, (C) m. longissimus capitis. (After Gray 1936.)

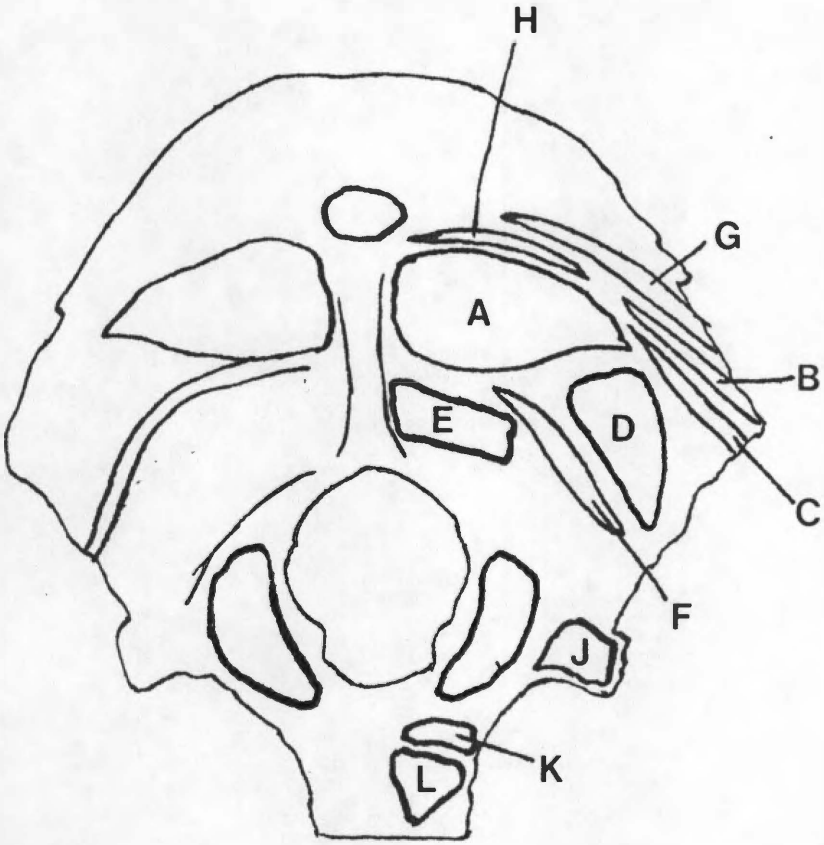


Figure 3. External view of the occipital showing the areas of muscle attachment. The muscles are: (A) m. semispinalis capitis, (B) m. sternocleidomastoideus, (C) m. splenius capitis, (D) m. deliquus superior, (E) m. rectus capitis posterior minor, (F) m. rectus capitis posterior major, (G) m. occipitalis, (H) m. trapezius, (J) m. rectus capitis lateralis, (K) m. rectus capitis interior, and (L) m. longus capitis. (After Gray 1936.)

Splenius capitis and Splenius cervicis

The splenius muscles arise medially and pass laterally as they are traced upward. The splenius capitis arises from the lower half of the ligamentum nuchae and the spinous processes of the seventh cervical and upper three or four thoracic vertebrae and inserts laterally on the mastoid process and occipital bone of the skull. The splenius cervicis arises from the spinous processes of about the third to sixth thoracic vertebrae and inserts laterally on the upper two to four cervical transverse processes. The muscles of one side, acting together, will rotate the head and cervical vertebral column toward the same side; when they act bilaterally they aid in extension of the head and neck. (Hollinshead 1969: 220-222) (See Figures 2 and 3.)

Longissimus thoracis, Longissimus cervicis, and Longissimus capitis

The fascicles composing the three divisions of this muscle arise from the common tendon of the erector spinae and from the transverse processes of the lower four cervical vertebrae. They insert into the lower nine or ten ribs and the corresponding transverse processes of most of the cervical vertebrae, and the mastoid process of the skull. (Hollinshead 1969:223) (See Figure 2.)

The function of this muscle is to extend, laterally flex, and rotate the vertebral column (Quiring and Warfel 1967:54).

III. THE SKELETAL SAMPLES

Introduction

In order to assess the functional morphology of the Posterior Cranial Complex it is necessary to examine this area in a series of modern crania as well as in the known Neandertals. Aside from the evolutionary aspects, examining modern samples is necessary primarily because the number of measurable Neandertal crania falls short of the sample size requirements for most of the statistical methods employed in this thesis to isolate and demonstrate the existence of functional relationships among structures and anatomical regions in this area. Consequently the establishment of functional interrelationships and/or complexes must depend on the analysis of modern cranial samples with an adequate number of specimens preserving the entire morphological region.

Furthermore there is a problem regarding the nature of the Neandertal sample. In any attempt to isolate functional patterns or to examine the significance of a morphological trait, it is best to first examine them in a specific population. This allows the determination of normal ranges of variability and gives some insights into the morphologies being examined. Since the Neandertal specimens are recovered from such a large geographical area and span several thousand

years it is not possible to regard them as a population in the same sense that this concept is used in the modern biological sciences. Only the Krapina sample comes close to representing a population in this sense. It is a large sample from one site, but the hominid specimens are found in different strata which temporally ". . . extend over several alternating cool-warmer periods, probably extending from the end of the Riss-Würm Interglacial to the end of the Würm II stadial" (Smith 1978:104). According to Smith (1980), however, all known temporals are from the Hominid zone defined by Gorjanivić.

Thus examining a morphological region in modern crania which, as clearly as possible, represents a "true biological population" provides a useful and necessary model for the analysis of the Neandertal series.

Larson Site Arikara

The Larson (39WW2) Site Arikara, a Plains Indian group, meet the above requirements. The sample size is large, consisting of 692 human skeletons. Also, the site was occupied for a relatively short period of time—A.D. 1750 to 1785 (Jantz 1973:17), and Owsley (1975) suggests that the burials from Larson may be drawn from a single breeding population.

The Larson site is one of several Arikara sites in South Dakota. The site is located on the east bank of the

Missouri River approximately two miles southeast of Mobridge (Owsley, Berryman and Bass 1977:119). The site consists of a fortified village and its neighboring cemetery.

Three phases of excavations have been undertaken at Larson. During the summers of 1963 and 1964 the village was excavated by the River Basin Survey crews under the direction of Alfred W. Bowers. Further excavations at the village were conducted by the River Basin Survey in 1966 under the direction of J. J. Hoffman. The cemetery was excavated by crews from the University of Kansas during the summers of 1966, 1967, and 1968 under the direction of William M. Bass (Owsley, Berryman, and Bass 1977:119). The skeletal material is housed at the Anthropology Department of The University of Tennessee, Knoxville.

The cranial sample measured for this study consists of 48 male and 51 female specimens taken from the village as well as the cemetery. The former were, for the most part, recovered from the floors of the earth lodges. These burials may represent the remains of a raid and subsequent massacre that caused the abandonment of the village (Owsley, Berryman, and Bass 1977).

The Arikara at the Larson site were semisendentary horticulturalists ". . . but the villagers' role as <u>brokers</u> was far more significant" (Lehmer and Jones 1968:86). Apparently the Plains Indians had an insatiable desire for

trade goods and horses. This desire was met by the creation of a barter economy and a system of distribution of which the Arikara were an important link (Lehmer and Jones 1968:86). Increased contact with Europeans brought not only more trade goods but smallpox as well. The Arikara were especially hard-hit. The epidemic of 1780-1781 reportedly killed 75% of the Arikara population (Lehmer and Jones 1968:91; Lehmer 1971:172). Due to the effects of the epidemic and raid at Larson, it appears that the resultant burials represent deaths over a relatively short period of time and thus do represent a true biological population.

Neandertals

Measurements for 33 Neandertal cranial specimens were obtained from the literature or made available by F. H. Smith for use in this study. The specimen name, country of origin, approximate date, and measurement source are summarized in Table 1. The dates for the various sites range from circa 250,000 to 32,000 years BP. The sample includes the "Classic" Neandertals of Western Europe as well as specimens from Central Europe, North Africa, Southwest Asia, and Sub-Saharan Africa. Also included are what some would term "transitional" or "progressive" forms (i.e. Steinheim, Ehringsdorf, Skhūl, Amud, Qafzeh, and Jebel Irhoud) but which are still similar enough in morphology to the Neandertal grade to be included in it for certain comparisons.

TABLE 1. DESCRIPTIVE INFORMATION FOR NEANDERTALS

Specimen		Country	Date	Source*
1	Forbes Quarry	Gibralter	50,000	2,3,6
2	La Ferrassie 1	France	35,000-70,000	1,2,6
3	La Ferrassie 2	France	35,000-70,000	5
4	La Chapelle	France	35,000-70,000	1,2,3,6
5	La Quina 5	France	35,000-70,000	1,2,6
6	La Quina 10	France	35,000-70,000	1
7	La Quina 27	France	35,000-70,000	1,5
8	Le Moustier	France	35,000-70,000	3,4
9	Saccopastore	Italy	60,000	2,6
10	Monte Circeo	Italy	35,000-70,000	2,4
11	Spy 1	Belgium	35,000-70,000	1,2,3
12	Spy 2	Belgium	35,000-70,000	1,2,3
13	Neanderthal	Germany	35,000-70,000	2,3
14	Steinheim	Germany	200,000-250,000	3
15	Ehringsdorf	Germany	Riss-Würm	3
16	Krapina C	Yugoslavia	Riss-Würm/Würm	5
17	Krapina 38.7/38.11	Yugoslavia	Riss-Würm/Würm	5
18	Krapina 38.2/38.14	Yugoslavia	Riss-Würm/Würm	5
19	Krapina 38.12	Yugoslavia	Riss-Würm/Würm	5
20	Krapina 38.21	Yugoslavia	Riss-Würm/Würm	5
21	Krapina 39.1	Yugoslavia	Riss-Würm/Würm	5
22	Tabun 1	Israel	45,000-60,000	2,3,5
23	Skhūl 4	Israel	35,000	2,3
24	Skhūl 5	Israel	35,000	1,2,3,6
25	Skhūl 9	Israel	35,000	2,3
26	Qafzeh 3	Israel	30,000-35,000	2
27	Qafzeh 6	Israel	30,000-35,000	2,5
28	Qafzeh 9	Israel	30,000-35,000	2,3
29	Amud 1	Israel	45,000-60,000	2,3
30	Jebel Irhoud 1	Morocco	32,000	5
31	Jebel Irhoud 2	Morocco	32,000	5
32	Shanidar 1	Iraq	46,000	2,3
33	Broken Hill	Rhodesia	35,000-70,000	3,6

*1, Vallois (1969); 2, Vandermeersch (1977); 3, Suzuki (1970); 4, Heim (1976); 5, Smith (1980); 6, Cast.

IV. METHODS

Introduction

Corruccini (1978:140-141) has proposed a set of criteria for use in any multivariate study. In the present study I have followed these criteria as closely as possible. These criteria can be briefly stated as:

1. Adequate justification should be given for the necessity of doing a morphometric analysis instead of some other approach.
2. The reason for taking each measurement should be explained. If one is undertaking a functional comparative study, the functional significance of the measurement should be defended.
3. Analysis of the measurements must be competently done.
4. The multivariate results should be related back to the original anatomy.

In the present study I have attempted to show the interrelatedness of the various components of the Posterior Cranial Complex. To do this requires that a large battery of measurements be taken to insure complete description of the size and shape variation. By definition this requires a multivariate approach. Such an approach is capable of analyzing many dimensions simultaneously, and reducing the number of variables to a more easily interpretable number.

Variables

Fifteen measurements and two angles were taken on the series of Arikara from the Larson Site. Appendix A is a list of the measurements and angles as well as their definitions. Due to the incomplete nature of the Neandertal specimens, however, it was not possible to obtain all of the measurements on every specimen.

The battery of measurements used in the present study is patterned after Howells' (1973) study of the worldwide cranial variation in man. Thus, indices and linear combinations of measurements are excluded as well as arcs or circumferences since they contribute no information to shape variation but only to size. Howells (1957) suggests that the linear measurements adequately account for size variation. Some measurements used in the present study are taken directly from Howells' (1973) study (biasterionic breadth, occipital chord, occipital chord subtense, occipital chord fraction, basion-bregma height, and glabello-occipital length) and their usefulness is explained by him.

Other measurements were devised by myself and Fred H. Smith for specific application to the problems examined in this thesis. These measurements were devised to cover as many different aspects of size and shape variation as possible. Towards this end they contain many transverse and sagittal diameters as well as two radii that are perpindicular to the transmeatal axis.

Two measurements developed by Zoja (see Vallois 1969) are included that describe the size and shape of the mastoid process (mastoid base length and mastoid projection). Figure 4 illustrates these two measurements. Zoja's technique for measuring mastoid projection differs considerably from the most commonly used technique developed by Martin (see Vallois 1969) in that Zoja's measurement is not referenced to the ear-eye plane. It is taken on the midpoint of the medial aspect of the process from the floor of the digastric sulcus. I find this to be a more reproducible and therefore a more reliable measurement. Vallois (1969:397) discusses the various techniques of measuring the mastoid and concludes that Zoja's methods are superior since they more effectively reflect the projection of the process and clearly show the broadness of the base in Neandertals.

A third method of measuring mastoid projection that may prove superior to the others, for certain comparisions, is one devised by Fred H. Smith. It is measured from porion to mastoidale (easily identifiable fixed points on both Neandertals and modern man), and it is not affected by differences in the angle or extension of the nuchal plane.

Two angles are calculated that define certain aspects of occipital shape. The occipital angle (see Figure 5) is taken directly from Howells (1973). This angle was taken on some Neandertal specimens (those measured from casts) while

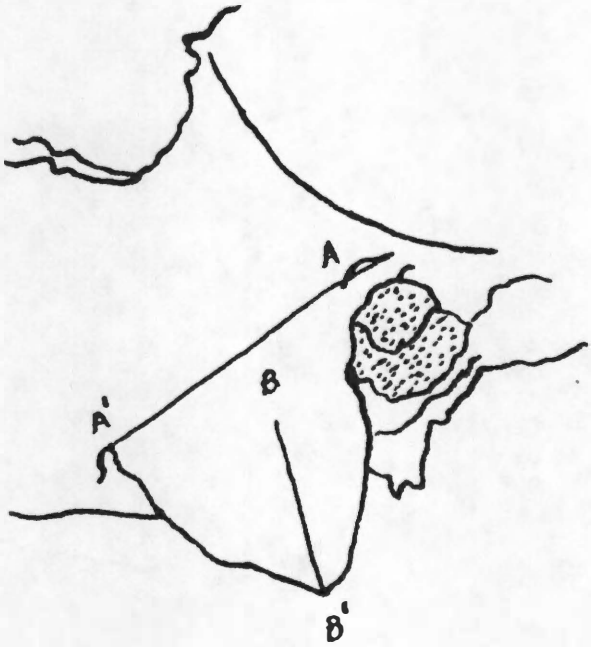


Figure 4. Height (projection) of the mastoid and breadth of the base of the process. Projection is measured from B to B' (B is located on the floor of the digastric sulcus). Length of the base is measured A to A'. After Zoja (see Vallois 1969).

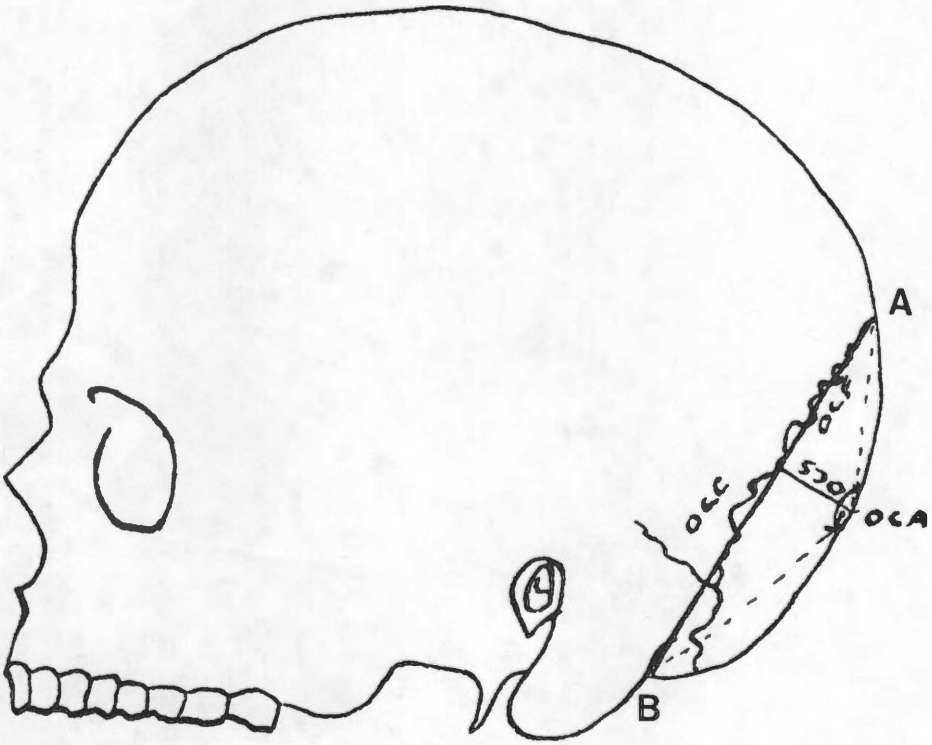


Figure 5. Angle of occipital curvature. Measured from the maximum height above the occipital chord (OCC). The other measurements needed to obtain this angle are the occipital chord subtense (OCS) and the occipital chord fraction (OCF). The anatomical points are lambda (A) and opisthion (B).

for others it was obtained from the literature. The two are not exactly the same. Howells specifies that the angle be measured by the curvature of the occipital bone at its maximum height above the occipital chord. In the literature the angle is obtained from the triangle formed by opisthion-inion-lambda. Howells' maximum height above the occipital chord and inion are not always the same point. The difference in the resulting angle is slight, in my opinion, and is therefore ignored to obtain a large sample size for this variable. This opinion is supported by the similarity of the occipital angle values obtained for certain Neandertal specimens from the literature and from Howells' (1973) technique [e.g. Suzuki (1970) obtained a value of 115° for Skhūl V using the lambda-inion-opisthion technique while I obtained a value of 119° on a cast of Skhūl V using Howells' (1973) technique]. I believe that the angle contains important shape information, the usefulness of which compensates for the error between the two measurement techniques. The second angle, porion angle (see Figure 6), was devised by myself. It is computed from lambda radius, occipital chord, and opisthion radius. The angles were computed by ANGLE, a FORTRAN program written and provided by Patrick J. Key.

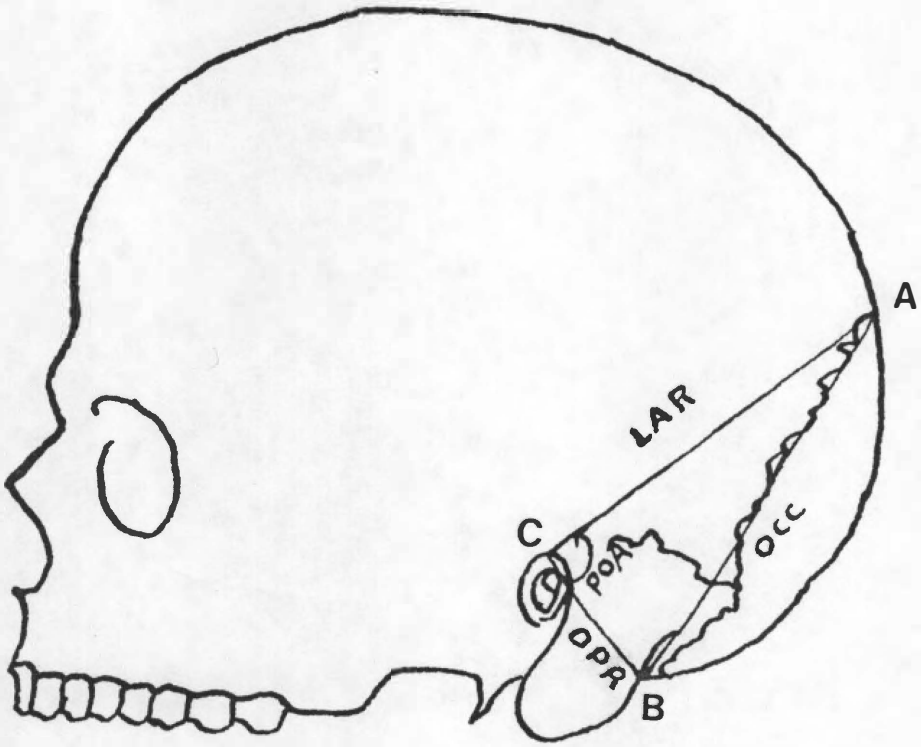


Figure 6. Porion angle. Obtained from the triangle formed by lambda radius (LAR), occipital chord (OCC), and opisthion radius (OPR). The anatomical landmarks are lambda (A), opisthion (B), and porion (C).

Descriptive Statistics

Descriptive statistics for each variable are calculated by means of DISTAB, a FORTRAN program written and provided by Patrick J. Key. They are given in Table 2 for the Larson Site Arikara males, Table 3 for the Larson Site Arikara females, Table 4 for the Larson Site Arikara males and females combined, and Table 5 for the Neandertals. The Arikara males and females are combined in order to better facilitate comparisons with the Neandertals, which are of unknown sex. These data are the input for the various statistical methods described below.

Multiple Regression Analysis

This technique analyzes the relationship between a single dependent variable and several independent variables both of which are quantitative (Hair et al. 1979). Multiple regression is superior to simple regression with only one independent variable since more than one factor influencing the dependent variable can be accounted for. Rarely can one variable alone adequately predict the behavior of the dependent variable. The objective of multiple regression analysis is to predict the unknown value of the dependent variable with the known values of the independent variables. The formula for such a regression is:

$$Y = b_0 + b_1(x_1) + b_2(x_2) + \ldots + b_n(x_n) \qquad (4\text{-}1)$$

TABLE 2. DESCRIPTIVE STATISTICS OF THE LARSON SITE ARIKARA MALE CRANIA

	VARIABLE	CODE NAME	N	MEAN	VARIANCE	STD. DEV.	RANGE	SKEWNESS	KURTOSIS
1	BAS BREG HT	BBH	48	134.6	20.2	4.5	124.0 - 145.0	-0.082	-0.409
2	GLAB OCC L	GCL	48	181.5	34.1	5.8	169.0 - 191.0	-0.182	-0.766
3	BI AST BR	BAB	48	107.0	22.1	4.7	98.0 - 116.2	0.177	-0.628
4	OPS INN L	OIL	48	53.4	27.4	5.2	40.4 - 65.4	-0.146	-0.108
5	INN LAM L	ILL	48	56.8	65.8	8.1	40.7 - 75.8	0.396	0.275
6	MAS FOR BR	MFB	48	105.3	37.8	6.2	91.0 - 117.5	-0.337	-0.229
7	MASTOID PRO	MAP	48	10.6	4.3	2.1	6.4 - 14.4	0.108	-0.881
8	MAS BS L	MBL	48	24.8	8.0	2.8	19.7 - 31.3	0.297	-0.532
9	POR MAS L	PML	48	32.0	6.6	2.6	27.7 - 40.0	0.728	0.498
10	OCM CRT BR	OMB	48	96.8	24.5	5.0	84.7 - 110.8	0.080	0.459
11	OPS RADIUS	OPR	48	39.9	17.1	4.1	25.0 - 50.0	-0.956	2.512
12	LAM RADIUS	LAR	48	99.9	14.2	3.8	92.0 - 109.0	0.139	-0.567
13	PORION ANGLE	POA	48	69.6	24.7	5.0	57.0 - 82.0	0.076	0.343
14	OCC CHORD	OCC	48	93.9	26.6	5.2	85.0 - 105.0	0.323	-0.695
15	OCC SUBTENSE	OCS	48	27.0	14.7	3.8	16.0 - 39.0	0.319	1.613
16	OCC FRACTION	OCF	48	40.8	34.8	5.9	28.0 - 58.0	0.525	0.627
17	OCC ANGLE	OCA	48	119.2	30.3	5.5	105.0 - 137.0	0.365	1.465

TABLE 3. DESCRIPTIVE STATISTICS OF THE LARSON SITE ARIKARA FEMALE CRANIA

VARIABLE	CODE NAME	N	MEAN	VARIANCE	STD. DEV.	RANGE	SKEWNESS	KURTOSIS
1 BAS BREG HT	BPH	51	128.2	31.3	5.6	113.0 - 141.0	-0.292	0.358
2 GLAB OCC L	GCL	51	172.8	28.7	5.4	162.0 - 184.0	-0.150	-0.714
3 BI AST BR	BAB	51	104.9	23.5	4.9	96.3 - 118.0	0.798	0.878
4 OPS INN L	OIL	51	50.5	25.3	5.0	38.2 - 63.6	0.222	0.315
5 INN LAM L	ILL	51	56.1	41.8	6.5	40.5 - 71.6	0.056	-0.203
6 MAS FOR BR	MFB	51	98.0	44.2	6.6	83.4 - 112.0	-0.310	-0.629
7 MASTOID PRO	MAP	51	7.7	5.0	2.2	3.9 - 13.2	0.200	-0.620
8 MAS BS L	MBL	51	22.9	4.8	2.2	17.7 - 27.9	-0.038	-0.202
9 POR MAS L	PML	51	28.5	6.3	2.5	23.2 - 34.0	-0.220	-0.375
10 OCM CRT BR	OMB	51	92.0	20.9	4.6	77.4 - 100.6	-0.599	0.284
11 OPS RADIUS	OPR	51	36.7	13.1	3.6	29.0 - 45.0	-0.049	-0.494
12 LAM RADIUS	LAR	51	97.3	12.2	3.5	91.0 - 106.0	0.385	-0.410
13 PORION ANGLE	POA	51	70.2	22.1	4.7	61.0 - 80.0	0.050	-0.717
14 OCC CHORD	OCC	51	91.5	15.2	3.9	84.0 - 102.0	0.275	-0.138
15 OCC SUBTENSE	OCS	51	26.2	7.3	2.7	21.0 - 33.0	0.188	-0.233
16 OCC FRACTION	OCF	51	40.6	20.9	4.6	27.0 - 55.0	0.057	1.671
17 OCC ANGLE	OCA	51	119.8	17.3	4.2	111.0 - 129.0	-0.008	-0.533

TABLE 4. DESCRIPTIVE STATISTICS OF THE LARSON SITE ARIKARA CRANIA SEXES COMBINED

VARIABLE	CODE NAME	N	MEAN	VARIANCE	STD. DEV.	RANGE	SKEWNESS	KURTOSIS
1 BAS BREG HT	BBH	99	131.3	35.9	6.0	113.0 - 145.0	-0.414	0.267
2 GLAB OCC L	GOL	99	177.0	49.8	7.1	162.0 - 191.0	0.030	-0.604
3 BI AST BR	BAB	99	105.9	23.7	4.9	96.3 - 118.0	0.459	-0.086
4 OPS INN L	OIL	99	51.9	28.1	5.3	38.2 - 65.4	0.060	-0.100
5 INN LAM L	ILL	99	56.5	53.0	7.3	40.5 - 75.8	0.316	0.339
6 MAS FOR BR	MFB	99	101.5	54.3	7.4	83.4 - 117.5	-0.288	-0.353
7 MASTOID PRO	MAP	99	9.1	6.6	2.6	3.9 - 14.4	0.023	-0.617
8 MAS BS L	MBL	99	23.8	7.2	2.7	17.7 - 31.3	0.393	0.025
9 POR MAS L	PML	99	30.2	9.5	3.1	23.2 - 40.0	0.194	0.428
10 OCM ORT BR	OMB	99	94.3	28.3	5.3	77.4 - 110.8	-0.071	0.571
11 OPS RADIUS	OPR	99	38.3	17.5	4.2	25.0 - 50.0	-0.323	0.326
12 LAM RADIUS	LAR	99	98.5	14.7	3.8	91.0 - 109.0	0.281	-0.508
13 PORION ANGLE	POA	99	69.9	23.2	4.8	57.0 - 82.0	0.054	-0.140
14 OCC CHORD	OCC	99	92.7	21.9	4.7	84.0 - 105.0	0.484	-0.185
15 OCC SUBTENSE	OCS	99	26.6	10.9	3.3	16.0 - 39.0	0.420	1.766
16 OCC FRACTION	OCF	99	40.7	27.4	5.2	27.0 - 58.0	0.389	1.181
17 OCC ANGLE	OCA	99	119.5	23.5	4.8	105.0 - 137.0	0.200	1.165

TABLE 5. DESCRIPTIVE STATISTICS OF THE NEANDERTAL CRANIA

VARIABLE	CODE NAME	N	MEAN	VARIANCE	STD. DEV.	RANGE	SKEWNESS	KURTOSIS
1 BAS BREG HT	BBH	5	130.6	60.3	7.8	123.0 - 141.0	0.329	-1.484
2 GLAB OCC L	GOL	17	200.9	94.6	9.7	178.0 - 215.0	-0.873	0.401
3 BI AST BR	BAB	19	121.8	61.9	7.9	106.0 - 134.0	-0.303	-0.615
4 OPS INN L	OIL	4	44.4	5.6	2.4	41.5 - 47.2	-0.104	-1.074
5 INN LAM L	ILL	15	59.7	38.9	6.2	51.0 - 75.0	0.814	0.429
6 MASTOID PRO	MAP	22	6.7	6.3	2.5	3.0 - 11.3	0.213	-0.867
7 MAS BASE L	MPL	22	25.5	16.9	4.1	17.3 - 37.6	0.665	1.843
8 POR MAS L	PML	18	32.6	18.0	4.2	26.0 - 39.0	0.104	-1.227
9 OPS RADIUS	OPR	5	43.0	41.0	6.4	35.0 - 52.0	0.230	-0.989
10 LAM RADIUS	LAR	3	108.0	12.0	3.5	106.0 - 112.0	0.707	-1.500
11 PORION ANGLE	PCA	3	58.0	57.0	7.5	51.0 - 66.0	0.239	-1.500
12 OCC CHORD	OCC	12	52.0	41.3	6.4	84.0 - 105.0	0.726	-0.504
13 OCC SUBTENSE	OCS	4	29.0	100.7	10.0	19.0 - 42.0	0.720	-1.000
14 OCC FRACTION	OCF	4	25.8	122.9	11.1	16.0 - 40.0	0.434	-1.412
15 OCC ANGLE	OCA	17	115.1	110.3	10.5	93.0 - 134.0	-0.439	-0.185

where Y is the unknown dependent variable, b_0 is the intercept, (b_1, b_2, b_n) are the regression coefficients, and (x_1, x_2, x_n) are the known independent variables.

This technique is used in the present study to determine if the relationship between mastoid projection (dependent variable) and a number of independent variables is the same for Neandertals and modern man. If a regression line calculated on the Arikara sample can also predict the values for the Neandertals (within two standard deviations) then one can assume that the relationship is similar.

Principal Components Analysis

This is a data reduction technique. A large series of measurements, containing overlapping information, can be reduced to a series of nonoverlapping orthogonal vectors (components). According to Howells (1973:121) the purpose of the analysis is ". . . to produce uncorrelated factors and factor scores, to elucidate the patterns of difference of the individuals within a population."

The analysis is performed upon the total variance of the populations as represented in the within groups correlation matrix, with unity in the diagonals (Hair et al. 1979: 224). The analysis produces a set of orthogonal factors that contain certain percentages of the total variation (this amount can be determined from the eigenvalue of each component). An original set of unrotated components accounts for more of

the variance in the data as a whole than any other linear combination of variables. Therefore, the first component contains the largest portion of the variance, the second component the second largest (remembering that it is orthogonal to the first) and so on to the last component (Hair et al. 1979:225-226).

The unrotated components, however, may not be the most adequate interpretation of the variables. One of several rotational techniques can often be used to achieve a more interpretable solution. In this study the VARIMAX (Kaiser 1958) procedure is used. Common convention suggests that components with eigenvalues greater than or equal to 1.0 should be extracted and rotated.

The rotated components can then be morphologically interpreted. Each component will have some variables that load heavily on that component. These "heavy" loadings define the nature of the component. For example, Howells' (1973:129-130) first factor is interpreted as representing facial forwardness since the original variables that measured forwardness had high loadings on this factor (zygoorbital radius, ectoconchion radius, frontomalare radius, dacryon radius, and glabello-occipital length). The biological reality of the factors is by no means assured, however. This depends upon the original set of measurements and the number of components that are rotated. Developing accurate and

functionally significant measurements and applying the proper rotational technique should safeguard the biological reality of the components (Howells 1973:129).

Principal components analysis is applied here for two reasons. First, it acts to reduce the original set of variables to a smaller, more morphologically interpretable multivariate set. Second, it will obtain component scores for each individual to be used as input data in a discriminant function analysis and a multivariate analysis of variance.

Discriminant Function Analysis

Discriminant function analysis is similar to regression analysis since:

> . . . a linear combination of metric measurements for two or more independent variables is used to describe or predict the behavior of a single dependent variable. The key difference is that discriminant analysis is appropriate for research problems in which the dependent variable is categorical (nominal or nonmetric), whereas in regression the dependent variable is metric. (Hair et al. 1979:86)

The analysis extracts the function(s) from the between groups covariance matrix (the number of functions that can be created is equal to the number of populations minus one). The functions have the following formula:

$$Z = W_1X_1 + W_2X_2 + \ldots + W_nX_n \qquad (4\text{-}2)$$

where Z is the discriminant score, W is the discriminant weight (coefficient), and X is the independent variable.

Multidimensional means (centroids) are calculated about which the discriminant scores vary. An individual will be grouped with a population based upon which centroid it is closest to. It should be remembered that it is the nature of the analysis to classify an individual with a population even if, in reality, that individual is not a member of that population. Thus, it would be possible to have a Bushman classified as an American Indian if the only populations used in the analysis are American Indian. Also, a discriminant function works best on the population from which it was calculated. In most instances care should be taken not to apply a function to a population that is vastly different from the original one.

Discriminant functions, historically, have been used to classify individuals into populations or to classify an unknown individual (e.g. Giles and Elliot 1962, 1963). While it is used here in this manner, it is also used to determine which components produced by the principal components analysis are responsible for the discriminating efficiency. The exploration of the significance of the components (are they functional or sex related?) is the desired goal and not their ability to discriminate. This use of discriminant functions as an exploratory tool is recommended by Howells (1973).

In the present study the following discriminant function analyses are performed:

1. Sex of the Larson Site Arikara is the dependent variable and the component scores are the independent variables. The purpose of this run is to permit a functional interpretation of the components based upon their ability to discriminate between the sexes.
2. Sex of the Larson Site Arikara is the dependent variable and the three mastoid measurements are the independent variables. The purpose of this run is to determine the efficiency of these variables as sex discriminators.

Analysis of Variance (ANOVA)

ANOVA, like regression and discriminant function analysis, determines the relationship between a dependent variable and one or more independent variables. Like regression analysis, but unlike discriminant analysis, the dependent variable is quantitative. Unlike either regression of discriminant analysis, the independent variables in ANOVA may be qualitative (Neter and Wasserman 1974:420).

The basis of ANOVA is that true population differences can be estimated from sample groups and that comparisions of these sample groups will reveal any real differences in the populations. If the population means are equal (no difference) then the three estimates of population differences or sum of squares (total sum of squares, SSTO; between or treatment sum

of squares, SSTR; and within or error sum of squares, SSE) should be equal (Hair et al. 1974:130).

To test the significance of the analysis an F-value is formed. Dividing the SSTR and SSE by their respective degrees of freedom results in mean squares (mean squares treatment, MSTR; and mean squares error, MSE). To test the overall significance of the model the MSTR is divided by the MSE to produce the F-value. To test the individual treatments of the model (if there is more than one factor in the model) the individual MSTRs are divided by the MSE (this is the most common procedure, with more complicated ANOVA models the denominator may not always be the MSE). The F-value follows the F distribution and its significance at the appropriate level can be found in the usual tables.

ANOVA is used here to determine the relationship between mastoid projection (dependent variable) and sex and age (independent variables) in the Larson Site Arikara. Age is considered in the model to determine if there are any age related (degenerative) changes in the size of the mastoid that may otherwise be mistaken for sex related differences.

Summary of the Analytical Techniques

The multivariate techniques described above have as their goal the elucidation of functional and sex related patterns and relationships within the morphology of the

Posterior Cranial Complex. While the techniques are performed on the Larson Site Arikara sample their interpreted results should be applicable to the same questions in Neandertals.

V. RESULTS

Multiple Regression Analysis

The Larson Site Arikara sample was subjected to a multiple regression analysis from the General Linear Models (GLM) procedure of SAS76 (Barr et al. 1976). Sexes were combined to simulate the conditions in Neandertals which are of unknown sex. Mastoid projection, as measured by porion-mastoidale length (PML) is the dependent variable rather than mastoid projection (MAP), because (PML) has higher correlation coefficients with the other variables. Eight variables were chosen that could be applied to the Arikara as well as to the Neandertal sample [basion-bregma height (BBH), glabello-occipital length (GOL), biasterionic breadth (BAB), opisthion-inion length (OIL), inion-lambda length (ILL), lambda radius (LAR), porion angle (POA), and occipital chord (OCA)]. Only two Neandertal specimens are complete enough to be tested in the regression (La Chapelle-aux-Saints and La Ferrassie 1). Lowering the number of variables to accomodate more Neandertal specimens would greatly reduce the predictability of the regression.

The regression accounts for 33% of the total variation with the following formula for the line of best fit:

$$Y = 35.485 + 0.143(x_1) + 0.138(x_2) + (-0.003)(x_3) + (-0.134)(x_4) + 0.016(x_5) + (-0.889)(x_6) + (-0.595)(x_7) + 0.933(x_8) \quad . \qquad (5\text{-}1)$$

The regression line is highly significant with six of the eight independent variables contributing to the significance of the line. Table 6 presents the results of the analysis.

The standard deviation of the residuals is 2.402. The largest absolute value for a residual is 6.11; more than two standard deviations from the fitted value (one Arikara male, 924, was dropped from the analysis when it was discovered that this individual represented an outlier with a residual value over three standard deviation units from the fitted value).

When the two Neandertal specimens' values are entered into the Arikara's regression equation the results are:

Specimen	Observed Value	Predicted Value	Residual
La Chapelle	32.3	35.791	2.791
La Ferrassie I	33.0	31.705	-0.595

Both specimens are well within two standard deviations of the fitted value.

Principal Components Analysis

The Larson Site Arikara sample was subjected to the principal components analysis procedure (PA 1 option) of SPSS (Nie et al. 1975). Again, in order to simulate the conditions in Neandertals, the sexes were combined (separate principal components analyses were run on the males and females producing similar component structures).

TABLE 6. LARSON SITE ARIKARA REGRESSION ANALYSIS SUMMARY

Variable	Source	D.F.	Sum of Squares	Mean Squares	F
Porion-Mastoidale Length					
	Model	8	275.160	34.395	5.47*
	Error	89	559.796	6.289	
	Total	97	834.956		
	BBH	1	35.569**	35.569	5.66*
	GOL	1	35.993**	35.993	5.72
	BAB	1	0.002**	0.002	0.00
	OIL	1	17.702**	17.702	2.81*
	ILL	1	0.273**	0.273	0.04
	LAR	1	21.948**	21.948	3.49*
	POA	1	19.913**	19.913	3.17*
	OCC	1	20.383**	20.383	3.24*

*Significant at the .05 level.

**Type II Sum of Squares.

Seventeen components were produced from the raw data matrix: only five with eigenvalues greater than 1.0 were extracted and rotated. These five components account for 71.6% of the total variation of the original data matrix. Table 7 presents the VARIMAX rotated component matrix and the communalities.

Morphological interpretations. Each component is interpreted by examining its loadings. At the end of each interpretation the major loadings are listed.

I. Posterior length. This component, accounting for 20.3% of the total variation, represents the length of the posterior cranium. The highest loadings are on lambda radius (LAR), the most direct measurement of posterior cranial length, opisthion radius (OPR), and glabello-occipital length (GOL). The high loading on basion-bregma height (BBH) reflects its high original correlation with glabello-occipital length (.554). The occipital chord (OCC) also reflects posterior cranial length, though somewhat more obliquely than LAR, OPR, or GOL.

BBH	.601	MBL	.474
GOL	.698	OPR	.704
BAB	.556	LAR	.812
MFB	.477	OCC	.555

II. Occipital angle. This component, accounting for 13.6% of the total variation, quite clearly represents the

TABLE 7. LARSON SITE ARIKARA VARIMAX ROTATED COMPONENT MATRIX AND ORIGINAL COMMUNALITIES

Variable	Communality	I	II	III	IV	V
1 Basion-Bregma Height	0.693	0.601	-0.189	0.103	0.255	0.470
2 Glabello-Occipital Length	0.781	0.698	0.328	-0.105	0.390	0.149
3 Biasterionic Breadth	0.319	0.556	0.028	0.061	0.068	-0.023
4 Opisthion-Inion Length	0.825	0.081	0.212	0.003	-0.738	0.876
5 Inion-Lambda Length	0.891	0.326	0.337	0.569	0.163	-0.567
6 Bimastoid Foramen Breadth	0.485	0.477	-0.038	0.097	0.358	0.345
7 Mastoid Projection	0.769	-0.012	-0.021	0.069	0.873	0.029
8 Mastoid Base Length	0.449	0.474	0.073	-0.206	0.421	-0.016
9 Porion-Mastoidale Length	0.812	0.262	0.013	0.057	0.859	-0.023
10 Bioccipitomastoid Crest Breadth	0.482	0.366	-0.135	0.008	0.151	0.554
11 Opisthion Radius	0.622	0.704	0.030	0.135	-0.058	0.322
12 Lambda Radius	0.733	0.812	0.216	0.142	0.067	-0.031
13 Porion Angle	0.887	-0.108	0.030	0.926	-0.031	0.128
14 Occipital Chord	0.894	0.555	0.199	0.734	0.057	0.064
15 Occipital Chord Subtense	0.986	0.229	0.896	0.362	0.012	-0.012
16 Occipital Chord Fraction	0.608	0.117	0.402	0.558	0.110	-0.330
17 Occipital Angle	0.939	-0.022	-0.967	-0.031	0.024	-0.043

angle of the occipital. The highest loading is the occipital angle (OCA) which measures the "bending" of the occipital or in other words, the angulation between the occipital plane and the nuchal plane. The only other major loading is on the occipital chord subtense (OCS), which is an intergral component in the formulation of the occipital angle.

OCS	.896	OCA	0.967
OCF	.402		

III. Porion angle. This component, accounting for 13.5% of the total variation represents the angling of the occipital bone as measured from porion. The radii used to calculate it measure the distance of the cranial base from porion (opisthion radius, OPR) and the length and height of the occipital bone (lambda radius, LAR). The highest loading is on porion angle (POA) with occipital chord (OCC) having the second highest. The occipital chord forms one side of the triangle needed to calculate the porion angle. The high loading on inion-lambda length (ILL) is interesting, it measures the height of the occipital plane in the midsagittal plane.

ILL	.569	OCC	.734
POA	.926	OCF	.558

IV. Mastoid projection. This component, accounting for 15.3% of the total variation, clearly represents the projection of the mastoid. High loadings are produced on Zoja's

mastoid projection (MAP) and on porion-mastoidale length (PML). The only other major loading is on mastoid base length which adds a mastoid breadth factor to the component.

MAP	.873	PML	.860
MBL	.421		

V. Occipital shape. This component, accounting for 11.7% of the total variation appears to represent general occipital height. The highest loading is on opisthion-inion length (OIL) which measures the length of the nuchal plane in the midsagittal plane. The other major loadings are on inion-lambda length (ILL) and bioccipitomastoid crest breadth (OMB) which measure the height of the occipital plane in the midsagittal plane and the internal breadth of the nuchal plane respectively. The relatively high loading on basion-bregma height (BBH) is interesting. This may reflect the contribution of the height of the occipital to overall cranial height.

BBH	.470	ILL	-.567
OIL	.876	OMB	.554

Discriminant Function Analysis of Arikara Component Scores

The principal component scores for each individual from the Larson Site Arikara sample were subjected to a discriminant function analysis procedure from SPSS (Nie et al. 1975). Sex is the dependent variable and the five component scores

are the independent variables. Table 8 presents the results of the discriminant function analysis.

One function was extracted from the between groups covariance matrix. The matrix has 97 degrees of freedom. The discriminant function is highly significant ($\chi^2 = 91.04$ with 5 degrees of freedom; probability of 0.0000). The function has the following formula:

$$Z = -0.73341(X_1) + (-0.11305)(X_2) + 0.04594(X_3) + (-0.98014)(X_4) + (-0.66476)(X_5) \quad . \qquad (5\text{-}2)$$

The group centroids are -1.29887 (males) and 1.22247 (females).

As a sexual discriminator, the function has approximately 94% discriminating efficiency. This undoubtedly is an inflated estimate but, in this particular analysis the concern is with the significance of the function; its discriminating ability is of secondary importance only.

Three of the five components contribute to the significance of the function; components 1, 4, and 5 (posterior cranial length, mastoid projection, and occipital shape). These three components represent size variation as opposed to the two angle components which represent shape variation.

Discriminant Function Analysis of Arikara Mastoid Measurements

The three mastoid measurements (MAP, MBL, and PML) for the Larson Site Arikara were subjected to a discriminant

TABLE 8. LARSON SITE ARIKARA DISCRIMINANT FUNCTION ANALYSIS OF COMPONENT SCORES SUMMARY

Variable	Wilke's Lambda**	F**	Coefficients	Means		Standard Deviations	
				Males	Females	Males	Females
1 Posterior Cranial Length	0.851	17.010*	-0.73341	0.39	-0.37	0.93	0.92
2 Occipital Angle	0.997	0.294	-0.11305	0.06	-0.05	1.15	0.84
3 Porion Angle	0.999	4.830	0.04594	-0.02	0.02	1.09	0.92
4 Mastoid Projection	0.653	51.64*	-0.98014	0.61	-0.57	0.81	0.81
5 Occipital Height	0.882	13.01*	-0.66476	0.35	-0.33	0.99	0.90

*Significant at the .05 level.

**1 and 97 degrees of freedom.

function analysis procedure from SPSS (Nie et al. 1975). Sex is the dependent variable and the three measurements are the independent variables. Table 9 presents the results of the analysis.

One function is extracted from the between-groups covariance matrix. The matrix has 97 degrees of freedom. The discriminant function is highly significant ($\chi^2 = 51.849$ with 3 degrees of freedom; probability of 0.0000). The function has the following formula:

$$Z = -0.63099(X_1) + (-0.35321((X_2) + (-0.41827)(X_3) \quad . \tag{5-3}$$

The group centroids are -0.866 (males) and 0.815 (females).

As a sexual discriminator the function has approximately 80% discriminating efficiency. All three measurements contribute to the significance of the function.

Analysis of Variance of Arikara Mastoid Projection

The Larson Site Arikara were subjected to the analysis of variance (ANOVA) procedure of the General Linear Models procedure from SAS76 (Barr et al. 1976). The dependent variable is mastoid projection (MAP). The independent variables are sex and age (skeletal). Age was divided into six categories (levels); five year intervals from 20 to 39 and ten year intervals from 40 to 59+ years of age.

TABLE 9. LARSON SITE ARIKARA DISCRIMINANT FUNCTION ANALYSIS OF MASTOID MEASUREMENTS

Variable	Wilke's Lambda**	F**	Coefficients	Means		Standard Deviations	
				Males	Females	Males	Females
1 Mastoid Projection	0.694	42.73*	-0.63099	10.57	7.74	2.08	2.23
2 Mastoid Base Length	0.869	14.57*	-0.35321	24.79	22.86	2.83	2.19
3 Porion-Mastoidale Length	0.670	47.76*	-0.41827	31.99	28.47	2.57	2.51

*Significant at the .05 level.

**1 and 97 degrees of freedom.

Table 10 presents the results of the ANOVA. The model (mastoid projection = sex + age + sex*age) is highly significant (F value = 5.39 with 11 and 80 degrees of freedom; probability of 0.0001). Sex and the sex*age interaction are the significant treatments, with age being nonsignificant (see Table 10).

TABLE 10. LARSON SITE ARIKARA ANALYSIS OF VARIANCE SUMMARY

Variable	Source	D.F.	Sum of Squares	Mean Squares	F
Mastoid Projection					
	Model	11	266.307	24.210	5.39*
	Error	80	359.060	4.488	
	Total	91	625.367		
	Sex	1	185.679**	185.679	41.37*
	Age	5	13.281**	2.656	0.59
	Sex*Age	5	63.347**	13.469	3.00*

*Significant at the .01 level.

**Type I Sum of Squares.

VI. DISCUSSION

Functional Interpretation of the Mastoid Process

In this thesis I have hypothesized that, functionally, the mastoid process is not an isolated structure. Rather it is an integral and integrated part of a larger structural-functional unit that I have termed the Posterior Cranial Complex. Isolation of this complex and the various subcomplexes that make it up was accomplished on a sample of modern hominid crania (Larson Site Arikara). My second hypothesis was that the same complex and interrelationships between subcomplexes should exist in Neandertals, even though the overall number of relatively complete crania made the formulation of the model impossible on the Neandertal sample.

The multiple regression analysis performed in this study supports both hypotheses. First, the mastoid process is demonstrated to be a component of the Posterior Cranial Complex because the predicted values (based on the eight independent variables) for mastoid projection in the Arikara are accurate estimates of the actual observed mastoid projection values. This accuracy is reflected by the fact that the predicted values for the vast majority (95%) of the Arikara sample lie within two standard deviations of the fitted value (confining the deviation to two standard deviations means that, hypothetically, 95% of the population

will be within this range; Sokal and Rohlf 1969:83). Second, the regression analysis demonstrates that for Neandertals and modern man, the relationship between projection of the mastoid and the various independent variables is similar, thus supporting the second hypothesis. This is shown specifically by the Arikara regression line's ability to successfully predict mastoid projection values for the two Neandertal specimens (La Chapelle and La Ferrassie 1) complete enough to enable the taking of all measurements needed to define the Posterior Cranial Complex.

The principal components analysis reveals that within the Posterior Cranial Complex certain definitive subcomplexes can be isolated. These can be interpreted as structural-functional units that are interrelated to form the whole. There are five such subcomplexes identified by the analysis and these are called:

1. Occipital angle.
2. Porion angle.
3. Posterior cranial length.
4. Mastoid projection.
5. Occipital shape.

Each of these subcomplexes can be functionally interpreted with regard to the morphology of the Neandertal posterior cranium. Before discussing this, however, it is necessary to examine the Neandertal dento-facial complex;

since it appears to have a strong influence on the morphology of the entire cranium, especially the posterior vault.

The first impression one has of the Neandertal face is that it is of great relative height (Hrdlička 1930; McCown and Keith 1939; Stewart 1977). This is reflected in virtually all height dimensions of the Neandertal face, especially the upper facial and alveolar heights (Brose and Wolpoff 1971; Smith 1976). In addition to the increased height, the Neandertal face is strongly buttressed in that there is a general thickening of certain portions of the facial skeleton. This buttressing can best be seen in the thickened nasal bones, interorbital region, side walls of the nasal aperture and other portions of the zygomatic and maxilla (Heim 1976). Hrdlička (1930:165) describes the combined effects of this buttressing as they appear in the Gibralter skull:

> The side walls of the aperture and the nasal bones are very perceptibly thicker than they are in modern skulls. A remarkable feature which gives the face its characteristic appearance is the fullness, to mild convexity, of the suborbital (canine) fossae and of the nasal processes of the maxilla. All these parts look as if inflated from behind.

The lateral margins of the face are strengthened also. Smith (1976:47) discussing the Krapina C specimen states that: ". . . the frontal process of the zygomatic bones on both sides almost form a continuation of the brow ridges in terms of thickness and general robusticity." The posterior aspect of the frontal process of the zygomatic bone shows evidence

of increased thickening also. In modern crania the process is "V" shaped when viewed from above. But, in many Neandertals this "V" is filled-in with bone creating a strong pillar-like structure (Smith and Ranyard, in press).

In addition to the buttressing and marked height dimensions, the Neandertal face is characterized by extreme prognathism of both the alveolus and midface (Heim 1976; Brose and Wolpoff 1971; Trinkaus and Howells 1979; Smith 1976).

It is certainly not within the scope of this paper to explain the significance of Neandertal facial morphology, though some hypotheses have been formulated (for example see Brace 1962, 1964, 1979; Brose and Wolpoff 1971; Coon 1962; Wolpoff 1980; Smith 1976; Trinkaus and Howells 1979; Heim 1974, 1976). However, whatever the explanation, the projection and weight of the face (due to the buttressing) would have created the need for an efficient counter-balancing mechanism in the cranium. It is suggested that this mechanism is provided by the form of the Posterior Cranial Complex in Neandertals and that each subcomplex or component of the Complex is involved.

Components 1 and 2, Occipital angle and porion angle. The discriminant function analysis shows that these angles (components 2 and 3) are not efficient sex discriminators, due most likely to the kind of variation they express.

These angles reflect shape variation as opposed to the size variation represented by the other components. This shape variation more accurately reflects the function of the component. The angles express the relationship of the nuchal plane to the occipital plane (occipital angle) and the posterior cranial length and occipital height to the positioning of the cranial base (porion angle). The means of the two samples for POA are:

	POA
Neandertals	58
Arikara	70

In Neandertals the angle is smaller reflecting a relatively low cranial base, shortened occipital plane (reflected by the occipital chord fraction), and a generally lower and longer cranial vault. The lower cranial base in Neandertals brings the nuchal plane into a more horizontal position relative to the foramen magnum. Thus, the insertions of the nuchal muscles are rendered more perpendicular to the line of muscle action, making the nuchal muscles much stronger and more efficient in terms of counter-balancing the large projecting face and in terms of generating force for the utilization of the masticatory apparatus (particularly in anterior dental loading). The orientation of the nuchal plane in the modern sample is less perpendicular reflecting the decreased demand for nuchal muscle force and facial

counter-balance in modern hominids. Thus, in the Arikara the angle is larger reflecting the more evenly contoured curve from opisthion to lambda and the general heightening of the cranial vault.

The occipital angle does not show the same degree of difference:

	OCA
Neandertals	115
Arikara	119

This may be the result of the discrepancies in measurement techniques or it may reflect a biological reality that is more complex than the model presented here.

Component 3, Posterior cranial length. In Neandertals the measurements comprising this component are larger than in modern hominids, not only in length (LAR) but, also in breadth (BAB) and caudal projection of the cranial base (OPR):

	LAR	BAB	OPR
Neandertals	108	122	43
Arikara	99	106	38

This indicates that in Neandertals the posterior cranial vault is considerably larger (both longer and broader) and more horizontally oriented than in modern hominids. These data support the interpretation discussed in conjunction with subcomplex 1 regarding the production of the most efficient moment arms for the nuchal muscles. Additionally

this subcomplex demonstrates that there is significantly more area for nuchal muscle insertion in Neandertals than in modern hominids.

Component 4, Occipital shape. This component accounts for the smallest amount of the total variation (11.7%) and is therefore more difficult to interpret. Morphologically, the relationship between the nuchal and occipital plane has changed through time. Smith (1976:69) has described this change: ". . . the occipital plane becomes increasingly larger in relation to the nuchal plane." This is clearly observable morphologically; however, in the samples of the present study this is not metrically demonstrable. Comparison of the means for inion-lambda length and opisthion-inion length (the two measurements that traditionally express this relationship) show that the height of the occipital plane has actually decreased slightly while the length of the nuchal plane has increased:

	OIL	ILL
Neandertals	45	60
Arikara	52	57

This can be explained, however, if it is taken into consideration that inion, which is used in calculating both measurements, does not always mark the point of demarcation between the two planes. Howells' (1973) point of maximum height above the occipital chord (OCC), from which the

occipital chord subtense (OCS) and the occipital chord fraction (OCF) are measured, may be a more accurate landmark for the demarcation. Therefore, OCF may be a better measure of occipital plane height (see Figure 5, p. 25). If this is assumed it can be seen that metrically, the height of the occipital plane has increased from Neandertals to modern hominids:

	OCF
Neandertals	26
Arikara	41

Thus, this component represents the lengthening and broadening of the posterior cranial vault at the expense of posterior cranial vault height. Again, this is necessary in order to obtain the required size and shape of the nuchal plane.

Component 5, Mastoid projection. It is interesting and satisfying that the principal components analysis identifies the mastoid area as a distinct subcomplex of the Posterior Cranial Complex. It demonstrates that the mastoid does represent a functional unit by itself as well as a part of the larger more complex posterior cranial functional unit. The regression analysis supports the latter assertion. Therefore, functional demands affecting the overall posterior cranial region will have an effect on the mastoid as well. These demands, as mentioned above, are most likely the result

of differing needs in Neandertals and Arikara in terms of counter-balancing the face and producing certain types of masticatory forces. One effect of these differing demands is the broadening of the nuchal plane to provide increased areas of attachment for the nuchal musculature. Obviously, there is a limit to the width to which the nuchal plane can expand. As a compromise between an excessively wide nuchal area and the need for more area of muscle attachment the occipitomastoid crest is more fully developed in Neandertals. This crest quite often projects beneath the cranial base further than the tip of the mastoid, fostering the illusion of a reduced, nonprojecting Neandertal mastoid process.

The strongly developed nuchal muscles of Neandertals, especially the splenius capitis, have ample room for attachment on the occipitomastoid crest, the mastoid process, and the optimally broadened nuchal plane. With the reduction of the dento-facial complex in modern hominids; however, there is a concurrent reduction of the nuchal plane and occipitomastoid crest, the latter to the extent that it no longer projects noticably from the remainder of the cranial base. The mastoid process does not reduce appreciably as a part of this reduction and alteration of the nuchal plane region. Thus, in modern hominids what remains is a mastoid process which projects markedly not because of any increase in its dimensions but because of the reduction of the nuchal

plane. If anything, Neandertal dimensions are larger than those of modern hominids as is evidenced by a comparison of their means (excepting MAP, which measures the projection from the cranial base):

	PML	MBL
Neandertals	33	26
Arikara	30	24

It is my opinion that the mastoid process does not reduce with the rest of the nuchal plane because it continues to fulfill a need for some extension of the nuchal plane. It might be argued that it is the mastoid process that should become greatly reduced and not the occipitomastoid crest. This argument ignores the fact that the mastoid is the area of insertion for the m. sternocleidomastoideus while the occipitomastoid crest's primary function is only to provide additional area for attachment of the nuchal musculature. Thus, in modern hominids the mastoid can provide some additional attachment area for the splenius complex as well as position the insertions of the sternocleidomastoids in a way which enhances their efficiency as rotators and perhaps flexors of the head (cf. Smith 1971; Krantz 1963). The occipitomastoid crest would not serve the latter functions, consequently the reduction of the crest and maintenance of the mastoid in its same relative position is quite logical in a functional sense.

Sexual Dimorphism of the Neandertal Mastoid Process

It has been clearly demonstrated that it is possible to determine the sex of human skeletal material on the basis of certain observable and measurable characteristics (Bass 1971; Giles and Elliot 1963; Keen 1950; Krogman 1962; Phenice 1969; Washburn 1948). Most sexing techniques rely upon the assessment of the innominate bones, since it is on these bones that the primary sex characteristics (those associated with the expanded birth canal of females and the differences in attachment of the external genetalia) are found. Secondary sex characteristics reflect general size and robusticity differences between males and females. These are generally found in the cranium and long bones (Smith, in press). One should be able to accurately determine the sex of an unknown specimen 95% of the time using the pelves only. This percentage rises when the whole skeleton is used and decreases if only secondary characteristics are employed.

In Neandertals, however, one can not rely upon the pelves for sexing purposes due to their unique morphology (Trinkaus 1976; Smith 1976; see Smith, in press, for an excellent discussion of the problems involved in sexing Neandertal specimens). Instead, one must rely upon the secondary sex features found on the cranium. Assessment of one such feature, the mastoid process, is a portion of the focus of the present study. It is the purpose of this part

of the present thesis to examine the degree of sexual dimorphism of the Neandertal mastoid process, and to determine if it can be used to sex individual Neandertal crania.

Mastoid processes in modern man are known to exhibit sexual dimorphism (Bass 1971; Keen 1950; Krogman 1962; Giles and Elliot 1963). The present study has also confirmed this. For example, the ANOVA procedure indicates that there is a relationship between the sex of an individual and mastoid projection; there is no age dependent effect; the sex*age interaction, like all interactions, is difficult to interpret, but it appears to indicate that sexual dimorphism varies between age*sex categories. This is confirmed by an examination of the sex*age means. Over the first five sex*age categories the difference between the means remains fairly constant—1.1 to 3.4—but the difference for the last category is 7.19. This relatively large value undoubtedly disproportionately contributes to the significance of the model. This indicates that the older individuals at Larson are more sexually dimorphic; this may be the result of some genetic or environmental factor. More likely however, it is the result of the small sample sizes for this category (4 for the males and 5 for the females).

Furthermore, the first discriminant function analysis indicates that mastoid projection (component 4 which contains

all three mastoid measurements) is a significant sex discriminator (see Table 8, p. 48). While the analysis reveals that the mastoid component is an efficient sex discriminator it does not indicate which of the original measurements (MAP, PML, and MBL) are responsible for the discrimination. The second discriminant function analysis suggests that all three original measurements are efficient sex discriminators (see Table 9, p. 50).

All of these analyses are performed on the Arikara, a modern sample and not the Neandertals. However, the multiple regression analysis shows that the parts that make up the Posterior Cranial Complex in Neandertals as well as modern hominids are related in the same manner. It is not unreasonable to assume then that the Neandertals should express sexual dimorphism in a similar manner. Also, given the same degree of sexual dimorphism it should be possible to achieve similar levels of discriminating ability.

An index of sexual dimorphism that expresses the female mean as a percentage of the male mean was calculated in order to compare the degree of sexual dimorphism between Neandertals and modern hominids (the value for the Neandertal index was obtained from the Neandertal specimens that could be reliably sexed by the sciatic notch on the innominate or that were obviously males based on a variety of secondary sex characteristics; see Smith, in press, for the sex determinations).

The index values indicate that Neandertals are somewhat less dimorphic than modern hominids:

	PML	MAP	MBL	SAMPLE SIZES MALES	FEMALES
Neandertals	81%	50%	80%	4	3
Arikara	89%	70%	92%	48	51

Given the above information, it should be possible to sex individual Neandertal specimens on the basis of the three mastoid measurements. Specifically, it should be possible to sex a number of individual Neandertal specimens that fall toward the extremes of the Neandertal range for these measurements. This assumes, of course, that variation in the Neandertal mastoid reflects the same thing as it does in modern hominids; sexual dimorphism. Since all the results of this study indicate that the mastoids of Neandertals function similarly to the same structures in modern hominids, this assumption appears sound.

Obviously, it is not feasible to develop a descriminant function on the available Neandertal sample. However, there are alternative solutions available. One such solution is to plot the three measurements against each other in two dimensional space to determine if two groups are formed that could be interpreted as representing sex differences. This produces three such plots. Figure 7 is a plot of MBL against PML, it is representative of all three plots (results were nearly identical).

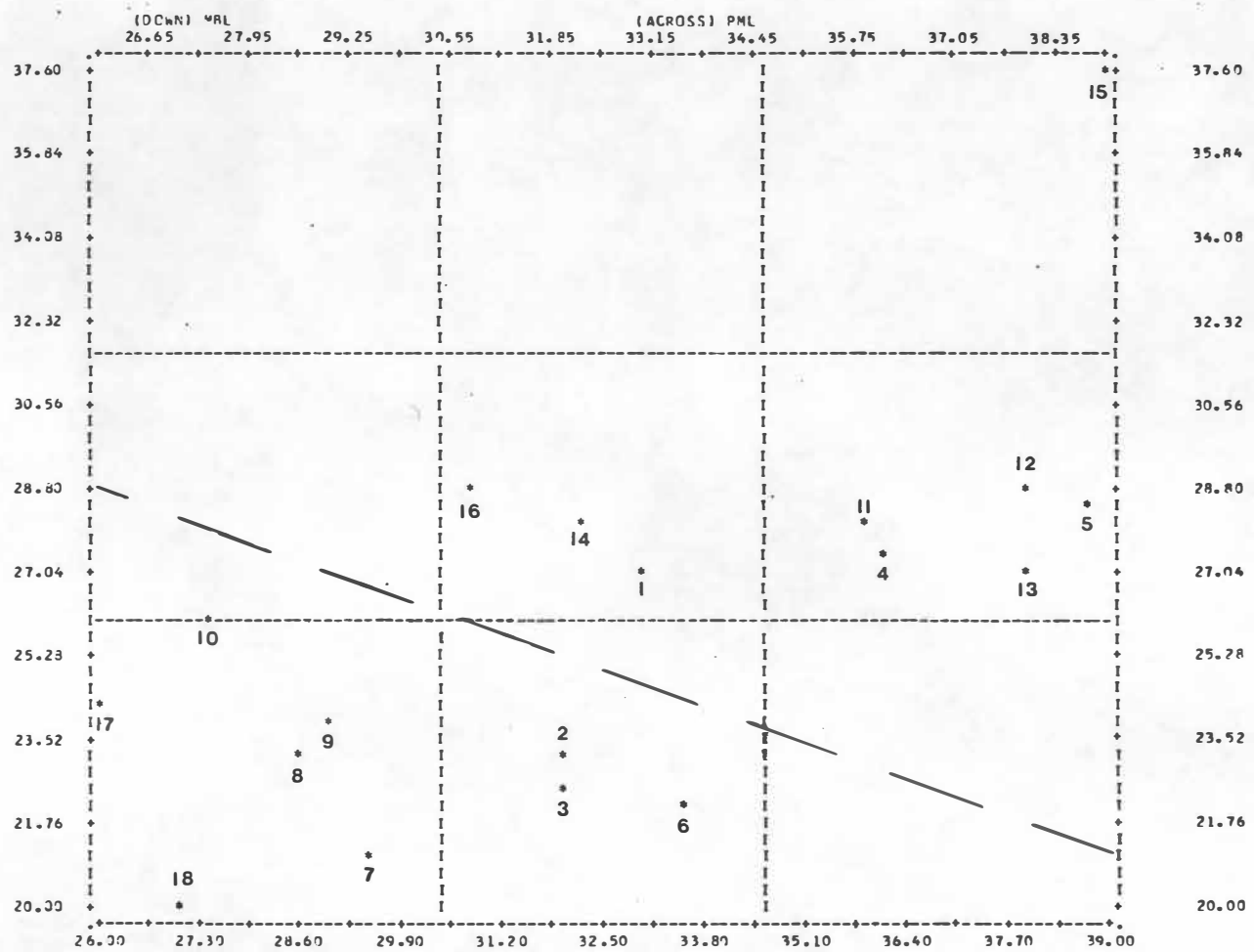


Figure 7. Two dimensional plot of porion-mastoidale length (PML) on mastoid base length (MBL) for Neandertal crania illustrating sexual dimorphism. Numbers are specimen codes corresponding to the ordering of the Neandertal specimens in Table 11, page 69.

Another solution is to subject the Neandertal values for the three mastoid measurements to the Arikara discriminant function. Calcagno (1980) has demonstrated that this may be a useful and valid procedure. He was able to correctly sex (92.3%) a sample of gorillas and chimpanzees (moving the sectioning points) using a function computed from 29 mandibular measurements taken on a modern human sample. Applying this procedure to the Neandertals I have obtained discriminant scores for 18 Neandertal specimens. The group means are -1.797 (males) and 1.410 (females) with a sectioning point of -0.788 (these means indicate that the Neandertal sample is more dimorphic for these dimensions than the Arikara which directly contradicts the results of the sexual dimorphism indices. This is interesting, but for the present study the significant point is that Neandertals exhibit a marked degree of sexual dimorphism with regard to the mastoid process). The composition of the two groups produced by this procedure are identical to the composition of the groups produced by the two dimensional plot, with the exception of La Ferrassie I which is classified as a female by the discriminant function and as a male by the plot. Table 11 presents the sex classification, obtained from the plot and the discriminant function, for the Neandertal sample.

Obviously, caution should be exercised in evaluating the results of these procedures. However, results for specimens

TABLE 11. ESTIMATED SEX FOR EUROPEAN NEANDERTAL CRANIA BASED ON THE MASTOID PROCESS

Specimen	Sex Estimate*	Plot of PML on MBL	Discriminant Function
1 La Ferrassie I	Indet.	Male	Female
2 La Ferrassie II	Female	Female	Female
3 Krapina C	Female	Female	Female
4 Krapina 38.7/38.11	Male	Male	Male
5 Krapina 38.2/38.14	Male	Male	Male
6 Krapina 39.1	Female	Female	Female
7 Krapina 38.21	Female	Female	Female
8 Krapina 38.12	Female	Female	Female
9 La Quina 5	Female	Female	Female
10 La Quina 27	Female	Female	Female
11 Jebel Irhoud 1	Male	Male	Male
12 Jebel Irhoud 2	Male	Male	Male
13 Broken Hill	Male	Male	Male
14 La Chapelle	Male	Male	Male
15 Qafzeh 6	Male	Male	Male
16 Skhul 5	Male	Male	Male
17 Gibralter	Female	Female	Female
18 Saccopastore	Female	Female	Female

*Sex estimations are assigned only if the results of both procedures agree. Some of the estimates do not agree with those obtained by other researchers (e.g. La Quina 5); however it should be remembered that the above estimates are based only on the mastoid and not the whole cranium.

that can be sexed postcranially (on the basis of the sciatic notch) give very encouraging results. The sex determinations based on the plot of the mastoid dimensions agree with the determination for the three specimens (La Chapelle, La Ferrassie I, and La Ferrassie II) that can be sexed postcranially, while the discriminant function only misclassified La Ferrassie I. Also, other specimens (Gibralter and Krapina C) that are considered females by all who study Neandertals are clearly classed as females by the plot of the mastoid dimensions as well as by the discriminant function. Thus, I feel that mastoid dimensions can be used as good indicators of sex affiliation in individual Neandertal specimens. Of course the closer to the sectioning point the values lie, the less reliable the estimate becomes; and obviously other features should be employed when possible. With these cautions in mind it is my opinion that the methods applied here are a reasonable beginning to the solution of the problem of sexing individual Neandertal specimens.

VII. CONCLUSIONS

The present analysis has determined two very significant things about the Neandertal mastoid process.

First, the function of the mastoid process (as a component of the Posterior Cranial Complex) in Neandertals is similar to its function in modern hominids; to supply an area for the insertions of the m. sternocleidomastoideus and additional area for the insertion of the nuchal musculature. The main difference is that in Neandertals there is a need for increased areas for attachment of the nuchal muscles. This need is a response to the development of the Neandertal dento-facial complex with its increased weight (due to the buttressing of certain facial bones) and prognathism (both alveolar and midfacial). The mastoid provides some of this additional area but, it can not provide all of it and still perform its primary function of providing an area of insertion for the sternocleidomastoids. A solution to this problem is reached with the broadening of the nuchal plane and the extreme development of the occipitomastoid crest. This crest which lies medially to the mastoid process provides the additional area of attachment for the nuchal musculature of Neandertals. The projecting nature of this crest, in association with the other morphological developments in this region (a longer, lower, broader, more horizontally oriented posterior vault,

and thus a less rounded cranial contour from opisthion to lambda) creates the illusion of a nonprojecting Neandertal mastoid process.

Second, the mastoid process of Neandertals exhibits a marked degree of sexual dimorphism. This dimorphism, to a certain extent, can be utilized to sex individual Neandertal specimens. The reliability of the method employed here can be illustrated by the fact that it is able to correctly sex Neandertal specimens (La Chapelle, La Ferrassie II, and Tabun 1) that have been reliably sexed by the morphology of the sciatic notch of the innominate.

Secondary results of this study are of interest also. First, in my opinion, the multivariate techniques employed in this study are well suited to the aims and objectives of the study. The results are clearly interpretable and while it may be possible to interpret them in other ways I believe that the present interpretations are sound and logical.

Second, the measurement porion-mastoidale length (PML) proves to be a superior indicator of mastoid projection compared to the projection measurement of Zoja, particularly if the objective of the researcher is to compare mastoid projection between two or more populations. If the objective of the researcher is to determine the projection of the mastoid relative to the cranial base then I would recommend Zoja's technique of measuring mastoid projection (MAP in this study).

Further research in this problem area should include the use of more than one comparative sample. This would serve as a check on the principal components structure. Also, the Neandertal sample should be increased if possible. Finally, other measurements may be devised that more accurately reflect the functional relationships that exist in the posterior cranium. Some of the measurements employed in this study did not seem to contain much useful information (i.e. mastoid foramen breadth and bioccipitomastoid breadth).

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APPENDIX

The following is a list of variable names, variable name codes, sources, required instruments, and definitions for the 2 angles and 15 linear measurements taken on the Larson Site Arikara. Following each variable is a three letter variable name code patterned after Howells (1973). The angles and linear measurements are selected from three sources (A) Zoja (see Vallois 1969), (B) Howells (1973), and (C) devised for the present study. There are four instruments required to take these measurements (1) spreading calipers, (2) sliding calipers, (3) coordinate calipers, and (4) Western Reserve head spanners.

Basion-bregma height (BBH, B, 1). The distance from basion to bregma.

Glabello-occipital length (GOL, B, 1). The greatest length, from the glabellar region, in the median sagittal plane.

Biasterionic breadth (BAB, B, 1). The direct measurement from one asterion to the other.

Opisthion-inion length (OIL, C, 2). The distance from opisthion to inion in the midplane.

Inion-lambda length (ILL, C, 2). The distance from inion to lambda in the midplane.

Bimastoid foramen breadth (MFB, C, 2). The distance from one mastoid foramen to the other.

Mastoid projection (MAP, A, 2). The distance from the midpoint of the mastoid base, on the medial aspect of the process to mastoidale (see Figure 4, p. 24).

Mastoid base length (MBL, A, 2). The maximum breadth of the base of the mastoid process (see Figure 4, p. 24).

Porion-mastoidale length (PML, C, 2). The distance from porion to mastoidale.

Bioccipitomastoid crest breadth (OMB, C, 2). The distance from one occipitomastoid crest to the other, taken at the midpoint of each crest.

Opisthion radius (OPR, C, 4). The perpindicular to the transmeatal axis from opisthion.

Lambda radius (LAR, C, 4). The perpindicular to the transmeatal axis from lambda.

Occipital chord (OCC, B, 3). The external occipital chord, or the direct distance from lambda to opisthion taken in the midplane and at the external surface.

Occipital chord subtense (OCS, B, 3). The maximum subtense, at the most prominent point on the basic contour of the occipital bone in the midplane.

Occipital chord fraction (OCF, B, 3). The distance along the occipital chord, recorded from lambda, at which the occipital subtense falls.

Occipital angle (OCA, B). In the sagittal plane, the angle underlying the curvature of the occipital bone at its maximum height above the occipital chord, computed from OCC, OCS, and OCF.

Porion angle (POA,C). The angle formed at porion by the lambda radius and opisthion radius, computed from OCC, LAR, and OPR.

VITA

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