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# A FUNCTIONAL MORPHOMETRIC STUDY OF THE POSTERIOR CRANIUM

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Steven M. Donnelly

May 1990

For my parents

Dudley and Ruth Donnelly

# ACKNOWLEDGEMENTS

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# ABSTRACT

Neandertal crania are characterized by large prognathic faces, mastoid processes that appear to be small and non-projecting, and a long, low, broad and horizontally oriented nuchal plane. It has been argued that these features are functionally related: the large horizontally oriented nuchal plane enhances the ability of the nuchal musculature to balance and support the large and prognathic face, and the small appearance of the mastoids is engendered by the low position and horizontal orientation of the nuchal plane.

The purpose of this thesis is to identify the functional and morphological implications of a large and horizontally oriented nuchal plane and to determine if the functional relationships that have been hypothesized to exist in Neandertals also exist in modern humans. The posterior cranial morphology of 114 male and 102 female crania representing three modern populations was examined.

Seven morphological and functional complexes in the posterior cranium were identified by principal components analysis: occipital plane length; posterior vault size; nuchal plane orientation; nuchal plane length; mastoid size; occipital curvature; and posterior breadth. The nuchal plane can be regarded as one of the functional complexes of the posterior cranium, and both size and orientation are significant aspects of its morphology.

The size and orientation of the nuchal plane appear to be related to the morphology of the mastoid region of the temporal and the size and prognathism of the face, but the pattern of relationships is only partially similar to the morphological pattern seen in Neandertals. The size of the nuchal plane, particularly the anterior breadth, appears to be functionally related to the size of the face and the lowness of the cranial base; as the face becomes larger and the cranial base inferiorly positioned the nuchal area becomes broader and the occipital more posteriorly projecting. There is no relationship between the orientation of the nuchal plane and the size or projection of the mastoid processes, and the the relationship between nuchal plane orientation and facial prognathism is quite different from the pattern seen in Neandertals. In modern humans a prognathic face appears to be associated with a more posteriorly, not inferiorly, oriented nuchal plane.

In modern humans the size of the nuchal plane, particularly its breadth, appears to be functionally related to the size of the face and the lowness of the cranial base, but the orientation of the nuchal plane may be related more to the morphology of other areas of the posterior cranium than to the functional demands placed upon it by the nuchal musculature.

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# CHAPTER I

## INTRODUCTION

Since the discovery of the Neandertal type specimen in 1856 the distinctive craniofacial morphology of Neandertals has been described and commented upon countless times by a multitude of authors (e.g. Boule 1911-1913; Boule and Vallois, 1957; Brose and Wolpoff, 1971; Coon, 1962; Hrdlicka, 1930; Mann and Trinkaus, 1973; Rak, 1986; Santa Luca, 1978; Smith, 1976, 1983; Trinkaus, 1983; Wolpoff, 1980). The most salient features of the Neandertal skull are: a large and broad face that is markedly prognathic in the mid-facial region, a broad nasal aperture, an inflated maxilla lacking a canine fossa, an oblique zygomatico-alveolar crest that merges evenly into the maxillary alveolar process, a large and broad palate, and thick frontal processes of the maxilla and zygomatic; the mandible is also prognathic, consequently the symphysis is receding and there is a distinct gap between the distal edge of the third molar and the anterior margin of the ascending ramus; the anterior teeth are large even though the posterior teeth are within the modern human range; the cranial vault is long and low, with a low receding forehead and thick, projecting tori above the orbits; the occipital is flattened in the area of lambda and the nuchal plane is horizontally oriented, which causes the occipital to protrude posteriorly and creates an occipital 'bun', the occipital is also broad and is traversed by a nuchal torus; the mastoid processes appear to be small and non-projecting, but the occipito-mastoid crest is very well developed and the cranial base is not as strongly flexed as it is in modern humans.

## The Adaptive Significance of Neandertal Craniofacial Morphology

A number of aspects of the Neandertal skull are highly derived, yet most authors have chosen to emphasize the differences between Neandertals and modern humans, often with the purpose of showing how the two might or might not be related, without attempting to explain the adaptive significance of Neandertal morphology. However, it has been argued (e.g. Smith, 1983; Smith, Falsetti and Donnelly, 1989; Smith and Paquette, 1989; Trinkaus and Smith, 1985) that to understand how Neandertals are related to modern humans it is first necessary to understand the adaptive significance of Neandertal morphology. Several hypotheses have been developed to explain the functional aspects of Neandertal craniofacial morphology.

In the 1950s it was believed that much of Neandertal craniofacial morphology could be explained as an adaptation to the harsh, intensely cold climate of glacial Europe. Howell (1952, 1957) noted that "classic Neandertals" were restricted to western and southern Europe during the first stadial of the last glacial period. He argued that the harsh periglacial climate would have been a strong selective force and would also have been a barrier to gene flow, isolating western European Neandertals from other archaic Homo sapiens. Consequently Howell (1957) regarded the 'peculiar and distinct' features of Neandertals as the result of a combination of natural selection, isolation and drift.

Howell, however, did not identify which features he regarded as being cold adaptations. Coon (1962), like Howell, thought that much of Neandertal morphology was an adaptive response to a periglacial climate. He believed that the 'prime architect' of the Neandertal face was the large, broad and projecting nose, which he considered to be of major adaptive significance. According to Coon (1962) the forward position of the nasal aperture increased the distance between it and the arteries supplying the brain, thereby protecting the brain from cooling; the enlarged aperture facilitated the warming and moistening of inspired air.

Hylander (1977) has shown that there are a number of shortcomings in the cold adaptation hypothesis, and cold adaptation is no longer regarded as being the primary determinant of Neandertal facial morphology. Nevertheless, there are some workers who still see some degree of cold adaptation in the Neandertal face. For example, Wolpoff has described the differences between European Neandertals and other archaic hominids as being "mainly centered on the cold-adapted features that are superimposed over a 'grade' morphology ...." (Wolpoff, 1980:294).

It has also been suggested that the Neandertal face is adapted for withstanding heavy occlusal loads generated primarily by the anterior dentition. There is strong evidence that Neandertals habitually used their anterior teeth "in ways not common to and to an extent never reached in modern *H. sapiens*." (Smith, 1983:143). The anterior teeth of Neandertals are larger than those of modern humans, although the posterior teeth are within the modern range; they are also characterized by well developed marginal ridges and basal tubercles (Brace, 1962; Trinkaus, 1978, 1983; Smith, 1976; Wolpoff, 1980). The morphology and large size of these teeth make them more resistant to attrition, and more importantly, increase their ability to withstand heavy occlusal loads (Smith, 1983). However, in spite of their size and morphology the anterior teeth of Neandertals tend to be extensively worn, almost always to a greater degree than the posterior teeth (Smith, 1976; P. Smith, 1976; Trinkaus, 1983). In some Neandertals the anterior teeth are so heavily worn that all of the enamel has been worn away even though the posterior teeth still retain some enamel (Trinkaus, 1983).

Brace (1962; 1964) believed that Neandertals had used their teeth, primarily the anterior teeth, as tools, and that much of the morphology of the Neandertal face was determined by its role in supporting the teeth and withstanding and dissipating occlusal forces. However, Brace's hypothesis was rather superficial, and he did not specify how the architecture of the Neandertal face would facilitate this.

More specific models have been presented by several workers (Rak, 1986; Smith, 1983; Trinkaus, 1984; 1987). The two most explicit models are those of Rak (1986) and Smith (1983). Rak (1986) has argued that the distinctive facial morphology of Neandertals is primarily the result of a change in the orientation of the infraorbital area from a coronal to a more sagittal plane. He believes that this reorientation rendered the anterior face more efficient in resisting sagittal rotation generated by the use of the anterior teeth as tools. The absence of the canine fossa and the oblique zygomatico-alveolar crest are believed to be adaptations which maximize the resistance of the infraorbital area to rotation.

Smith (1983) regards much of the morphology of the Neandertal face as an adaptation for both resisting and dissipating the forces generated by the anterior dentition. According to Smith the large prognathic face allows the roots of the anterior teeth to be larger and more vertically positioned, improving their efficiency in dissipating the vertical occlusal forces generated by anterior dental loading. The large size of the face is also believed to reduce the bending moments acting on the face during anterior biting. The thick frontal processes of the maxilla and zygomatic and the well-developed supraorbital torus act as buttresses which further reduce the bending moments in the face and transmit compressive forces to the cranial vault.

Most models which have attempted to explain the biomechanical significance of Neandertal craniofacial morphology have considered the face only. But Smith has argued that the distinctive morphology of the posterior neurocranium is also functionally related to the use of the anterior teeth as tools.

> a larger, more projecting face would need to be compensated for by either increasing the lever arm (post-occipital condylar portion) or the efficiency of the nuchal muscles (which provide the force) or both. Additionally, loading of the anterior dentition requires that the nuchal muscles exert considerable force in producing tension and torsion. On the basis of these factors, I see Neandertal occipital bunning as a compensatory phenomenon, not so much because it adds mass to the postcondylar cranium, but because it provides a more horizontal orientation for the nuchal plane and expands its area. Biomechanically, the former would substantially improve the physiological efficiency of the nuchal musculature by maintaining a greater cross-section of the muscle roughly parallel to the axis of contraction and by shortening the contractional lever arm (i.e. decreasing the distance between the origin and insertion of the nuchal muscles). (Smith, 1983:154)

The well-developed occipitomastoid crest could also be an adaptation to accommodate the demands of anterior dental loading because it further increases the area of attachment for the nuchal muscles.

In Smith's model many of the specialized and distinctive features of the Neandertal face and neurocranium are functional adaptations directly related to the use of the anterior teeth as tools. Another characteristic feature of the Neandertal skull may be an indirect consequence of these functional adaptations. Neandertals are often described as having mastoid processes which are small and non-projecting. It may be however, that the small size of the mastoids is more apparent than real (Smith, 1982; Trinkaus, 1983; Zobeck, 1980), and may be engendered by the prominence of the occipito-mastoid crest and the lower, more horizontally positioned nuchal plane.

## Defining the Research Problem

The purpose of this thesis is to examine the functional significance of the lower, more horizontally positioned nuchal plane characteristic of Neandertals by studying variability in the posterior skull of modern humans. Its goals are: (1) to identify the morphological and functional complexes that make up the posterior neurocranium of modern humans; (2) to test the hypothesis that the nuchal plane is one of these functional complexes; (3) to determine how the size and orientation of the nuchal plane are related to the morphology of other areas of the posterior cranium; and (4) to ascertain if there is a relationship between the size and/or the orientation of the nuchal area and facial size and prognathism and the size and projection of the mastoid process, and to explain these relationships in functional terms.

Research Assumptions and Limitations

To assess the functional significance of posterior cranial morphology it is necessary to use samples of modern human crania. Modern humans are used rather than Neandertals for a number of reasons. Some of the measurements used in this thesis are not commonly taken and others were defined specifically for this study. Even if it were possible to take these measurements on the original fossil specimens the number of complete crania would be too small to allow for the kinds of statistical analyses used in this thesis.

In addition, using modern human crania makes it possible to use samples which are representative of actual biological populations, and to determine how much variability in posterior cranial morphology exists within and between such populations. A collection of Neandertal crania would comprise a sample representing populations from a wide geographic area and a time span of tens of thousands of years. With such a sample it would be impossible to identify the nature of the observed variability: variability could be attributed to differences between contemporary but separate populations, changes in morphology through time, or simply differences between individuals from the same population.

There are, however, potential problems with the approach taken in this study. The growth and development of the skull is an extremely complex process involving interactions between the different areas of the skull and between genetic factors and biomechanical demands. The nature of these interactions is, at best, poorly understood. This makes it very difficult to develop and test functional/ behavioral hypotheses.

This thesis does attempt to test hypotheses about posterior cranial morphology, but these are not functional hypotheses. They are concerned only with determining if the orientation of the nuchal plane is related to the size and prognathism of the face and the size and projection of the mastoids. These relationships will be explained in functional terms, but these explanations are not being tested. Thus, questions of cause and effect are not being directly addressed. In reality a simplistic, functional, cause and effect interpretation of craniofacial morphology would provide very little insight on such a complex subject.

The potential difficulties are magnified when hypotheses are tested with modern humans and then the results and explanations derived from them are extended to fossil hominids. Neandertals are a group of humans genetically, behaviorally and technologically distinct from modern humans. For example, no group of modern humans have faces as large and prognathic as those of Neandertals. There are also no living people which are technologically equivalent to Neandertals, and there are no living people who use their anterior teeth in the manner or to the extent that they were presumably used by Neandertals.

However, in all hominids the roles of the various functional complexes that make up the skull are similar, even though the demands placed on these complexes might be very different in magnitude. In modern humans some individuals or groups may possess features that are to some degree more Neandertal-like than those of other individuals or groups. If the functional relationships that exist among the different areas of the skull are similar, then it is likely that such individuals may possess other Neandertal-reminiscent features. Thus, if there is a meaningful, functional relationship between the orientation of the nuchal plane and the morphology of other areas of the skull in modern humans it is possible that these relationships may foreshadow a morphological pattern similar to that of Neandertals, even though these features are not developed to the same degree as they are in Neandertals.

# CHAPTER II

# MORPHOLOGY AND MUSCULATURE OF THE POSTERIOR CRANIUM IN MODERN HUMANS AND NEANDERTALS

## Modern Humans

Morphology of the posterior cranium. The bones of the posterior cranium which provide areas of attachment for the nuchal musculature are the left and right temporal and the occipital.

The temporal bone is a paired bone located at the side and rear of the skull posterior to the sphenoid and anterior and lateral to the occipital. The bone has three parts: the squamous, petrous, and mastoid portions (Anson and Donaldson, 1981; Bass, 1987; Bast and Anson, 1949; Gray, 1977). The squamous portion comprises the anterior and superior part of the bone. It forms the infero-lateral braincase, and its external surface provides much of the area of attachment for m. temporalis. The petrous portion, which contains the inner ear, is situated at the base of the temporal between the sphenoid and occipital.

The mastoid portion is located in the posterior area of the temporal bone. It extends below to form a conical projection, the mastoid process, the lateral surface of which serves as an area of attachment for the sternocleidomastoideus, splenius capitis and longissimus capitis muscles (see Figure 1). On the medial aspect of the process is a

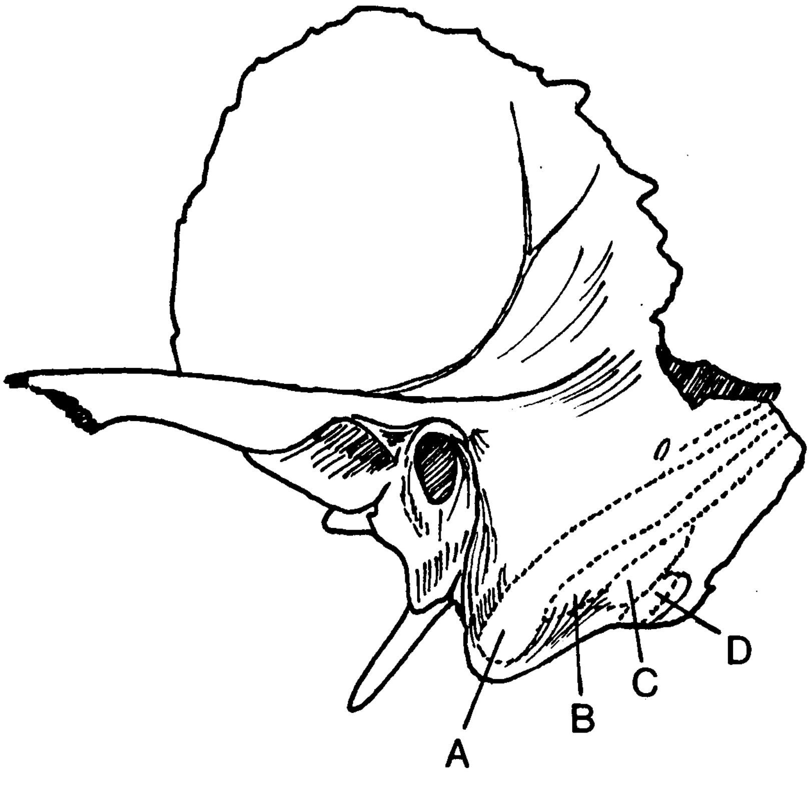


Figure 1. Left Temporal Bone in Lateral View Showing the Areas of Muscle Attachment. (A) m. sternocleidomastoideus; (B) m. splenius capitis; (C) m. longissimus capitis; (D) m. digastricus. (After Gray, 1977).

deep groove, the digastric notch, which is the area of insertion for the digastric muscle. The process itself is filled with numerous mucous lined cavities, the mastoid air cells, which communicate with one another as well as the tympanum via the tympanic antrum (Anson and Donaldson, 1981; Bast and Anson, 1949; Gray, 1977).

The occipital bone is an unpaired bone situated at the posterior and inferior part of the skull. There are four parts to the occipital (Bass, 1987; Gray, 1977). The basilar portion is located in front of the foramen magnum, and articulates with the sphenoid at the basilar synchondrosis. Located on either side of the foramen magnum are the condylar portions, these bear the occipital condyles which articulate with the atlas. Posterior to the foramen magnum is the squamous portion; this area forms the posterior portion of the braincase and its external surface provides an area of attachment for many of the nuchal muscles.

The external surface of the squamous portion bears several prominent ridges of bone (see Figure 2), which tend to be developed to varying degrees in different crania (Gray, 1977; pers. obs.). Located midway between the posterior margin of the foramen magnum and lambda is a triangular tubercle, the external occipital protuberance, which projects downward. On each side, passing outward from this protuberance are two arcs of bone, the supreme and superior nuchal lines. The more inferior of these is the

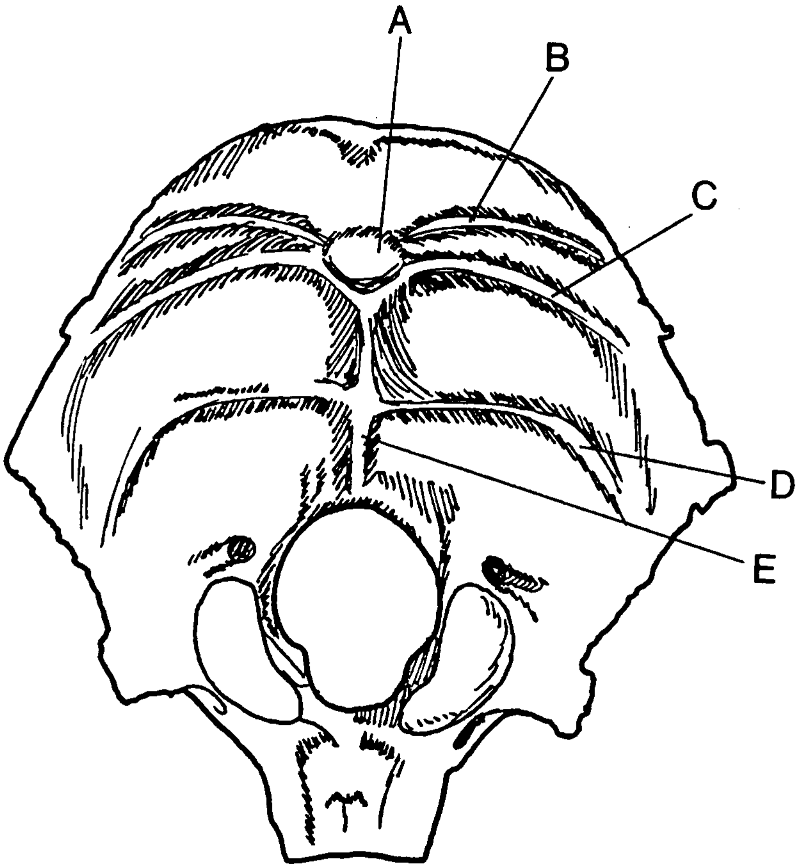


Figure 2. External Aspect of the Occipital Bone. (A) external occipital protuberance; (B) supreme nuchal line; (C) superior nuchal line; (D) inferior nuchal line; (E) medial nuchal line.

superior nuchal line which marks the boundary between the nuchal and occipital planes (Weidenreich, 1940). Above this line there is a second, less distinct ridge of bone, the supreme nuchal line. The nuchal plane itself is divided into a right and a left half by the medial nuchal line, which extends from the external occipital protuberance to the foramen magnum; this crest and the external occipital protuberance give attachment to the *ligamentum nuchae*. The nuchal plane is further divided by the inferior nuchal lines, which are parallel to the superior lines and extend outward from approximately the midpoint of the medial line.

*Musculature of the posterior cranium*. There are a number of muscles which have their origin or insertion on the posterior cranium. The muscles of this area which are the prime movers of the head and neck are:

1. *Sternocleidomastoideus*. This muscle has its origins by two heads; one on the manubrium and the other on the medial clavicle. From its origin the muscle runs obliquely upward and backward to its insertion on the mastoid process (see Figures 1 and 3). Contraction of the muscles on both sides flexes the cervical vertebral column, elevates the chin and moves the head forward; unilateral contraction flexes the cervical vertebral column laterally moving the head closer to the shoulder of the same side, elevating the chin and turning the face to the opposite side (Crouch, 1972; Hollinshead and Jenkins, 1981).

Figure 3. M. sternocleidomastoideus. (After Kapit and Elson, 1977).

2. Splenius capitis and splenius cervicis. The splenius capitis takes its origin from the lower half of the ligamentum nuchae and the spinous processes of the seventh cervical and upper three or four thoracic vertebrae. The muscle extends laterally and upward, and inserts on the mastoid process and the occipital in the lateral area of the superior nuchal line. Splenius cervicis arises from the spinous processes of the third to sixth thoracic vertebrae and inserts laterally on the transverse processes of the second to sixth cervical vertebrae (see Figures 4 and 5). Bilateral contraction of the splenius capitis and cervicis muscles extends the neck; contraction of the muscles on only one side rotates the head and neck toward the same side (Hollinshead and Jenkins, 1981; Warfel, 1985).

3. Longissimus capitis and longissimus cervicis. The longissimus capitis has its origin on the transverse processes of the upper three or four thoracic vertebrae and the articular processes of the lower three or four cervical vertebrae, and inserts on the posterior margin of the mastoid process. The longissimus cervicis takes its origin from the transverse processes of the upper four or five thoracic vertebrae, and inserts on the transverse processes of the second to sixth cervical vertebrae (see Figures 4 and 5). The function of these muscles is to extend, laterally flex and rotate the spinal column (Hollinshead and Jenkins, 1981; Warfel, 1985).

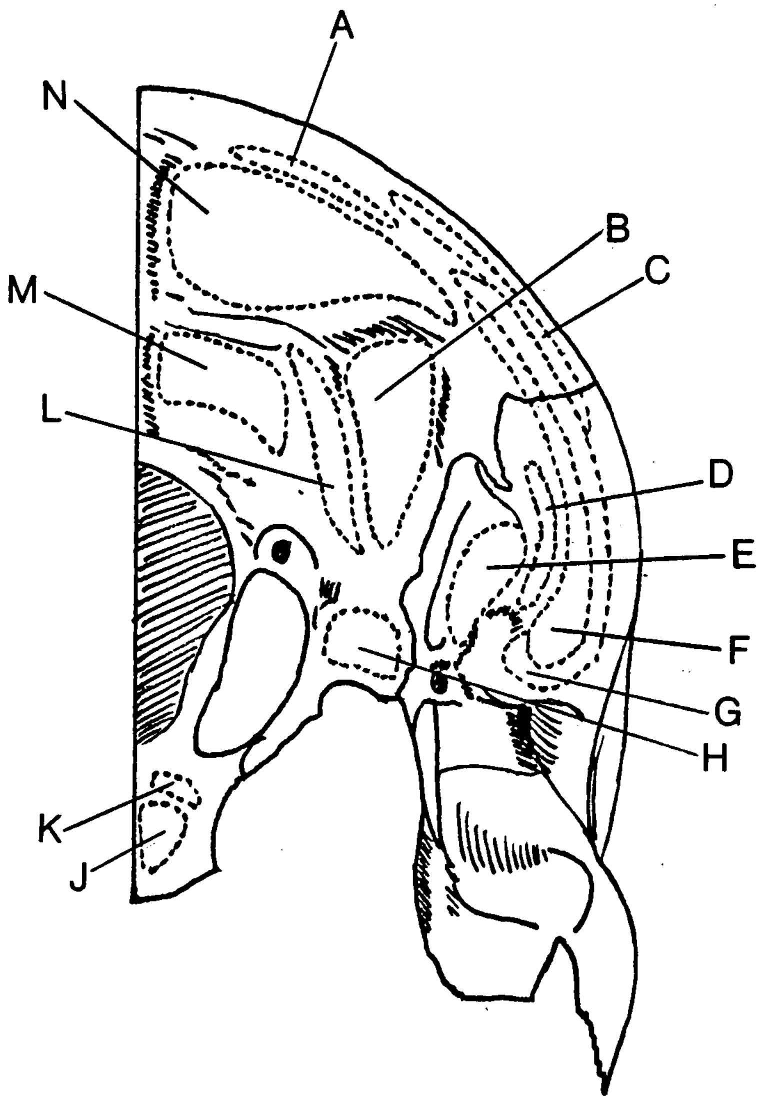


Figure 4. External Aspect of the Inferior Occipital and Temporal Showing the Areas of Muscle Attachment. (A) m. trapezius; (B) m. obliquus capitis superior; (C) m. occipitalis; (D) m. longissimus capitis; (E) m. digastricus; (F) m. splenius capitis; (G) m. sternocleidomastoideus; (H) m. rectus capitis lateralis; (J) m. longus capitis; (K) m. rectus capitis anterior; (L) m. rectus capitis posterior major; (M) m. rectus capitis posterior minor; (N) m. semispinalis capitis. (After Gray, 1977).

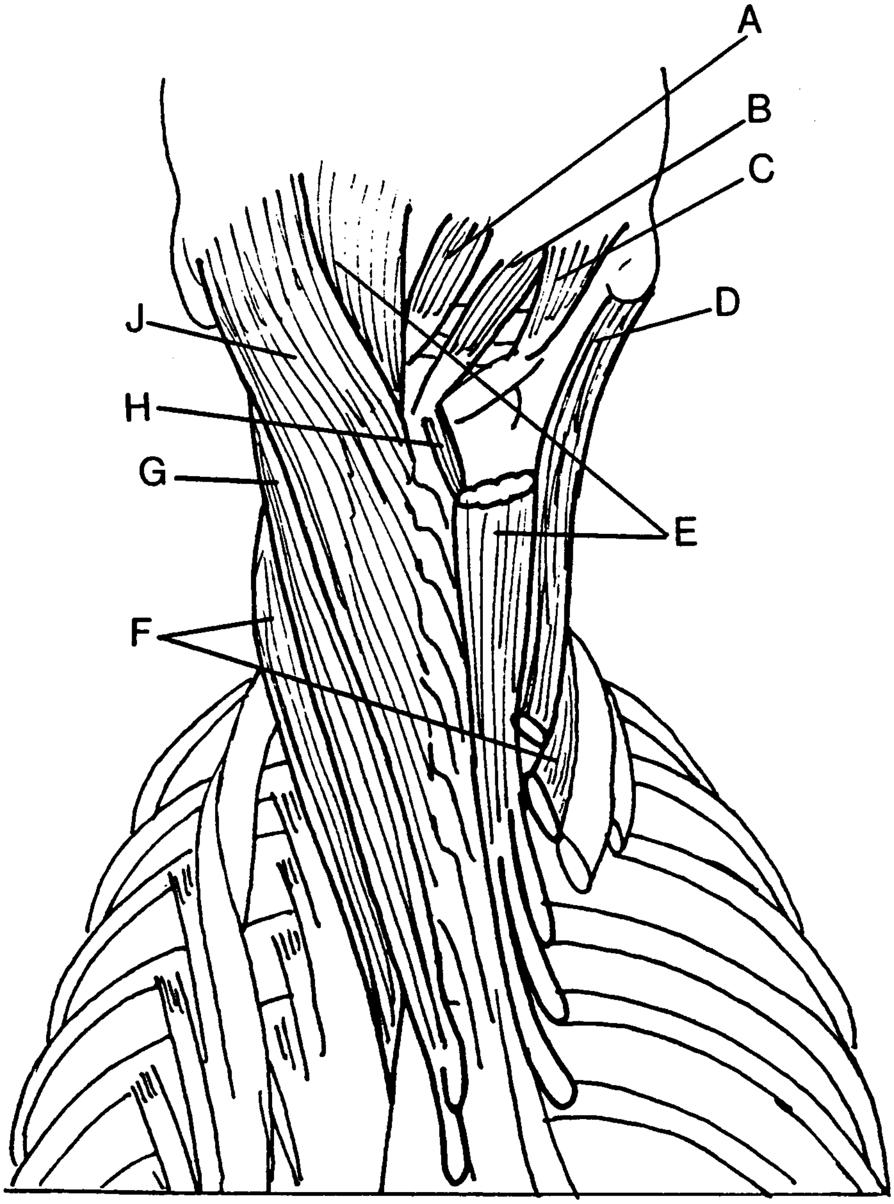


Figure 5. Musculature of the Upper Back and Neck. (A) m. rectus capitis posterior minor; (B) m. rectus capitis posterior major; (C) m. obliquus capitis superior; (D) m. longissimus capitis; (E) m. semispinalis capitis. (F) m. longissimus cervicis; (G) m. splenius cervicis; (H) m. semispinalis cervicis; (J) m. splenius capitis. (After Hollinshead and Jenkins, 1981).

4. Semispinalis capitis and semispinalis cervicis. The semispinalis capitis takes its origin from the transverse processes of the upper six thoracic and seventh cervical vertebrae and the articular processes of the fourth to sixth cervical vertebrae. From its origin the muscle passes superiorly and medially to its insertion on the occipital bone between the inferior and superior nuchal lines. The semispinalis cervicis has its origin on the transverse processes of the upper six thoracic and the articular processes of the lower four cervical vertebrae. Its insertion is on the spinous processes of the second to fifth cervical vertebrae (see Figures 4 and 5). The function of these muscles is to extend and laterally flex the neck and extend the head (Hollinshead and Jenkins, 1981; Warfel, 1985).

5. Rectus capitis lateralis, rectus capitis anterior, rectus capitis posterior major and rectus capitis posterior minor. Rectus capitis lateralis takes its origin from the upper surface of the atlas and inserts on the inferior surface of the jugular process of the occipital. Rectus capitis anterior originates from the lateral body of the atlas, its insertion is on the basilar portion of the occipital. The rectus capitis posterior major has its origin on the spine of the axis and inserts on the occipital in the lateral area of the inferior nuchal line. Rectus capitis posterior minor takes its origin from the posterior tubercle of the atlas, its insertion is on the occipital

bone below the inferior nuchal line (see Figures 4 and 5). The function of the rectus capitis muscles is to extend, laterally flex and rotate the head (Crouch, 1972; Gray, 1977; Warfel, 1985).

6. Obliquus capitis superior. The obliquus capitis superior takes its origin from the transverse process of the atlas. From its origin the muscle passes upward and inward to its insertion on the occipital bone above the inferior nuchal line (see Figures 4 and 5). Contraction of this muscle extends and rotates the head (Warfel, 1985).

Neandertals

In the posterior cranium Neandertals exhibit many of the features found in modern humans, yet they possess a morphological pattern that is unique. In fact, a number of features of this area are regarded as diagnostic of Neandertals, distinguishing them from other groups of archaic H. sapiens (Santa Luca, 1978). Many of these are adaptations to accommodate the more powerful nuchal musculature of Neandertals; increasing their area of attachment and/or their biomechanical efficiency.

One of the most distinctive features of the Neandertal skull is the occipital chignon or bun. This is an evenly rounded posterior projection of the occipital squama. The chignon is associated with flattening of the cranial vault in the area of lambda and a nuchal plane that is lower and more horizontally positioned (Trinkaus and LeMay, 1982). As described in the introduction the low, horizontal position of the nuchal plane increases the biomechanical efficiency of the nuchal muscles by shortening the distance between their origins and insertions and placing them in a position that is more parallel with their plane of contraction (Smith, 1983).

The nuchal plane itself is large, broad and quite rugose, indicating that the muscles of the neck were more developed than they are in modern humans (Smith, 1976; Trinkaus, 1983; Weidenreich, 1940). The nuchal plane is separated from the occipital plane by the transverse occipital torus. This is a more or less horizontal thickening of bone which lies between the superior and supreme nuchal lines and extends from inion to the area of asterion (Weidenreich, 1940).

In the temporal bone one of the most distinctive Neandertal features is the appearance of the mastoid processes, which are often described as being small and non-projecting (e.g. Boule and Vallois, 1957; Hrdlicka, 1930). The lateral surface of the mastoids exhibit prominent muscle markings, indicating well-developed muscles (Smith, 1976; Trinkaus, 1983). The small size of the mastoids is therefore somewhat surprising.

It may be however, that the oft-cited small size of the mastoids is more apparent than real. When it is measured from the Frankfort horizontal plane or the trans-meatal axis, rather than the floor of the digastric groove, mastoid height falls within the modern human range (Smith, 1982; Trinkaus, 1983; Zobeck, 1980). The mastoids appear to be small because they are dwarfed by the occipitomastoid crest. This is a ridge of bone which is situated along the suture between the occipital and temporal bone, medial to the mastoid process (Olson, 1985). The crest is separated from the mastoid by the digastric groove, which is broad and shallow in Neandertals but deep and narrow in modern humans. In modern humans the occipitomastoid crest is only weakly developed (pers. obs.) but in Neandertals it is very prominent, and tends to project beyond the tip of the mastoid process (Angel, 1972; Santa Luca, 1978; Trinkaus, 1983). For example, Trinkaus (1983) estimates that in Shanidar 1 the height of the occipitomastoid crest as measured from the floor of the digastric groove is 136% the height of the mastoid as measured in the same way. The crest is also quite long, extending posteriorly beyond the mastoid almost to asterion (Trinkaus, 1983). The enlarged crest provides a greater area of attachment for the nuchal musculature; Trinkaus (1983) believes that it enlarged the area of attachment for *m. digastricus* and possibly *m. rectus capitis posterior major*.

Thus, the small appearance of the mastoids is not created by small mastoids per se. It is produced by the prominently developed occipitomastoid crest, the shallower digastric groove and possibly the lower, more horizontally positioned nuchal plane.

It is important to realize that these features are not merely biomechanical responses to the intense use of the nuchal muscles. They appear even in Neandertal children, and undoubtedly have a strong genetic component (Minugh-Purvis, 1988). Obviously, it would be unreasonable to expect any modern humans to exhibit a morphological pattern like that of Neandertals, but it is possible that some may be more Neandertal-like than others in some features.

# CHAPTER III

## SKELETAL SAMPLES

In this study a total of 216 crania, representing three populations, were examined. Two of these groups, the Arikara and the Haida, are North American Indian. The third group, the Tolai, is from the Melanesian island of New Britain. These groups were chosen with the objective of collecting as heterogeneous a group of crania as possible and because the samples are large and well-preserved, rather than because of any interest in these three groups *per se*.

### Arikara

The Arikara belong to the Caddoan linguistic group, and were formerly closely allied with, or a part of, the Skidi Pawnee (Deetz, 1965; Dorsey, 1904). After their split with the Pawnee, which occurred in the late Sixteenth or early Seventeenth Century (Deetz, 1965) the Arikara moved slowly up along the Missouri River and into the Middle Missouri area. This region lies in the Dakotas between the Little Missouri River in northwestern North Dakota and the Niobrara river which forms a part of the Nebraska-South Dakota border. The climate of the area is harsh, with extremes of dry, hot summers and harsh, cold winters and variable annual rainfall (Krause, 1972; Lehmer, 1971).

The Arikara were sedentary horticulturists who lived in large permanent villages located along the rivers and major streams of the area (Lehmer, 1970). These villages consisted of sod-covered lodges clustered together in a defensive location, usually on the first or second terrace above the river (Holder, 1970) and were often fortified with elaborate earthworks (Holder, 1970; Lehmer, 1971). The size of a village was determined by the amount of arable land and wood supplies available in the river bottoms (Holder, 1970), but usually a village consisted of 20 to 40 lodges (Lehmer, 1971).

The Indians cultivated corn, pumpkins and squash on small patches of land on the river bottom (Denig, 1939). In years when the climate was favorable, and precipitation sufficient the crop would be good, but Denig (1939) notes that droughts and floods were frequent. Crops from these gardens were a major source of food for the Arikara but hunting was equally important to their economy. The bison was by far the most commonly hunted animal, and provided the Arikara with meat, skins and raw materials for tools (Lehmer, 1954; 1970).

During the proto-historic and historic periods the Arikara underwent drastic changes in their lifestyle. As European traders arrived in the Middle Missouri area they used the villages along the river as bases of operations (Holder, 1970). The Indians derived many advantages from the trade goods which passed through their villages, and also acted as middle-men in the horse trade of the area

(Holder, 1970). But ultimately the arrival of Europeans had catastrophic consequences for the Arikara in the form of measles, smallpox and venereal disease (Abel, 1939; Holder, 1970; Lehmer, 1968; Nasatir, 1952). According to Truteau (cited in Nasatir, 1952) at one time the Arikara inhabited 32 large villages, and Holder (1970) believes that there may have been as many as 30,000 Arikara in the prehistoric period. However, in the latter half of the Eighteenth Century diseases rapidly decimated their population to such an extreme that by the beginning of the Nineteenth Century there were only three inhabited villages (Abel, 1939; Krause, 1971; Lehmer, 1968).

The Arikara of the post-contact period primarily buried their dead in individual graves in cemeteries located near the village, although multiple burials are sometimes found and occasionally the dead were buried in the villages (Lehmer, 1971). Bodies were usually partly flexed and laid on the back or side (Lehmer, 1971).

The Arikara sample used in this study is composed of 52 male and 49 female crania from the village and cemetery of the Larson site (39WW2). This site consists of an earth lodge village and its cemetery located on the east bank of the Missouri River about two miles southeast of Mobridge, South Dakota. The village was situated on a high terrace overlooking the river and the cemetery was located on a slope 100 to 300 yards northeast of the village (Owsley and

Bass, 1979). According to Jantz and Owsley (1984) the site was occupied between 1679 and 1733, which places it within the post-contact variant of the Plains Coalescent Tradition.

Excavation of the cemetery was carried out between 1966 and 1968. During this time a total of 628 individuals were recovered. The skeletal remains are now curated by the University of Tennessee.

### Tolai

The Tolai are a Melanesian people who inhabit the Gazelle Peninsula of New Britain. The Tolai live on the northern coast of the peninsula in an area of approximately 300 square miles (A. Epstein, 1969; T. Epstein, 1968). The area is hilly with a narrow fringe of coast, and is isolated from inland areas by high mountains.

The Tolai are a people of Melanesian stock (T. Epstein, 1968) who speak an Austronesian language (A. Epstein, 1969). In general their culture and social organization resembles that of the other peoples of Melanesia and New Guinea. Before European contact the Tolai were primitive horticulturists who are reputed to have been cannibals and headhunters (Salisbury, 1970). The volcanic soil of the area is extremely fertile, and capable of supporting a wide variety of crops. The Tolai cultivated large crops of coconuts, taro, yams and sugar cane (A. Epstein, 1969; T. Epstein, 1968; Salisbury, 1970). The peninsula is not rich in fauna and the primary source of animal protein was fish which were very abundant (A. Epstein, 1969). The abundance of natural resources is reflected by the fact that the Gazelle peninsula had one of the densest populations of Melanesia (Salisbury, 1970).

Prior to contact Tolai society was extremely fragmented and there was no centralized authority. The only political units were matrilineal groups of two to three hundred people known as gunans (T. Epstein, 1968). The Tolai are reputed to have been extremely war-like: gunans frequently fought with one another, and the Tolai were also chronically at war with the other inhabitants of the peninsula (T. Epstein, 1968).

The island of New Britain was discovered by Europeans in 1699, but it wasn't until the end of the Nineteenth Century that Westerners began to have any systematic effect on the Tolai. The culture began to change in 1872 when German traders and Methodist missionaries established themselves on the peninsula. Shortly after that Europeans began to establish permanent plantations, and in 1884 the island was annexed by Germany.

The Tolai quickly adapted and made the best of the changing conditions (Hastings, 1973). Even before European contact the Tolai had a system of shell currency and an elaborate, highly developed system of trade and exchange with inland groups (A. Epstein, 1969; T. Epstein, 1968; Salisbury, 1970). When the European traders arrived the

Tolai exchanged coconuts for steel axes, knives, guns and ammunition and then often used these goods to trade inland along their traditional trade routes for shell money or more coconuts. The possession of guns also allowed the Tolai to steal money and coconuts from their neighbors (T. Epstein, 1968). At the same time the better tools enabled them to clear more land for growing more coconuts as well as other food crops which they could sell to foreign laborers who worked on the plantations, providing yet another source of wealth for the Tolai (T. Epstein, 1968).

The Tolai sample used in this thesis consists of 32 male and 31 female crania curated by the Field Museum of Natural History, Chicago. These crania were collected between 1882 and 1896 by Richard Parkinson, a plantation owner and amateur anthropologist. Exactly how and where these crania were collected is unknown. According to Parkinson (cited in Howells, 1969) the Tolai buried their dead and these crania were apparently exhumed by Parkinson as he collected them. The crania are not identified as Tolai but the natives of the Gazelle Peninsula were not referred to as 'Tolai' until well after the beginning of the Twentieth Century (A. Epstein, 1969). The crania were collected in an area of the peninsula inhabited by the Tolai, and there are crania of other natives of the peninsula, such as the Butam, in the collection and these are clearly marked as such. Based on this circumstantial evidence the crania used in this study are assumed to be Tolai.

Haida

The Haida are the aboriginal inhabitants of the Queen Charlotte's Islands, an archipelago of two large and many small islands located off the coast of British Columbia. Physically and culturally the Haida resemble other Northwest Coast Indians. However, their language, which is very distantly related to the Athapaskan language families (Murdock, 1967; Woodcock, 1977), is very different from those of their neighbors, whose languages belong to the Tsimshian, Salish and Nootka families (Woodcock, 1977).

The climate of the islands is mild, and resources on and around them were abundant, which allowed the Haida to live in permanent villages and maintain a ranking system based on wealth and hereditary status (Stearns, 1981); a way of life quite different from those of most other North American Indians. The islands possess abundant plant and animal life, but the Haida obtained most of their food from the sea and the islands' rivers and streams. Their primary source of food was fish, but they also made extensive use of shellfish, seaweed and sea mammals such as seals and otters (Murdock, 1967). During the late Eighteenth and early to middle Nineteenth centuries the Haida were the most affluent of Northwest Coast Indians. Much of their wealth came from their extensive and extremely profitable trade in sea otter skins with Europeans (Van den Brink, 1974). They also added to their wealth by raiding their neighbors; the Haida were extremely war-like and fought frequently with their neighbors, both for plunder and for slaves (Murdock, 1967; Stearns, 1981).

The Haida lived in villages of one to twenty communal houses which were usually located along the coast near areas where resources were abundant (Stearns, 1981). It is estimated that when Europeans first encountered the Haida in 1774 the population was between six and eight thousand (Van den Brink, 1974). However, throughout the middle and late Nineteenth Century the population was decimated by epidemics and emigration (Stearns, 1981; Woodcock, 1977). A survey by the Hudson's Bay Company carried out between 1835 and 1841 estimated that there were 6,693 Indians living in 13 permanent villages. By the 1880's only five villages were inhabited and the total Indian population of the islands had been reduced to about eight hundred individuals (Van den Brink, 1974).

The Haida had a variety of mortuary practices including the use of communal mortuary houses, burial caves and rock shelters, and they also occasionally cremated their dead or deposited them in trees. Historically the most common practice involved disposal of the dead in mortuary houses, which were similar to but smaller than the houses in which the Haida lived. These houses were usually located directly behind dwellings. The dead were also frequently disposed of in caves or rock shelters located near villages. In both cases the dead were placed in a mortuary box, tightly flexed and wrapped in a cedarbark mat. The box was then deposited among the stacks of coffins along the walls of the mortuary house, or stacked in burial caves (MacDonald, 1973). Deans, who visited the islands in 1890, described a mortuary house:

> The tomb was eighteen feet square. In the centre of the house a large frog three feet in height had been placed in a sitting posture. Around this frog, forming a square twelve feet were placed three tiers in height boxes holding the dead of the frogs. In them the bodies had been placed with knees drawn up under the chin, and finally covered with mats and bog myrtle (cited in MacDonald, 1973:2).

Deans also described Haida burial caves and rock shelters.

> In the steep and rugged conglomerate and limestone cliffs which everywhere abound in the Queen Charlotte's Islands are numerous cliffs hollowed out by the erosion of waves.... Every cave of any dimension near to a village is full of boxes, containing past generations of these villages. They are piled up in tiers in the recesses of these caverns. These boxes are square. In them the bodies had been placed with knees drawn up under the chin, wrapped in cedar blankets and covered with mats (cited in MacDonald, 1973:4).

The Haida sample used in this study is comprised of 30 male and 22 female crania curated by the Field Museum of Natural History, Chicago. These remains were collected from the Queen Charlotte's Islands in July of 1897 by George Dorsey and C. F. Newcombe for the Field Columbian Museum. There is little information in the museum archives regarding the sites where the remains were collected from. The records do indicate that they came from the areas of Skidegate, Kaisun, Cumshewa and Skincuttle. Skidegate, Kaisun and Cumshewa are all the names of villages which were inhabited in the middle of the Nineteenth Century, but only Cumshewa and Skidegate were inhabited at the end of the century (Van den Brink, 1974). Skincuttle is the name of an inlet at the southern extremity of the archipelago. Hand-written notes found with some specimens suggest that they were taken from mortuary houses near villages.

# CHAPTER IV

## METHODS

A large number of measurements are needed to provide an adequate description of the size and shape variation present in the posterior skull. Because of the large number of variables, and because they are interrelated in a complex manner, a multivariate approach to data analysis is necessary. Using multivariate statistics makes it possible to reduce the number of variables while retaining the majority of the information in the original data set, and also allows for consideration of the simultaneous relationships that exist among the variables (Dillon and Goldstein, 1985).

Corruccini (1978) however, has pointed out that multivariate morphometric studies are often misused by physical anthropologists, both in terms of intention and understanding. Corruccini (1978:140-141) has suggested that such analyses should be planned and judged by the following criteria:

1. Adequate justification should be given for the necessity of doing a morphometric analysis rather than some other approach. This requires a specific definition of the problem orientation of the study and how the problem is to be addressed.

2. The reason for taking each measurement should be explained. If the study is a functional comparative study

the functional significance of the measurements should be explained. The relevance of the suite of measurements to the testing of a defined hypothesis should also be explained. This means that individual measurements must be accurately described and defined.

3. Analysis of the measurements must be competently done. The results should be adequately and clearly presented and addressed to the hypothesis being tested.

4. Most importantly, the multivariate results must be related back to the original anatomy. The functional significance of the results, if any, must be made explicit.

Justification for the use of a multivariate morphometric approach, as well as an explicit statement of the problems addressed by this study have already been given. Careful consideration has been given to the last three criteria during the selection of the variables, the analysis of the data and the interpretation of the results.

## Variables

In this study the variables to be used were selected by first identifying the features of the skull that are of interest and then choosing the measurements that best reflect as many aspects of the size and shape of those features as possible. The aspects of the skull that are relevant to this study are: vault size; facial size and projection; occipital curvature; size and projection of the mastoid process and occipitomastoid crest; size of the nuchal area; and orientation of the nuchal area. In many cases commonly used measurements are appropriate. For some features, however, it was necessary to define new measurements or use measurements that are not commonly taken. Complete definitions of all measurements are provided in Appendix A.

Three variables were chosen to measure vault size: glabello-occipital length (GOL); basion-bregma height (BBH); and maximum cranial breadth (XCB). Facial size and projection are measured by four variables. Three variables, prosthion radius (PRR), nasion radius (NAR), and zygoorbitale radius (ZOR) measure the projection of three different areas of the face. This makes it possible to determine if the orientation of the nuchal plane is related to projection of a specific area of the face, such as the lower midfacial region, or the lateral face. Facial size is measured by nasion-prosthion height (NPH). Occipital curvature (OCA) is calculated from three measures: occipital cord (OCC); occipital subtense (OCS) and occipital cord fraction (OCF).

To measure the size and projection of the mastoid process three variables are used. The first of these is mastoidale radius (MAR), the distance from the transmeatal axis to mastoidale; this reflects the size of the mastoids and is unaffected by the orientation or position of the nuchal area. To assess the degree to which the mastoid projects below the cranial base Zojas's method of measuring mastoid projection (MAP) is used (described in Vallois, 1969). Mastoid projection is the height of the mastoid from the midpoint of the mastoid base, on its medial aspect, to mastoidale. The other measure of mastoid size is mastoid base length (MBL) (see Figure 6).

One other measurement, occipitomastoid radius (OMR) was developed to measure the position of the area of the cranial base medial to the mastoid. Occipitomastoid radius is the distance from the transmeatal axis to the occipitomastoid crest, medial to the midpoint of the mastoid base on the medial aspect of the process. Perhaps a better measure would be the height of the crest above the digastric groove. However, in modern humans the crest tends to be poorly developed and the morphology of the surrounding area makes it difficult to take this measurement.

To measure the size of the nuchal plane two transverse and two sagittal dimensions were taken. Bimastoid foramen breadth (BMF) and asterionic breadth (ASB) measure the breadth of the nuchal plane. Opisthion-inion[1] length (OIL) and inion radius (INR) reflect the sagittal length of the nuchal plane. Inion-lambda length (ILL) was also taken;

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[1]Inion has been defined in various ways (Weidenreich, 1940). In this study Martin's (1928) definition is followed. Inion is defined as the intersection of the midline with a line drawn tangent to the uppermost convexity of the right and left superior nuchal lines (see also Bass, 1987).

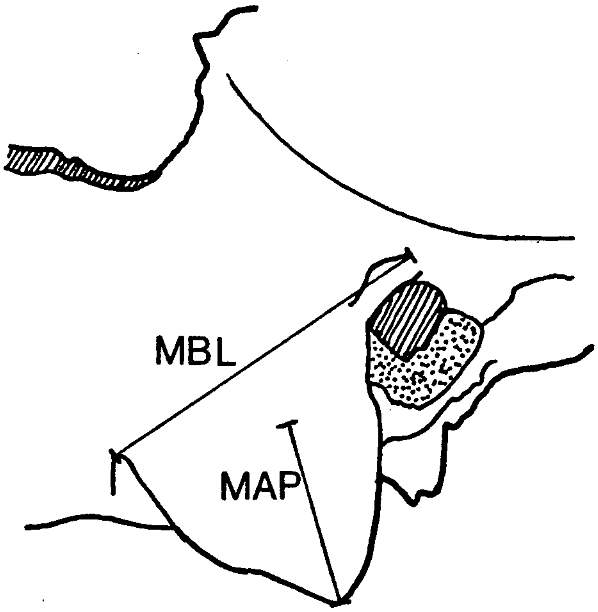


Figure 6. Mastoid Projection and Mastoid Base Length. Mastoid projection is the distance from the midpoint of the mastoid base on the medial aspect of the process, to mastoidale, after Zoja (Vallois, 1969). Mastoid base length is the width of the mastoid process at its base, through its transverse axis; from the posterior end of the digastric groove to a corresponding level on the external aspect of the mastoid (Howells, 1973).

this measures the size of the plane of the occipital which lies above the nuchal plane.

To measure the orientation of the nuchal plane two angles were defined specifically for this study. One angle, opisthion angle (OPA) is calculated from opisthion radius (OPR), INR and OIL. This is the angle at opisthion between OPR and OIL (see Figure 7).

It is possible however, that the orientation of the triangle defined by OPR, INR and OIL could vary about a horizontal plane without altering the angle at OPA. Therefore it is necessary to find a way of determining if the orientation of the nuchal area varies about a horizontal reference plane. It was decided to use the plane extending from the transmeatal axis to prosthion as the reference plane and to calculate an angle, prosthion-opisthion angle (POA,) which measures the orientation of the triangle defined by OPR, INR and OIL relative to the reference plane. POA is the angle at the transmeatal axis between PRR and OPR; it is calculated from PRR, OPR and prosthion-opisthion length (POL) (see Figure 8).

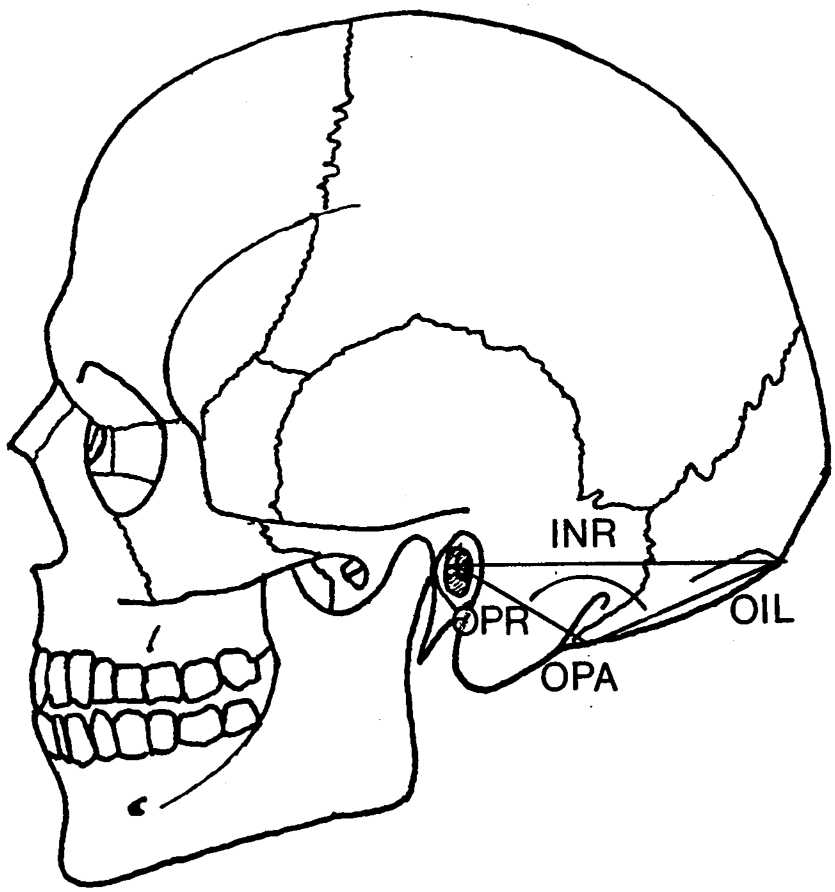


Figure 7. Opisthion Angle (OPA). The angle at opisthion between opisthion radius (OPR) and opisthion-inion length (OIL). The angle is calculated from OPR, OIL and inion radius (INR).

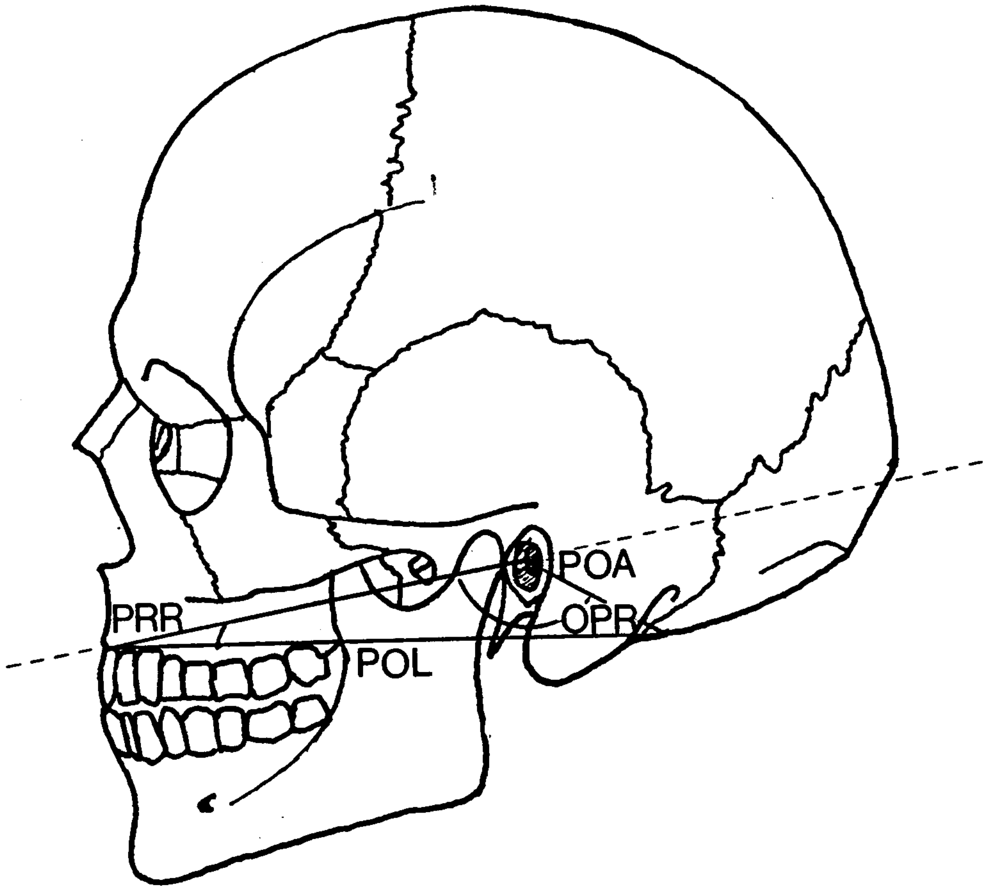


Figure 8. Prosthion-opisthion Angle (POA). The angle at the transmeatal axis between prosthion radius (PRR) and opisthion radius (OPR). The angle is calculated from POA, OPR and prosthion-opisthion length (POL).

## Principal Components Analysis

Principal components analysis is a data reduction method, the purpose of which is to find the minimum number of independent dimensions (principal components) needed to account for most of the variance in the original set of variables (Dillon and Goldstein, 1984; Kim and Mueller, 1978a; 1978b; Zegura, 1978).

Analysis begins with the transformation of the raw data matrix into a correlation or covariance matrix. A correlation matrix must be used when the variables have different units and scales (Dillon and Goldstein, 1984), which is the case for this study where some variables are linear measurements and others are angles. In this study the analyses were based on the male and female pooled within-groups correlation matrices which are provided in Appendix B. These were calculated using the SAS Candisc procedure and the subsequent principal components analyses were performed using the Factor Analysis/Principal Components procedure of StatSoft's Complete Statistical System (CSS). Since the purpose of the analysis is to identify the functional complexes that comprise the posterior cranium the measures that reflect facial size and projection, PRR, NAR, ZOR, POL and NPH, were not included.

A principal components analysis is performed by sequentially extracting components. A component is simply a weighted linear combination of the original variables where the weights maximize the variances associated with the original variables relative to the total variation. The first principal component is the component which accounts for the largest amount of variance in the data. The second component accounts for the largest remaining amount of variance in the data, subject to the constraint that it is uncorrelated (orthogonal) to the first. The process of extracting components continues until there are as many principal components as there are original variables. Thus, the analysis will result in x number of uncorrelated components, where x is the number of original variables, with the first component accounting for the largest amount of variance in the original data, the second accounting for the second largest amount of variance and so on to the xth component which accounts for the least amount of variance.

Since principal components analysis extracts the components in their order of magnitude the important components are extracted first, followed by a number of unimportant components which only account for a small proportion of the total variance (Zegura, 1978). The purpose of principal components analysis is to reduce the number of dimensions in a data set, so after the components are extracted it is necessary to determine how many are significant and should be retained. There are a number of ways of doing this, but the simplest and most widely used method is to retain only those that have an eigenvalue greater than one (Dillon and

Goldstein, 1984; Kim and Mueller, 1978a; 1978b). This is the criterion used in this study.

Interpretation of the components is based upon an examination of the matrix of component loadings. Component loadings are the correlations between a variable and a component and indicate which variables are involved in which components and to what degree. For a given component the variables with high loadings identify the dimension of variability embodied within it. Normally however the matrix of loadings obtained after the initial extraction of components will not be the simplest or most easily interpretable. To obtain an alternate but equivalent matrix of component loadings that is simpler and easier to interpret it is necessary to rotate the components.

There are a multitude of techniques that can be used to achieve this. In this study Varimax rotation was used. The procedure rotates the components so that the variation of the squared loadings is large, while preserving the original orientation of the components so that they remain orthogonal (Dillon and Goldstein, 1984; Kim and Mueller, 1978a).

Morphological interpretations of the rotated components are based upon the variables that have the highest loadings. After rotation each component should have only a few variables with high loadings. This facilitates interpretation. It bears repeating however, that a meaningful morphological explanation of the results depends as much upon the judicious selection of the original variables as the statistical methods used to derive them (Corruccini, 1978; Howells, 1969).

The interpretation of the results is based upon the dimensions of variability that exist within populations, and are those which differentiate individuals. One aim of this thesis is to ascertain if variation in the morphological structures identified in the principal components analyses differentiate groups as well as individuals. This is tested by calculating component scores for the retained components for all cases and then comparing the mean group scores to determine if they are significantly different. An individual's score on a given component is simply the sum of the standardized variables multiplied by their respective loadings on that component. Component scores were calculated for all cases for all of the retained components using the Data Transformation operation of CSS. The scores were then used as the data for analyses of variance.

## Analysis of Variance

The purpose of an analysis of variance (ANOVA) is to determine the likelihood of the hypothesis that the means of several groups of scores were drawn from the same population (McCall, 1975). In an ANOVA the total variability in scores, measured in terms of the deviation of scores around the grand mean and designated SSTO (sum of squares total), is partitioned into two components. One component, designated SSTR (sum of squares treatment), is the variation of the group means around the grand mean. SSTR is a measure of the degree of the differences that exist between group means. If all group means are equal then SSTR will be zero, the more the means differ from one another the larger SSTR will be. The other component is the deviation of the individual scores about their respective group means, this is designated SSE (sum of squares error). SSE measures random variation of scores about their respective means; the smaller the variation the smaller SSE will be (McCall, 1975).

To test the significance of the differences in group means an F-value is calculated. This is done by first dividing SSTR and SSE by their associated degrees of freedom to obtain the mean squares treatment (MSTR) and the mean squares error (MSE). For SSTR the degrees of freedom equal the number of groups minus one, and for SSE the degrees of freedom equal the total number of cases minus the number of groups. The F-statistic is then calculated by dividing MSTR by MSE (McCall, 1975; Neter, Wasserman and Kuten, 1985).

The F-value is the test statistic used for choosing between the null hypothesis that all group means are equal, and the alternative hypothesis that all group means are not equal. The value of F is compared to a sampling distribution of F-ratios to determine the probability that it merely reflects sampling error. Large values of F support the hypothesis that the group means are significantly different, since MSTR will tend to exceed MSE when this is the case. F-values near one support the null hypothesis because under the conditions of this hypothesis MSTR and MSE are estimating the same value (McCall, 1975; Neter, Wasserman and Kuten, 1985; Ott, Larson and Mendenhall, 1987).

In this study ANOVA is used to test the significance of differences in mean group scores for the retained components. The MANOVA procedure of CSS was used to perform the analyses.

Canonical Correlation Analysis

Canonical correlation analysis is a multivariate statistical technique that allows one to investigate the relationship between two sets of variables when each variable set consists of two or more variables, or between a single variable and a set of variables (Dillon and Goldstein, 1984; Thompson, 1988). The two sets of variables can be treated symmetrically but in most cases one is treated as the predictor set (i.e. the independent variables) and the other as the criterion set of variables (the dependent variables). The use of canonical correlation analysis makes it possible to identify the extent to which one set of variables can be predicted by another set of variables, and to determine the contribution that a single variable makes to the explanatory power of the set of variables to which it belongs (Thompson, 1988).

The use of canonical correlation analysis is appropriate when the goal is to analyze several predictor variables and several criterion variables simultaneously, and it is particularly appropriate when the criterion variables are themselves correlated. In these cases canonical correlation analysis can reveal complex relationships that reflect the structure between the criterion and predictor variables (Dillon and Goldstein, 1984).

The objective of canonical correlation analysis is to find a weighted linear combination of predictor variables that are maximally correlated with a weighted linear combination of the criterion variables (Dillon and Goldstein, 1984). The method is similar to multiple regression where the goal is to find a weighted linear combination of the original predictor variables that best explains the variation in the criterion measure. In canonical correlation analysis the idea is much the same except that the goal is to find two linear combinations, one for the predictor set and one for the criterion set, such that the correlation between the two is as large as possible (Dillon and Goldstein, 1984). The canonical correlations are analogous to ordinary simple correlation coefficients, but they represent the association between the canonical variables, and not the original variables themselves (Dillon and Goldstein, 1984).

Canonical correlation analysis proceeds by finding the most highly correlated pair of linear combinations of the predictor and criterion variables out of all the possible linear combinations of the predictor and criterion variables. After the first correlation is found the second most highly correlated pair out of all possible linear combinations that are uncorrelated with the first pair of canonical variables is found; this is the second canonical correlation. The third correlation is the third most highly correlated pair out of all possible linear combinations that are uncorrelated with the first and second variates and so on (Dillon and Goldstein, 1984). This process continues until the number of correlations is equal to the number of variables in the smaller of the two sets of variables (Dillon and Goldstein, 1984; Thompson, 1988).

However, some or all of these correlations may be insignificant. There are a multitude of ways of determining which, if any, correlations are significant (Dillon and Goldstein, 1984; Johnson and Wichern, 1988; Mardia, Kent and Bibby, 1979; Thompson, 1988). One way of estimating the importance of a canonical correlation is by determining the proportion of explained variance. This is the amount of variance in the original data accounted for by a given canonical correlation (Johnson and Wichern, 1988). A more rigorous test of the significance of a canonical correlation is the likelihood ratio, which tests the null hypothesis that the predictor variables do not have any influence on the criterion variables (Dillon and Goldstein, 1984; Johnson and Wichern, 1988).

The likelihood ratio makes it possible to identify how many, if any, of the linear relationships between the variable sets are significant. This is done by testing whether any significant relationships exist between the variable sets when the effects of all the canonical variate pairs are considered. It then tests whether any significant relationships exist between the variable sets after the effects of the first, second, third and so on canonical variate pairs have cumulatively been removed (Tatsuoka, 1980).

After the significant correlations are identified it is still necessary to determine their meaning. It is important to realize that, like the components identified by principal components analysis, the correlations are artificial. They are interpreted in terms of the original variables based upon the canonical weights or the correlations between variables and their canonical variables (Dillon and Goldstein, 1984; Johnson and Wichern, 1988). Canonical weights transform the original variables so that the correlation between the predictor and criterion variables are as large as possible, and they are similar to regression weights. The magnitude of the weights indicate the contribution of each variable to the variance of its respective canonical variable (Dillon and Goldstein, 1984).

However, using the weights to interpret a canonical correlation can give a distorted picture of the relevance of the variables. The weights do not necessarily give an accurate picture of the association between variables across the sets, and they may be unreliable because of multicolinearity. A variable may have a small or even a negative weight because the variance in that variable has been accounted for by another variable or variables (Dillon and Goldstein, 1984).

An alternative method of interpreting canonical correlations is by using canonical loadings, which are analogous to component loadings. A canonical loading is the ordinary product-moment correlation between the original variable and its canonical variable, thus it reflects the degree to which a variable is represented by a canonical variable (Dillon and Goldstein, 1984).

In most cases the use of canonical loadings is recommended (Dillon and Goldstein, 1984; Johnson and Wichern, 1988; Mardia, Kent and Bibby, 1979; Thompson, 1988). However, their use can lead to an overestimation of the strength of the hypothesized linkages between variables. The criterion and predictor variables are linked based upon their loadings with their respective canonical variates and not on any direct measure of the covariation between the two variables. These hypothesized linkages can lead to an erroneous belief that the relationship between two variables in different sets is much stronger than it actually may be (Dillon and Goldstein, 1984).

In this study canonical correlation analysis is used to study the relationships between the size and orientation of the nuchal plane and the size and projection of the face, and the size and projection of the mastoid processes. In both analyses the variables describing the size and orientation of the nuchal plane are the predictor variables. In the first analysis the variables describing the size and projection of the face are the criterion variables, and in the second analysis the variables describing the size and projection of the mastoid processes are the criterion variables. The SAS Cancorr procedure was used to perform the analyses.

# CHAPTER V

# RESULTS

## Descriptive Statistics

Means and standard deviations were calculated for each variable using the Basic Statistics procedure of CSS. Grand and group means and standard deviations were calculated for each sex. The results for males are presented in Table 1 and the results for females are presented in Table 2.

## Principal Components Analysis

*Males*. Nineteen variables were included in the principal components analysis therefore nineteen components were extracted from the correlation matrix. Simple and relative eigenvalues are presented in Table 3. The relative eigenvalue of a component is simply the proportion of the total variance accounted for by that component. Examination of Table 3 shows that only the first six components have eigenvalues greater than one. Together these account for 72% of the total variance in the correlation matrix.

The first six components were retained and rotated. The communalities and rotated component loadings are given in Table 4. The communality of a variable is the proportion of the total variability in that variable accounted for by the first six components.

Component 1: Occipital plane length. The first principal component, accounting for 21.8% of the total

TABLE 1

DESCRIPTIVE STATISTICS FOR MALES

| | Combined | | Arikara | | Tolai | | Haida | |
|---|---|---|---|---|---|---|---|---|
| Var | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| INR | 83.5 | 5.1 | 84.1 | 4.0 | 79.8 | 5.4 | 86.3 | 4.1 |
| MAR | 27.4 | 2.8 | 26.8 | 2.9 | 28.4 | 2.3 | 27.4 | 2.8 |
| OMR | 26.7 | 2.2 | 26.9 | 2.3 | 26.2 | 2.1 | 26.7 | 2.2 |
| OPR | 43.2 | 3.5 | 43.6 | 3.8 | 41.4 | 3.1 | 44.4 | 2.8 |
| PRR | 106.5 | 4.2 | 104.2 | 3.3 | 109.3 | 3.8 | 107.5 | 3.6 |
| NAR | 96.9 | 3.5 | 97.2 | 3.3 | 94.9 | 3.1 | 98.5 | 3.1 |
| ZOR | 82.6 | 3.3 | 80.9 | 2.6 | 83.2 | 3.1 | 84.8 | 3.1 |
| GOL | 182.1 | 5.4 | 180.8 | 5.4 | 182.2 | 4.6 | 184.2 | 5.3 |
| BBH | 135.5 | 4.7 | 133.6 | 4.0 | 134.5 | 4.2 | 139.6 | 3.7 |
| XCB | 137.8 | 6.5 | 137.8 | 3.6 | 131.2 | 4.1 | 144.9 | 4.7 |
| OCS | 28.4 | 3.3 | 28.4 | 3.5 | 27.6 | 3.2 | 29.4 | 2.7 |
| OCF | 48.3 | 7.2 | 46.4 | 6.6 | 47.1 | 6.3 | 52.9 | 7.2 |
| OCC | 96.5 | 5.3 | 94.9 | 4.9 | 95.5 | 3.8 | 100.3 | 5.4 |
| ASB | 109.2 | 4.7 | 108.1 | 4.6 | 107.2 | 3.9 | 113.0 | 3.5 |
| MAP | 10.9 | 2.3 | 11.4 | 2.2 | 9.9 | 1.9 | 11.0 | 2.6 |
| MBL | 24.4 | 2.6 | 25.1 | 2.3 | 23.7 | 2.9 | 23.0 | 2.6 |
| BMF | 84.7 | 4.8 | 85.6 | 3.3 | 79.8 | 3.2 | 88.6 | 4.0 |
| OIL | 52.6 | 5.7 | 53.2 | 4.8 | 49.6 | 5.9 | 54.9 | 5.6 |
| ILL | 59.4 | 7.6 | 57.4 | 7.3 | 60.5 | 6.0 | 61.7 | 8.6 |
| POL | 137.3 | 5.9 | 134.0 | 5.4 | 139.5 | 5.0 | 140.6 | 4.8 |
| OPA | 121.4 | 6.8 | 120.8 | 6.9 | 123.0 | 6.8 | 120.7 | 6.4 |
| OCA | 118.6 | 5.2 | 117.9 | 5.3 | 119.5 | 5.5 | 118.8 | 4.4 |
| POA | 128.6 | 9.1 | 125.4 | 6.7 | 130.3 | 6.4 | 132.2 | 12.5 |

TABLE 2

DESCRIPTIVE STATISTICS FOR FEMALES

| | Combined | | Arikara | | Tolai | | Haida | |
|---|---|---|---|---|---|---|---|---|
| Var | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| INR | 77.4 | 4.7 | 78.3 | 4.1 | 73.5 | 3.4 | 80.8 | 3.7 |
| MAR | 24.5 | 2.4 | 24.3 | 1.9 | 24.8 | 2.8 | 24.6 | 2.8 |
| OMR | 24.9 | 2.1 | 25.3 | 1.9 | 23.9 | 2.0 | 25.1 | 2.1 |
| OPR | 40.5 | 2.9 | 40.6 | 3.0 | 39.2 | 2.3 | 42.2 | 2.3 |
| PRR | 102.8 | 4.0 | 100.8 | 3.4 | 103.8 | 3.0 | 105.8 | 3.9 |
| NAR | 92.1 | 4.0 | 93.1 | 4.2 | 89.5 | 3.0 | 93.7 | 2.9 |
| ZOR | 79.6 | 3.5 | 78.6 | 3.4 | 79.3 | 2.7 | 82.3 | 3.2 |
| GOL | 172.9 | 5.2 | 172.9 | 5.0 | 170.4 | 4.3 | 176.3 | 4.9 |
| BBH | 128.6 | 5.4 | 127.8 | 5.4 | 126.4 | 4.1 | 133.6 | 3.8 |
| XCB | 132.6 | 7.0 | 132.9 | 4.3 | 126.3 | 5.2 | 140.7 | 5.3 |
| OCS | 27.3 | 2.8 | 27.1 | 2.5 | 26.2 | 2.9 | 29.2 | 2.6 |
| OCF | 46.5 | 5.7 | 43.7 | 3.9 | 47.8 | 5.2 | 51.1 | 6.3 |
| OCC | 93.7 | 4.8 | 92.2 | 4.1 | 93.1 | 3.6 | 98.0 | 5.2 |
| ASB | 104.3 | 4.6 | 103.5 | 2.9 | 101.6 | 4.2 | 110.0 | 3.5 |
| MAP | 8.4 | 2.2 | 8.5 | 2.2 | 8.3 | 1.7 | 8.4 | 2.6 |
| MBL | 22.2 | 2.2 | 22.9 | 2.1 | 21.6 | 2.4 | 21.6 | 1.8 |
| BMF | 79.6 | 5.0 | 80.8 | 4.1 | 74.6 | 2.9 | 83.9 | 3.6 |
| OIL | 48.4 | 4.8 | 49.2 | 4.8 | 45.6 | 3.8 | 50.5 | 4.4 |
| ILL | 59.5 | 6.5 | 57.1 | 6.3 | 60.7 | 4.8 | 62.9 | 7.0 |
| POL | 131.2 | 5.8 | 129.0 | 5.5 | 131.4 | 4.7 | 136.0 | 5.0 |
| OPA | 121.3 | 6.7 | 122.0 | 6.9 | 120.5 | 6.7 | 121.0 | 6.0 |
| OCA | 119.4 | 4.4 | 118.8 | 4.2 | 121.2 | 4.6 | 118.2 | 3.7 |
| POA | 127.3 | 5.9 | 126.6 | 6.5 | 127.8 | 5.5 | 128.2 | 4.8 |

TABLE 3

SIMPLE AND RELATIVE EIGENVALUES FOR MALES

| Component | Simple Eigenvalues | Relative Eigenvalues |
|---|---|---|
| 1 | 4.136 | .2177 |
| 2 | 3.141 | .1653 |
| 3 | 2.117 | .1114 |
| 4 | 1.630 | .0858 |
| 5 | 1.369 | .0720 |
| 6 | 1.266 | .0666 |
| 7 | .901 | .0474 |
| 8 | .860 | .0453 |
| 9 | .780 | .0411 |
| 10 | .644 | .0339 |
| 11 | .470 | .0247 |
| 12 | .427 | .0225 |
| 13 | .385 | .0203 |
| 14 | .355 | .0187 |
| 15 | .316 | .0167 |
| 16 | .170 | .0089 |
| 17 | .025 | .0013 |
| 18 | .006 | .0003 |
| 19 | .002 | .0001 |

TABLE 4

COMMUNALITIES AND ROTATED COMPONENT LOADINGS FOR MALES

| Var | Communality | Component Loadings | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| INR | .829 | -.202 | -.471 | .732 | .092 | .147 | .023 |
| MAR | .718 | .146 | -.081 | -.081 | .823 | .078 | -.006 |
| OMR | .534 | .030 | -.314 | .217 | .615 | .044 | .086 |
| OPR | .594 | .148 | -.731 | -.095 | .155 | .057 | -.043 |
| GOL | .642 | .062 | -.420 | .478 | .394 | -.278 | -.024 |
| BBH | .673 | -.029 | -.793 | .093 | .053 | -.040 | .174 |
| XCB | .786 | .318 | .061 | -.028 | -.017 | -.137 | .813 |
| OCS | .950 | .471 | .091 | .832 | .113 | -.104 | .065 |
| OCF | .762 | .829 | .133 | .016 | .116 | -.018 | .207 |
| OCC | .832 | .834 | -.300 | .146 | .095 | .119 | .039 |
| ASB | .530 | .072 | .008 | .034 | .427 | -.165 | .561 |
| MAP | .535 | .121 | .034 | .120 | .689 | .173 | -.006 |
| MBL | .556 | -.057 | -.061 | .077 | .560 | -.449 | .165 |
| BMF | .696 | -.056 | -.373 | .131 | -.029 | .278 | .677 |
| OIL | .851 | -.321 | -.233 | .649 | -.005 | .522 | .000 |
| ILL | .945 | .892 | -.026 | .020 | .105 | -.365 | .059 |
| OPA | .824 | .102 | .437 | .192 | .004 | -.762 | .075 |
| OCA | .870 | -.144 | -.242 | -.864 | -.083 | .183 | -.061 |
| POA | .532 | .062 | -.179 | -.019 | -.167 | -.685 | -.021 |

within sample variation, represents the length of occipital, primarily the length of the occipital plane. The variable with the highest loading is inion-lambda length (ILL) which is a direct measure of the length of the occipital plane. Occipital chord (OCC) and occipital chord fraction (OCF) also have high loadings on this component. Occipital chord obliquely measures the length of the entire occipital and it is therefore highly correlated with inion-lambda length. The high loading for occipital chord fraction is not surprising since it also measures the length of the occipital plane and is highly correlated with inion-lambda length. Inion-lambda length is the distance from lambda to inion whereas occipital chord fraction is the distance from lambda to the most prominent point on the contour of the occipital. The two points are not always identical, but they often coincide and are almost always near one another. Occipital chord subtense (OCS) also has a relatively high loading on this component, reflecting its high correlations with occipital chord fraction, occipital chord and inion-lambda length.

| | | | |
|---|---|---|---|
| ILL | .892 | OCF | .829 |
| OCC | .834 | OCS | .471 |

Component 2: Posterior vault size. This component accounts for 16.5% of the total within sample variation and represents the size of the posterior vault. The variables with the highest loadings are basion-bregma height (BBH),

opisthion radius (OPR) and inion radius (INR). These are all lengths, but each represents a different dimension; basion-bregma height measures the height of the vault, inion radius measures the posterior projection of the vault, and opisthion radius measures the inferior and posterior projection of opisthion. Opisthion angle (OPA) and glabello-occipital length (GOL) also have relatively high loadings on this component. Glabello-occipital length measures the length of the entire cranium and the length of the posterior vault is a large component of this dimension. The relatively high loading for opisthion angle suggests that the size of the posterior vault is related to the orientation of the nuchal plane. Basion-bregma height, opisthion radius, inion radius and glabello-occipital length all have negative loadings but opisthion angle has a positive loading which indicates that as the size of the posterior vault increases opisthion angle becomes more acute and the nuchal plane is oriented more posteriorly.

| | | | |
|---|---|---|---|
| BBH | -.793 | OPA | .437 |
| OPR | -.731 | GOL | -.420 |
| INR | -.471 | | |

Component 3: Occipital curvature. The third component accounts for 11.1% of the within sample total variability. The variable with the highest loading is occipital angle (OCA) and this component undoubtedly reflects occipital curvature. Occipital subtense (OCS) also has a high load-

ing, which is to be expected since it is one of the variables used to calculate occipital angle and is therefore very highly correlated with it. Inion radius (INR) and opisthion-inion length (OIL) also have high loadings on this component. Inion radius and opisthion-inion length measure the length of the nuchal plane and the posterior projection of the cranium, and both are negatively correlated with occipital angle.

| | | | |
|---|---|---|---|
| OCA | -.864 | INR | .732 |
| OCS | .832 | OIL | .649 |

Component 4: Mastoid size. This component, which accounts for 8.6% of the total within sample variability, represents the size of the mastoid process and the inferior projection of the cranial base medial to the mastoid. The three variables that measure the size and projection of the mastoid, mastoid radius (MAR), mastoid projection (MAP) and mastoid base length (MBL), all have high loadings on this component, as does occipitomastoid radius (OMR) which measures the inferior projection of the cranial base medial to the mastoid.

| | | | |
|---|---|---|---|
| MAR | .823 | OMR | .615 |
| MAP | .689 | MBL | .560 |

Component 5: Nuchal plane orientation. This component represents the orientation of the nuchal plane and accounts for 7.2% of the total within sample variability. The variables with the highest loadings are opisthion angle (OPA)

and prosthion-opisthion angle (POA). Opisthion-inion length, which is highly correlated with opisthion angle, also has a relatively high loading on this component. The two angles have negative loadings whereas opisthion-inion length has a positive loading. This indicates that as these angles become more acute the length of the nuchal plane increases.

| | | | |
|---|---|---|---|
| OPA | -.762 | OIL | .522 |
| POA | -.685 | | |

Component 6: Posterior breadth. This last component, which accounts for 6.7% of the total within sample variability, clearly represents the breadth of the posterior cranium. All three variables with high loadings on this component measure the width of this area. Maximum cranial breadth (XCB) has the highest loading, but biasterionic breadth (ASB) and bimastoid foramen breadth (BMF) also have high loadings.

| | | | |
|---|---|---|---|
| XCB | .813 | BMF | .561 |
| ASB | .677 | | |

Females. Simple and relative eigenvalues for the nineteen principal components extracted from the female correlation matrix are shown in Table 5. Only the first six components have eigenvalues greater than one. These six components account for 72% of the total variance in the correlation matrix. Communalities and rotated component loadings for these components are given in Table 6.

TABLE 5

SIMPLE AND RELATIVE EIGENVALUES FOR FEMALES

| Component | Simple Eigenvalues | Relative Eigenvalues |
|---|---|---|
| 1 | 4.070 | .2143 |
| 2 | 2.888 | .1520 |
| 3 | 2.381 | .1253 |
| 4 | 1.951 | .1027 |
| 5 | 1.308 | .0688 |
| 6 | 1.107 | .0583 |
| 7 | .946 | .0498 |
| 8 | .778 | .0410 |
| 9 | .657 | .0346 |
| 10 | .589 | .0310 |
| 11 | .483 | .0254 |
| 12 | .454 | .0239 |
| 13 | .388 | .0204 |
| 14 | .370 | .0195 |
| 15 | .312 | .0164 |
| 16 | .282 | .0149 |
| 17 | .041 | .0022 |
| 18 | .002 | .0004 |
| 19 | .001 | .0001 |

TABLE 6

COMMUNALITIES AND ROTATED COMPONENT LOADINGS FOR FEMALES

| | | Component Loadings | | | | | |
|---|---|---|---|---|---|---|---|
| Var | Communality | 1 | 2 | 3 | 4 | 5 | 6 |
| INR | .869 | .013 | .125 | -.862 | .149 | .293 | -.047 |
| MAR | .755 | .176 | .125 | -.050 | -.073 | -.003 | -.837 |
| OMR | .729 | -.027 | .073 | -.049 | -.025 | .462 | .712 |
| OPR | .798 | -.121 | .206 | -.046 | -.006 | .852 | -.107 |
| GOL | .657 | .259 | .208 | -.461 | .415 | .365 | -.167 |
| BBH | .603 | .411 | -.017 | -.207 | -.216 | .560 | -.173 |
| XCB | .626 | .748 | .096 | .119 | .007 | .012 | -.208 |
| OCS | .907 | -.108 | .760 | -.358 | .405 | -.157 | .025 |
| OCF | .663 | .140 | .781 | -.050 | -.103 | .037 | -.137 |
| OCC | .843 | .187 | .813 | -.124 | -.172 | .319 | .015 |
| ASB | .643 | .679 | .165 | -.304 | .220 | .009 | -.118 |
| MAP | .422 | .305 | .157 | .193 | .056 | -.298 | -.418 |
| MBL | .503 | .176 | -.072 | .022 | .205 | .115 | -.641 |
| BMF | .644 | .530 | -.060 | -.062 | -.044 | .580 | -.133 |
| OIL | .934 | .067 | -.086 | -.918 | -.259 | -.066 | .087 |
| ILL | .949 | .050 | .863 | .423 | .127 | .035 | -.070 |
| OPA | .710 | .091 | .057 | .108 | .753 | -.302 | -.169 |
| OCA | .803 | .238 | .449 | .340 | -.562 | .335 | .005 |
| POA | .647 | .135 | -.285 | .102 | .675 | .274 | .079 |

Component 1: Posterior breadth. This component, which accounts for 21.4% of the total within sample variance, corresponds to the sixth male component and represents the breadth of the posterior cranium. Maximum cranial breadth (XCB), biasterionic breadth (ASB) and bimastoid foramen breadth (BMF) all of which measure the width of the posterior cranium, have high loadings on this component.

| | | | |
|---|---|---|---|
| XCB | .748 | BMF | .530 |
| ASB | .679 | | |

Component 2: Occipital plane length. The second component accounts for 15.2% of the total within sample variability. This component represents the length of the occipital, primarily the length of the occipital plane, and is equivalent to the first male component. The variable with the highest loading is inion-lambda length (ILL). Occipital chord (OCC), occipital chord fraction (OCF) and occipital chord subtense (OCS) also have high loadings on this component.

| | | | |
|---|---|---|---|
| ILL | .863 | OCF | .781 |
| OCC | .813 | OCS | .760 |

Component 3: Nuchal plane length. This component, which accounts for 12.5% of the total within sample variability, represents the length of the nuchal plane. The variable with the highest loading is opisthion-inion length (OIL) which directly measures the length of the nuchal plane. Inion radius (INR), which also measures the length

of the nuchal plane although more obliquely, has a high loading on this component. Glabello-occipital length (GOL) and inion-lambda length (ILL) also have relatively high loadings. Glabello-occipital length is strongly correlated with inion radius which is to be expected since a large component of glabello-occipital length is the posterior length of the vault. Inion-lambda length has a positive loading on this component whereas the other variables have negative loadings. This indicates that there is an inverse relationship between the length of the nuchal plane and the length of the occipital plane.

| | | | |
|---|---|---|---|
| OIL | -.918 | GOL | -.461 |
| INR | -.862 | ILL | .423 |

Component 4: Occipital angle/nuchal plane orientation. This component accounts for 10.3% of the total within sample variability. There are three variables with high loadings on this component and all of them are angles: occipital angle (OCA), prosthion-opisthion angle (POA) and opisthion angle (OPA). The high loadings for the angles suggest that this component represents occipital curvature and the orientation of the nuchal plane. For the males these two complexes emerged as separate components. The relationships among the variables are interesting. The positive loading for prosthion-opisthion angle and the negative loading for occipital angle indicate that as the occipital angle becomes more acute prosthion-opisthion angle becomes more obtuse,

which would result in a more posteriorly oriented nuchal plane. The positive loading for opisthion angle demonstrates that as the first two angles increase the angle of the nuchal plane relative to opisthion, like prosthion-opisthion angle, becomes more obtuse, which would result in a more horizontally oriented nuchal plane.

| | | | |
|---|---|---|---|
| OPA | .753 | POA | .675 |
| OCA | -.562 | | |

Component 5: Posterior vault size. This component represents 6.8% of the total within sample variability, and like the second male component, represents the size of the posterior vault. Opisthion radius OPR), which measures the posterior and inferior projection of opisthion, has the highest loading. Bimastoid foramen breadth (BMF), which measures the width of the cranial base, basion-bregma height (BBH), which measures the height of the vault, and occipito-mastoid radius (OMR) which measures the inferior and posterior projection of the cranial base, also have relatively high loadings on this component.

| | | | |
|---|---|---|---|
| OPR | .852 | BBH | .560 |
| BMF | .580 | OMR | .462 |

Component 6: Mastoid size. The last component, which accounts for 5.8% of the total variability, corresponds to the fourth male component and represents mastoid size. The four variables that measure the size and projection of the

mastoid and the area medial to it, mastoid radius (MAR), occipitomastoid radius (OMR), mastoid base length (MBL) and mastoid projection (MAP) all have high loadings on this component.

| | | | |
|---|---|---|---|
| MAR | -.837 | MBL | -.641 |
| OMR | .712 | MAP | -.418 |

## Analysis of Variance

Males. Component scores for all of the retained components were calculated for all cases. Group means were then calculated and the significance of the differences in group means was tested using analyses of variance. Group means are given in Table 7 and the results of the ANOVA are presented in Table 8. Graphs of the means are also given in Figures 9 and 10.

The results shown in Table 8 represent the results of six individual analyses of variance. If a confidence level of .05 is used for each of these tests the likelihood of incorrectly rejecting the null hypothesis for at least one of these tests is actually much greater than .05. To avoid this a family confidence interval of .05 is used. This means that for an individual test the obtained value of F must have a probability of less than .0083 (.05/6) before the null hypothesis for that test can be rejected.

TABLE 7

MEAN COMPONENT SCORES FOR MALES

| | Mean Component Scores | | |
|---|---|---|---|
| Component | Arikara | Tolai | Haida |
| 1 | -0.941 | -0.295 | 1.944 |
| 2 | 0.268 | 1.368 | -1.923 |
| 3 | -0.978 | -1.979 | 0.523 |
| 4 | -0.019 | -0.638 | 0.713 |
| 5 | 0.496 | -0.747 | -0.623 |
| 6 | -0.070 | -2.037 | 2.296 |

TABLE 8

F-RATIOS FOR BETWEEN-GROUP DIFFERENCES
IN MALE COMPONENT SCORES

| Component | F-ratio | p |
|---|---|---|
| 1 | 9.256 | 0.0039 |
| 2 | 17.455 | 0.0000 |
| 3 | 18.662 | 0.0000 |
| 4 | 2.290 | 0.1040 |
| 5 | 3.605 | 0.0295 |
| 6 | 75.883 | 0.0000 |

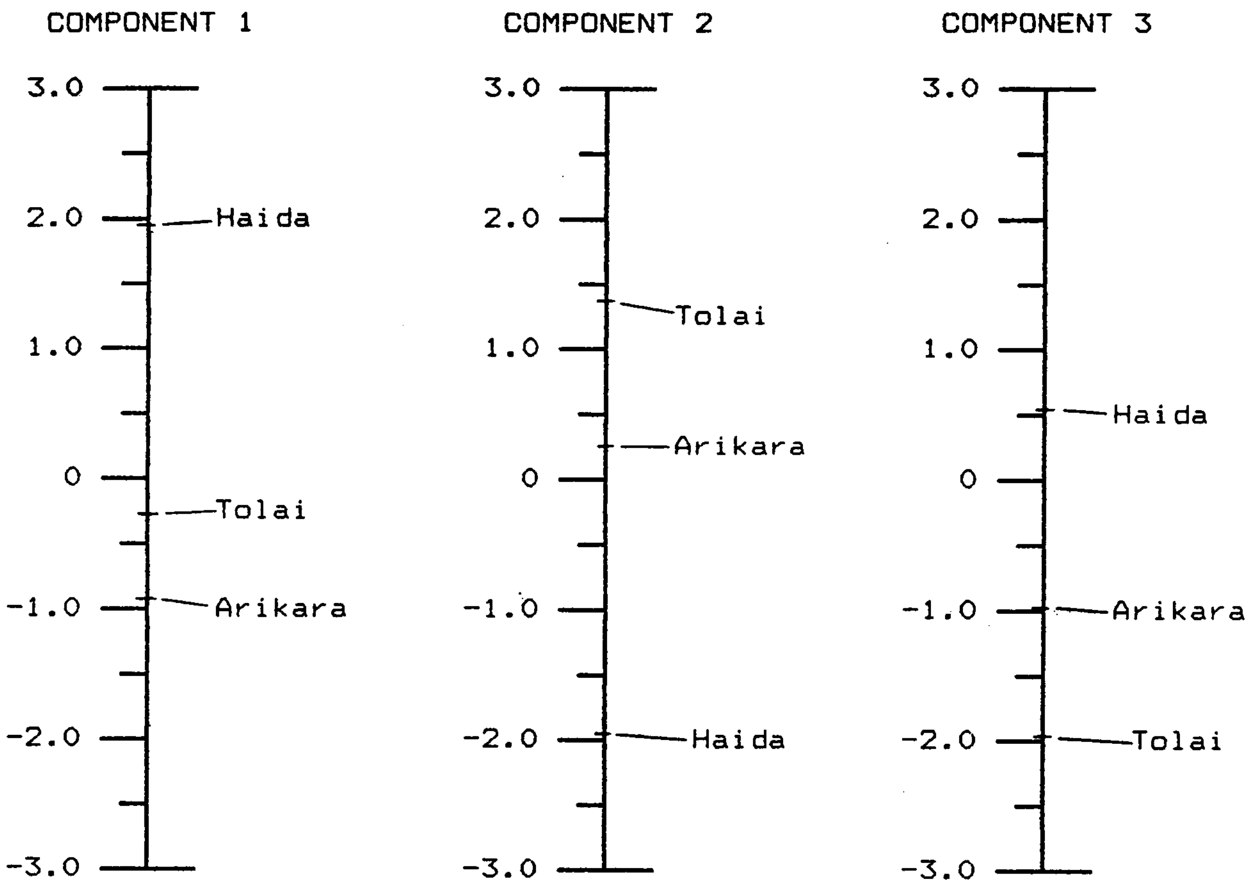


Figure 9. Male Group Means for Components 1 - 3.

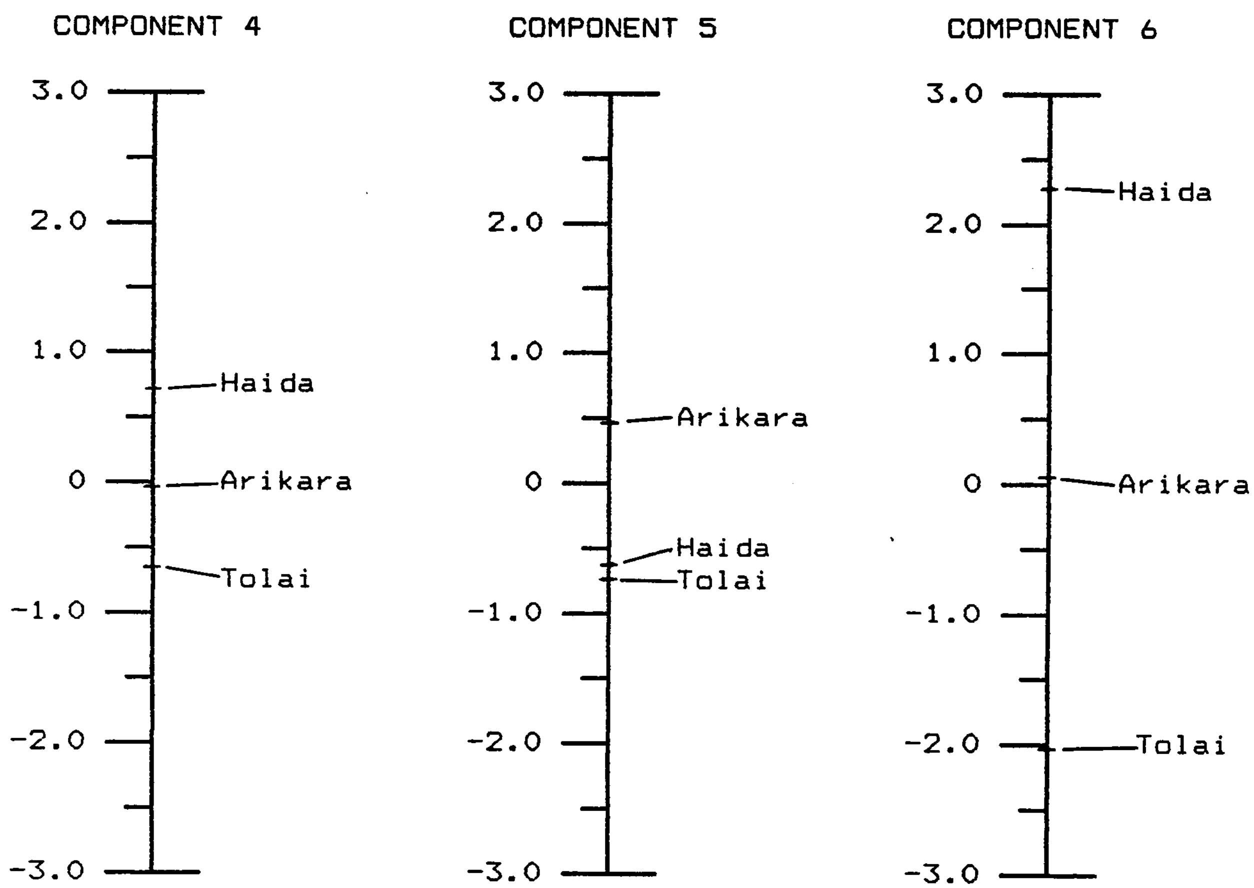


Figure 10. Male Group Means for Components 4 - 6.

Examination of Table 8 shows that for the six components group means are significantly different for components 1, 2, 3 and 6. These represent, respectively: occipital plane length; posterior vault size; occipital curvature; and posterior breadth. Group means are not significantly different for component 4, which represents mastoid size, and component 5, which represents nuchal plane orientation. Those components for which the group means are significantly different are discussed below.

Component 1. This component represents occipital plane length and a high score indicates a long occipital plane. The Haida, who have the highest mean inion-lambda length, occipital chord and occipital chord fraction, have the highest mean score and Figure 9 shows that this component separates the Haida from the Arikara and Tolai.

Component 2. Component 2 represents the size of the posterior vault, and a high score on this component indicates a vault that is relatively low and an occipital that is non-projecting. The Tolai have the highest mean score on this component and the Haida have the lowest. The Arikara are intermediate between these two groups.

Component 3. This component represents occipital curvature. A high score indicates a small occipital angle, a large occipital subtense and a long, posteriorly projecting nuchal plane. The Haida have the highest mean on this component, and the Tolai have the lowest, the Arikara are intermediate.

Component 6. Component 6 represents the breadth of the posterior cranium, and a high score indicates a broad posterior cranium. Examination of Figure 10 shows that the Haida, who have the largest average maximum cranial breadth, biasterionic breadth and bimastoid foramen breadth, have the highest average score, and the Tolai have the lowest mean score. The Arikara are intermediate.

Females. The mean group component scores for females are given in Table 9 and the results of the ANOVA are presented in Table 10. Graphs of the means are shown in Figures 11 and 12.

The results in Table 10 show that of the six components retained four have group means that differ significantly from one another. These are: component 1, which represents posterior breadth; component 2, which represents occipital plane length; component 3, which represents nuchal plane length; and component 5, which represents posterior vault size. Group means are not significantly different for component 4, which represents occipital angle/nuchal plane orientation, or component 6, which represents mastoid size. Component 6 corresponds to the 4th male component for which mean group scores are also not significantly different.

Component 1. The first component represents the breadth of the posterior cranium. A high score signifies a

TABLE 9

MEAN COMPONENT SCORES FOR FEMALES

| | Mean Component Scores | | |
|---|---|---|---|
| Component | Arikara | Tolai | Haida |
| 1 | -0.140 | -1.746 | 2.772 |
| 2 | -0.960 | -0.659 | 3.066 |
| 3 | -0.025 | 0.631 | -0.833 |
| 4 | 0.150 | -0.638 | 0.565 |
| 5 | 0.016 | -1.577 | 2.186 |
| 6 | 0.089 | 0.328 | -0.659 |

TABLE 10

F-RATIOS FOR BETWEEN-GROUP DIFFERENCES
IN FEMALE COMPONENT SCORES

| Component | F-ratio | p |
|---|---|---|
| 1 | 43.286 | 0.0000 |
| 2 | 14.663 | 0.0000 |
| 3 | 11.344 | 0.0013 |
| 4 | 2.570 | 0.0797 |
| 5 | 17.397 | 0.0000 |
| 6 | 2.973 | 0.0541 |

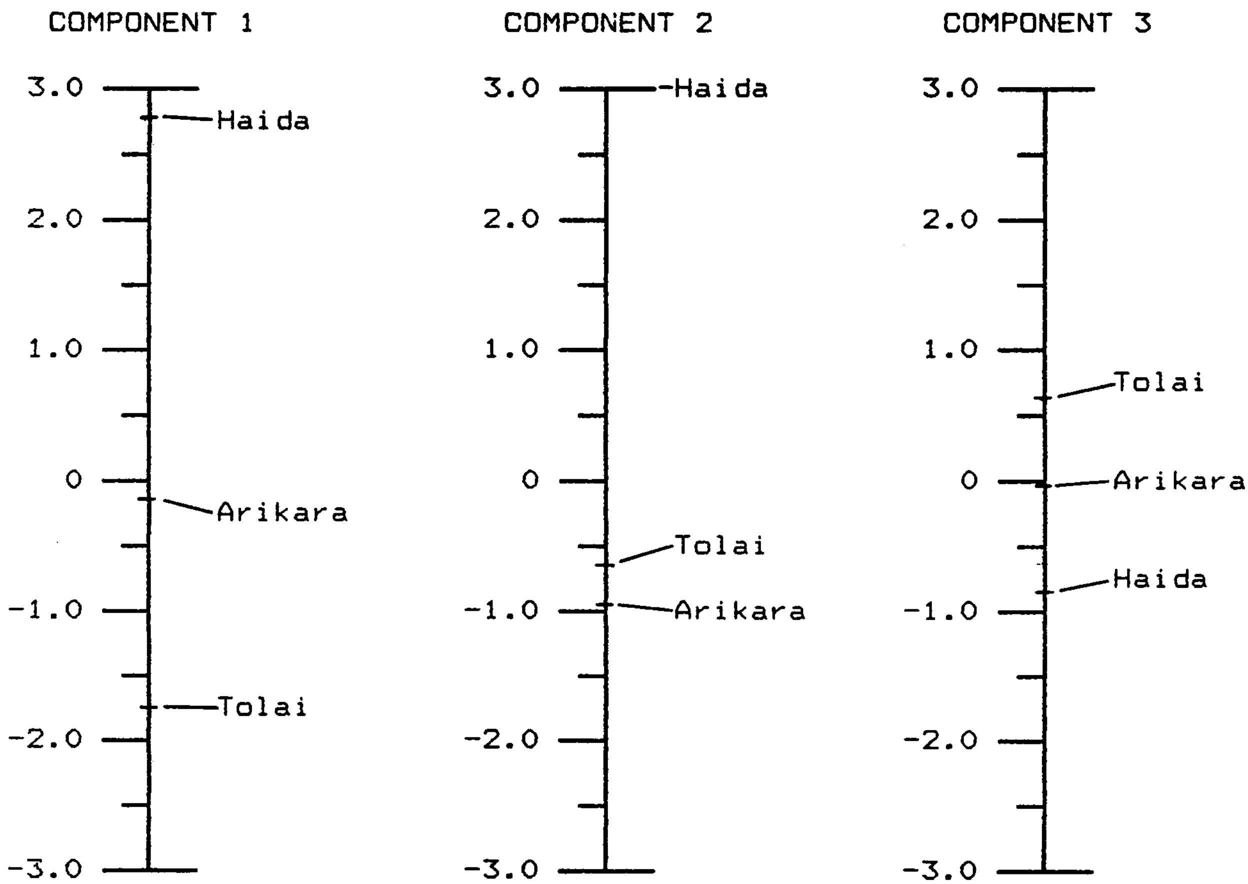


Figure 11. Female Group Means for Components 1 - 3.

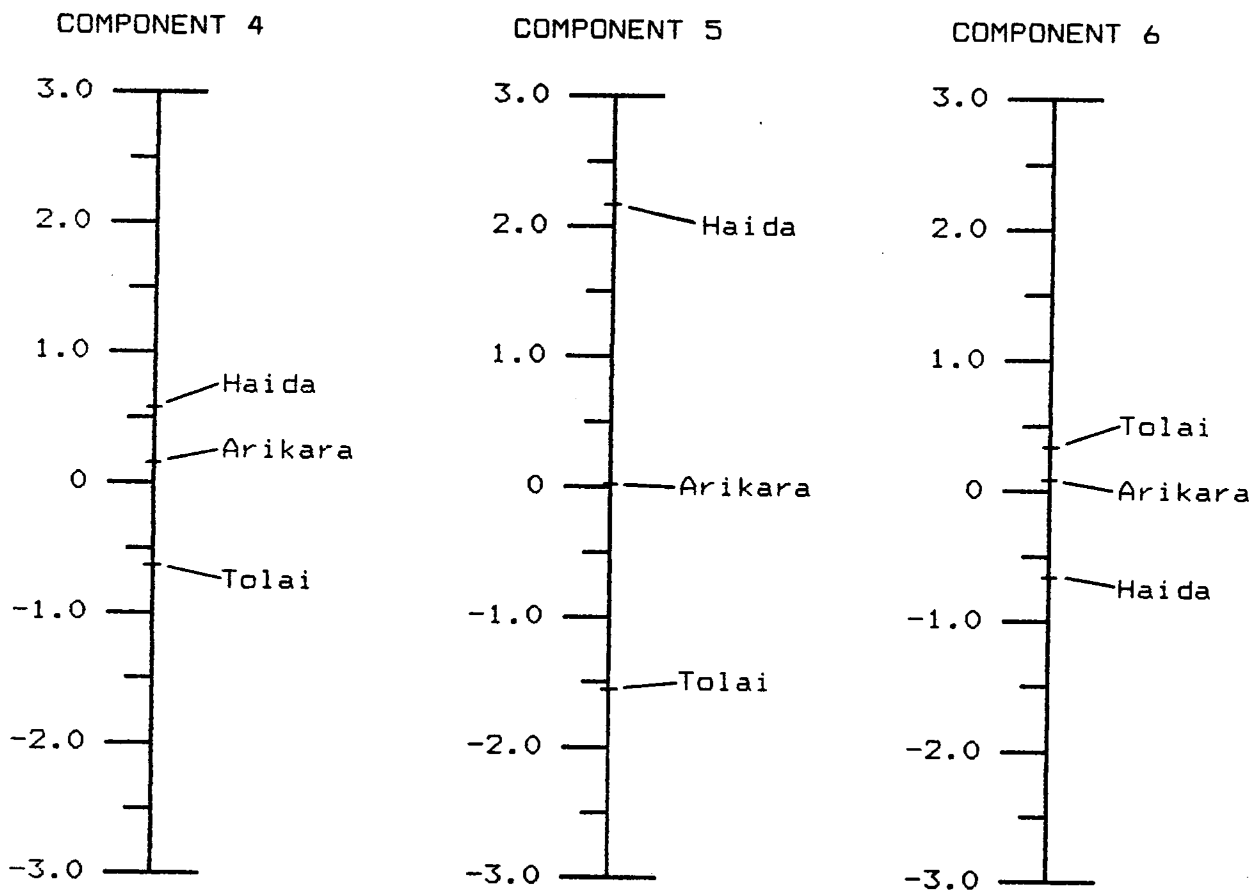


Figure 12. Female Group Means for Components 4 - 6

posterior cranium that is broad, and the Haida who have the greatest maximum cranial breadth, biasterionic breadth and bimastoid foramen breadth, have the highest mean score on this component. Figure 11 shows that the Haida and Tolai are widely separated on this component, with the Arikara intermediate. This component corresponds to component 6 of the males for which group means are also significantly different.

Component 2. The second female component represents the length of the occipital plane and a high score reflects a long occipital plane. The Haida have the highest mean component score, and Figure 11 shows that this component separates the Haida from the Tolai and Arikara. This component corresponds to the first male component, for which group means are also significantly different.

Component 3. This component represents the length of the nuchal plane and a low score indicates a long nuchal plane. The Tolai, who have the smallest average opisthion radius and inion radius, have the highest score on this component. The Haida have the lowest score and the Arikara are intermediate.

Component 5. This component represents the size of the posterior vault. A high score indicates a posterior vault that is broad, high and projects posteriorly. The Haida have the highest score. Examination of Figure 10 shows that this component separates the Tolai and the Haida with the Arikara intermediate between these two groups.

## Canonical Correlation Analysis

Canonical correlations between the face and occipital. There are four variables in the smaller of the two variable sets used in the first canonical correlation analysis, therefore four canonical correlations were obtained.

Males. Canonical correlations for the males, their associated eigenvalues and the proportion of variance explained by each are provided in Table 11. Table 12 gives the likelihood ratios, F-ratios and the associated probabilities for these correlations. The results presented in Table 12 show that the first three correlations are statistically significant. The canonical loadings for the variables of the face are shown in Table 13, and Table 14 gives the canonical loadings for the occipital variables. The canonical correlations that are significant are interpreted in morphological terms based upon the variables that have the highest loadings.

First canonical correlation. The first canonical correlation of .679 ($p < .0001$) accounts for 51.5% of the total variability. Examination of Table 13 shows that the facial variable with the highest correlation with its canonical variable is zygoorbitale radius (.611), and Table 14 shows that the occipital variable with the highest correlation with its canonical variable is prosthion-opisthion

TABLE 11

CANONICAL CORRELATIONS BETWEEN THE FACE AND OCCIPITAL FOR MALES

| Eigenvalue Number | Canonical Correlation | Eigenvalue | Proportion |
|---|---|---|---|
| 1 | 0.679 | 0.855 | 0.515 |
| 2 | 0.600 | 0.563 | 0.339 |
| 3 | 0.419 | 0.213 | 0.128 |
| 4 | 0.167 | 0.029 | 0.017 |

TABLE 12

LIKELIHOOD RATIOS AND F-STATISTICS FOR CANONICAL CORRELATIONS BETWEEN THE FACE AND OCCIPITAL FOR MALES

| Eigenvalues Removed | Likelihood Ratio | F-ratio | p |
|---|---|---|---|
| 0 | 0.276 | 5.706 | 0.0001 |
| 1 | 0.513 | 4.360 | 0.0001 |
| 2 | 0.801 | 2.460 | 0.0084 |
| 3 | 0.972 | 0.763 | 0.5517 |

TABLE 13

CANONICAL LOADINGS OF FACIAL VARIABLES
FOR MALES

| Variable | Canonical Variable | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| PRR | -0.202 | -0.050 | 0.912 | 0.354 |
| NAR | 0.266 | 0.557 | 0.029 | 0.787 |
| ZOR | 0.611 | 0.353 | 0.651 | 0.280 |
| NPH | -0.344 | 0.934 | -0.091 | -0.013 |

TABLE 14

CANONICAL LOADINGS OF OCCIPITAL VARIABLES
FOR MALES: FIRST ANALYSIS

| | Canonical Variable | | | |
|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 |
| INR | -0.351 | 0.789 | 0.219 | 0.011 |
| OPR | -0.202 | 0.504 | 0.209 | -0.510 |
| ASB | 0.174 | 0.631 | 0.150 | 0.324 |
| BMF | -0.092 | 0.826 | -0.362 | -0.153 |
| OIL | -0.390 | 0.569 | 0.319 | 0.304 |
| OPA | 0.292 | -0.167 | -0.490 | 0.118 |
| POA | 0.900 | 0.164 | 0.080 | -0.115 |

angle (.900). Zygoorbitale radius measures the projection of the lateral face, and prosthion-opisthion angle measures the angle of the nuchal plane. As this angle increases, if the angle of the nuchal plane relative to opisthion does not change, the nuchal plane becomes more posteriorly oriented. Both variables have positive loadings, indicating that as the projection of the lateral face increases prosthion-opisthion angle also increases and the nuchal plane becomes more posteriorly oriented.

Second canonical correlation. The second canonical correlation of .600 ($p < .0001$) accounts for 33.9% of the total variability. For this correlation the criterion variable with the highest loading is nasion-prosthion height (.934). The variables of the occipital with the highest loadings are bimastoid foramen breadth (.826), inion radius (.789) and biasterionic breadth (.631). These variables are all positively correlated with their respective canonical variables. This means that as the size of the face increases the breadth of the nuchal area increases, primarily in the more anterior portion of the nuchal area. The posterior projection of the occipital also increases to some extent.

Third canonical correlation. The third significant correlation of .419 ($p < .0084$) accounts for 12.8% of the total variability. The facial variable with the highest loading is prosthion radius (.912). Zygoorbitale radius

(.651) also has a relatively high loading. None of the predictor variables is very highly high correlated with their canonical variable and the occipital variable with the highest loading is opisthion angle (-.460). Opisthion angle is the angle of the nuchal plane relative to opisthion, as this angle become smaller the nuchal plane becomes more posteriorly oriented. Prosthion radius and zygoorbitale radius have positive loadings, whereas the loading for opisthion angle is negative. This indicates that as lower facial and lateral facial projection increases opisthion angle decreases to some degree, and the nuchal plane becomes somewhat more posteriorly oriented.

Females. Canonical correlations for the females, their associated eigenvalues and the proportion of variance explained by each are given in Table 15. Likelihood ratios, F-ratios and associated probabilities are presented in Table 16. The results in Table 16 show that only the first two canonical correlations are significant.

First canonical correlation. The first canonical correlation of .721 ($p < .0001$) accounts for 70.4% of the total variability. This correlation corresponds to the second male correlation. Table 17 shows that the criterion variable with the highest loading is nasion-prosthion height (.934). The results presented in Table 18 show that the variables in the predictor set with the highest loadings are

TABLE 15

CANONICAL CORRELATIONS BETWEEN THE
FACE AND OCCIPITAL FOR FEMALES

| Eigenvalue Number | Canonical Correlation | Eigenvalue | Proportion |
|---|---|---|---|
| 1 | 0.721 | 1.080 | 0.704 |
| 2 | 0.502 | 0.336 | 0.220 |
| 3 | 0.314 | 0.109 | 0.071 |
| 4 | 0.084 | 0.007 | 0.005 |

TABLE 16

LIKELIHOOD RATIOS AND F-STATISTICS FOR
CANONICAL CORRELATIONS BETWEEN THE
FACE AND OCCIPITAL FOR FEMALES

| Eigenvalues Removed | Likelihood Ratio | F-ratio | p |
|---|---|---|---|
| 0 | 0.322 | 4.346 | 0.0001 |
| 1 | 0.670 | 2.206 | 0.0038 |
| 2 | 0.895 | 1.062 | 0.3942 |
| 3 | 0.993 | 0.169 | 0.9539 |

TABLE 17

CANONICAL LOADINGS OF FACIAL VARIABLES
FOR FEMALES

| | Canonical Variable | | | |
|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 |
| PRR | 0.355 | 0.923 | -0.132 | 0.072 |
| NAR | 0.787 | 0.237 | 0.555 | -0.128 |
| ZOR | 0.512 | 0.605 | 0.372 | 0.484 |
| NPH | 0.934 | -0.247 | -0.257 | 0.041 |

TABLE 18

CANONICAL LOADINGS OF OCCIPITAL VARIABLES
FOR FEMALES: FIRST ANALYSIS

| | Canonical Variable | | | |
|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 |
| INR | 0.684 | -0.415 | 0.123 | 0.294 |
| OPR | 0.437 | 0.225 | -0.408 | 0.260 |
| ASB | 0.663 | 0.188 | -0.036 | 0.391 |
| BMF | 0.950 | 0.176 | -0.138 | -0.183 |
| OIL | 0.477 | -0.337 | 0.455 | 0.036 |
| OPA | 0.028 | -0.460 | -0.120 | -0.155 |
| POA | 0.170 | 0.263 | 0.578 | 0.191 |

bimastoid foramen breadth (.950), inion radius (.684) and biasterionic breadth (.663). These loadings are all positive, indicating that, as in the males, as the size of the face increases the breadth of the nuchal plane, primarily the anterior breadth, also increases. The posterior projection of the occipital also increases somewhat.

Second canonical correlation. The second canonical correlation for the females corresponds to the third male correlation. This correlation of .721 ($p < .0038$) accounts for 22.0% of the total variability. The facial variables with the highest loadings are prosthion radius (.923) and zygoorbitale radius (.605). No variables in the predictor set have very high Loadings, but opisthion angle has the highest (-.460). As is the case for the males prosthion radius and zygoorbitale radius are positively correlated with their canonical variable whereas opisthion angle is negatively correlated with its canonical variable. This indicates that as the lower midface and lateral face become more prognathic opisthion angle becomes smaller, and the nuchal plane is oriented somewhat more posteriorly.

<u>Canonical correlations between the mastoid and occipital</u>. In the second canonical correlation analysis there are four variables in the smaller of the two sets of variables, therefore four canonical correlations were obtained.

Males. The canonical correlations for the males, their eigenvalues and the proportion of variability explained by each are given in Table 19. The likelihood ratios, F-ratios and associated probabilities for these correlations are given in Table 20. The results in Table 20 show that only the first canonical correlation of .454 is statistically significant ($p < .0033$). The canonical loadings for the variables of the mastoid are given in Table 21, and the loadings for the occipital variables are given in Table 22.

The first canonical correlation accounts for 48.5% of the total variation. The results in Table 21 show that the criterion variables most highly correlated with their first canonical variable are occipitomastoid radius (.753) and mastoid projection (.654). In the predictor set the variables with the highest loadings are bimastoid foramen breadth (.825) and inion radius (.775). Occipitomastoid radius primarily measures the inferior, and to some degree the posterior, projection of the area of the cranial base medial to the mastoid and mastoid projection measures the degree to which the mastoid projects below the digastric groove. All of the variables are positively correlated with their respective canonical variables, which indicates that as the cranial base becomes more inferiorly positioned, and as the projection of the mastoid processes beyond the digastric groove increases, the anterior area of the nuchal

TABLE 19

CANONICAL CORRELATIONS BETWEEN THE MASTOID AND OCCIPITAL FOR MALES

| Eigenvalue Number | Canonical Correlation | Eigenvalue | Proportion |
|---|---|---|---|
| 1 | 0.454 | 0.260 | 0.485 |
| 2 | 0.354 | 0.143 | 0.268 |
| 3 | 0.315 | 0.110 | 0.206 |
| 4 | 0.147 | 0.022 | 0.041 |

TABLE 20

LIKELIHOOD RATIOS AND F-STATISTICS FOR CANONICAL CORRELATIONS BETWEEN THE MASTOID AND OCCIPITAL FOR MALES

| Eigenvalues Removed | Likelihood Ratio | F-ratio | p |
|---|---|---|---|
| 0 | 0.612 | 1.943 | 0.0033 |
| 1 | 0.771 | 1.578 | 0.0645 |
| 2 | 0.881 | 1.371 | 0.1955 |
| 3 | 0.978 | 0.585 | 0.6741 |

TABLE 21

CANONICAL LOADINGS OF MASTOID VARIABLES
FOR MALES

| Variable | Canonical Variable | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| MAR | -0.102 | 0.798 | 0.586 | -0.097 |
| OMR | 0.753 | 0.383 | 0.127 | -0.520 |
| MBL | 0.316 | -0.248 | 0.908 | -0.120 |
| MAP | 0.654 | 0.468 | 0.186 | 0.565 |

TABLE 22

CANONICAL LOADINGS OF OCCIPITAL VARIABLES
FOR MALES: SECOND ANALYSIS

| | Canonical Variable | | | |
|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 |
| INR | 0.775 | 0.090 | -0.020 | 0.008 |
| OPR | 0.552 | 0.373 | 0.085 | -0.679 |
| ASB | 0.339 | 0.424 | 0.614 | 0.256 |
| BMF | 0.825 | -0.154 | -0.139 | -0.104 |
| OIL | 0.547 | 0.168 | -0.419 | 0.271 |
| OPA | -0.156 | -0.562 | 0.659 | 0.359 |
| POA | -0.141 | -0.190 | 0.065 | 0.134 |

plane becomes broader and the posterior projection of the occipital also increases.

Females. The canonical correlations for the females as well as their eigenvalues and the proportion of the variability explained are given in Table 23 and the likelihood ratios, F-ratios and associated probabilities for these correlations are given in Table 24. The results in Table 24 show that only the first canonical correlation of .609 is statistically significant ($p < .0001$).

The loadings of the variables of the mastoid are given in Table 25, and the loadings for the variables of the occipital are given in Table 26. Examination of these tables shows that this canonical correlation is somewhat similar to the first male correlation. Only one variable in the criterion set, occipitomastoid radius (.902), has a high loading. In the predictor set of variables opisthion radius (.817) and bimastoid foramen breadth (.760) have the highest loadings. Occipitomastoid radius, opisthion radius and bimastoid foramen breadth are all positively correlated with their respective canonical variables. This indicates that as the area of the cranial base medial to the mastoid processes becomes more inferiorly, and to some degree more posteriorly, positioned opisthion also becomes more posteriorly and inferiorly positioned, and the breadth of the anterior nuchal plane increases as well.

TABLE 23

CANONICAL CORRELATIONS BETWEEN THE MASTOID AND OCCIPITAL FOR FEMALES

| Eigenvalue Number | Canonical Correlation | Eigenvalue | Proportion |
|---|---|---|---|
| 1 | 0.609 | 0.590 | 0.723 |
| 2 | 0.327 | 0.120 | 0.147 |
| 3 | 0.302 | 0.100 | 0.123 |
| 4 | 0.072 | 0.005 | 0.007 |

TABLE 24

LIKELIHOOD RATIOS AND F-STATISTICS FOR CANONICAL CORRELATIONS BETWEEN THE MASTOID AND OCCIPITAL FOR FEMALES

| Eigenvalues Removed | Likelihood Ratio | F-ratio | p |
|---|---|---|---|
| 0 | 0.507 | 2.437 | 0.0001 |
| 1 | 0.807 | 1.142 | 0.3118 |
| 2 | 0.904 | 0.965 | 0.4754 |
| 3 | 0.995 | 0.124 | 0.9736 |

TABLE 25

CANONICAL LOADINGS OF MASTOID VARIABLES
FOR FEMALES

| | Canonical Variable | | | |
|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 |
| MAR | 0.071 | 0.128 | 0.977 | -0.156 |
| OMR | 0.902 | 0.196 | 0.375 | 0.083 |
| MBL | 0.250 | 0.685 | 0.161 | -0.665 |
| MAP | -0.175 | 0.764 | 0.311 | 0.538 |

TABLE 26

CANONICAL LOADINGS OF OCCIPITAL VARIABLES
FOR FEMALES: SECOND ANALYSIS

| | Canonical Variable | | | |
|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 |
| INR | 0.555 | -0.089 | 0.037 | -0.448 |
| OPR | 0.817 | -0.199 | 0.193 | -0.130 |
| ASB | 0.135 | 0.247 | 0.674 | -0.068 |
| BMF | 0.760 | 0.377 | 0.179 | 0.332 |
| OIL | 0.217 | -0.235 | -0.200 | 0.128 |
| OPA | -0.096 | 0.618 | 0.246 | -0.645 |
| POA | -0.047 | 0.647 | -0.338 | -0.201 |

# CHAPTER VI

# DISCUSSION

The purpose of this thesis is to examine the morphological and functional implications of one feature of the Neandertal cranium: a long and horizontally oriented nuchal plane. Its goals are: (1) to identify the functional and morphological complexes that make up the posterior cranium; (2) to test the hypothesis that the nuchal plane is one of these functional complexes and to determine if the size and/or orientation of the nuchal plane are important functional aspects of its morphology; (3) to determine how the size and orientation of the nuchal plane are related to the morphology of other areas of the posterior cranium; and (4) to specifically ascertain if there is a relationship between the size and/or the orientation of the nuchal area and facial size and prognathism and the size and projection of the mastoid processes, and to explain these relationships in functional terms.

## The Morphological Complexes of the Posterior Cranium

Principal components analysis was used to identify the functional and morphological complexes that comprise the posterior cranium. The results support the hypothesis that the nuchal plane is one of the functional complexes of the posterior skull and also suggest that both the size and orientation of the nuchal plane are significant aspects of its morphology.

For each sex the principal components analysis identified six morphological complexes in the posterior cranium. The correspondence between the complexes isolated in the two sexes is extremely good. Of the six components identified in the females four correspond to male components, one component seems to represent two components isolated separately in the males, and one component represents a morphological feature not identified in the males.

Altogether seven morphological components were identified. These are: (1) occipital plane length (the first male and the second female component); (2) posterior vault size (the second male and fourth female component); (3) mastoid size (the fourth male and sixth female component); (4) posterior breadth (the sixth male and first female component); (5) occipital curvature (the third male component); (6) nuchal plane orientation (the fifth male component); and (7) nuchal plane length (the third female component). One component in the females, the fourth, represents both occipital curvature and nuchal plane orientation.

The hypothesis that the nuchal plane comprises one of the morphological complexes of the posterior cranium is supported by the fact that for both males and females a component representing nuchal plane orientation and in the females another component representing the length of the nuchal plane were isolated. The fact that components representing nuchal plane orientation and a separate component representing its length were identified suggests that both size and orientation are significant aspects of the morphology of this region.

The results of the principal components analysis also demonstrate that the nuchal plane is not an isolated structure. Rather, it is an integral part of the posterior cranium and its size and orientation are directly related to the size and shape of other areas of the posterior skull.

The pattern of component loadings for the second male component suggests that the size of the posterior vault may be related to the orientation of the nuchal plane. Four of the five variables with high loadings on this component (basion-bregma height, opisthion radius, inion radius and glabello-occipital length) reflect the size of the posterior skull. However, one angle, opisthion angle, also has a relatively high loading on this component. The four size-related variables all have negative loadings, but opisthion angle has a positive loading. This indicates that the orientation of the nuchal plane is related to the size of the posterior vault. Specifically, as the size of the vault increases the angle of the nuchal plane relative to opisthion decreases, making the angle more acute and the nuchal plane more posteriorly oriented.

The length of the nuchal plane also seems to be related to the shape of the occipital. The third male component represents occipital curvature, and the variables with the highest loadings are occipital angle and occipital subtense. However, inion radius and opisthion-inion length also have relatively high loadings on this component. Opisthion-inion length is a direct measure of the length of the nuchal plane and inion radius also measures the length of the nuchal plane, although more obliquely. Inion radius and opisthion inion length both have positive loadings whereas occipital angle has a negative loading. The opposite signs indicate that as the occipital angle becomes more acute and the occipital more strongly curved the length of the nuchal plane increases.

The fifth male component represents the orientation of the nuchal plane. The two variables with the highest loadings are opisthion angle and prosthion-opisthion angle, both of which have negative loadings. Opisthion-inion length also has a relatively high loading on this component but its loading is positive. This means that as the two angles become more acute the length of the nuchal plane increases. What this means in terms of the orientation of the nuchal plane is somewhat difficult to determine because as opisthion angle increases the nuchal plane becomes more horizontally oriented, but as prosthion-opisthion angle increases the nuchal plane becomes more posteriorly oriented. Both angles become more acute as the length of the nuchal plane increases and it could be the case that as opisthion-inion length increases the two angles change but the orientation of the nuchal plane is unaltered or only slightly changed.

However, it is more likely that the two angles do not cancel each other out entirely. The two angles are not strongly correlated with one another. If the two angles negate each another they should be more positively correlated. Given the results of the principal components analysis it is impossible to determine if the nuchal plane becomes more horizontally or more posteriorly oriented as it increases in length. There is a negative correlation between opisthion angle and opisthion-inion length, which suggests that as the nuchal plane becomes longer it may also become more posteriorly oriented, but the correlation is not particularly strong and there is also a smaller negative correlation between opisthion-inion length and prosthion-opisthion angle. Thus, the orientation of the nuchal plane does not appear to be very highly correlated with its length.

In the females the principal component analysis isolated one component representing nuchal plane length and another that represents both occipital curvature and nuchal plane orientation. The third female component represents the length of the nuchal plane; the variables with the highest loadings are opisthion-inion length and inion radius, both of which measure the length of the nuchal plane. Glabello-occipital length also has a relatively high loading, and all three of these variables have positive loadings, which indicates that as the length of the posterior vault increases the length of the nuchal plane also increases.

The fourth female component reflects two complexes that are represented by separate components in the males. Occipital angle, opisthion angle and prosthion opisthion angle all have high loadings on this component and it appears to represent occipital curvature and nuchal plane orientation. Opisthion angle and prosthion-opisthion angle both have positive loadings, whereas occipital angle has a negative loading. This indicates that as the curvature of the occipital increases and occipital angle becomes smaller prosthion-opisthion angle becomes larger, which would make the nuchal plane more posteriorly oriented. Opisthion angle also becomes larger as occipital angle increases; as the occipital becomes less curved the angle of the nuchal plane relative to opisthion becomes more obtuse, and the nuchal plane becomes more horizontally oriented. What this may mean in terms of the overall orientation of the nuchal plane is difficult to determine because as prosthion-opisthion angle increases the nuchal plane becomes more posteriorly oriented but as opisthion angle increases the nuchal plane becomes more horizontally oriented. As is the case for the third male component, the two angles could conceivably negate each other and the orientation of the nuchal plane may be largely unrelated to the curvature of the occipital.

For the females nuchal plane length and nuchal plane orientation are two separate components, and the relationship between the two is not clear. As is the case for the males there is a negative correlation between opisthion-inion length and opisthion angle, which suggests that as the length of the nuchal plane increases it may also become more posteriorly oriented. However, the correlation is not very large and the orientation of the nuchal plane does not seem to be very highly correlated with its length.

The principal components analysis is based upon the dimensions of variability that exist within populations and which differentiate individuals. One aim of this thesis is to determine if these same dimensions of variability exist between populations and differentiate populations. To test this mean group component scores were compared using ANOVA.

The results of the ANOVA show that for most of the components identified in the principal components analysis mean group scores are significantly different. For each sex six components were retained and in each sex group means are significantly different for four of the six retained components. In addition there is a very good correspondence between the males and females in terms of which components have significantly different means. For the males group means are significantly different for the components representing occipital plane length, posterior vault size, occipital curvature and posterior breadth. Group means are not significantly different for the components that represent mastoid size and nuchal plane orientation. For the females group means are significantly different for the components representing occipital plane length, posterior vault size, posterior breadth and nuchal plane length. Group means are not significantly different for the components that represent mastoid size and occipital curvature/ nuchal plane orientation.

Altogether the results of the ANOVA show that the three groups used in this study differ significantly from one another with regard to the morphological complexes identified by the principal components analysis. Many of the dimensions of variability that differentiate individuals from the same population are similar to those that differentiate populations. The exceptions are the size and projection of the mastoid processes in both sexes, the orientation of the nuchal plane in males and occipital curvature/ nuchal plane orientation in females.

## Occipital Morphology and its Relationship to the Morphology of the Face and Mastoid Process

In addition to being characterized by a long, low, broad and horizontally oriented nuchal plane Neandertals possess large prognathic faces and mastoid processes that appear to be small and non-projecting. It has been argued that the morphology of the nuchal plane is functionally related to the large and prognathic face (Smith, 1983) and the appearance of the mastoid processes (Trinkaus, 1983; Zobeck, 1980).

In this thesis I have hypothesized that the morphology of the nuchal plane is functionally related to both the morphology of the face and the appearance of the mastoids. I have also hypothesized that in modern humans the functional and morphological relationships among these areas may be similar to those seen in Neandertals, and therefore the pattern of relationships seen in modern humans may foreshadow a morphological pattern similar to that of Neandertals.

Canonical correlation analysis was used to test the latter hypothesis. In the first analysis the relationship between occipital morphology and facial morphology is examined using the variables of the occipital as the predictor variables and the variables of the face as the criterion variables. In the second canonical correlation analysis the association between occipital morphology and the morphology of the mastoids is assessed. The occipital variables are the predictor variables and the mastoid variables are the criterion variables.

Relationship between occipital morphology and facial size and prognathism. In the analysis examining the relationship between occipital morphology and facial size and prognathism four canonical correlations were obtained for each sex. For the males the first three correlations are significant, and for the females the first two are significant. The patterns of canonical loadings show that the correspondence between the correlations isolated in the males and females is quite good, and for the most part they reflect similar relationships. The first male correlation has no equivalent female correlation, but the first female correlation corresponds to the second male correlation, and the second female correlation is equivalent to the third male correlation.

The first female and second male correlations represent the relationship between the size of the face, as measured by nasion-prosthion height, and the breadth of the nuchal plane and the posterior projection of the occipital. In both sexes the patterns of canonical loadings indicate that the size of the face is positively correlated with the breadth, particularly the anterior breadth, of the nuchal plane as well as the posterior projection of the occipital.

The relationship between the orientation of the nuchal plane and the morphology of the face is not as clear. The first male canonical correlation demonstrates that in males lateral facial prognathism is related to the orientation of the nuchal plane: as lateral facial prognathism increases prosthion-opisthion angle also increases and the nuchal plane becomes more posteriorly oriented.

The second female and third male canonical correlations are more difficult to interpret; they appear to reflect a relationship between lower and lateral facial prognathism and the orientation of the nuchal area similar to that seen in the first male correlation. Two facial variables, prosthion radius and zygoorbitale radius have high loadings, but none of the variables of the occipital have very large loadings. Opisthion angle has the highest loading, but it is not particularly large. The pattern of loadings suggests that as the lower and lateral face become more prognathic the angle of the nuchal plane relative to opisthion becomes more acute to some extent and the nuchal plane becomes somewhat more posteriorly oriented. The loading for opisthion angle is not, however, very large and it is likely that the association between opisthion angle and facial prognathism is weak.

The results of the first canonical correlation analysis show that the morphology of the nuchal area is related to facial size and prognathism. However, the pattern seen in modern humans is only partially like that of Neandertals. The first female and second male correlations clearly show that the size of the face is related to the size of the nuchal area. As facial height increases the nuchal plane becomes broader, with the greatest increase occurring in the anterior nuchal area. The posterior projection of the occipital, measured by inion radius, also increases. Inion radius obliquely measures the length of the nuchal plane and it is highly correlated with opisthion-inion length. Its high loading on this correlation suggests that the nuchal plane also becomes somewhat longer as the face becomes larger.

These results show that facial size is related to the breadth of the nuchal plane and this relationship does seem to resemble the morphological pattern seen in Neandertals who do have large faces and very broad nuchal areas. In functional terms the correlation between facial size and the area of the nuchal plane is logical. The increased area of the nuchal plane compensates for a larger face by enlarging the area of attachment for the nuchal muscles which maintain the posture of the head.

The relationship between the orientation of the nuchal plane and the size and projection of the face is not as clear. The first male correlation does show that as the lateral face becomes more prognathic the nuchal plane becomes more posteriorly oriented. The third male and second female correlations may also reflect a similar relationship between lower and lateral facial prognathism and the orientation of the nuchal plane. These correlations suggest that the nuchal plane becomes oriented more posteriorly as the face becomes more prognathic. Although the results are far from clear, and these relationships are difficult to understand in functional terms, they certainly do not provide any evidence that a horizontally oriented nuchal plane is functionally related to a large and prognathic face. On the contrary, the results indicate that rather than becoming more horizontally oriented the nuchal plane becomes more posteriorly oriented as the face becomes more prognathic. Thus, the hypothesis that the morphological and functional relationship between the orientation of the nuchal plane and facial morphology is similar in Neandertals and modern humans cannot be supported.

It is quite interesting, however, that the results of the canonical correlation analysis show that facial prognathism seems to be correlated with a posterior orientation of the nuchal plane. The principal components analysis suggests that in males a large posterior vault is also associated with a posteriorly oriented nuchal plane. The principal components analysis also indicates that the morphology of the nuchal plane is related to the size and shape of other areas of the posterior cranium. It may be that the orientation of the nuchal plane is largely determined by the size and shape of other areas of the vault such as the size of the posterior vault or the morphology of the cranial base, rather than by the functional demands of the nuchal muscles.

The relationship between occipital morphology and mastoid size and projection. In the second canonical correlation analysis the nature of the relationship between occipital morphology and the size and projection of the mastoid processes is investigated. For each sex only one of the four canonical correlations is significant. Although these two correlations do not correspond with one another exactly they both seem to represent a similar morphological relationship between the occipital and temporal.

In the males the pattern of loadings for the first correlation indicates that as the cranial base becomes more inferiorly positioned and the projection of the mastoid processes below the digastric groove increases the anterior nuchal plane broadens and the length of the posterior vault increases. In the females the pattern of loadings for the first correlation reflects a somewhat similar relationship. In this case it appears that as the cranial base becomes more inferiorly positioned the anterior nuchal area becomes broader and opisthion is more posteriorly positioned.

The results of the second canonical correlation analysis suggest that there may be a functional relationship between the morphology of the nuchal area and the temporal but this relationship involves only the size of the nuchal area and not the orientation of the nuchal plane. As the length of the posterior vault increases the anterior nuchal area becomes broader and the area of the temporal bone medial to the mastoid processes becomes more inferiorly positioned. A larger nuchal area increases the area of attachment for the nuchal muscles, compensating for the longer posterior vault. The lower position of the cranial base also increases the efficiency of these muscles by shortening the distance between their origins and insertions. In males mastoid projection also increases as the anterior nuchal area broadens. This would further enhance the efficiency of those nuchal muscles which insert on the mastoid by increasing their area of attachment and decreasing the distance between their origins and insertions.

The orientation of the nuchal plane, on the other hand, does not appear to be related to the morphology of the temporal. The only significant canonical correlations reflect relationships involving size. Thus, the hypothesis that the mastoid processes may appear to be small as a consequence of a lower, more horizontally oriented nuchal plane cannot be supported. In modern human the orientation of the nuchal plane is not related to the morphology of the temporal.

# CHAPTER VII

# CONCLUSIONS

In this thesis I have attempted to test a number of hypotheses concerning the morphology of the posterior cranium. The results obtained support some of these hypotheses. Others, however, are not supported by the results, and there are some questions that remain unanswered.

In the posterior cranium seven morphological and functional complexes were identified. These are: occipital plane length, posterior vault size, mastoid size, occipital curvature, nuchal plane orientation and nuchal plane length. The fact that in each sex a component representing nuchal plane orientation and in the females another representing nuchal plane length were isolated supports the hypothesis that the nuchal plane is one of the functional complexes of the posterior cranium, and also suggests that both size and orientation are significant aspects of its morphology. The results of the principal components analysis also indicate that the length of the nuchal plane, and perhaps its orientation as well, are related to the size and shape of other areas of the posterior skull.

The results of the canonical correlation analysis suggest that in modern humans the morphology of the nuchal region may be functionally related to the morphology of the temporal and the size and projection of the face, and some aspects of these relationships appear to be similar to the functional relationships which are believed to have existed in Neandertals. In this study it was demonstrated that as facial height increases the nuchal plane, particularly the anterior nuchal plane, becomes broader and the occipital projects more posteriorly. This relationship resembles the morphological pattern seen in Neandertal crania, which are characterized by a large face and a very broad nuchal area.

On the other hand, the relationship between the orientation of the nuchal plane and facial size and prognathism is not as obvious. Although the results are somewhat equivocal they do not provide any support for the hypothesis that a large and prognathic face is associated with a horizontally oriented nuchal plane. On the contrary they seem to indicate that in modern humans as the face becomes more prognathic the nuchal plane becomes somewhat more posteriorly oriented.

The results of the canonical correlation analyses also suggest that in modern humans the morphology of the nuchal area may be functionally related to the morphology of the temporal. However, the morphological pattern found in modern humans is not entirely similar to that found in Neandertals. The results show that in males as the cranial base becomes more inferiorly positioned and the inferior projection of the mastoid processes increases the anterior nuchal plane becomes broader and the posterior vault becomes longer. In females the relationship between occipital and temporal morphology appears to be similar. As the cranial base becomes more inferiorly positioned the anterior nuchal area becomes broader and opisthion is positioned more posteriorly. There is no evidence that mastoid projection is inversely related to the orientation or the position of the nuchal plane.

Altogether the results of the canonical correlation analyses do show that in modern humans the morphology of the nuchal area is related to the morphology of the face and temporal and these relationships can be explained in functional terms. These relationships are similar in some aspects and quite different in others to the morphological pattern seen in Neandertals. The similarities in the observed patterns relate to the association between the size, especially the breadth, of the nuchal plane and the size of the face and the lowness of the cranial base. As the face becomes larger, and the cranial base more inferiorly positioned the nuchal area, especially the anterior nuchal area, becomes broader and the length of the occipital also increases. Expansion of the nuchal area may compensate for a larger face by increasing the area of attachment for the muscles that maintain the posture of the head. The lower position of the cranial base would further increase the efficiency of these muscles by decreasing the distance between their origins and insertions (Crouch, 1972).

It is very interesting that the breadth of the nuchal plane appears to have such an important role in the functional relationships that exist between the nuchal plane and the morphology of the face and temporal. In the transition from archaic to modern Homo sapiens the area of the nuchal plane is reduced, and the most dramatic reduction is in the breadth, rather than the length (Smith and Paquette, 1989).

On the other hand the orientation of the nuchal plane does not appear to be at all related to the morphology of the mastoid region of the temporal, and the relationship between nuchal plane orientation and facial prognathism is very different from the pattern seen in Neandertals. In modern humans the nuchal plane seems to become more posteriorly, rather than inferiorly, oriented as facial prognathism increases. The results of the principal components analysis also seem to indicate that as the size of the posterior vault increases the nuchal plane becomes more posteriorly oriented.

If one considers the nuchal plane as a structure isolated from the other areas of the posterior cranium, the only function of which is provide an area of attachment for the muscles of the neck, the association between facial prognathism and a posteriorly oriented nuchal plane makes little sense in functional terms. However, the results of the principal components analysis show that the nuchal plane is not an isolated complex, it is an integral part of the posterior cranium and its size and orientation are related to the morphology of other areas of the posterior skull. It is possible that in modern humans the orientation of the nuchal plane is determined primarily by the size and shape of other areas of the posterior cranium, rather than as a response to the functional demands of the nuchal musculature.

It is not clear how much variability exists in modern populations with regard to the orientation of the nuchal plane. In this study it was necessary to use two angles, opisthion angle and prosthion-opisthion angle, to measure nuchal plane orientation but the relationship between these two angles and nuchal plane orientation is unclear. As prosthion-opisthion angle increases the nuchal plane becomes more posteriorly oriented but as opisthion angle increases the nuchal plane becomes more horizontally oriented. In both sexes the two angles are rather highly correlated with one another and to some undetermined extent they do apparently negate one another. It may be the case that an increase in one angle is associated with an equivalent increase in the other angle and the end result is little or no significant change in the actual orientation of the nuchal plane. In the principal components analysis when both angles have high loadings on a component these loadings have the same sign. Thus it is impossible to ascertain how the orientation of the nuchal plane is related to its length or the curvature of the occipital or the size of the posterior vault.

However, it is clear that the occipital bun cannot be regarded as merely an extension of the type of variability seen in modern humans. This conclusion underscores the uniqueness of the occipital bun and suggests that it is related to some process or factor no longer present in modern humans.

Thus, consideration must be given to the possibility that the argument that in Neandertals the orientation of the nuchal area is functionally related to the large, prognathic face and the appearance of the mastoids, and all of these characteristics are primarily adaptations to facilitate the use of the anterior teeth as tools is incorrect. In Neandertals the functional relationships between the orientation of the nuchal plane and other areas of the skull may be very different from the relationships that are believed to exist by the proponents of the anterior dental loading hypothesis.

For example, Trinkaus and LeMay (1981) have argued that in Neandertals the pattern of brain growth is different from that of modern humans, and they regard the occipital bun as the result of this different growth pattern. Specifically, they hypothesized that the occipital bun "is the product of a significant increase in brain size relatively late in the normal period of brain development." (Trinkaus and LeMay, 1982:32) They argued that if this late growth was directed posteriorly, and occurred after the parietals and occipital have largely reached their adult curvature the occipital squama would be displaced posteriorly, and if the new bone formed along the lambdoid suture was relatively horizontal an occipital bun would result.

Thus, if Trinkaus and LeMay (1982) are correct the pattern of relationships between the orientation of the nuchal plane and the morphology of the face and temporal seen in modern humans is unlike that seen in Neandertals not because of any differences related to the functional demands placed upon the nuchal musculature, but rather because the pattern of brain growth is quite different from that of Neandertals. Even if Trinkaus and LeMay (1982) are correct however, it does not follow that the occipital bun has no adaptive or functional significance with regard to the use of the anterior teeth as tools. Even if the primary determinant of the occipital bun is the pattern and timing of brain growth the bun might still significantly enhance the efficiency of the nuchal musculature.

This thesis has not attempted to test the hypothesis that the morphology of the Neandertal cranium is primarily a functional adaptation related to anterior dental loading. It has merely attempted to determine if the pattern of relationships seen in modern human crania resemble in any way the functional relationships that have been hypothesized to exist in Neandertals. The former hypothesis cannot be tested, and therefore its acceptance rests upon the plausibility of the arguments for or against it. This study has merely shown that in modern humans the size of the nuchal plane, particularly its breadth, appears to be functionally related to the size of the face and the lowness of the cranial base. This pattern of relationships does resemble the functional relationships that have been hypothesized to exist in Neandertals. However, there is no evidence that the functional relationship between the orientation of the nuchal plane and the morphology of the temporal resembles in any way a pattern similar to that seen in Neandertals.

# REFERENCES CITED

Abel AH (1939) Tabeau's Narrative of Loisel's Expedition to the Upper Missouri. Norman OK: University of Oklahoma Press.

Angel JL (1972) A middle Paleolithic temporal bone from Darra-I-Kur, Afghanistan. American Philosophical Society Transactions 62:54-56.

Anson BJ and Donaldson JA (1981) Surgical Anatomy of the Temporal Bone. Philadelphia: WB Saunders.

Bass WM (1987) Human Osteology: A Laboratory and Field Manual. Columbia MO: Missouri Archaeological Society.

Bast TH and Anson BJ (1949) The Temporal Bone and Ear. Springfield IL: Charles C Thomas.

Boule M (1911-1913) L'homme fossile de La Chapelle-aux-Saints. Annales de Paléontologie 6:111-172; 7:21-56, 85-192; 8:1-70.

Boule M and Vallois HV (1957) Fossil Men. New York: Dryden Press.

Brace CL (1962) Cultural factors in the evolution of the human dentition. In MF Montagu (ed.): Culture and the Evolution of Men. New York: Oxford University Press, pp 343-354.

Brace CL (1964) The fate of "classic Neanderthals": A consideration of hominid catastrophism. Current Anthropology 5:3-43.

Brookfield HC and Hart D (1971) Melanesia: A Geographical Interpretation of an Island World. London: Methuen and Co.

Brose DS and Wolpoff MH (1971) Early Upper Paleolithic man and late Middle Paleolithic tools. American Anthropologist 73:1156-1194.

Coon CS (1962) The Origin of Races. New York: Alfred A. Knopf.

Corruccini RS (1978) Morphometric analysis: Uses and abuses. Yearbook of Physical Anthropology 21:135-150.

Crouch JE (1972) Functional Human Anatomy. Philadelphia: Lea and Febiger.

Deetz J (1965) The Dynamics of Stylistic Change in Arikara Ceramics. Urbana IL: University of Illinois Press.

Denig ET (1939) Five Indian Tribes of the Upper Missouri. Norman OK: University of Oklahoma Press.

Dillon WR and Goldstein M (1984) Multivariate Analysis: Methods and Applications. New York: John Wiley and Sons.

Dorsey GA (1904) Traditions of the Arikara. Washington: Carnegie Institution of Washington.

Epstein AL (1969) Matupit: Land, Politics, and Change Among the Tolai of New Britain. Berkeley: University of California Press.

Epstein TS (1968) Capitalism, Primitive and Modern: Some Aspects of Tolai Economic Growth. East Lansing, MI: Michigan State University Press.

Gray H (1977) Gray's Anatomy. New York: Bounty Books.

Hastings P (1973) New Guinea: Problems and Prospects. Melbourne: Cheshire Publishing.

Holder P (1970) The Hoe and the Horse on the Plains. Lincoln NE: University of Nebraska Press.

Hollinshead WH and Jenkins DB (1981) Functional Anatomy of the Limbs and Back. Philadelphia: WB Saunders.

Howell FC (1952) Pleistocene glacial ecology and the evolution of "classic Neandertal" man. Southwestern Journal of Anthropology 8:377-410.

Howell FC (1957) The evolutionary significance of variation and varieties of "Neandertal" man. Quarterly Review of Biology 32:330-347.

Howells WW (1969) Criteria for the selection of osteometric dimensions. American Journal of Physical Anthropology 30:451-458.

Howells WW (1973) Cranial Variation in Man: A Study by Multivariate Analysis of Patterns of Difference Among Recent Human Populations. Cambridge MA: Papers of the Peabody Museum, Vol. 67, Harvard University.

Hrdlicka A (1930) The Skeletal Remains of Early Man. Smithsonian Miscellaneous Collections 83:1-379.

Hylander WL (1977) The adaptive significance of Eskimo craniofacial morphology. In AA Dahlberg and TM Graber (eds.): Orofacial Growth and Development. The Hague: Mouton.

Jantz RL and Owsley DW (1973) Long bone growth variation among Arikara skeletal populations. American Journal of Anthropology 63:13-20.

Johnson RA and Wichern DW (1988) Applied Multivariate Statistical Analysis. Englewood Cliffs, NJ: Prentice Hall.

Kapit W and Elson LM (1977) The Anatomy Coloring Book. New York: Harper and Row.

Kim J-O and Mueller CW (1978a) Factor Analysis: Statistical Methods and Practical Issues. Beverly Hills: Sage Publications.

Kim J-O and Mueller CW (1978a) Factor Analysis: What it is and How to do it. Beverly Hills: Sage Publications.

Krause RA (1972) The Leavenworth Site: Archaeology of an Historic Arikara Community. University of Kansas Publications in Anthropology No. 3.

Lehmer DJ (1954) The Sedentary Horizon of the Northern Plains. Southwestern Journal of Anthropology 10:139-152.

Lehmer DJ (1968) Epidemics among the Indians of the Upper Missouri. Paper presented to the Western History Association.

Lehmer DJ (1970) Climate and culture history in the Middle Missouri. In W Dort and JK Jones (eds.): Pleistocene and Recent Environments of the Central Great Plains. Lawrence KS: University of Kansas Press, pp 511-516.

Lehmer DJ (1971) Introduction to Middle Missouri Archeology. National Park Service Anthropology Papers No. 1.

MacDonald GF (1973) Haida Burial Practices: Three Archaeological Examples. Archaeological Survey of Canada No. 9. Report of the National Museum of Man, Ottawa.

Mann A and Trinkaus E (1973) Neandertal and Neandertal-like fossils from the Upper Pleistocene. Yearbook of Physical Anthropology 17:169-193.

Mardia KV, Kent T and Bibby JM (1979) Multivariate Analysis. New York:

Martin R (1928) Lehrbuch der Anthropologie in Systematischer Darstellung. Vol. 2: Kraniologie, Osteologie. Jena: Gustav Fischer.

McCall RB (1975) Fundamental Statistics for Psychology. New York: Harcourt Brace Jovanovich, Inc..

Minugh-Purvis N (1988) Patterns of Craniofacial Growth and Development in Upper Pleistocene Hominids. Doctoral Dissertation, University of Pennsylvania.

Murdock GP (1967) Our Primitive Contemporaries. New York: MacMillan Co..

Nasatir AP (1952) Before Lewis and Clark. St. Louis: St. Louis Historical Documents Foundation.

Neter J, Wasserman W and Kutner MH (1985) Applied Linear Statistical Models. Homewood, IL: Richard D. Irwin, Inc..

Olson TR (1985) Cranial morphology and systematics of the Hadar formation hominids and "Australopithecus" africanus. In E Delson (ed.): Ancestors: The Hard Evidence. New York: Alan R. Liss, Inc., pp 102-119.

Ott L, Larson RF and Mendenhall W (1987) Statistics: A Tool for the Social Sciences. Boston: Duxbury Press.

Owsley DW and Bass WM (1979) A demographic analysis of skeletons from the Larson site (39WW2) Walworth county, South Dakota: Vital statistics. American Journal of Physical Anthropology 51:145-154.

Rak Y (1986) The Neanderthal: A new look at an old face. Journal of Human Evolution 15:151-164.

Salisbury RF (1970) Vunamami: Economic Transformation in a Traditional Society. Berkeley: University of California Press.

Santa Luca AP (1978) A re-examination of presumed Neandertal-like fossils. Journal of Human Evolution 7:619-636.

Smith FH (1976) The Neandertal Remains From Krapina: A Descriptive and Comparative Study. University of Tennessee Department of Anthropology Report of Investigations No. 15.

Smith FH (1982) Upper Pleistocene human evolution in South-Central Europe: A review of the evidence and analysis of trends. Current Anthropology 23:667-703.

Smith FH (1983) Behavioral interpretations of changes in craniofacial morphology across the archaic/modern Homo sapiens transition. In E Trinkaus (ed.): The Mousterian Legacy: Human Biocultural Change in the Upper Pleistocene.

Smith FH, Falsetti A and Donnelly SM (1989) A review of modern human origins. Yearbook of Physical Anthropology.

Smith FH and Paquette SP (1989) The adaptive basis of Neandertal facial form, with some thoughts on the nature of modern human origins. In E Trinkaus (ed.): The Emergence of Modern Humans: Biocultural Adaptations in the Later Pleistocene. New York: Cambridge University Press.

Smith P (1976) Dental pathology in fossil hominids: What did Neanderthals do with their teeth? Current Anthropology 17:149-151.

Stearns ML (1981) Haida Culture in Custody. Vancouver: Douglas and McIntyre.

Tatsuoka MM (1980) Multivariate Analysis: Techniques for Educational and Psychological Research. New York: John Wiley and Sons.

Thompson B (1984) Canonical Correlation Analysis: Uses and Interpretation. Beverly Hills: Sage Publications.

Trinkaus E (1978) Dental remains from the Shanidar adult Neandertals. Journal of Human Evolution 7:369-382.

Trinkaus E (1983) The Shanidar Neandertals. New York: Academic Press.

Trinkaus E (1984) Western Asia. In FH Smith and F Spencer (eds.): The Origins of Modern Humans: A World Survey of the Fossil Evidence. New York: Alan R. Liss Inc., pp 251-293.

Trinkaus E (1987) The Neandertal face: evolutionary and functional perspectives on a recent hominid face. Journal of Human Evolution 16:429-443.

Trinkaus E and LeMay M (1982) Occipital bunning among later Pleistocene hominids. American Journal of Physical Anthropology 57:27-35.

Trinkaus E and Smith FH (1985) The fate of the Neandertals. In E Delson (ed.): Ancestors: The Hard Evidence. New York: Alan R. Liss Inc., pp 325-333.

Vallois HV (1969) Le temporal Néandertalien H 27 de La Quina. Etudie Anthropologique. L'Anthropologie 73: 365-400; 525-544.

Van den Brink JH (1974) The Haida Indians: Culture Change Mainly Between 1876-1970. Leiden: E. J. Brill.

Warfel JH (1985) The Head Neck and Trunk. Philadelphia: Lea and Febiger.

Weidenreich F (1940) The torus occipitalis and related structures and their transformations in the course of human evolution. Bulletin of the Geological Society of China 19:479-559.

Wolpoff MH (1980) Paleoanthropology. New York: Alfred A Knopf.

Woodcock G (1977) Peoples of the Coast: The Indians of the Pacific Northwest. Bloomington IN: Indiana University Press.

Zegura SL (1978) Components, factors and confusion. Yearbook of Physical Anthropology 21:151-159.

Zobeck TS (1980) An Analysis of the Functional Significance and Sexual Dimorphism of the Neandertal Mastoid Process. Master's Thesis, University of Tennessee-Knoxville.

# APPENDIXES

# APPENDIX A

# VARIABLES

The following is a list of the variables used in this study. Twenty-one measurements were taken, and three angles calculated. Variables, varaible codes, required instruments, references (for measurements described or defined by other workers; measurements and angles for which no references are cited were devised for this study) and definitions for each are given. When possible all measurements that are bilateral were taken on the left side. When a skull was damaged or incomplete in a manner that precluded taking all measurements on the left side all bilateral measurements were taken from the right side. Angles were calculated using the CSS Data Transformation operation. For an explanation of how angles are derived from direct measurements see Howells (1973:187-188).

1. Glabello-occipital length (GOL; spreading calipers; Howells, 1973). The greatest length from the glabellar region, in the median sagittal plane.

2. Basion-bregma height (BBH; spreading calipers; Howells, 1973). The distance from basion to bregma.

3. Maximum cranial breadth (XCB; spreading calipers; Howells, 1973). The maximum cranial breadth perpendicular to the median sagittal plane, above the level of the supramastoid crests.

4. Occipitomastoid radius (OMR; radiometer). The distance from the transmeatal axis to the occipitomastoid

crest, medial to the midpoint of the mastoid base on the medial aspect of the process.

5. Mastoidale radius (MAR; radiometer). The distance from the transmeatal axis to mastoidale.

6. Mastoid projection (MAP; radiometer; Vallois, 1969). The distance from the midpoint of the mastoid base, on the medial aspect of the process, to mastoidale.

7. Mastoid base length (MBL; sliding calipers; Howells, 1973). The width of the mastoid process at its base, through its transverse axis; from the posterior end of the digastric groove to a corresponding level on the external surface of the mastoid.

8. Bimastoid foramen breadth (BMF; sliding calipers). The distance from one mastoid foramen to the other.

9. Biasterionic breadth (ASB; sliding calipers; Howells, 1973). The direct measurement from one asterion to the other.

10. Opisthion-inion length (OIL; sliding calipers). The distance from opisthion to inion in the midline.

11. Opisthion radius (OPR; radiometer). The distance from the transmeatal axis to opisthion.

12. Inion radius (INR; radiometer). The distance from the transmeatal axis to inion.

13. Opisthion angle (OPA). The angle at opisthion between OPR and INR; calculated from OPR, OIL and INR.

14. Occipital cord (OCC; coordinate calipers; Howells, 1973). The direct distance from lambda to opisthion in the midline.

15. Occipital subtense (OCS; coordinate calipers; Howells, 1973). The maximum subtense, at the most prominent point on the basic contour of the occipital bone in the midline.

16. Occipital cord fraction (OCF; coordinate calipers; Howells, 1973). The distance from lambda along the occipital chord at which the occipital subtense is located.

17. Occipital angle (OCA; Howells, 1973). The angle in the sagittal plane underlying the curvature of the occipital bone at its maximum height above the occipital chord; calculated from OCC, OCF and OCS.

18. Inion-lambda length (ILL; sliding calipers). The distance from inion to lambda in the midline.

19. Prosthion-opisthion length (POL; sliding calipers). The distance from prosthion to opisthion in the midline.

20. Prosthion radius (PRR; radiometer; Howells, 1973). The distance from the transmeatal axis to prosthion.

21. Nasion radius (NAR; radiometer; Howells, 1973). The distance from the transmeatal axis to nasion.

22. Nasion-prosthion height (NPH; sliding calipers; Howells, 1973). Upper facial height from nasion to prosthion.

23. Zygoorbitale radius (ZOR; radiometer; Howells, 1973). The distance from the transmeatal axis to zygoorbitale.

24. Prosthion-opisthion angle (POA). The angle at the transmeatal axis between PRR and OPR; calculated from PRR, OPR and POL.

# APPENDIX B

# POOLED WITHIN-GROUPS CORRELATION MATRICES

TABLE A-1

POOLED WITHIN GROUPS CORRELATION MATRIX FOR MALES

| | INR | MAR | OMR | OPR | PRR | NAR | ZOR | GOL | BBH | XCB | OCS | OCF | OCC | ASB | MAP | MBL | BMF | OIL | ILL | NPH | POL | OPA | OCA | POA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INR | - | .08 | .26 | .38 | .32 | .02 | .07 | .47 | .37 | -.09 | .42 | -.11 | .09 | .11 | .16 | .06 | .26 | .78 | -.24 | .32 | .39 | -.13 | -.41 | -.01 |
| MAR | | - | .40 | .19 | .22 | .21 | .20 | .26 | .13 | .04 | .08 | .23 | .21 | .28 | .46 | .39 | .02 | .01 | .17 | .39 | .15 | -.07 | .00 | -.10 |
| OMR | | | - | .28 | .23 | .17 | .19 | .38 | .30 | .02 | .26 | .07 | .16 | .19 | .39 | .31 | .27 | .15 | .11 | .22 | .22 | -.12 | -.22 | -.06 |
| OPR | | | | - | .21 | -.07 | .07 | .24 | .34 | -.02 | -.03 | .05 | .08 | .00 | .11 | -.04 | .04 | .35 | -.14 | .34 | .56 | -.32 | .00 | -.32 |
| PRR | | | | | - | .41 | .46 | .39 | .21 | -.21 | .04 | -.08 | .08 | .00 | .11 | -.04 | .04 | .35 | -.14 | .34 | .56 | -.33 | .00 | -.32 |
| NAR | | | | | | - | .71 | .60 | .21 | .07 | .05 | -.02 | .17 | .16 | .13 | .13 | -.05 | .03 | .12 | .25 | .37 | .07 | .02 | .23 |
| ZOR | | | | | | | - | .48 | .21 | -.02 | .00 | -.05 | .16 | .12 | .13 | .18 | -.02 | .05 | .09 | .20 | .53 | -.07 | .08 | .32 |
| GOL | | | | | | | | - | .36 | .04 | .42 | -.03 | .31 | .30 | .24 | .30 | .07 | .23 | .23 | .34 | .40 | .12 | -.32 | .06 |
| BBH | | | | | | | | | - | .06 | .02 | -.01 | .28 | .07 | .03 | .15 | .37 | .26 | .04 | .11 | .34 | -.22 | .10 | .06 |
| XCB | | | | | | | | | | - | .19 | .38 | .27 | .39 | .04 | .14 | .33 | -.18 | .34 | .00 | -.08 | .19 | -.09 | .11 |
| OCS | | | | | | | | | | | - | .39 | .46 | .14 | .19 | .19 | .09 | .26 | .51 | .11 | .00 | .29 | -.90 | .02 |

TABLE A-1 (continued)

| | INR | MAR | OMR | OPR | PRR | NAR | ZOR | GOL | BBH | XCB | OCS | OCF | OCC | ASB | MAP | MBL | BMF | OIL | ILL | NPH | POL | OPA | OCA | POA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OCF | | | | | | | | | | | | - | .60 | .22 | .17 | .09 | .05 | -.23 | .70 | .04 | .02 | .21 | -.16 | .11 |
| OCC | | | | | | | | | | | | | - | .16 | .19 | .05 | .07 | .06 | .71 | .21 | .10 | -.11 | -.06 | .02 |
| ASB | | | | | | | | | | | | | | - | .22 | .25 | .12 | -.04 | .20 | .19 | .05 | .16 | -.09 | .02 |
| MAP | | | | | | | | | | | | | | | - | .14 | .07 | .12 | .09 | .23 | .10 | -.03 | -.13 | -.01 |
| MBL | | | | | | | | | | | | | | | | - | .04 | -.11 | .20 | .04 | .06 | .24 | -.19 | .10 |
| BMF | | | | | | | | | | | | | | | | | - | .24 | -.05 | .11 | .08 | -.27 | -.07 | -.10 |
| OIL | | | | | | | | | | | | | | | | | | - | -.51 | .25 | .04 | -.42 | -.26 | -.22 |
| ILL | | | | | | | | | | | | | | | | | | | - | .00 | .09 | .37 | -.25 | .20 |
| NPH | | | | | | | | | | | | | | | | | | | | - | .22 | -.06 | -.01 | -.07 |
| POL | | | | | | | | | | | | | | | | | | | | | - | -.16 | .06 | .43 |
| OPA | | | | | | | | | | | | | | | | | | | | | | - | -.38 | .36 |
| OCA | | | | | | | | | | | | | | | | | | | | | | | - | -.03 |
| POA | | | | | | | | | | | | | | | | | | | | | | | | - |

TABLE A-2

POOLED WITHIN GROUPS CORRELATION MATRIX FOR FEMALES

| | INR | MAR | OMR | OPR | PRR | NAR | ZOR | GOL | BBH | XCB | OCS | OCF | OCC | ASB | MAP | MBL | BMF | OIL | ILL | NPH | POL | OPA | OCA | POA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INR | - | .09 | .19 | .39 | -.05 | .15 | .04 | .52 | .27 | -.03 | .36 | .19 | .28 | .38 | -.14 | .05 | .18 | .75 | -.20 | .17 | .16 | .02 | -.26 | -.01 |
| MAR | | - | .49 | .11 | .20 | .20 | .22 | .23 | .23 | .25 | .02 | .25 | .14 | .30 | .31 | .41 | .19 | -.04 | .17 | .24 | .13 | .11 | .04 | -.08 |
| OMR | | | - | .42 | .33 | .24 | .31 | .28 | .34 | .22 | .00 | .15 | .18 | .10 | .14 | .33 | .40 | -.03 | .10 | .26 | .37 | -.02 | .07 | .00 |
| OPR | | | | - | .23 | .06 | .10 | .30 | .36 | .02 | .02 | .21 | .36 | .07 | -.14 | .10 | .38 | -.07 | .16 | .10 | .59 | -.24 | .15 | .10 |
| PRR | | | | | - | .59 | .69 | .31 | .45 | .28 | -.08 | .02 | .12 | .10 | .09 | .22 | .52 | -.05 | .02 | .39 | .77 | -.19 | .15 | .10 |
| NAR | | | | | | - | .78 | .65 | .40 | .26 | .00 | .08 | .14 | .28 | .14 | .12 | .37 | .17 | -.03 | .34 | .53 | -.10 | .08 | .27 |
| ZOR | | | | | | | - | .46 | .32 | .26 | -.08 | .07 | .11 | .10 | .15 | .18 | .37 | .07 | -.02 | .29 | .56 | -.15 | .13 | .20 |
| GOL | | | | | | | | - | .34 | .20 | .37 | .17 | .38 | .42 | .00 | .20 | .26 | .19 | .22 | .32 | .41 | .19 | -.24 | .21 |
| BBH | | | | | | | | | - | .27 | -.11 | .06 | .28 | .21 | -.02 | .19 | .55 | .19 | -.06 | .24 | .41 | -.20 | .27 | -.03 |
| XCB | | | | | | | | | | - | .00 | .15 | .11 | .34 | .21 | .25 | .42 | -.11 | .17 | .26 | .17 | .13 | .07 | -.05 |
| OCS | | | | | | | | | | | - | .46 | .49 | .17 | .08 | -.02 | -.09 | .17 | .55 | .06 | -.08 | .28 | -.89 | -.06 |

TABLE A-2 (continued)

| | INR | MAR | OMR | OPR | PRR | NAR | ZOR | GOL | BBH | XCB | OCS | OCF | OCC | ASB | MAP | MBL | BMF | OIL | ILL | NPH | POL | OPA | OCA | POA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OCF | | | | | | | | | | | | - | .61 | .25 | .20 | .05 | .06 | .02 | .59 | .11 | .02 | .00 | -.20 | -.15 |
| OCC | | | | | | | | | | | | | - | .26 | .10 | .04 | .18 | .13 | .70 | .21 | .14 | -.18 | -.05 | .17 |
| ASB | | | | | | | | | | | | | | - | .14 | .23 | .27 | .21 | .11 | .22 | .16 | .20 | -.07 | .15 |
| MAP | | | | | | | | | | | | | | | - | .16 | .03 | -.13 | .21 | .22 | .07 | .16 | -.03 | .13 |
| MBL | | | | | | | | | | | | | | | | - | .19 | -.08 | .07 | .25 | .26 | .15 | .02 | .17 |
| BMF | | | | | | | | | | | | | | | | | - | .07 | -.05 | .29 | .56 | -.16 | .20 | .15 |
| OIL | | | | | | | | | | | | | | | | | | - | -.49 | .07 | -.14 | -.31 | -.10 | -.13 |
| ILL | | | | | | | | | | | | | | | | | | | - | .12 | .04 | .21 | -.27 | -.09 |
| NPH | | | | | | | | | | | | | | | | | | | | - | .33 | .04 | .03 | .10 |
| POL | | | | | | | | | | | | | | | | | | | | | - | -.08 | .15 | .58 |
| OPA | | | | | | | | | | | | | | | | | | | | | | - | -.42 | .26 |
| OCA | | | | | | | | | | | | | | | | | | | | | | | - | -.01 |
| POL | | | | | | | | | | | | | | | | | | | | | | | | - |

# VITA

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