THE BIOLOGY AND EVOLUTION OF LANGUAGE

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CHAPTER 12

The Evolution of Human Speech: The Fossil Record

THE COMPARATIVE STUDIES THAT I have just discussed allow us to trace the evolution of the human supralaryngeal airway through the fossil record. The correlation between the soft tissue of the supralaryngeal airways and the basicranium was established, and the conservative nature of the basicranium and the selective value of human speech were noted. I shall start the analysis of the fossil record with a qualitative discussion of the recent classical Neanderthal fossils that will hopefully point out the relevant issues. I shall then discuss quantitative, statistically based methods and the evolution of the supralaryngeal vocal tract in other archaic hominids.

The classic Neanderthal hominids are of particular interest because they were quite advanced in many ways but nonetheless appear to have retained certain primitive features. They lived until comparatively recent times, had large brains, developed an advanced culture, and coexisted with populations of anatomically modern *Homo sapiens*. They, however, preserved the archaic features of the general mammalian basicranium noted in Chapter 11. Figure 12-1 shows inferior views (looking up) of the basicraniums of a newborn human infant, the La Chapelle-aux-Saints Neanderthal fossil, and a modern adult man. Figure 12-2 shows lateral views of these skulls and the mandibles. The skulls and mandibles have been drawn to the same size. There are many similarities between the newborn and Neanderthal skulls and mandibles. Note the length of dimension *S*, the distance between the posterior border of the palate and the anterior border of the foramen magnum, relative to dimension *P*, the length of the palate. Whereas dimension *S* is equal to or longer than dimension *P* in the human newborn and the adult Neanderthal fossil, it is usually shorter in adult human beings. In only two out of a sample of fifty modern adult human skulls were these dimensions equal (Lieberman and Crelin, 1971).

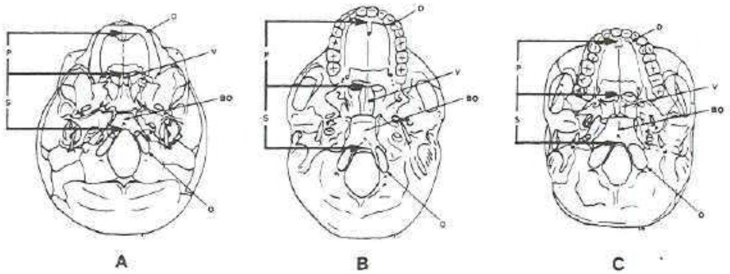


FIGURE 12-1.
Views of the bottoms of the skulls of modern newborn (*A*) and adult (*C*) *Homo sapiens* and the La Chapelle-aux-Saints Neanderthal fossil (*B*). *D* indicates the dental arch; *V*, the vomer bone; *BO*, the basilar part of the occipital bone; and *O*, the occipital condyle. The skulls, which are quite different in size, have been drawn to the same scale. (After Lieberman and Crelin, 1971.)

Distance *S* is quite long, 6.2 cm, in the Neanderthal fossil. It is also quite long relative to the short length of the newborn skull: 2.6 cm average with a range of 2.5 cm to 2.7 cm. The anterior-posterior length of the newborn larynx is about 2 cm (Crelin, 1973). The newborn skull thus has sufficient room for its larynx to be positioned high relative to the basicranium, almost in line with the tongue, so that it can lock into the nasopharynx during respiration. The length of the largest adult male larynx illustrated in the work of Negus (1949) is 4.5 cm. The range, as estimated from Negus's data (1949, p. 177) and Goldstein's compilation (1980, p. 65), is about 3.5 cm to 4.5 cm for adult males. Consequently there is more than enough room for the larynx to be positioned in a *similar* place in the Neanderthal fossil. In contrast, in the fifty skulls of modern adult males measured in Lieberman and Crelin (1971), dimension *S* averaged 4.1 cm with a range of 3.6 cm to 4.9 cm. There just is not enough space in a modern adult human skull between the hard palate and the spinal column for a larynx that is positioned close to the basicranium with the pharynx located behind the opening of the larynx.

The high laryngeal position and respiratory "locking" function of the larynx in the standard-plan airway is also apparent in the lateral views of Figure 12-2. The basicraniums of the newborn human and the Neanderthal fossil are flattened out in the region between the end of the palate and the basion (the anterior edge of the foramen magnum). The roof of the nasopharynx in the newborn and Neanderthal skulls is a relatively shallow and elongated arch, whereas in adult human beings it forms a deep, short arch. In the skulls that support a standard-plan supralaryngeal airway, the occipital bone between the foramen magnum and the sphenoid bone of the skull is only slightly inclined away from the horizontal plane (Bergland, 1963; Lieberman and Crelin, 1971; Laitman, Heimbuch, and Crelin, 1978).

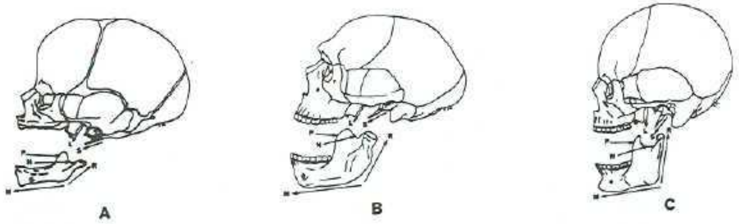


FIGURE 12.2.
Lateral views of skulls of modern newborn (*A*) and adult (*C*) *Homo sapiens* and the La Chapelle-aux-Saints Neanderthal fossil (*C*). *L* indicates angle of pterygoid lamina; *S*, angle of styloid process; *R*, ramus of mandible; *M*, body of mandible. (After Lieberman and Crelin, 1971.)

The relationship between the bones that form this part of the basicranium is again different in newborns compared with adult human beings (Lieberman and Crelin, 1971; Laitman and Crelin, 1976). The distance between the vomer bone and the synchondrosis of the sphenoid and occipital bones is relatively long in newborns (Crelin, 1973). As children mature, this distance decreases. The vomar often overlaps the synchondrosis in adults (Takagi, 1964). The skeletal features that support the muscles and ligaments of the supralaryngeal vocal tract and mandible are similar in newborn *Homo sapiens* and the Neanderthal fossil. For example, the pterygoid process of the sphenoid bone is relatively short, and its vertical lamina is more inclined away from the vertical plane than is the case in adult human skulls. The medial pterygoid plate, which is one of the points where the superior pharyngeal constrictor muscle is attached, is also similar in the modern newborn and fossil Neanderthal skulls. This muscle plays a part in swallowing (Bosma, 1975) and in speech production (Bell-Berti, 1973). It is active in the production of nonnasal sounds, where it helps seal the nasal cavity, and in the production of sounds like the vowel [a], where it pulls the tongue body back.

The body of the newborn mandible, dimension *M* in Figure 12-2, is longer than the ramus, dimension *R*. The length of the body of the mandible in the newborn skull is consistent with the fact that the newborn tongue is long and is positioned entirely within the month. The length of the mandible has to be long to hold the tongue. The body of the newborn mandible is thus about 3.5 cm compared with the 2.0-cm length of the ramus. The proportions of the Neanderthal fossil's mandible are similar to those of the newborn's mandible. In contrast, the lengths of the mandibular body and ramus are usually almost equal in adult human beings (Crelin, 1973). Other details of the newborn and Neanderthal mandibles also differ from those of adult modern *Homo sapiens.* The posterior border of the mandibular ramus is more inclined away from the vertical plane. There is a similar inclination of the mandibular foramen leading to the mandibular canal through which the inferior alveolar artery and nerve pass. The mandibular coronoid process is broad, and the mandibular notch is relatively shallow (Lieberman and Crelin, 1971).

The skeletal features of the human newborn and the classic Neanderthal La Chapelle-aux-Saints fossil that make up what Le Gros Clark called "the total morphological pattern" supporting the soft tissue of the supralaryngeal airways are so similar that by following the methods of comparative anatomy, the Neanderthal fossil would most likely have had a supralaryngeal airway quite similar in form to that of a human newborn. These similarities probably led Negus and Sir Arthur Keith to conclude that the airways of the classic Neanderthal were similar to that of a newborn. They led Edmund S. Crelin to the similar reconstruction reported in Lieberman and Crelin (1971) and the similar independent reconstruction by Grosmangin (1979). A diagram of Crelin's reconstruction is presented in Figure 12-3. Note the position of the tongue with respect to the palate. The tongue, like that of a human newborn, is positioned almost entirely within the mouth. The larynx is positioned close to the base of the skull; the pharynx is positioned behind the larynx. The supralaryngeal airway differs markedly from that of a modern adult human being. It essentially is a nonhuman single-tube system.

Could A Neanderthal Skull Support a Modern Vocal Tract?

Although one can argue about using correlations between skeletal morphology and soft tissue, it is reasonably clear that the skeletal morphology of the Neanderthal skull could *not* support an adult human supralaryngeal vocal tract. The relevance of the length of the palate to the reconstruction of the supralaryngeal airway has been discussed before (Lieberman, 1975a, p. 137; Lieberman, 1979, 1982). The length of the palate in a fossil like the La Chapelle-aux-Saints Neanderthal, for example, precludes that hominid's having a modern human supralaryngeal vocal tract. It is straightforward to demonstrate, even if I were to limit this discussion to the length of the classic Neanderthal palate, that a modern human supralaryngeal vocal tract most likely could not occur with a classic Neanderthal skull. In the debate concerning the reconstruction of Lieberman and Crelin (1971) a number of authors, including LeMay (1975), Carlisle and Siegel (1974), DuBrul (1977), and Falk (1975), have claimed that classic Neanderthal hominids had normal human adult vocal tracts. I shall go through the steps of a reconstruction, keeping in mind the length of the palate, and see whether this is possible.

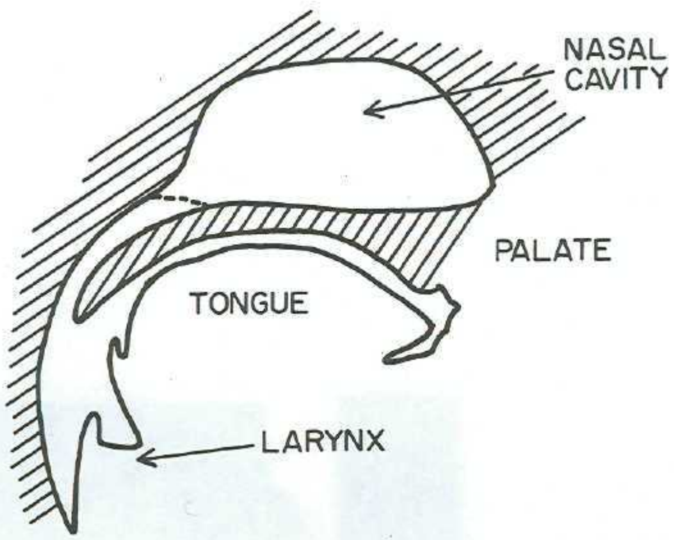


FIGURE 12-3.
Reconstruction of the supralaryngeal vocal tract of the La Chapelle-aux-Saints Neanderthal hominid. Note the high position of the larynx relative to the palate and the tongue, which is positioned almost entirely within the oral cavity. The pharynx lies behind the larynx. (After Lieberman and Crelin, 1971.)

The first step entails placing the La Chapelle skull on a "normal"

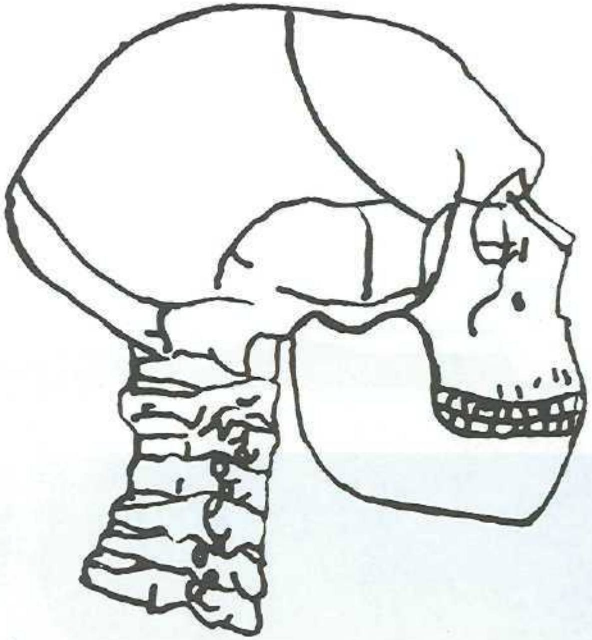


FIGURE 12-4.
Can one give a Neanderthal hominid a modern human vocal tract? Step 1. The La Chapelle-aux-Saints skull and mandible are placed on a modern vertebral column.

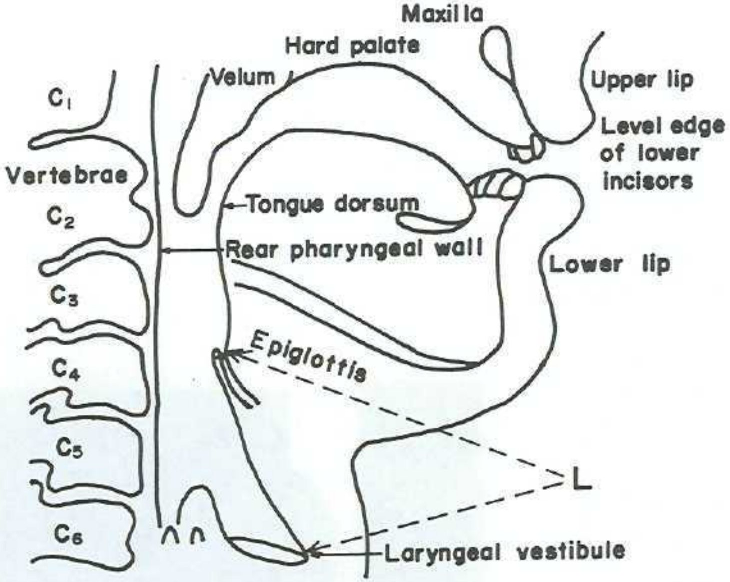


FIGURE 12-5.
Step 2. Cross-sectional view of a normal adult human male supralaryngeal vocal tract. Note that the tongue obviously fills the oral cavity. The various pellets and the coin were markers used in a cineradiographic study of speech, from which this view was taken. (After Perkell, 1969.)

vertebral column, as shown in Figure 12-4. This follows the observation of Strauss and Cave (1957) and yields normal upright posture. Strauss and Cave found that the La Chapelle-aux-Saints fossil suffered from arthritis during his life. Boule (1911–1913) did not take account of the arthritic condition of the fossil and incorrectly reconstructed the normal posture of classic Neanderthal fossils as a stoop. Though the Neanderthal vertebral column is not quite similar to that of a normal human adult, having some infantile features (Crelin, 1973), it would not have resulted in a habitual stoop. The reconstruction reported in Lieberman and Crelin (1971) also starts with a normal human vertebral column. Comments like those of Carlisle and Siegel (1974) and DuBrul (1977), which imply or claim that an "error" was thereby introduced into the reconstruction noted in Lieberman and Crelin (1971) by not taking note of the arthritic condition of the La Chapelle fossil, are thus irrelevant. Note the distance between the front of the palate and the vertebral column.

Step two involves considering the morphology of the normal human adult supralaryngeal vocal tract. Figure 12-5 shows a cross-sectional view of a normal adult male vocal tract derived from a cineradiographic study of speech production (Perkell, 1969). As I have noted before (see Figures 11-7 and 11-8), the curved tongue body forms both the floor of the oral cavity and the anterior wall of the pharynx. The posterior contour of the tongue body is almost circular (Nearey, 1978). The laryngeal opening is quite low, but it is positioned *within* the neck between the fifth and sixth cervical vertebrae. The distance between the front of the hard palate and the vertebral column in this figure has been made identical to that of Figure 12-4. The length of the vocal tract between the epiglottis and the laryngeal vestibule has been marked with the letter *L*.

The next step in this reconstruction involves considering the range of variation in the proportions of the tongue body. That there is a range of variation is evident in radiographic studies like that of King (1952). During the production of human speech the larynx, moreover, moves up and down. It is usually at its lowest level in the production of a vowel like [u]. It is high during the production of a vowel like [i] (Fant, 1960; Perkell, 1969; Ladefoged et al., 1972; Nearey, 1978). As will be seen in step four, the *lowest* position of the larynx is a crucial factor regarding the validity of a vocal tract reconstruction. Hence, granting the Neanderthal fossil the benefit of the doubt, I will give him a tongue contour that is derived from x rays of human speakers producing acute, or front, vowels like [i], [I], and [e], in which the larynx is not lowered. The tongue contours in Figure 12-6 are thus derived from the data of Ladefoged and associates (1972) for normal adult speakers producing these vowels. Note that the tongue contour is approximately circular, except that the vertical pharyngeal sections tend to be longer than the oral section. I will, however, again "tilt" the reconstruction to give the La Chapelle fossil the benefit of the doubt by using tongue contour *T*, in which the pharyngeal and oral sections have equal lengths. This tongue contour will keep the larynx positioned as high as possible, and I will give the Neanderthal skull a normal human vocal tract.

In step four the vocal tract is put together. Figure 12-7 shows the Neanderthal skull in relation to the putative vocal tract. I have placed tongue contour *T* plus laryngeal section *L* (from epiglottis to laryngeal vestibule) on the Neanderthal skull and vertebral column. Note that the larynx is positioned *below* the seventh cervical vertebra at the level of the sternum. This position is most unlikely, if not impossible, since no primate has a larynx in its chest. The difficulty stems from the long span between the front of the Neanderthal palate and the vertebral column. This span is consistent with the probable nonhuman Neanderthal supralaryngeal anatomy. If I were to insist on spanning this distance with an adult human tongue, I would end up with an anatomical monster. If I had used one of the other five tongue contours from Figure 12-6, the larynx would be even lower! It thus is most unlikely that classic Neanderthal hominids had normal human supralaryngeal vocal tracts. Similar considerations apply to the skeletal morphology and supralaryngeal vocal tracts of the australopithecine and *erectus*-grade fossils that I will discuss. The length of the palate is simply too

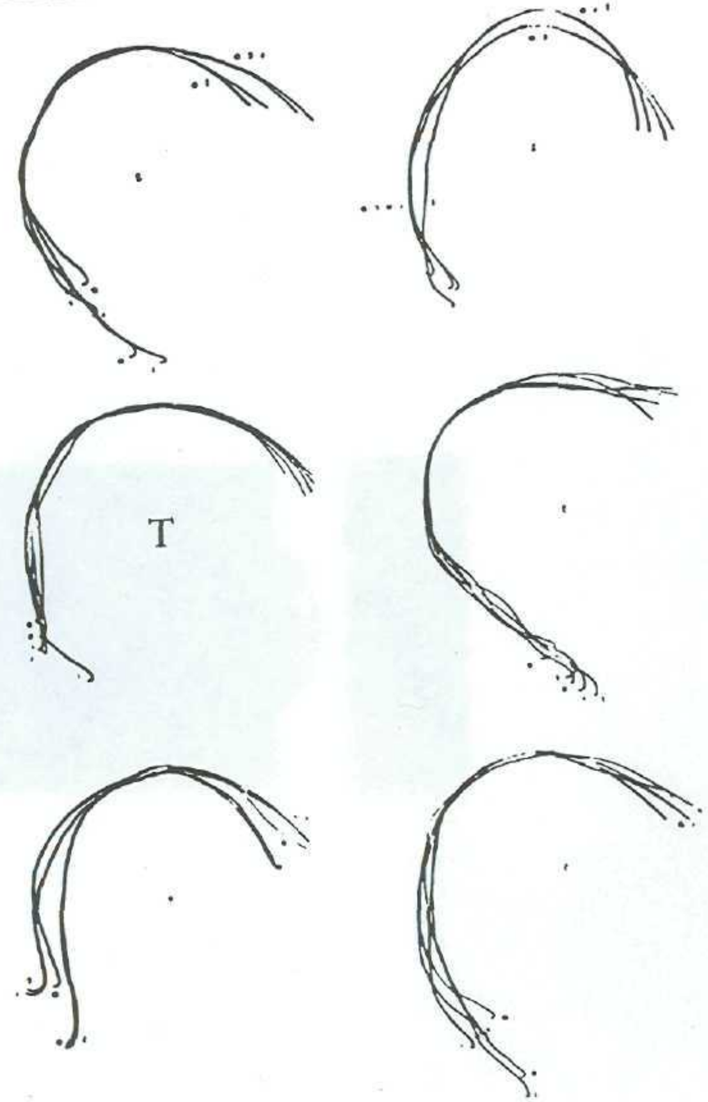


FIGURE 12-6.
Step 3. Tongue contours for normal adult human speakers. These tongue contours were derived from a cineradiographic study of vowel production (Ladefoged et al., 1972). They are shown in this figure in the scale that would be necessary for them to fit the skull in Figure 12-4. The tongue must fill the oral cavity of the Neanderthal fossil, just as it fits the modern oral cavity in Figure 12-5.

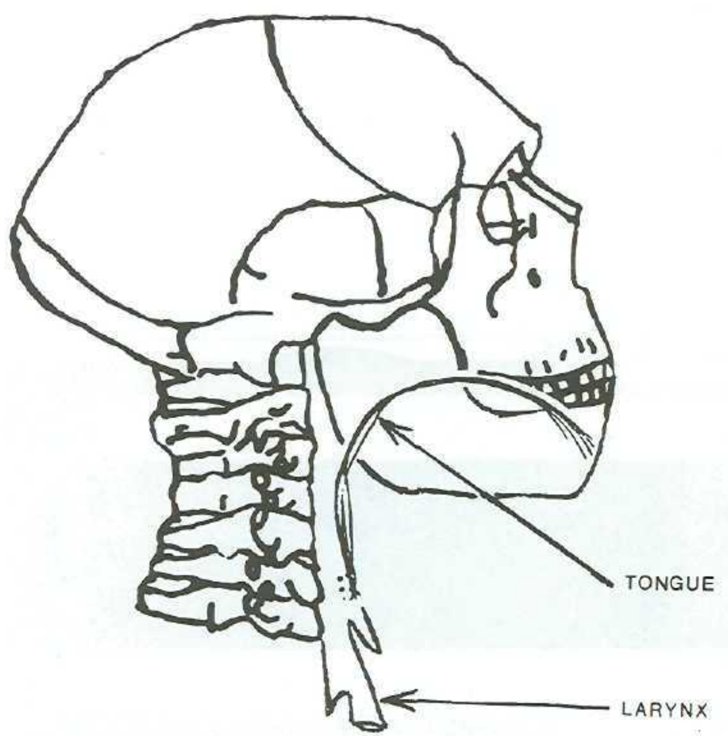


FIGURE 12-7.
Step 4. Tongue contour *T* from Figure 12-6 has been placed under the Neanderthal skull, as has the modern human laryngeal section *L* from Figure 12-5. Note that this places the larynx below the cervical vertebrae in the Neanderthal chest! It is essentially impossible to give a Neanderthal hominid a modern human vocal tract. The modern human tongue has the wrong shape.

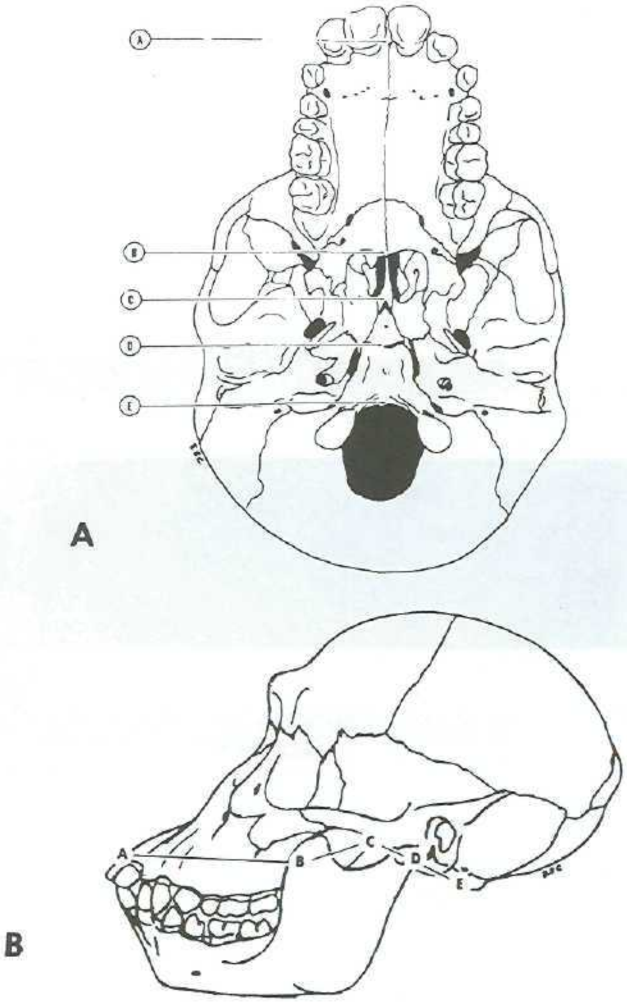
long. If one insists on giving these hominids human tongues that are thick and have equally long oral and pharyngeal sections, then their larynges must be placed in their chests! Since no primate at any phylogenetic level—lemur, monkey, ape, human being—has its larynx in its chest, this "solution" is essentially impossible. The long palates of australopithecine, *Homo erectus,* and classic Neanderthal fossils instead must support nonhuman standard-plan supralaryngeal vocal tracts in which the tongue is long and thin and is positioned almost entirely within the oral cavity.

QUANTITATIVE STATISTICAL COMPARISONS

The comparisons of skeletal morphology that I have already discussed can be applied on an individual case-by-case basis to all existing fossil hominid skulls. However, there are variations between each of these skulls, just as there are variations between the skulls of modern adult human beings. Human observers are very good in recognizing similar shapes and forms when confronted with a set of skulls, each of which varies slightly. As Le Gros Clark noted, there is a "total morphological pattern" that is the skeletal correlate of a function like upright bipedal posture that trained human observers can recognize in the pattern of individual variation. The total morphological pattern that is the skeletal correlate of the standard-plan versus the modern adult human supralaryngeal vocal tract is also evident when trained observers look at skulls that are at the end points, that is, skulls that have either standard-plan or adultlike human vocal tracts. Quantitative statistical methods that group skulls in terms of their shape, however, force us to generate explicit hypotheses concerning the specific anatomical features that we think are significant and allow us to test these hypotheses against large sample sizes. Quantitative statistical procedures, moreover, are especially well suited to analyzing the tempo of evolution—whether evolutionary changes in the bones of the skull are gradual or instead occur in spurts—and to determining whether these changes are correlated with other factors like upright posture.

Recent studies that make use of quantitative measures of the flexure of the basicranium make it possible to compare large numbers of skulls within the population that defines a species and to compare the skulls of different species. Figure 12-8 shows three views of the skull of an adult female chimpanzee with craniometric points that are appropriate for comparing the flexure and form of the basicranium. The basion, point *E* in Figure 12-8, is, as I noted earlier, the anterior margin of the foramen magnum. Point *D* is the sphenobasion—the point where the sphenoid and occipital bones meet. The occipital bone spans the distance *ED*. The hormion, point *C*, is the posterior margin of the vomer bone. Point *B*, the staphylion, is the posterior limit of the bony palate. The distance *AB* thus is an accurate measure of the length of the palate.

Figure 12-9 shows these points for a newborn and an adult human skull. The study of Laitman, Heimbuch, and Crelin (1978) derived these measures from a sample of 228 primate skulls. Table 12-1 shows the number of skulls used for each species and the age of each individual at time of death as defined by the dental stage. Stage 1 included skulls of individuals who died prior to the eruption of



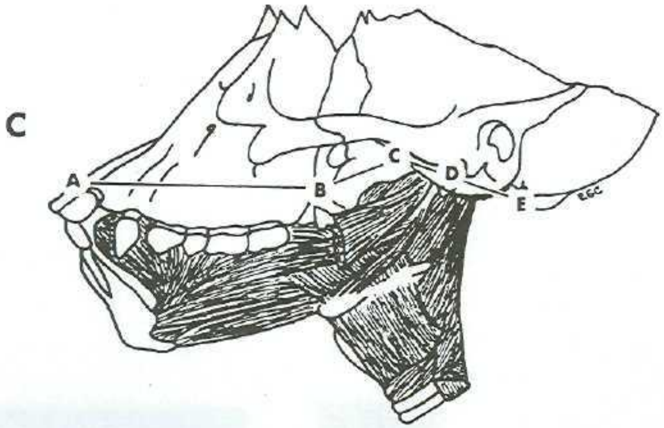


FIGURE 12-8.
A: Craniometric points on the midline of the basicranium of an adult female chimpanzee (*pan troglodytes*)—*A*, prosthion; *B*, staphylion; *C*, hormion; *D*, sphenobasion; *E*, endobasion. Note the exposed sphenoid bone between points *C* and *D*. *B:* Topographic projection of the basicranial line on the skull of an adult female chimpanzee. *C:* Topographic projection of the basicranial line on the skull of an adult chimpanzee, lateral view, with the left half of the mandible removed to show the muscles of the tongue, the pharyngeal constrictors, and some of the extrinsic muscles of the larynx. (After Laitman, Heimbuch, and Crelin, 1978.)

deciduous dentition. Stage 2 included skulls of individuals between the eruption of the first central incisor to the completion of deciduous dentition; stage 3, the eruption of the first permanent molar; stage 4, the eruption of the second permanent molar; and stage 5, the eruption of the third permanent molar. Previous studies (Bergland, 1963) demonstrated that the angular relationships and distances in the region of the skull defined by points *B–E* in Figure 12-9 were quite stable in a sample of 223 Norwegian and Lapp skulls. Bergland also demonstrated that these craniometric measures differed from ones derived from nonhuman primates. As Bergland points out, the difference between humans and other primates with regard to the flexure of the basicranium in the nasopharynx, the region defined by points *B–E*, has been noted since the end of the nineteenth century.

The statistical procedures used by Laitman, Heimbuch, and Crelin (1978) replicate these earlier studies as well as the qualitative

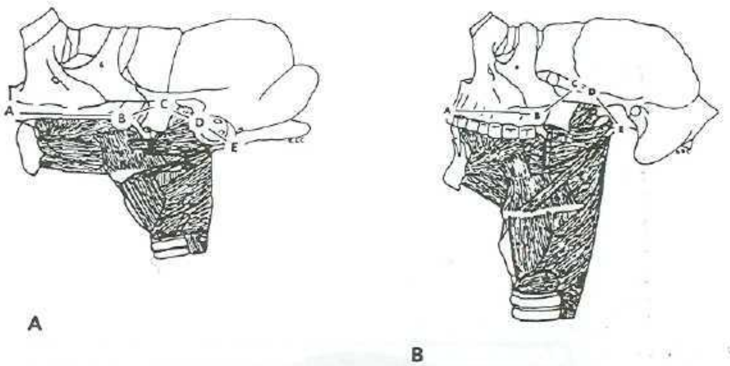


FIGURE 12-9.
Topographic projections of the basicranial line on the skulls of newborn (*A*) and adult (*B*) human skulls, lateral views with the left half of the mandible removed to show muscles of pharynx, tongue, and some extrinsic laryngeal muscles. Note the relative orientation of line *DE* in the newborn and adult. The superior pharyngeal constrictor muscle runs forward and down almost perpendicular to line *DE*, which defines the plane of the basioccipital. (Adapted from Laitman, Heimbuch, and Crelin, 1978.)

observations of recent comparative studies (Negus, 1949; Lieberman, 1968, 1975a, 1979; Lieberman and Crelin, 1971, 1972; Laitman and Crelin, 1976). Nonhuman primates and stage-1 human beings have a basicranium that is essentially nonflexed from the posterior border of the palate to the basion. Gibbons (Hylobates) and macaque monkeys (Macaca) show little change as they develop. The basicranium becomes flatter as these nonhuman primates develop. In contrast, human beings show a unique developmental pattern. They start with the same basicranium as other primates. The statistical metrics that involve multivariate analysis of variance and discriminant analysis consistently placed stage-1 humans and other primates in the same class. They then flex. After stage 2, modern human specimens were misidentified only with other human specimens; stage-5 individuals were sometimes misassigned to stage 4. The pattern of change in basicranial flexure can be seen in Figure 12-10, in which the basicranial lines derived from gorilla, chimpanzee, and human skulls by Laitman, Heimbuch, and Crelin (1978) are shown. The diagrams show the basicranial lines drawn to the same scale since the statistical metrics operate in terms of shape, ignoring absolute size. Note that the human newborn basicranial line is similar to that of the chimpanzee (*Pa*) and stage-1 gorilla (*Go*). The chimpanzee basicranial line becomes somewhat flatter while the gorilla's becomes very flat, as Gould (1977) correctly notes. However, the human basicranium also changes, becoming *more* flexed, with the greatest change occurring between stages 1 and 2. The difference in the orientation of the basioccipital reflects the direction and size of the pharyngeal constrictor muscles in the standard-plan versus the adultlike human supralaryngeal airway. The descent of the tongue and larynx in human beings, which yields the human pharynx, results in a change in the direction in which the pharyngeal constrictors run (see Figures 12-5 and 12-9). The angulation of the adultlike human basioccipital segment *ED* in these figures corresponds to the uniquely human pharyngeal musculature.

TABLE 12-1. Number of Primate Skulls Studied for 7 Species

Dental stage	1	2	3	4	5	Total
Macaca arctoides	0	3	1	4	6	14
Hylobates species	1	5	5	5	11	26
Symphalangus syndactylus	0	1	2	5	10	18
Pongo pygmaeus	2	4	7	7	9	29
Pan troglodytes	0	5	7	6	11	29
Gorilla gorilla	1	5	3	6	9	24
Homo sapiens	24	12	11	13	28	88
Total	28	35	35	46	84	228

SOURCE: Laitman, Heimbuch, and Crelin, p. 969.

The independent craniometric data of George (1978) and Grosmangin (1979) are consistent with these results. The major restructuring of the human basicranium takes place quite early in life. George (1976, 1978) derived her data from x rays of a sample of sixteen boys and sixteen girls. The x rays form part of a cephalometric series and were taken at ages 1 month, 3 months, 9 months, and thereafter once a year until 5 years 9 months. George's data complement the measurements derived from skulls by Laitman and Crelin (1978). George measured the cranial base deflection by five sets of angles. Statistical analysis shows a major decrease in the angle size by 9 months, with significant changes between 1 and 3 months for some individuals. The mean cranial base angle changed from 137 degrees at 1 month to 125 degrees at 9 months. This angle is 134 degrees in the La Chapelle-aux-Saints Neanderthal fossil (Howell, 1951). A cranial base angle of 125 degrees is within the human adult range. George (1978) concludes that the change of the human cranial angle is almost complete by age 1

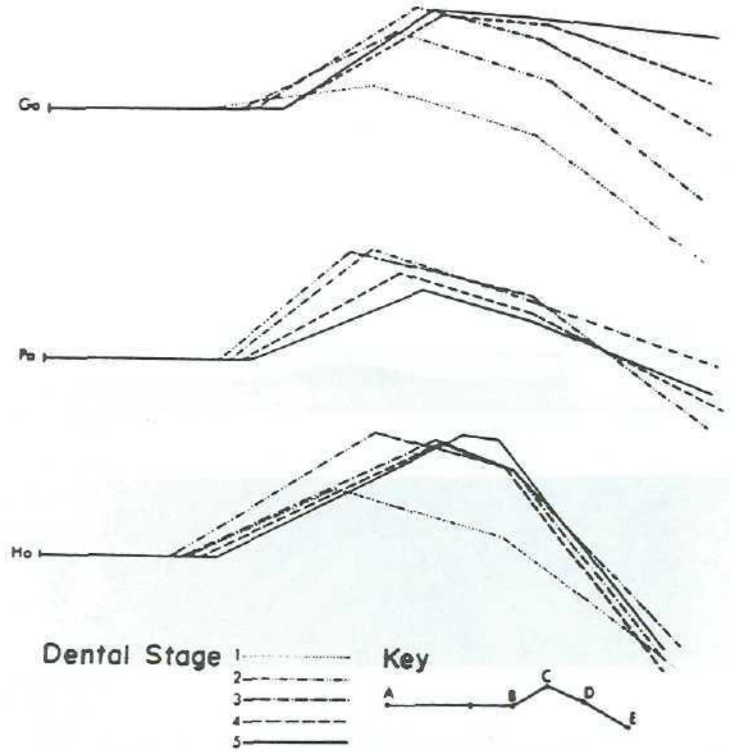


FIGURE 12-10.
Ontogenetic development of the basicranial line in modern human beings; *Ho*; chimpanzees, *Pa*; and gorillas, *Go*. The measurements were derived from the sample noted in Table 12-1. (Adapted from Laitman, Heimbuch, and Crelin, 1978.)

year 9 months. George's study is significant since its data are derived from x rays of living subjects and replicate observations derived from either cadavers or dried skulls.

The independent study of Grosmangin (1979) is based on a detailed series of craniometric measures of the basicranium that includes, among other points, the series measured by Laitman, Heimbuch, and Crelin (1978, 1979). Grosmangin's sample includes a series of twenty-five infants and children from newborns to 19-year-olds, thirty European adults, a series of six non-European adults selected to establish the limits of variability, a series of nonhuman primate skulls including adults and juveniles, and five fossil hominid skulls. The fossil skulls include the classic La Chapelle-aux-Saints Neanderthal, La Ferrassie I, Pech de l'Aze, and La Quina skulls, plus the archaic but anatomically modern Cro-Magnon skull (Oakley, Campbell, and Molleson, 1971). Grosmangin documents her measurements and analysis in detail. Her conclusions (pp. 134–154) regarding the development of the basicranium in human beings compared with nonhuman primates is consistent with those of Laitman and Crelin (1976). She, however, concludes that the classic Neanderthal skulls are closer to those of juvenile chimpanzees (that is, they are less flexed) than to those of human newborns[1] (Grosmangin, 1979, pp. 186–191).

The analyses of Laitman, Heimbuch, and Crelin (1979), Laitman (1983), and Laitman and Heimbuch (1982) involve consideration of the flexure of the basicranium in the skulls of a large population of modern human beings and living primates. These studies and the independent studies of Bergland (1963), George (1978), and Grosmangin (1979) show that a flexed basicranium supports a humanlike supralaryngeal airway. Laitman, Heimbuch, and Crelin apply these metrics to fourteen fossil hominid skulls. Their analysis shows that there "appear to be at least two pathways taken in the evolution of man's upper respiratory system after a common pongid-like stage exhibited by the australopithecines. One line appears to have terminated with the Classic Neanderthals. The other line, encompassing those hominids with basicrania and upper respiratory structures of more modern appearance, may have given rise to modern man" (1979, p. 15). These conclusions, which are based on the statistical analysis of the flexure of the basicranium, are similar to the hypothetical scheme for the late stages of hominid evolution noted in Chapter 11 (Lieberman, 1968a, 1973, 1975a). The discussion that follows refers to the supralaryngeal airways of human beings as the "vocal tract." The claim implicit in this terminology is that the supralaryngeal airways of humans have a distinct function in the production of speech and that they evolved, in part, to serve this function. In other words, at functional branch-point IV (see Figure 11-2), the course of human evolution diverged from that of other hominids to select for variations that enhanced our phonetic ability.

Figure 12-11 shows a number of cranial base lines that are derived from Laitman, Heimbuch, and Crelin (1978, 1979) and Grosmangin (1979). I have restored the sections of the hard palate that were removed in the illustrations of Laitman and his co-workers.

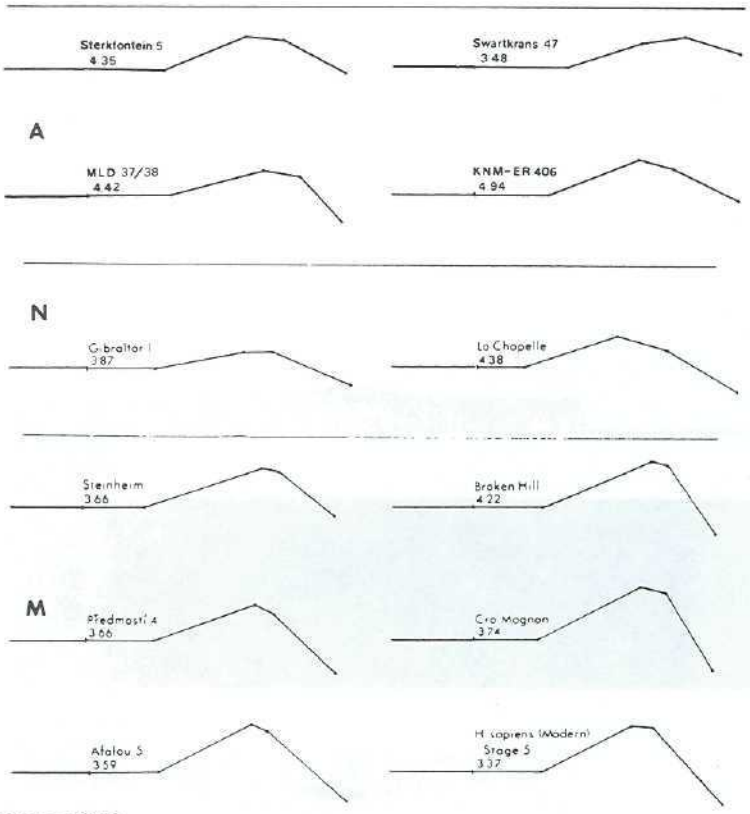


FIGURE 12-11.

A: Basicranial lines showing entire length of palate for the gracile australopithecine Sterkfontein-5 and MLD-37/38 fossils and the robust australopithecine Swartkrans-47 and KNM-ER-406 fossils. *N:* Basicranial lines for the Neanderthal Gibraltar-1 and La Chapelle-aux-Saints fossils. *M:* Basicranial lines for the Steinheim and Broken Hill fossils, fossil skulls that are archaic but have anatomically modern basicranial lines, and modern adult *Homo sapiens.*

Palatal length, however, was preserved in their statistical analyses. The length of the palate is an important element in determining the functional aspects of the supralaryngeal vocal tract if one is concerned with the properties of *human* speech. If you recall the discussion of the quantal properties of human speech production in Chapter 8, the special acoustic properties of the vowel [i] follow from the fact that abrupt changes in the cross section of the vocal tract occur at its approximate midpoint. We thus have to keep track of two factors in the evolution of the human supralaryngeal vocal tract. The formation of a pharynx that is at a right angle to the oral cavity is one factor. The osteological features that are relevant in this regard are the flexure of the basioccipital bone and the shape and length of the basicranium between the basion and posterior border of the palate. These features are analyzed in detail by Laitman, Heimbuch, and Crelin (1978, 1979). The proportion of the pharynx relative to the oral cavity is the second factor. As noted earlier, the length of the palate in relation to the length of the neck is the osteological feature that is relevant to this factor.

A MODEL FOR THE EVOLUTION OF SPEECH AND LANGUAGE

The diagram presented in Figure 12-12 is an attempt to pattern one important aspect of the "recent" stages of hominid evolution — the evolution of human speech and language. The claim implicit in this model is that the recent stages of hominid evolution involved anatomical adaptations that yielded the special characteristics of human speech at the expense of vegetative functions like chewing, swallowing, and breathing in the archaic hominids who are among our more direct ancestors. The model further proposes that these anatomical adaptations have been matched by corresponding neural changes that in their totality yield encoded, high-speed human speech. The characteristic high rate of human speech, again coupled with the general cognitive power of the large hominid brain, yields human language — both our "thinking" language and our special "communicating" language. The biological cost of these changes is the relatively inefficient, distinctively human pattern of swallowing, breathing, jaw opening, and chewing as well as the crowding of the mandible with an excessively large complement of teeth.

The starting point in Figure 12-12 is the column at the top of the chart that includes the various gracile and robust australopithecine fossils. This column will be used to designate fossils that fall into the categories *Australopithecus africanus, Australopithecus robustus,* and *Australopithecus bosei* (Pilbeam, 1972). Although the fossils that have been so classified can be grouped in other ways, the data that I will review are consistent with this general classificatory scheme. The line to the left of the australopithecine column notes the *afarensis* fossils that have been described by Johanson and White (1981). These fossil hominids may be ancestral to the australopithecines grouped in the main column. The line to the right of the australopithecine column designates

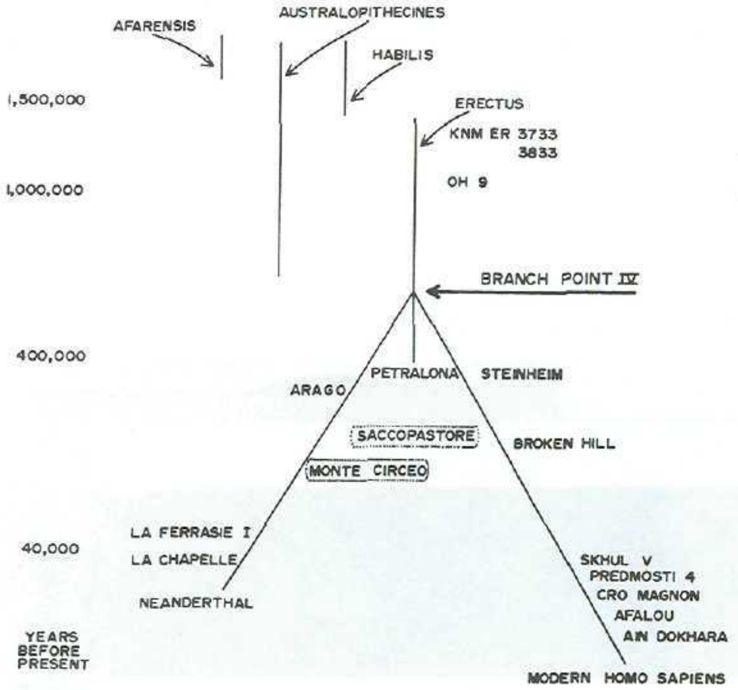


FIGURE 12-12.
The evolution of the modern human supralaryngeal vocal tract: branch-point IV.

the *Homo habilis* fossils described by Leakey (1973), which may be intermediate between the fossils to the left and *Homo erectus*–grade fossils; further data will, it is hoped, resolve this issue.

A number of fossils that lived during this period have been studied with respect to their probable supralaryngeal vocal tracts. Studies of the STS-5 gracile australopithecine female from the Sterkfontein caves of South Africa are reported in Lieberman (1973, 1975a), Laitman, Heimbuch, and Crelin (1979), Laitman (1983), and Laitman and Heimbuch (1982). The basicranium of this fossil shows that it supported a nonhuman standard-plan upper airway in which the larynx locked into the nasopharynx during respiration. The palatal length and the angulation of the basicranium are both consistent with this interpretation (see Figure 12-11). Analyses of other gracile and robust australopithecine material from South and East Africa show similar characteristics (Laitman and Heimbuch, 1982; Laitman, in press). These include the STS-19, Sterkfontein, and MLD-37/38 Makapansgat Lime Deposit craniums. All three of these fossils have been grouped in the taxon *Australopitheus africanus*, the "gracile" australopithecines (Howell, 1978). The "robust" australopithecine fossils KNM-ER 406 and 407 from East Africa and SK 47 from South Africa show differences compared with the gracile forms (Laitman, in press). However, these differences are similar to those that occur in the living species of apes—variations in the degree to which the basicranium is not flexed.

Laitman and Heimbuch (1982) apply these statistical procedures to a range of Plio-Pleistocene fossil hominids that lived prior to one million years before the present. With the exception of the OH-24 fossil, these hominids (STS 5, KNM-ER 406, MLD 37/38, Olduvai 5, Taung, Swartkrans 47, 48, and 83)

> all exhibit traits characteristic of the Pongidae and markedly differ from those of adult or subadult *Homo*. Overall these fossil hominids show relatively little exocranial flexion between the posterior border of the hard palate . . . and the most anterior point of the foramen magnum . . . The distance between the base of the vomer . . . and the spheno-occipital synchondrosis . . . is relatively large, as is characteristic of nonhuman primates and Stage 1 (infant) *Homo*.
>
> (Laitman and Heimbuch, 1982, p. 333)

The OH-24 fossil is the only specimen in the Laitman and Heimbuch (1982) study that has been classified as an example of the genus *Homo* (Howell, 1978). Its cranial capacity is in the order of 600 cc, about 50 percent greater than that of the other australopithecine-grade fossils studied. The reconstruction of the OH-24 *Homo habilis* basicranium appears to be distorted; the statistical analysis of the measurements derived from the present reconstruction also differs from that of the other australopithecine specimens studied by Laitman and Heimbuch (1982). Given the possible significance of this fossil, additional examination of the entire cranium with the view of refining the reconstruction of the basicranium is warranted. Thus, with the possible exception of specimens of *Homo habilis* up to one million years before the present, these hominids retained the standard-plan mammalian supralaryngeal airway. The configuration of the airway during breathing, swallowing, and vocalization is shown in the reconstructions of

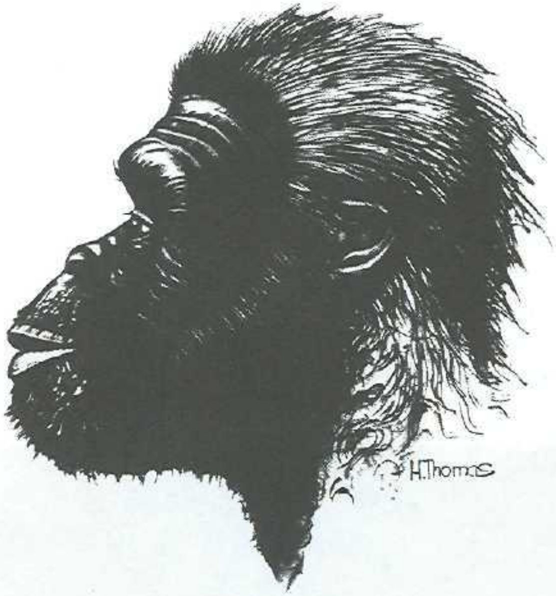


FIGURE 12-13a.
Reconstruction of the head and neck of a Plio-Pleistocene hominid during normal respiration. The reconstruction was based partly on the cranium of the australopithecine Sterkfontein-5 cranium, whose basicranial line is plotted in Figure 12-11. The mouth is closed since the individual probably was an obligate nose breather.

Laitman and Heimbuch based on the STS-5 gracile australopithecine shown in Figure 12-13.

The changes in the upper airway that occurred during the stage of human evolution generally identified with the taxon *Homo erectus* may have yielded the adaptive basis for functional branch-point IV. The designation *Homo erectus* incorporates a variety of fossil hominid specimens that generally are dated between 1 million and 500,000 years before the present, although some specimens dated at 1.5 million years before the present have been found in East Africa (Howells, 1980). Cranial capacity ranges up to 1000 cc. The internal volume of the skulls of *Homo sapiens*–grade fossils, in contrast, is at least 1300 cc. Unfortunately the features of the basicranium of *Homo erectus* skulls have not been studied in great detail owing to the absence of this region in most specimens and to a general lack of interest regarding the basicranium by most physical anthropologists. Howells (1980), for example, in his survey article "The state of information on *Homo erectus*," scarcely refers to any of the skeletal features of the basicranium. Laitman (1983), however, has derived some preliminary observations from recent finds in East Africa and the recently cleaned skull from Petralona in Greece (Stringer, Howell, and Melentis, 1979). The Petralona skull is probably at least 400,000 years old and is generally considered to be an "advanced" *Homo erectus* (Howells, 1980). The African material consists of two craniums from East Turkana, KNM-ER 3733 and KNM-ER 3883 (Leakey et al., in prep.) and

FIGURE 12-13b.
Reconstruction of the upper respiratory system during normal respiration. Note the high position of the larynx and the concomitant positioning of the tongue within the oral cavity. The epiglottis is in contact with the soft palate, providing a direct, sealed airway from the nose to the lungs.

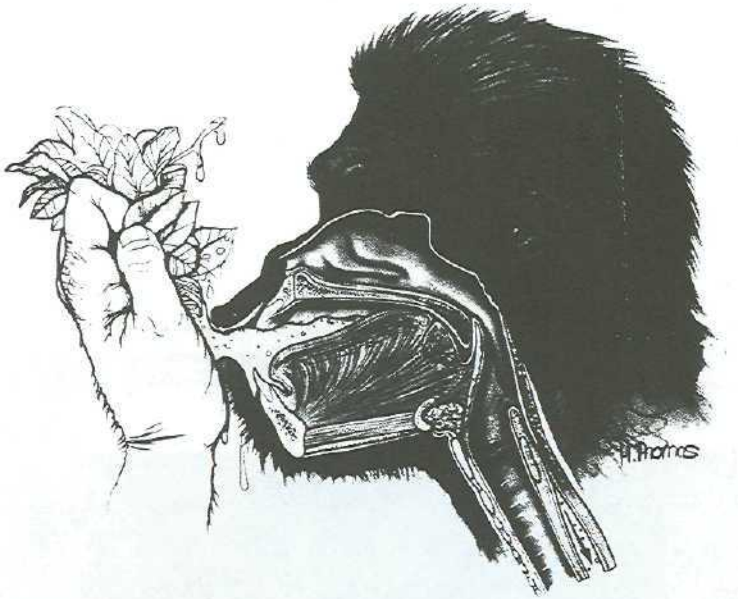


FIGURE 12-13c.

Reconstruction of the upper airways during the ingestion of liquid material. The larynx is elevated maximally. The airway from the nose to the lungs will remain sealed as liquid moves from the oral cavity, around both sides of the larynx via the piriform sinuses, and on to the esophagus (arrow). The hominidlike modern nonhuman mammals can simultaneously ingest liquids and breathe.

the Olduvai Gorge fossil OH 9 (Rightmire, 1979). The KNM-ER-3733 fossil is conservatively dated at 1.5 million years before the present and thus is contemporaneous in East Africa with the robust australopithecines as well as with the *Homo habilis* remains that also occur in this region. The ER-3733 fossil's cranial capacity is about 830 cc. The OH-9 fossil is dated at about 1.2 million years before the present and has a cranial capacity of about 1070 cc. The ER-3733 and OH-9 fossils are similar in many features (Rightmire, 1979) and suggest the persistence, with little change, of an *erectus*-grade hominid population from about 1.5 million years to 400,000 years ago (Howells, 1980).

The basicranium in these specimens of *Homo erectus*, though it does not show the flexion of anatomically modern *Homo sapiens*, is different from that of the australopithecines. Preliminary study of the

FIGURE 12-13d.

Reconstruction of the upper respiratory system during vocalization. The larynx is slightly depressed, and the epiglottis and soft palate are not in contact. Note that the nasal cavity is open, which yields a nasalized acoustic signal. The tongue is positioned entirely within the oral cavity, yielding a one-tube vocal tract that inherently cannot produce formant frequency patterns of sounds like the vowel [u] or [i]. (Figures 13a–d are after Laitman and Heimbuch, 1982.)

casts of the OH-9 and Petralona fossils shows that the distance between the vomer bone and the spheno-occipital synchondrosis, which is a prime indicator of the degree of basicranial flexion, is much smaller than is the case in living apes or in australopithecine-grade hominids (Laitman, 1983).

This change may have been retained for its role in facilitating mouth breathing. As Laitman notes,

> The gradual attainment of flexion may well have corresponded to the partial descent of the posterior third of the tongue, hyoid musculature and larynx. Laryngeal descent, while probably not

> comparable to the extreme descent found in modern *sapiens,* would surely have caused a separation between the epiglottis and soft palate to occur. As a result the larynx could no longer lock into the nasopharynx, providing a direct airway from the nasal cavity to the lungs. This change in respiratory structure would have altered the breathing and swallowing abilities of these hominids from the basic mammalian pattern . . . the tendency for oral tidal respiration would have been greatly increased. Due to the permanent separation of the larynx and nasopharynx, a patent airway during the ingestion of liquids could no longer have been possible. The mammalian ability to breathe and swallow liquids simultaneously could no longer exist.
>
> (1983, p. 6)

As I noted earlier, the neural control of respiration in human infants is coordinated with the restructuring of their supralaryngeal airways. Human newborns are obligate nose breathers; their neural mechanisms that control respiration are matched to their standard-plan airways to minimize the possibility of choking. Although newborn infants could breathe through their mouths, they do not do so because they would have to lower the larynx and food could fall into it. It is safe to breathe through the nose, given the standard-plan mammalian airway in which the larynx is locked into the nasopharynx. At about age 3 months, when the larynx has begun its descent (George, 1976, 1978), the neural mechanisms that regulate breathing in human infants change, and voluntary mouth breathing usually can occur (Laitman, Crelin, and Conlogue, 1977). Since the larynx no longer locks into the nasopharynx, there is no selective advantage to obligate nose breathing—liquids can fall into the lowered larynx whether the air comes from the nose or from the mouth. There is instead a selective advantage for voluntary mouth breathing since respiration can continue even when the nose is blocked. The neural mechanisms that control respiration thus restructure in synchrony with the changes in the supralaryngeal airway, from obligate nose breathing to voluntary mouth breathing.

A similar synchrony involving the neural mechanisms that regulate respiration and the supralaryngeal airway probably occurred somewhere in the evolution of *Homo erectus.* The process may have started in the earlier *Homo habilis* lineage that perhaps is ancestral to *erectus*-grade *Homo.* Whenever the process started, however, voluntary mouth breathing would have had a selective value insofar as it would permit respiration when the nose was blocked. It would also have had the more important function of decreasing the resistance of the primate airway to the flow of air, particularly at high flow rates when turbulence is generated at the "bends" in the nasal pathway (Negus, 1949).

Mouth breathing thus would have had a selective value during strenuous physical activities. The heavily constructed *Homo erectus* skull was heavily muscled compared with that of the modern human being (Howells, 1980); life in the primitive conditions that occurred one million years ago undoubtedly depended more on the expenditure of muscular power. Hence there would have been a strong selective value for mouth breathing and for the anatomical and neural adaptations that make mouth breathing possible. Other factors, as Laitman (1983) notes, may have been involved in the restructuring of the *erectus* supralaryngeal airway, such as the effects of cerebral enlargement and the anterior movement of the foramen magnum to improve head balance. Probably no single factor was involved. Whatever the causes, once the respiratory system was restructured, the possibility would be present for further changes directed at increasing phonetic ability through the further descent of the tongue and larynx. The *erectus*-grade of hominid evolution thus yields a functional branch-point. Two main pathways can follow from the *erectus* solution to coping with the problems of life. One pathway is the one that our ancestors followed—toward increased communication and linguistic-cognitive ability. The other pathway, while it undoubtedly involved the enhancement of cognitive ability, relied to a greater extent on retaining and enhancing muscular ability.

MOSAIC EVOLUTION AND THE HUMAN VOCAL TRACT'S EVOLUTION

The divergence that follows functional branch-point IV, which is implicit in the *erectus*-grade airway, cannot really be viewed as a simple, binary bifurcation. A number of anatomical components are involved in the restructuring of the human supralaryngeal airway from the probable *erectus* configuration. These anatomical features are under separate genetic regulation in the present human population. Orthodontists thus are constantly correcting undershot and overshot bite patterns since an individual's mandible does not always match his or her maxilla. More extreme mismatches also occur which demonstrate that we are put together in bits and pieces that are under separate genetic regulation. The skeletal features that are related to the restructuring of the supralaryngeal vocal tract from the standard-plan mammalian to the modern human configuration involve the reduction of the distance between the front of the palate and the vertebral column and the flexure of the basicranial line, particularly in the basioccipital region (region *DE* in Figure 12-8). Variations, or "experiments of nature," involving the way in which these components go together can be seen in the present human population; extreme variations are considered to be "craniofacial anomalies" (Pruzansky, 1973) and can result in speech deficiencies (Landahl, Peterson-Falzone, and Lieberman, 1978). The fossil record also shows the presence of many experiments involving the way in which these features go together. The successful experiment — the anatomically modern human vocal tract and its supporting skeletal structure — appears to be the result of evolutionary experiments that go back at least to the *erectus*-grade hominid.

The line radiating to the right of the vertical *erectus* plot in Figure 12-12 indicates a hypothetical line of development toward the basicranium and supralaryngeal vocal tract of anatomically modern *Homo sapiens.* Some of the fossil hominids whose skeletal features conform to relevant skeletal features of the human basicranium are entered on this line with their approximate dating, which is derived from the recent survey paper of Howells (1980). The skeletal features of the Skhul-V hominid are within the range of modern human variation, as are those of the fossil hominids that follow. Fossils like Cro-Magnon from France, which is probably about 33,000 years old, have traditionally been considered archaic forms of anatomically modern *Homo sapiens* on the basis of both nonmetrical (Boule and Vallois, 1957) and metrical analyses (Howells, 1974, 1976) of skeletal features other than the basicranium. They also fall into the modern human range with respect to the morphology of their basicraniums. Both the length of the palate (line *AB* in Figure 12-8) and the flexure of the basicranial line (between points *B* and *E* in Figure 12-8) are human. Their vocal tracts would have had a human form. There simply is not sufficient room between the anterior margin of the palate and the basion for a larynx positioned high, close to the base of the skull, with the pharynx positioned behind it. The length of the palate and the mandible have been reduced, crowding the teeth together.

The Steinheim fossil, which is 200,000 to 400,000 years old (Butzer and Isaac, 1975), represents an experiment in which the length of the palate is clearly within the human range, though the basicranial line is somewhat less flexed than in modern human beings. The Steinheim skull, nevertheless, is closer to modern *Homo sapiens* with regard to its supralaryngeal vocal tract than it is to classic Neanderthal fossils like La Chapelle. Statistical multivariate analysis of its basicranium places it closer to modern *Homo sapiens* than to classic Neanderthal hominids (Laitman, Heimbuch, and Crelin, 1979). In contrast, multivariate analysis of the more plastic bones of the skull place it close to classic Neanderthal forms (Trinkaus and Howells, 1979). The difference in classification follows from the skeletal features that one chooses to take into account. Trinkaus and Howells's comparison proceeds in terms of various facial features that, for the most part, have no known functional value. The basicranium, besides being a more conservative feature (Laitman, 1983), is related to the functional aspects of the supralaryngeal airways.

The Broken Hill fossil is more recent than the Steinheim fossil, probably somewhat older than 100,000 years B.P. (Klein, 1973). It represents an evolutionary experiment in which the basicranial flexure is great and falls into the human range (Laitman, Heimbuch, and Crelin, 1979). However, the palate is quite long by human standards. The Skhul-V fossil probably is not older than 40,000 years (Trinkaus and Howells, 1979). Its basicranium is completely human (Lieberman, 1973, 1975a), as are the more recent Predmosti-4 fossil from Czechoslovakia and the Afalou, Taforlat-12, and Ain Dokhara fossils from North Africa.

The course of evolution along the line leading to modern *Homo sapiens* thus is not even, as would be the case if simply a regulatory gene changed the rate of development of the basicranium. There seem to have been various experiments that involved either selection of alletic variations in the existing hominid population or mutations that resulted in changes in the basicranial line's flexure and/or the length of the palate. Two of these experiments are entered in Figure 12-12 in the dotted boxes to the left of the human vocal tract line.

These experiments represent fossils that are usually identified as Neanderthal hominids. The Saccopastore fossil, which was found in Italy, lived in the last interglacial age, 130,000 years ago and has been identified as a precursor of classic Neanderthal man (Trinkaus and Howells, 1979). Its basicranial line is more flexed than the classic Neanderthal forms that I will discuss, but it has an extremely long palate and could not have had a modern human supralaryngeal airway in which the pharynx and oral cavities had the same approximate length. However, it represents a variation in the direction of modern *Homo sapiens* compared with later classic Neanderthal hominids. The Monte Circeo – 1 fossil, which was found in Italy, is undated. Its palate is shorter than that of Saccopastore 2, but it falls outside the human range with respect to the flexure of the basicranial line (Laitman, Heimbuch, and Crelin, 1979). However, it is more flexed than those of the other Neanderthal fossils. It is possible that the restructuring of the hominid basicranium occurred not only at the time of the hypothetical "initial" Neanderthal (branch-point IV) sketched in Figure 12-12 but also independently from early Neanderthal hominids. The fossil record, in short, is not consistent with the hypothesis of the sudden, coordinated restructuring of the basicranium and mandible. The various experiments of nature, such as long palates with flexed skull bases or short palates with unflexed skull bases, are instead consistent with the hypothesis of gradual mosaic evolution over the course of the past 250,000 years. Almost nothing appears to have happened with regard to the restructuring of the basicranium and mandible during the millions of years that intervened between the divergence of hominids from other primates until this recent period. However, we do not have to invoke any special mechanism of punctuated equilibria to explain this initial period of stasis. The standard-plan mammalian supralaryngeal vocal tract is well adapted for most of the vegetative aspects of life. The selective advantages of the standard-plan mammalian supralaryngeal airway for chewing, swallowing, and breathing have resulted in its retention in all other living animals.

NEANDERTHAL HOMINIDS

The line radiating to the left of the vertical *erectus* plot in Figure 12-12 represents the pattern of evolution that culminated in classic Neanderthal man. The name derives from the Neander valley in Germany, where fossil bones were discovered in 1856. Since that time Neanderthal remains have been found throughout Europe and Asia, from Portugal to Uzbekistan in Soviet Central Asia. They developed over a long period and diverged from the *erectus* base line and fossils like Petralona at least 400,000 years ago, through intermediate forms like the Arago fossils that were found in France, to the classic Neanderthal fossils like La Chapelle-aux-Saints and La Ferrassie, who lived about forty thousand to thirty-five thousand years ago (Trinkaus and Howells, 1979). Though the cranial capacity of classic Neanderthal skulls falls within the modern human range, these skulls are quite different from those of modern human beings or archaic forms of *Homo sapiens* like Skhul V and Predmosti, which were noted in the right branching line in Figure 12-12.

The data of detailed craniometric studies using recent populations from all major regions of the world show that classic Neanderthal skulls fall outside the pattern of variation that typifies either modern or archaic populations of *Homo sapiens* (Howell, 1951; Howells, 1970, 1974, 1976; Bergland, 1963; Laitman, Heimbuch, and Crelin, 1979; Trinkaus and Howells, 1979). The Neanderthal skull is massive and supports an array of teeth that are "positioned so far forward with respect to the face that in a profile view there is a gap between the last molar (the wisdom tooth) and the edge of the ascending mandible" (Trinkaus and Howells, 1979). The muscle that moves the mandible upward, the masseter, is massive and would generate a powerful bite. The swept tooth area involved in chewing would have yielded more efficient chewing. Neanderthal hominids would not have suffered from impacted wisdom teeth, which are our legacy as the human mandible has decreased in length, squeezing in the same number of teeth, albeit reduced in size. The Neanderthal ankle bones, finger bones, arches of the feet, shoulder blade, and so on likewise supported massive muscles that would have yielded superhuman strength, coupled with the full range of human dexterity. The full classic Neanderthal physique lasted for a period of about sixty thousand years down to the recent present, about forty thousand to thirty-five thousand years ago. The retention over this long period of the standard-plan mammalian supralaryngeal vocal tract in hominids who were completely bipedal (Straus and Cave, 1957) also argues against correlating the development of the human supralaryngeal vocal tract with upright posture.[2] Indeed the australopithecine and *erectus*-grade hominids also had bipedal upright locomotion (Campbell, 1966), though they had standard-plan nonhuman vocal tracts.

The data discussed so far, relating the basicranium to the supralaryngeal vocal tract, indicate that classic Neanderthal hominids like the La Chapelle fossil had vocal tracts that were close to the nonhuman, standard-plan system. As I noted earlier in connection with Figure 12-3, the reconstructed airway of the La Chapelle-aux-Saints fossil is functionally similar to that of a newborn human infant (Lieberman and Crelin, 1971). The tongue is positioned entirely within the oral cavity; the pharynx is positioned behind the larynx; and the larynx is positioned close to the base of the skull. The range of formant frequency patterns, which define the phonetic inventory of the Neanderthal vocal tract, does not include vowels like [i], the optimal vocal tract "calibrating" signal.

The basis for this assertion, that the Neanderthal vocal tract cannot produce vowels like [i], rests in computer-implemented modeling studies which have determined the range of formant frequency patterns that the reconstructed Neanderthal vocal tract can produce (Lieberman and Crelin, 1971; Lieberman et al., 1972). As I noted in Chapters 6 through 8, formant frequency patterns define vowel distinctions like [i], [u], [I]. Although the vowels of a language like English also differ in their intrinsic duration, the formant frequency patterns are necessary parameters for vowel quality in all known human languages (Chiba and Kajiyama, 1941; Fant, 1960; Greenberg, 1963). Formant frequency patterns also follow uniquely from the supralaryngeal area function. We could determine the formant frequency pattern that corresponds to a particular area function by constructing a physical model and "exciting" it with a source. The nineteenth-century experiments of Willis (1828) used this technique. However, computer-implemented models of the supralaryngeal vocal tract have been developed that allow us systematically to explore the effects of moving the tongue, lips, jaw, and larynx about in a reconstructed supralaryngeal vocal tract.

The Neanderthal modeling study reported in Lieberman and Crelin (1971) and Lieberman, Crelin, and Klatt (1972) used the computer model developed by Henke (1966). The area functions that we thought the reconstructed Neanderthal vocal tract could have assumed were derived with reference to cineradiographic motion pictures of the newborn vocal tract (Truby, Bosma, and Lind, 1965), the adult human vocal tract (Perkell, 1969), and the constraints imposed by the essentially nonhuman airway that does not allow abrupt changes in the cross-sectional area function. We actually skewed the modeling toward maneuvers that would be more typical of an adult human but that would be somewhat acrobatic in the reconstructed Neanderthal vocal tract or in the vocal tract of a living nonhuman primate (Lieberman and Crelin, 1971). Despite these acrobatic maneuvers, the reconstructed Neanderthal supralaryngeal vocal tract could not generate the formant frequency patterns of vowels like [a], [u], and [i] or the formant transitions that define the stop consonants [k] and [g].

The results of acoustic analyses of the cries of newborn human infants and the calls of nonhuman primates are consistent with this modeling study (George, 1978; Buhr, 1980; Stark, Rose, and McLagen, 1975; Richman, 1976; Lieberman, 1980).[5] It is important to derive acoustic data when discussing the possible sounds that an infant or a nonhuman primate produces. Our ears can play tricks on us. As George notes, "There was the general inclination to perceive the limits of the infant's vowel space as larger than actually was the case. Thus [ℰ] would be heard as [I] before [I] was produced and [I] would often be heard as [i] before an [i] . . . was produced" (1976, p. 82). The special properties of vowels like [i] with respect to vocal tract calibration follow from its particular formant frequency pattern (Nearey, 1978; Sawusch and Nusbaum, 1979). Though an [I] may sound like an [i], it will not serve this function.

Computer modeling of the range of formant frequency patterns that the newborn human and chimpanzee supralaryngeal vocal tracts can produce yield similar results (Lieberman et al., 1972). The newborn human infant computer modeling is consistent with the data derived by acoustic analysis of actual vocalizations (Lieberman et al., 1972; Stark, Rose, and McLagen, 1975; George, 1976; Buhr, 1980; Lieberman, 1980). Goldstein (1980) attempted to model the vocal tract of a newborn,[4] but she instead used measurements derived from the vocal tracts of 3-month-old infants. Her modeling is consistent with the phonetic repertoire of normal 3-month-old human infants (George, 1976; Buhr, 1980; Lieberman, 1980). Infants and chimpanzees inherently cannot produce the formant frequency patterns of vowels like [u], [a], or [i]. The reconstructed australopithecine supralaryngeal vocal tracts noted in Lieberman (1975a), Laitman and Crelin (1976), and Laitman and Heimbuch (1982) would be subject to the same restrictions. The vocal tracts of *erectus*-grade hominids (Laitman, 1983) probably would have a somewhat greater range of formant frequency variation but would not be able to produce an [i] vowel that had the properties noted by Nearey (see Chapter 8) that make it a "supervowel."

NEANDERTHAL SPEECH, LANGUAGE, AND CULTURE

The discussion of Neanderthal speech has become quite intense. This is not too surprising since the Neanderthal question has always been a problem. Virchow (1872), for example, claimed that the original fossil skull found in the Neander valley was that of an idiot who had died in the recent past rather than that of an archaic, extinct hominid. Virchow's claim is understandable since Down's syndrome, which results in the retention of neonatal morphology (Benda, 1969), had not been identified at that time. Virchow may have been comparing the Neanderthal skull with adult victims of Down's syndrome who were classified as idiots. Many other archaic hominid fossils have been found in Europe and elsewhere since that time. Some of these, such as Cro-Magnon, Chancelade, and Grimaldi, are unquestionably archaic specimens of anatomically modern *Homo sapiens*. Others, such as the La Quina – 5, Le Moustier, La Chapelle-aux-Saints, and La Ferrassie fossils, are similar to the fossil that was found in the Neander valley. The genetic relationship of these fossils has posed a problem because fossil hominids like Cro-Magnon and Chancelade, whose morphology is within the range of modern *Homo sapiens*, were found in habitation sites that were close to the sites in which the Neanderthal fossils lived.

The replacement of Neanderthal fossils with ones that resemble modern *Homo sapiens* is startling in terms of its suddenness and extent and the subsequent changes in the cultural remains associated with the human populations who replaced the classic Neanderthal hominids. The dating in Europe, for example, indicates that the final Neanderthal occupation of sites in France occurred as late as 35,250 years ago. Carbon-14 datings across Europe indicate that modern human populations existed in these regions between 34,000 and 33,000 years ago (Trinkaus and Howells, 1979). The evidence of human culture again shows a series of rapid changes that occurred between 40,000 and 35,000 years ago. Although there is some continuity, the techniques of tool making and the inventory of tool types changed dramatically (Bordes, 1968). Again, though Neanderthal hominids had burial rituals, the development of art followed the replacement of Neanderthal hominids with modern human beings.

Two solutions to the Neanderthal problem have been proposed. One theory (Brace, 1964; Brose and Wolpoff, 1971) claims that the recent phases of hominid evolution, from the *erectus* grade to anatomically modern *Homo sapiens*, involve only one path. According to this theory, modern *Homo sapiens* evolved directly from Neanderthal hominids. This theory is plausible if, and only if, one includes in the Neanderthal classification fossils like Skhul V that indeed resemble modern *Homo sapiens*. Brace (1964) and Brose and Wolpoff (1971) in fact classify fossils like Skhul V and Broken Hill as Neanderthal, together with fossils like La Chapelle and La Ferrassie I. If the term *Neanderthal* is generalized to include *all* of these fossils, then it is true that the range of morphological variation of this redefined Neanderthal hominid level overlaps with many features of anatomically modern *Homo sapiens*. Natural selection then might have filtered out the variations that do not occur in anatomically modern *Homo sapiens* from this expanded, redefined Neanderthal class. However, the range of variation within this expanded class produces, as Howells notes, "a monster of which the morphological character is merely large cranial size and large brows, and of which the range of variation is simply illegitimate" (1976, p. 122). What Brace, Brose, and Wolpoff have done is to classify fossil hominids that have anatomical features that do not occur within the present population of *Homo sapiens* with fossils who in many ways are like us. Their motivation, as Howells (1976) notes, may involve the projection of the laudable "antiracist" sentiment of the 1960s into the fossil record. However, there is nothing racist in claiming that different groups of hominids lived between 250,000 and 35,000 years ago. The unique skeletal characteristics of classic Neanderthal hominids simply do not exist in the present population of *Homo sapiens*. For the theory proposed by Brace, Brose, and Wolpoff to work without any "special" evolutionary process, the hominids who traditionally have been classified as Neanderthals would have had to die without leaving any progeny. If, on the other hand, the classic Neanderthal hominids are supposed to be among our immediate ancestors, some rapid, special evolutionary process would have had to occur between 40,000 and 35,000 years ago that suddenly transformed Neanderthal hominids into modern human beings. If that were the case, we must wonder why this special evolutionary process applied only to hominids and why it suddenly stopped 35,000 years ago, leaving us with various maladapted structures. The curvature of the human spine is, for example, not particularly well engineered for upright posture, and we have too many large teeth crowded into our jaws. Despite these difficulties, advocates of the single-species hypothesis state that any claim that the Neanderthal hominids are not among our direct ancestors is an example of "hominid catastrophism." They instead propose that special evolutionary processes like neoteny rapidly transformed the progeny of the Neanderthal hominids into modern human beings (Gould, 1977).

The other, more conservative solution to the Neanderthal problem, which does not require any special, rapid evolutionary process restricted to human evolution, is that different forms of hominids lived until comparatively recent times. According to this theory, modern human beings are not directly related to the last of the Neanderthal hominids that were the contemporaries of our direct ancestors. According to this theory, hominid evolution did not involve a single path. Different hominid forms lived during the same epochs, and there are extinct hominid species just as there are extinct species of horses, rats, cats, and so on. Human evolution, in this view, does not involve any special mechanisms that would not be operant in the evolution of other animals. We thus do not "need" the putative mechanism of neoteny. We may be directly related to some of the Neanderthal hominids who lived some 200,000 years ago; some of their progeny may have retained changes in skeletal morphology that are species-specific characteristics of modern human beings. However, we are not directly related to their progeny, who instead retained the characteristic Neanderthal skeletal morphology and lived 35,000 years ago. Neanderthal fossils like La Chapelle-aux-Saints, according to this theory, are examples of a conservative hominid form that persisted into comparatively recent times.

As I noted earlier, the reconstruction of the supralaryngeal vocal tract of Neanderthal hominids and other fossils like Skhul V and Broken Hill is consistent with this second theory. The Skhul-V fossil can be readily differentiated from Neanderthal fossils like La Chapelle and La Ferrassie by using metics that do not directly bear on speech production (Howell, 1951; Howells, 1970, 1974, 1976; Trinkaus and Howells, 1979). Howells (1970), for example, derived discriminant functions by using a multiple discriminant analysis on seventy cranial measurements taken on seventeen recent human populations from all major regions of the world. Fifty individuals of each sex were in each population sample. The different groups were selected to represent the extremes of human skeletal morphology that approach those of classic Neanderthal fossils. Whereas measurements from Skhul V, which in all likelihood had a human vocal tract, fall within the range of normal human variation, the La Chapelle, La Ferrassie – I, and Shanidar-I Neanderthal fossils are extreme or fall completely out of modern limits. Measurements from the La Ferrassie – I skull, which is the most extreme of the Neanderthal types, fall between four and five standard deviations from the modern human mean. Similar results occur in univariate statistical studies (Howells, 1976; Howell, 1951).

The supralaryngeal vocal tract reconstructions and model for the evolution of speech and language discussed here are obviously consistent with the second theory, that there were parallel lines of hominid evolution that persisted until recent times. Some of the intense debate and claims that Neanderthal hominids could have produced the full range of human speech may be linked to this general debate on the nature of hominid evolution. Distinctions between Neanderthal fossils and other fossils based on speech, at the minimum, add to the distinctions noted by the independent studies of Howells, Howell, Trinkhaus, and others noted above. If one infers that the absence of human speech means the total absence of the other elements of human language and culture, then the distinction that I am making seems extreme and places Neanderthal hominids outside the *sapiens* range.[5] It is perhaps redundant to stress that I am not claiming that Neanderthal hominids lacked language and culture or could not reason because their phonetic ability differed from ours. The general theory for the biological bases of human language and their evolution that I have been discussing throughout this book argues against that. Neanderthal hominids would have had linguistic and cognitive abilities that are similar to ours if human language is built on neural mechanisms that structure the cognitive behavior of other species, plus a comparatively small number of species-specific mechanisms adapted to human speech. The genetic principle of mosaic evolution, in any case, argues against linguistic ability evolving as a complete system. Neanderthal hominids thus probably represent an interesting case of closely related hominids that had general cognitive and linguistic abilities similar to our more immediate ancestors but who lacked the special characteristics of human speech.

The evidence of Neanderthal culture indicates a highly developed tool-making and using culture, the use of fire, burial rituals, and a social order that cared for the elderly and infirm (Bordes, 1968; Pilbeam, 1972; Lieberman, 1975a; Trinkhaus and Howells, 1979). The fact that the La Chapelle fossil had severe arthritis (Strauss and Cave, 1957) and had lost most of his teeth years before he died argues, for example, for a culture in which the infirm were cared for. Other Neanderthal fossils likewise show signs of severe bone fractures that healed during their lifetimes (Trinkhaus and Howells, 1979). One of the adaptive values of human culture in which the aged, infirm, and injured are cared for is that these older people can impart their knowledge to the young. The group's collective knowledge thus is greater than the knowledge that a young, active member could possibly acquire through the process of trial and error. Obviously language enhances and indeed may be ultimately responsible for the adaptive value of this cultural pattern. I therefore find it hard to believe that Neanderthal hominids did not also have a well-developed language, particularly given the linguistic and cognitive ability of modern chimpanzees when they are taught sign language. Though it is, in the final analysis, impossible to state with certainty all the factors that might have differentiated the linguistic and cognitive ability of classic Neanderthal hominids from their anatomically modern human contemporaries, their speech ability was inferior.

SIGN LANGUAGE AND ISOLATING MECHANISMS

The evidence that Negus presents indicates that the primate larynx is adapted for vocalization at the expense of respiratory efficiency and argues against hominid language ever being exclusively a sign language, as Hewes (1973) claims. There indeed would be no selective advantage for *improved* vocal communication vis-à-vis either the *erectus* or Neanderthal levels if some form of vocal communication were not already in place.

A different form of vocal communication — the sounds that anatomically modern humans could have made compared to either *Homo erectus* or Neanderthal hominids — would undoubtedly have served as an isolating mechanism. Animals as different as wolf spiders (Stratton and Uetz, 1981) and cowbirds (King and West, 1979) will maintain breeding isolates on the basis of different "songs." Humans likewise will tend to form permanent bonds with members of the opposite sex who speak the same language or dialect (Neel and Ward, 1970). Different hominid populations thus would have lived and reproduced as isolates, given fundamentally different sound-producing ability. Similar isolates occur today as, for example, in the communities of Alpine Switzerland where until recent years dialect differences were a factor that maintained population isolates.[6] The differences that typify Neanderthal and anatomically modern populations of *Homo sapiens* are more profound than those that differentiate any human dialects. Vowels like [i], [u], and [a] are among the "universals" of human language and occur in all languages. Neanderthal hominids could not have produced these sounds. The speech of Neanderthal hominids would have lacked consonants like the velar stops, [k] and [g]; Neanderthal speech furthermore would have tended to be nasalized (Lieberman and Crelin, 1971). Neanderthal hominids would have lacked the innate, genetically transmitted neural mechanisms that human listeners use to decode place of articulation or velar stops. They would, at minimum, lack the innate neural mechanisms that human beings use to derive a "vocal tract length calibrating signal" from vowels like [i] and [u]. They probably lacked a fully encoded speech system.

THE SELECTIVE ADVANTAGES OF HUMAN SPEECH

The persistence of the standard-plan supralaryngeal vocal tract from its mammalian base through the australopithecines and its slight modification in *Homo erectus* and classic Neanderthal hominids argues for its selective advantages with respect to respiration, swallowing, and chewing. Only a relatively strong selective advantage with respect to some other aspect of human behavior could have provided a basis for the restructuring of the basicranium and vocal tract. Human speech is the probable basis for this last, most recent phase of hominid evolution. It provided one of the key elements of human society: rapid communication.

Human speech clearly is built on the biological base that is present in other primates. As I noted in earlier chapters, nonhuman primates use vocal call systems; electrophysiologic and psychoacoustic data show that some of these calls are perceived by means of innate neural mechanisms that are matched to the sound-producing mechanisms of the animals. The larynges of all primates are furthermore adapted for phonation at the expense of respiratory efficiency. Anatomically modern *Homo sapiens* continues this trend toward more efficient vocal communication. The fossil record indicates that the changes came over a period of time, in bits and pieces. The change could not have occurred instantly — the mechanisms of natural selection involve alletic variations that are present in a population and gradually diffuse through that population as more and more progeny survive because they have these variations. The presence of fossils like Saccopastore 2, which has some attributes of classic Neanderthal man but also has some aspects of the human basicranium, thus is not surprising. In a primitive period when muscular strength, efficient chewing, and less accident-prone respiration outweighed or were in balance with the advantages of a faster rate of information transfer, different hominid lines could coexist together with intermediate "experiments." As the central cognitive mechanism, the brain, gradually increased its power, the selective advantage of peripheral input-output mechanisms like human speech also would have increased. Moreover, any increase in the complexity of hominid culture would increase the selective advantage of human speech. Human speech, added to the technical and cognitive base already present, yielded our human ancestors a superior solution in their "infinitely complex relations to other organic beings and to external nature" (Charles Darwin, 1859, p. 61).

The presence of a fully encoded speech system in recent hominids may also have more directly contributed to the development of complex syntactic organization in human languages. The rapid data rate of human speech allows us to transmit a long sequence of words within a short interval. We can take the words that constitute a complex sentence into short-term memory and can effect a syntactic and semantic analysis. We have to keep track of the group of words that constitute a sentence in order to comprehend its meaning. Deficits like dyslexia, which interfere with a reader's ability to take in strings of words in a short time, thus often result in syntactic deficits. Dyslexic readers have difficulty in decoding the complex syntactic structures that occur in written material because they read words so slowly that they forget the words that started the sentence before they can analyze the sentence. The effects of a characteristically low rate of speech communication throughout an entire hominid population thus would probably limit syntactic complexity. Given the same constraints on short-term memory that are evident in modern *Homo sapiens*, a speech rate that was one-tenth that of modern human speech would limit vocal communication to very simple syntactic structures. You can easily perform the experiment of reading sentences to someone at a rate that is one-tenth of the normal rate. Your listener, and you, will forget the words that occurred at the start of anything other than a short, syntactically simple sentence. Rapid speech thus would, in itself, be an element that would provide a selective advantage for complex syntactic ability. It perhaps is again significant that pongids, which apparently lack the neural substrate that would allow them to produce human speech, do not seem able to progress beyond the two- or three-word stages of human language.

The vocal deficiencies of pongids and their comparative success in using sign language have led Hewes (1973) to propose that the initial modality for human language was sign and gesture. Human beings clearly can communicate rapidly by using manual gestures in a linguistic mode, as in American Sign Language. Present-day sign languages also can have a fairly complex syntax (Stokoe, 1978). However, it is probable that these systems work at a level comparable to vocal language only because we already have the neural substrate that evolved to structure vocal language. It is likely that our earliest hominid ancestors started from a syntactic and cognitive base that was only somewhat more advanced than that displayed by modern pongids. It is also likely that their communications were from the start vocal or that they at least made use of a wide range of vocal signals.

Sign languages inherently have a deficiency that is related to one of the crucial distinctions between human beings and other animals—habitual upright bipedal locomotion. The selective value of upright bipedal locomotion with respect to tool use and other manual tasks has long been recognized. One of the selective advantages of fully vocal language is that it enhances our ability to use tools, carry things, and indeed perform any of the tasks that involve using our hands. Vocal language thus continues the trend set by upright bipedal locomotion.

Vocal language has yet another inherent quality that structures human language. A spoken word is transitory and can have only an abstract relationship to a real object, event, or person. Words continually take on new references, perhaps in part because they are by their nature abstract. Manual signs, pictographs, and the like inherently can be iconic and thus may tend to have restricted references.

COLLECTIVE INSIGHT

Various "benefits" or contributions of language to human civilization have been noted. Language is supposed to reduce the degree of aggressive behavior, facilitate hunting and tool making, determine the person one will most likely marry, and so on. The fact is that language and speech enter into practically everything that we do or think about. Though some activities do not involve the overt use of language, such as brushing one's teeth, we first must learn what the function of a toothbrush is and why it is useful to brush one's teeth. The acquisition of these habits or modes of behavior almost always involves the use of human language. Imagine, if you will, a condition in which it takes ten times longer to communicate each thought. That undoubtedly was the situation in the course of hominid evolution before the encoded character of human speech communication evolved.

One of the mysteries of hominid evolution is the rapid rate at which cultural change has occurred in the last forty thousand years. Although there were changes in hominid culture in earlier periods, the pace of change seems to have quickened abruptly in the period of hominid evolution that is associated with anatomically modern *Homo sapiens* (Marshack, 1972; Pilbeam, 1972; Bordes, 1968; Boule and Vallois, 1957). Various proposals have been made to account for this fact. One possibility is that the data transmission rate of linguistic communication gradually increased throughout the course of hominid evolution through the process of speech encoding until it reached a level at which "collective" insight could function.

The process of problem solving usually is not "logical"; insight follows when a person suddenly sees the logical connections between various aspects of a problem that were previously opaque. Logic is not really a very useful process when we are confronted with a new problem. The logical connections are apparent only when we have solved the problem. Insight is the process wherein we consider the various parameters of a problem and then abruptly see the logical connections that we previously were not aware of. In a sense insight is akin to the process of artistic creation. It does not involve the principles of formal logic, though we usually can provide a formal logical analysis of a problem *after* we have had the flash of insight that allows us to solve the problem.

One of the steps necessary for the process of insight to operate is the preliminary step of data collection. If the mode of linguistic communication is rich enough to communicate the set of parameters that describe a problem, then more than one person can apply insight to the solution of that problem. This process of collective insight may be one of the factors responsible for the rapid advance in human culture that has occurred in the last forty thousand years. In a similar manner we can see the process of collective insight at work with regard to the advancement of science since the seventeenth century, when the crucial step of scientific publication took place. Publishing the results of experiments and scientific theories in journals that were accessible to comparatively large numbers of people perhaps was *the* crucial step in the development of the scientific age. It allowed collective scientific insight to be applied to problems. Many people could rapidly acquire the data that would let them apply their insight to the solution of a problem. It is possible that a similar though more general step occurred some forty thousand or so years ago when the rapid rate of speech communication that is typical of the linguistic system of anatomically modern *Homo sapiens became general throughout the hominid population.*

Precisely when the full system of human speech evolved is not clear. The evidence of the evolution of the human supralaryngeal vocal tract indicates that it probably occurred sometime in the last 250,000 years or so. However, it is impossible to know just when the neural mechanisms involved in "decoding" human speech were fully evolved. Even if we had a preserved fossil brain, it would not be possible to resolve this question, given our present knowledge of the brain. Attempts to identify gross features of the human brain that are not present in other primates and that presumably would indicate the presence or absence of language have been made, but they have not been successful (Falk, 1980). Saban's (1980, 1983) recent studies of the distribution of blood to various parts of the brain may lead to more definitive results. Saban traces the patterns of blood supply to those regions of the dominant hemisphere that are usually involved in the perception of speech by means of radioisotope techniques in living human beings and by charting the circulatory systems of fossil hominids from the impressions left on the inside surface of the skull. Saban notes that Neanderthal fossils like La Chapelle appear to have significantly fewer vascular connections to this area of the brain than do modern human beings. Saban's methods, however, have to be applied to a larger sample of both modern human and fossil hominid skulls before any definite conclusions can be drawn.

THE DEMISE OF THE NEANDERTHALS

Classic Neanderthal hominids thus appear to represent the terminal state of a conservative trend in hominid evolution. The muscular development of the *erectus* level is elaborated in classic Neanderthal hominids, together with increased neural development as evidenced by the large cranial capacity (though some of the cranial capacity may reflect their large muscles). The human beings who replaced these Neanderthal hominids had already developed elsewhere. The anatomically modern Mideastern Skhul-V and Jebel Qafzel fossils are contemporary with or slightly older than the last European Neanderthals. The most probable explanation for the replacement of the European Neanderthals is that they were pushed out by an influx of modern human beings who may have come from Africa and the Mideast. The solution that I propose is neither novel nor peculiar. The historical evidence of human habitation in Europe is replete with documented instances of the migration of peoples forcing the previous inhabitants of a region out of their homeland. It is consistent with the mechanisms of evolution and change that follow from the synthetic theory of evolution (Mayr, 1942). Changes in a population isolate become distributed throughout the entire range of a species as the better-adapted isolate diffuses throughout the entire range.

The model or "picture" of hominid evolution that is consistent with its earlier stages, as Gould (1973) notes, resembles a bush more than it does a ladder. The various australopithecine species became extinct, though they lived in proximity to various forms of *Homo erectus* for 500,000 years. Various species of australopithecines probably became extinct at different times, while others survived somewhat longer (Pilbeam, 1972). Ultimately they all became extinct. The extinction of a species is not an unusual circumstance limited to hominid evolution. Most of the different species that ever lived on earth are now extinct. Extinction is a necessary correlate to the process of evolution by means of natural selection. As Darwin noted,

> It inevitably follows that as new species in the course of time are formed through natural selection, others will become rarer and rarer, and finally become extinct. The forms which stand in closest competition with those undergoing modification and improvement will naturally suffer most . . . Consequently, each new variety or species, during the process of its formation will generally press hardest on its nearest kindred, and will tend to exterminate them.
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> (1859, p. 110)

Thus I propose that the extinction of Neanderthal hominids was due to the competition of modern human beings who were better adapted for speech and language. The synergetic effect of rapid data transmission through the medium of encoded speech and the cognitive power of the large hominid brain probably yielded the full human linguistic system. The rapid changes in human culture that occurred shortly after the replacement of the Neanderthals could be the result of a difference in the way in which humans thought. Though it is impossible to prove that human language and thought were the causative agents, the replacement of the Neanderthal population—adapted for strength and agility—by a population that was inferior save for enhanced speech abilities is consistent with this hypothesis.