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The Ratio of Vertical to Horizontal Supralaryngeal Vocal Tract and the Capacity for Speech in Neandertals: A Comparative Study

A Thesis Presented for Senior Honors in Anthropology and

Chancellor's Honors Program

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Abstract

The human supralaryngeal vocal tract is made up of two components, the vertical (SVTv) and horizontal (SVTh) supralaryngeal vocal tracts. It has been suggested that the unique human SVTv/SVTh ratio of approximately 1:1 is the morphological basis for modern human speech. This study compares the SVT lengths of both adult and sub-adult samples of various living and fossil groups. A comparison of the SVT lengths of young chimpanzees, modern humans, and Neandertals indicates that the developmental pattern of the Neandertal vocal tract is similar to that of modern humans. However, the SVTh lengths of Neandertal children are longer than those of modern humans, and their SVTv/SVTh ratios fall outside the modern human range. Also, a comparison of the adult SVT lengths of several hominid groups including *Austrilipithecus africanus, Homo ergaster,* early anatomically modern human, Neandertals, Late Pleistocene anatomically modern human, and modern human demonstrates that the average SVTv/SVTh ratio of adult Neandertals falls within the modern human range and that the relative SVTh lengths seem to support the theory of admixture between Neandertals and early anatomically modern humans. Further, these results indicate that the appearance of a vocal tract configuration compatible with the production of modern speech might not appear until adolescence in the developing Neandertal.

Table of Contents

1. Introduction

Speech, among other qualities considered to be unique to our species, is one of the most vital aspects of humanness. It allows us to "transmit information vocally at rates that are ten times as fast as we could achieve with other sounds" (Lieberman, 2006: 67). But how long has this mode of communication been a possibility and did other hominids before us have the same capacity for communication through speech? Of particular interest with respect to these questions are the ongoing paleoanthropological debates concerning the speech capability of the Neandertals. Since the early 1970's, scientists lead by Lieberman (Lieberman and Crelin, 1971; Lieberman et al., 1972; Lieberman, 1976, 1992, 1993) have contended that Neandertals did not have the anatomical ability to produce fully modern speech, although they have acknowledged that Neandertals possessed some form of symbolic, gestural, or rudimentary spoken language. Others, (Houghton, 1993, 1994; Arensburg, 1994; Kay et al., 1998) assert that evidence does not support such claims and that Neandertals were capable of producing fully modern speech. More recent anatomical studies of the vocal tract (Granat et al., 2007) also appear to confirm the idea that the Neandertal vocal tract was adequate for producing the range of sounds characteristic of modern speech. Also, human origins models have been shown to support one view or the other, and theories related to the origin of language and the relationship between language and cultural factors have been discussed. These debates have persisted for decades and remain unresolved.

2. Previous Research

2.1 Morpholigical Studies

Leiberman and several scientists from varied disciplines (Lieberman et al., 1972; DeGusta et al., 1999) have presented anatomical evidence to support the contention that Neandertals did not possess the speech producing capabilities of modern humans. At the center of this debate is a reconstruction of "the vocal apparatus of 'classic' Neandertal man" (Leiberman and Crelin, 1971 page; Leiberman et al., 1972). This reconstruction is based on a comparison of the skull anatomy of the La Chapelle aux Saints Neandertal fossil with the skull anatomies of two hominids that do not possess the ability to produce modern human speech, the newborn human and the chimpanzee. Leiberman et al. (1972) justify this comparison by noting several similarities among the three skulls, including but not limited to "a flattened-out base, …lack of mastoid processes, …lack of a chin," and a short mandibular ramus (Leiberman et al., 1972: 288). Based on these cranial similarities, they infer that the supralaryngeal vocal tract (SVT) of the La Chapelle aux Saints Neandertal is similar to those of the newborn human and the chimpanzee (Leiberman et al., 1972). The resulting reconstructed SVT of the Neandertal and the SVTs of the newborn human and the chimpanzee are compared to the SVT of the modern adult human male. Leiberman et al. (1972) note that the SVTs of the Neandertal, newborn human, and chimpanzee are relatively short when compared to that of the modern human. They point out that the position of the hyoid bone in Neandertals, newborn human, and chimpanzees is high in the neck, indicating that the larynx is also positioned high, with the tongue located "completely within the oral cavity" (Leiberman et al., 1972: 290). Leiberman (1994: 448) cites a "causal relationship between basicranial flexion and the descent of the larynx." This finding is also consistent with the "flattened-out" configuration of the basicranial line in these individuals (Leiberman, 1994: 447). In contrast, the larynx of the modern adult human, who has an acute basicranial line, is positioned lower, and the back of the tongue forms "the anterior wall of the supralaryngeal pharyngeal cavity" (Leiberman et al., 1972: 290-291; Leiberman, 1994). Using a "computer-implemented model," Leiberman et al. (1972: 293) assessed the ability of the Neandertal, newborn human, chimpanzee, and adult modern human to produce specific vowel sounds characteristic of modern human speech and found that only the adult modern human could produce the [i], [a], and [u] sounds. They reasoned that because Neandertals, newborn humans, and chimpanzees do not have a "supralaryngeal pharyngeal region," they can not perform the complex configurations of the tongue that are necessary for the production of certain vowel sounds which define human speech (Leiberman et al., 1972: 295). Thus, they conclude that the speech capability of Neandertal man is "inferior to that of modern man" (Leiberman et al., 1972: 287).

Other anatomical features associated with speech have also been debated, including the size of the hypoglossal canal (Kay et al., 1998; DeGusta et al., 1999) and the morphology of the hyoid bone (Arensburg et al., 1988, 1990; Laitman et al., 1990; Bar-Yosef et al.,1992). It has been noted that hypoglossal canal size and, thus, the associated nerve supply to the tongue of both modern humans and Neandertals are equal and that, as a result, Neandertals possess the ability to produce human speech (Kay et al., 1998). However, a study by DeGusta et al. (1999: 1800) refutes this claim by demonstrating that many "non-human primates have hypoglossal canals in the modern human size ranges." They also show that hypoglossal canal size is not related to either nerve size or number of axons per nerve and, therefore, is not associated with tongue function or speech capability (DeGusta et al., 1999). The human-like morphology of the hyoid bone of the Kebara KMH 2 fossil (considered to be Neandertal because of its robust characteristics) has also been used to demonstrate that Neandertals could produce the sounds necessary for human speech (Arensburg, 1988, 1990; Bar-Yosef, 1992). In a now famous, or perhaps infamous, pig comparison commentary, Laitman et al. (1990) criticize the logic of Arensburg et al. (1988, 1990) for using measurements of this single hyoid bone to conclude that the individual had an SVT similar to a modern human. They assert that the same logic could be used to draw a like conclusion for pigs. While these arguments do not directly support the case against Neandertal speech, they provide indirect support by defending attacks on that position.

Several scientists (Aeillo and Dunbar, 1993; Houghton, 1993, 1994; Arensburg et al., 1994; MacLarnon and Hewitt, 1999) have provided anatomical evidence supporting the case for Neandertal speech. Houghton (1993, 1994) and others (Arensburg et al., 1994) have presented evidence related to cranial anatomy, while MacLarnon and Hewitt (1999) have studied thoracic anatomy and breathing as it relates to speech; and Aiello and Dunbar (1993) have used neocortex size as a variable in a study of factors related to the evolution of language. More recently, Granat and colleagues (2007) have utilized skull reconstruction software (Labskull) to provide evidence that Neandertals possessed a vocal tract configuration compatible with the production of modern human speech.

Houghton (1993, 1994) takes issue with several conclusions drawn by other scientists (Leiberman and Crelin, 1971; Leiberman et al., 1972) following their reconstruction of the La Chapelle Neandertal cranium. Houghton (1993) provides an alternative reconstruction and makes several observations reflected by his changes. He reorients the head on a spinal column that has been given a "human anterior convexity" based on comments by Trinkaus (1983) and others (Strauss and Cave, 1957; Houghton, 1993: 140). Houghton (1993: 140) notes that a correct orientation of the head of the Neandertal will also alter the orientation of the styloid and pterygoid processes to a more vertical position, "thus resembling the modern human." Next, he notes that the size of the Neandertal oral cavity proposed in earlier works (Leiberman et al., 1972) does not allow sufficient room for both "soft tissue structures as well as an adequate airway" (Houghton, 1993: 142). Houghton (1993: 141) also states that oral cavity size can be determined from certain "skeletal landmarks" and argues that, in the earlier presentation (Leiberman et al., 1972), the "general tongue profile" is too low and can "be raised considerably … and still lie below the palate." Houghton (1993) further asserts that the larger size of the Neandertal oral cavity is due to midfacial prognathism and the resulting extension of the hard palate toward the front of the skull. He also proposes that the wide mandibular ramus found in Neandertals reflects "a substantial masticatory musculature," not "a posterior extension of the oral cavity" (Houghton, 1993: 143). Houghton (1993) concludes his discussion of the oral cavity by noting that if the tongue profile is reconfigured to a raised position, the resulting location of the larynx would be at approximately the same level in the neck as that of a modern human (Williams and Warwick, 1980). With regard to the cranial base angle of living humans, Houghton (1993: 144) reports that there is so much variation that even the flattened angle of the newborn (approximately 149°) noted by Ford (1956) falls within the range of some populations, specifically the South Pacific Polynesians with “a mean angle of 142° (S.D. 5.7, n = 60)” (Houghton, 1977). Also, the lack of a clear “definition of the term ‘basicranium’” makes it difficult to measure the cranial base angle of “intact skulls, let alone those with severe damage” such as the La Chapelle Neandertal fossil (Houghton, 1993:144). Finally, Houghton cites several reasons why the similarities between the Neandertal mandible and those of the newborn human and the chimpanzee that were noted by Leiberman et al. (1972) are biologically unimportant. He asserts that any “cranial similarities … appear … to be a consequence of a nonanatomical orientation of the bones” (Houghton, 1993: 145). It follows that Houghton’s alternate reconstruction of the Neandertal cranium directly supports the case for Neandertal speech.

Arensburg (1994) also comments on possible errors in the reconstruction of the cranial anatomy of the La Chapelle Neandertal as proposed by Leiberman (1993) and others (Leiberman and Crelin, 1971; Leiberman et al., 1972). He takes issue with two main points, the position of the hyoid and larynx and basicranial angle. First, Arensburg (1994: 279) contends that the continuous growth during ontogeny of the face and mandible in addition to that of the cervical vertebral column “are responsible for the relative change in position of the hyoid and larynx” in modern humans. He argues that the position of these structures does not change relative to the position of the mandible, and the cervical spine develops a characteristic lordosis, “growing up” along with the face (Arensburg, 1994). In contrast, the face of apes grows out, and cervical lordosis does not appear. Thus, in view of their presumed “modern bipedal posture” and “acquired cervical lordosis,” it can be argued that Neandertals are more like modern humans than apes with regard to anatomy and development (Arensburg, 1994: 279).

Arensburg (1994) next argues that, contrary to the position of Leiberman and others (Leiberman et al., 1972; Laitman and Reidenburg, 1988), several scientists (Morris, 1974; LeMay, 1975; Heim, 1989; Arensburg et al., 1990; Frayer, 1992; Houghton, 1993) have shown that that the angle of the basicranium and the ability to produce the sounds necessary for speech are not related. In conclusion, Arensburg's analysis of certain aspects of skeletal anatomy support the case for Neandertal speech capability.

MacLarnon and Hewitt (1999) explore the relationship between the anatomy of the thoracic region of the spinal column and the development of the advanced breathing control mechanisms necessary for the evolution of modern human speech. They estimate the size of the vertebral canal of hominids throughout the fossil record by recording specific measurements of the thoracic vertebra and an estimated body weight for each specimen. Their study demonstrates that the thoracic vertebral canal of Neandertals is similar to those of both early modern humans and extant humans and is unlike those of early hominids (represented in the sample by two australopithecine species and *Homo ergaster*) (MacLarnon and Hewitt, 1999). This finding also indicates that Neandertals, early modern humans, and extant humans possess similar thoracic innervation, specifically serving the thoracic and abdominal muscles (MacLarnon and Hewitt, 1999). The authors cite and dismiss possible reasons for the development of an increased nerve supply to these areas except one, breathing control (MacLarnon and Hewitt, 1999). They then eliminate various possible explanations for the development of increased breathing control except "for the evolution of modern human speech" (MacLarnon and Hewitt, 1999: 349). MacLarnon and Hewitt (1999: 353) also explain that the "central control of speech breathing is served by neural pathways that are functionally and anatomically distinct from those involved in the control of respiration for metabolic purposes" (Phillipson et al., 1978). Thus, this work provides direct support that Neandertals possessed the enhanced breathing control necessary for producing modern human speech.

Aiello and Dunbar (1993) supply further anatomical evidence supporting the case for Neandertal speech capability in their interesting study of the relationship between neocortex size and group size and the resulting implications for the evolution of language. Aiello and Dunbar (1993: 185) note that there is "a relationship between neocortex size and group size in primates" (Sawaguchi and Kudo, 1990; Dunbar, 1992). They propose that during the evolutionary process of primates, their need for large groups increased and resulted in "not only the evolution of language but also hominid encephalization" (Aiello and Dunbar, 1993: 184; Dunbar, 1992). Their study demonstrates that group sizes became large enough to need some type of language in order to "maintain social cohesion" during the first stages of the appearance of the genus *Homo* (Aiello and Dunbar, 1993:184). Aiello and Dunbar (1993:184) further propose that language developed as a result of the need for an efficient means to "service the relationships" in these large groups. Additionally, this research shows that the "grooming time requirements" (the time needed to service relationships within the group) for Neandertals are not significantly different from those for both archaic and modern humans (Aiello and Dunbar, 1993:187). This finding implies that neocortex development and the social pressure required for language development are similar for Neandertals, archaic humans, and modern humans. It is also interesting to note that Aiello and Dunbar (1993) found that the need for large groups experienced a rapid increase beginning in the later part of the Middle Pleistocene and not in the Upper Paleolithic. Apparently, human language and, therefore, speech evolved in a "gradual and continuous" process "from non-human primate communication systems" (Aiello and Dunbar, 1993: 187). Therefore, this study demonstrates that Neandertals, archaic humans, and modern humans had similar capacities for the development of speech.

Recent research (Nishimura et al., 2006; Granat et al., 2007) using more modern technological methods may provide additional insight concerning the issue of speech evolution. Nishimura and colleagues (2006:244) use Magnetic Resonance Imaging (MRI) technology to study the descent of the hyoid in chimpanzees and argue that it is not the descent of the larynx but "facial flattening…that paved the way for speech in the human lineage." This study found that the developmental descent of the larynx occurs similarly in chimpanzees and humans. Thus, the study "does not support the 'evolutionary' hypothesis that this descent occurred in the human lineage" (Nishimura et al., 2006:252). Also, Granat and colleagues (2007) use a computer model (LabSkull) to reconstruct the dimensions of the horizontal SVT (SVTh) and vertical SVT (SVTv) of certain skeletal hominids and chimpanzees. Following the determination of the "acoustic capabilities" of the various reconstituted skulls, the authors conclude that Neanderthals were able to "produce the same variety of speech sounds as we can today" (Granat et al., 2007:384). Finally, in a preliminary MRI study comparing the vocal tract anatomy of normal and Down Syndrome children, Vorperian and others (2004) found differences in their vocal tract structures. They found that Down Syndrome children have increased facial flattening, shorter hard palate length, and shorter vocal tract length than normally developing children. This finding is of particular interest because both Down Syndrome and normal children have speech capability. Thus, there is apparently no single vocal tract configuration that characterizes the ability to produce the sounds necessary for modern human speech.

2.2 Modern Human Origins and Language

In addition to functional skeletal morphology, evidence for speech in Neandertals can be discussed in terms of the theories surrounding modern human origins. Two conflicting primary theories have been debated during the last several decades (Wolpoff et al., 2001). The replacement, or Eve, theory proposes that modern human origins can be traced to a speciation event that occurred in Africa around 100,000 years ago (Stringer and Andrews, 1988). This date has recently been pushed back to at least 155 Ka with the discovery of a fully modern human skeleton in the Middle Awash region of Ethiopia (White et al., 2003). Subsequently, fully modern humans spread throughout the old world replacing previous regional archaic populations. In contrast, the multi regional hypothesis (Wolpoff et al., 2001) proposes that no single place or event is the source of modern humanity. Rather, humans evolved regionally from archaic ancestors across the old world. This implies that since first leaving Africa at least one million years ago, the genus *Homo* has maintained gene flow through time across genetically varying regional groups, and today's populations retain many of these regional differences. These two theories have interesting implications for the Neandertals in Europe and might give some insight into their speech capabilities.

In support of the replacement model in Europe, Mellars (1992, 1999) concludes that cultural evidence in Western Europe supports the fact that the Neandertal populations there coexisted with modern human populations from around 40,000-34,000 B.P. According to Mellars (1992), the earliest evidence of "distinctive" technological and symbolic culture in Europe can be found in the Aurignacian cultures of the Upper Paleolithic. These distinctive cultural features include a large range of lithic tools, complex shaped bone artifacts, evidence of personal ornamentation (characterized by animal teeth, shells, and shaped beads), and evidence of art and geometric drawing. These cultural innovations that define the Aurignacian industry are also said to be found only in association with the first evidence of fully modern skeletal anatomy (Mellars 1992). However, exceptions to this assertion have been discovered at St. Cesaire and Arcy-sur-Cure in France (Klein, 2000). These two sites contain Neandertal skeletal remains associated with artifacts typically attributed to modern humans. Klein (2000) agrees with Mellars that these exceptions to the rule are a result of Neandertal acculturation. While early modern humans in the early Upper Pleistocene are characterized by the Aurignacian industry, the contemporary Neandertals in Western Europe are defined by the Châtelperronian industry (Mellars, 1999). This industry "is characterized by the presence of distinctive curved, pointed, blunted-back blades," which are not found in the contemporary Aurignacian industry (Mellars, 1999:341). Also pertinent to Mellar's (1999) definition of the Châtelperronian industry is its origination from the earlier Mousterian of Acheulian tradition in Europe, its associations with Neandertal skeletal remains, and presence of cultural technology not appearing in the earlier Mousterian which seems to have been "acculturated" from contemporary early Upper Pleistocene modern human Aurignacian groups. The significance of Mellar's "acculturation" theory is that it implies that Neandertals and early modern human groups were separate species that coexisted for a time; but, ultimately, the fully modern humans replaced the Neandertals. Although Mellars (1999) uses his acculturation theory to hint at the possibility of Neandertal cognitive ability similar to modern humans, he speculates (1992:232) that the modern human populations also possessed "behavioral adaptations ... (possibly including language)" which helped them adapt to the extreme glacial environment of Western Europe and "compete effectively with local Neandertal populations in these regions." Thus, Mellar's support of the replacement theory in Europe also supports the case against Neandertal speech capibilities.

In contrast, other authors (Thorne and Wolpoff, 1992; Frayer et al., 1993; Brace, 1999; Kramer et al., 2001; Wolpoff et al., 2001) support a multi regional evolution model. This model can be applied to the Neandertals in Europe and, by showing that Neandertals and early modern humans were members of the same species, has clear implications for their speech capability. Using fossil evidence, several reports (Frayer et al., 1993; Duarte et al., 1999; Wolpoff et al., 2001; Kramer et al., 2001; Trinkaus et al., 2003) attempt to demonstrate continuity between the Neandertals and modern humans of Europe. For instance, Frayer and colleagues (1993) contend that for the replacement theory to be correct there must be no presence of Neandertal autapomorphies in later "modern" populations of Europe. In order to refute this condition they present the horizontal-oval (H-O) mandibular foramen as evidence. The H-O foramen is a bony bar that covers the mandibular foramen, and since it is infrequently found outside the Neandertal range of Europe and West Asia, it is a trait considered "unique" to Neandertals. In Europe, the trait is found in 53% of known Neandertals, 25% of early Upper Paleolithic humans, 7% of late Upper Paleolithic humans, and 2% of Mesolithic and medieval Hungarian samples. Since the trait is still reasonably present in post Neandertal populations, it is considered to be evidence of admixture between Neandertal and modern populations. It is also important to note that the H-O foramen is considered nonfunctional (Smith, 1978); and, therefore, its appearance in post Neandertal populations cannot be explained easily with parallel evolution. Using similar reasoning, Kramer and colleagues (2001) developed an experiment to test the likelihood of two *Homo* species coexisting in the Middle East during the Middle Pleistocene. Using a cladistic analysis of non-metric features of hominids from Amud and Tabun considered to be "Neandertal" and those of Skhul and Qafzeh considered to be "modern humans," they conclude that both sets fail to "display a unique set of characters" (Kramer et al. 2001:60), indicating admixture between "Neandertal" and "modern human" groups. If this is indeed the case, then Neandertals cannot be considered a separate species from *Homo sapiens*, and this study supports at least some form of multi regional evolution. Other recent publications (Duarte et al., 1999; Trinkaus et al., 2003) also provide evidence of Neandertal-modern human admixture in Europe. Thus, if early modern human groups appear to have had the capacity for fully modern speech as some contend (MacLarnon and Hewitt, 1999; Aiello and Dunbar, 1993), then the Neandertals must have as well. The only way this might not be the case is if the 'classic' Neandertals of Western Europe somehow lost the capacity for modern speech (Aiello and Dunbar, 1993). Again this explanation is highly unlikely. However, another possibility is that neither of these groups possessed fully modern speech at the time that Western European Neandertals began to adapt to Late Pleistocene conditions.

2.3 Language Predecessors

It is logical to think that modern spoken language must have developed from a less sophisticated form of vocal communication. It has been proposed that humans share basic vocalization patterns with other species for common emotions such as fear and aggression (Leinonen et al., 1991). This idea suggests that some similar form of vocalization has been in place within the primate lineage for quite some time. These older forms of hominid communication are referred to as "protolanguage" (MacLarnon and Hewitt, 1999: 342). Mithen (2005) describes two leading theories concerning the nature of protolanguage. The traditional view argues that protolanguage is compositional in nature, meaning that the hominid ancestors of modern humans first developed a "large lexicon of words, each of which related to a mental concept such as 'meat,' 'fire,' 'hunt,' and so forth" (Mithen, 2005: 3). Proponents of this view (Bickerton, 1990; Jackendoff, 2000) believe that this lexicon of words was characterized by simple rules and required the evolution of grammar in order to become modern speech. A second theory of modern speech has also been proposed (Wray, 1998) that describes it as being holistic in nature. In this case, a holistic protolanguage can be defined as "a communication system composed of 'messages' rather than words" (Mithen, 2005: 3). Using this language, hominids would have communicated with long expressions or sounds that each had a meaning, but in this case the expressions cannot be separated into individual units (words). Mithen (2005) argues that this type of holistic protolanguage was of sufficient complexity to accommodate the needs of Neandertal culture.

Cultural evidence such as ritual behavior, artistic expression, and lithic technology can be used to indirectly assess the degree of cognitive development of various groups within the genus *Homo* (Hayden, 1990; Simek, 1992; Brace, 1999). Brace (1999: 258-259) argues that the archaeological record yields cultural evidence that the "rise and refinement of linguistic capabilities … occurred throughout the entire range occupied by the genus *Homo,*" not just in Africa. Hayden (1990) echoes this view by noting that the archaeological record provides ample evidence supporting the fact that the societal structure of Neandertal populations was complex. He notes that they practiced ritual burial and "capably manipulated symbols and abstract concepts (Hayden, 1990: 120,123). Simek (1992) also cites archaeological evidence supporting the contention that Neandertal society was characterized by some artistic expression, possibly in the form of personal adornment; complex ritual burial; and stone technology as sophisticated as that found in some Upper Paleolithic assemblages, reflecting cognitive abilities equal to those found in Upper Paleolithic individuals. Thus, it can be indirectly argued that if cognitive abilities are equal, then the capacity for speech is also equal.

Alternatively, it has been argued that existing cultural evidence supports the view that Neandertals did not possess fully modern speech (Mithen, 2005). Mithen (2005) contends that in order for Neandertals to have possessed modern speech, ample evidence of symbolic artifacts within Neandertal assemblages is necessary. He reasons, "If Neandertals were able to use words- discrete utterances with symbolic meanings- they would have also been able to attribute symbolic meaning to objects" (Mithen, 2005: 228). He further argues that the relatively few instances of symbolic artifacts in the Neandertal record are evidence that they did not have symbolic speech. Additionally, he contends that the small group size and relative cultural stability of Neandertal society are evidence for a lack of fully modern speech. Instead, he asserts that a holistic protolanguage would have been of sufficient complexity for communication within their small social groups and for transmission of the information and social knowledge that Neandertals possessed. Thus, the question arises as to whether or not the structure of the supralaryngeal vocal tract anatomy of Neandertals would have allowed for the production of the vocalizations necessary to support a holistic proto-language, if not fully modern speech.

The purpose of this study is to examine the relationship between the ratio of the vertical to horizontal SVT and the capacity for speech in Neandertals. Previously published data from three sources were used to compare the vertical and horizontal components of the SVT and the SVTv/SVTh ratio of several hominid species and chimpanzees.

3. Materials and Methods

3.1 Data Sources

The first data source consists of longitudinal chimpanzee vocal tract data collected by Nishimura and colleagues (2006). In a study that examines the descent of the larynx in chimpanzees, the authors use magnetic resonance imaging (MRI) of the mid-sagittal plane to characterize vocal tract development and laryngeal descent in three chimpanzee specimens (two female, one male). Measurements of the horizontal (SVTh) and vertical (SVTv) components of the supralaryngeal vocal tract were taken at various intervals between four months and sixty months. The SVTh was measured as the linear distance between the "most anterior inferior point of the lingual surface of the alveolar premaxilla" to the "point on the posterior pharyngeal wall opposite the anterior tubercle of the atlas" (Nishimura et al., 2006: 247) (Fig. 1). The SVTv was measured as the distance between the vocal folds and the line between the anterior and posterior nasal spines (Nishimura et al., 2006).

The second source is comprised of human vocal tract data collected by D. Lieberman and colleagues (2001). This longitudinal study, designed to examine the development of the human vocal tract by measuring the descent of the hyoid and larynx, utilizes a radiograph sample of 15 males and 13 females from a growth study conducted by the Child Research Council at the University of Colorado School of Medicine. The sample contained Caucasian Americans radiographed between 1931 and 1966 at the ages of 1, 3, and 9 months and, subsequently, every 12 months until 165 months. Using these radiographs, measurements of the SVTv and SVTh were obtained using the same markers as Nishimura and colleagues (2006), except using the inferior point of the central incisors instead of the inferior portion of the premaxilla (Fig. 2) (Lieberman et al., 2001).

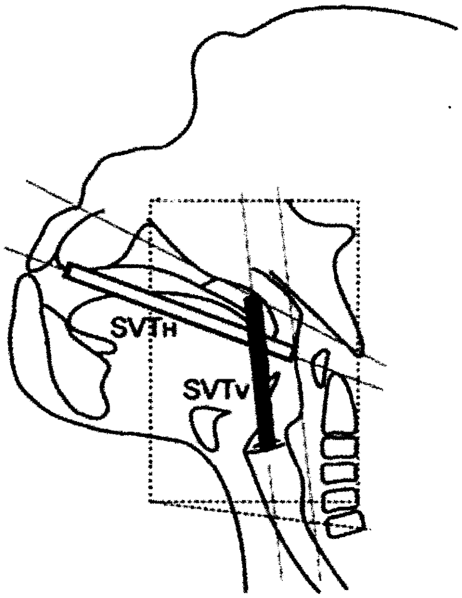

Figure 1. Diagram of Chimpanzee SVTv and SVTh measurements (Adapted from Nishimura et al., 2006).

Figure 2. Landmarks used for SVTv and SVTh measurements (Lieberman et al., 2001).

The third source of data is a graphical representation of vocal tract measurements generated by software-assisted (Labskull) reconstructions of skulls from thirty-two individuals from the work of Granat and colleagues (2007) in their study designed to predict the ability of fossil species to produce speech (Fig. 3). These individuals include chimpanzees, Australopithecines, *Homo ergaster* (Turkana Boy, ca. 1.6 Ma BP), Neandertals(45-90 Ka BP), early modern humans(90-200 Ka BP), modern humans(10-30 Ka BP), and skeletal humans from the present.

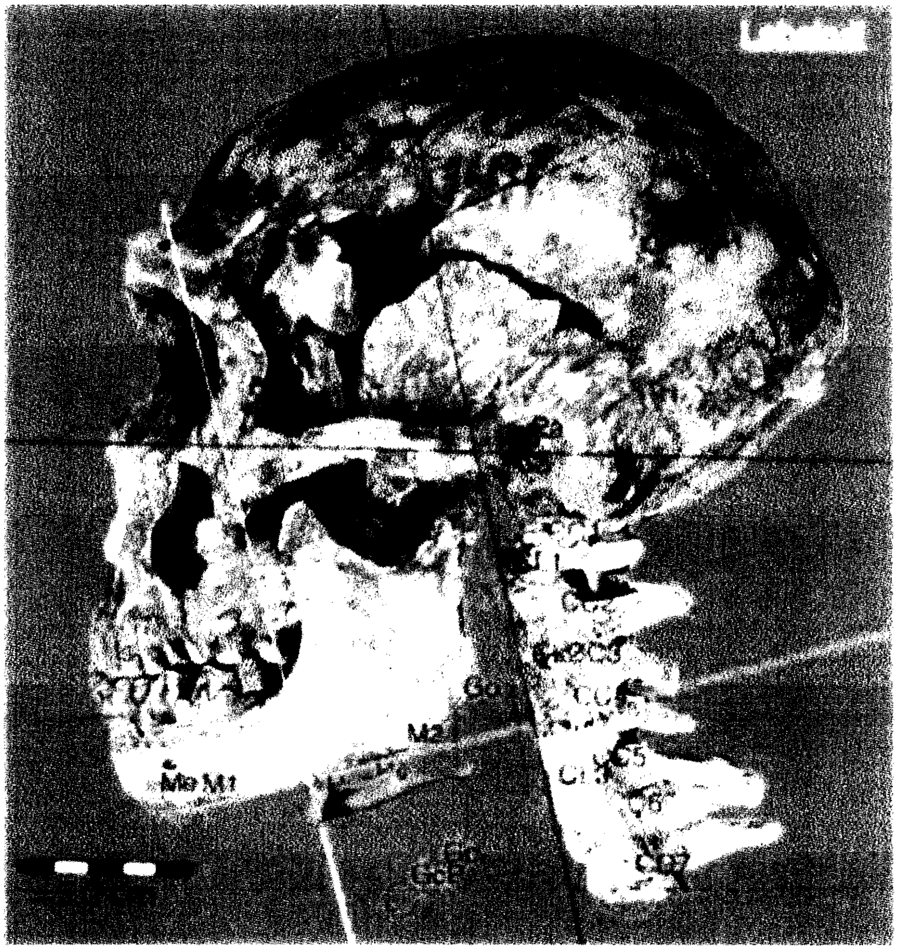

Figure 3. Reconstruction of vocal tract of Neandertal specimen *La Ferrassie* (Granat et al., 2007).

3.2 Data Conversion

Measurements of the SVTh and SVTv portions of the vocal tract were recorded from tables or extrapolated from graphs and rounded to the nearest tenth of a millimeter. SVTv/SVTh ratios were calculated to two decimal places.

Nishimura and colleagues (2006) recorded SVTv and SVTh data in tabular form by age for the three Chimpanzee individuals (two females, one male). The SVTv/SVTh ratio for each individual was calculated from these measurements and recorded by age. These ratios were utilized to determine the developmental pattern of the chimpanzee SVT for comparative purposes.

Lieberman and colleagues (2001) presented the SVTh/SVTv ratio of the 28 individuals for each age as an average by sex in graphic form. In order to extrapolate the required data, the graph was enlarged and a ruler accurate to the nearest millimeter was utilized to extract each value. The present study required converting the SVTh/SVTv ratio to SVTv/SVTh for comparative purposes. The SVTv/SVTh ratios were recorded for each age by sex. Values for individual components of the vocal tract were not extracted because this data set was only used to characterize the developmental pattern of the SVT of modern humans for comparative purposes.

Granat and colleagues (2007) presented the SVTv/SVTh ratio of their 32 skeletal individuals as data points in graphical form. Individual SVTv and SVTh values were obtained from this graph using the same extrapolation method described for the Lieberman graph, and the SVTv/SVTh ratio for each individual was calculated using these values. It should also be noted that in this study the modern human specimens and the human specimens from 10-30 Ka are of European descent. The human group from

90-200 Ka includes the Skhul V specimen, and the Neandertal group contains specimens from Amud and Tabun. As noted earlier, H. ergaster is represented by "Turkana Boy," ca. 1.6 Ma BP.

3.3 Data Storage and Analysis

For each calculated SVTv/SVTh ratio, the following data were recorded in a Microsoft Excel 2003 spreadsheet: species, age (in months, if known), sex (if known), SVTv (except Lieberman et al. data), SVTh (except Lieberman et al. data), SVTv/SVTh, original measurement source (skeletal reconstruction, MRI, radiograph), and authors of the original studies. Graphs were generated using the graphics package, Microsoft Excel, version 2003.

4. Results

4.1 Adult Data

A comparison of the SVTv/SVTh ratio for the six adult hominid groups shows an almost linear increase in the ratio from 0.4 to nearly 1.0 over time, with the exception of the Neandertals who have an average of 0.72 (Fig. 4).

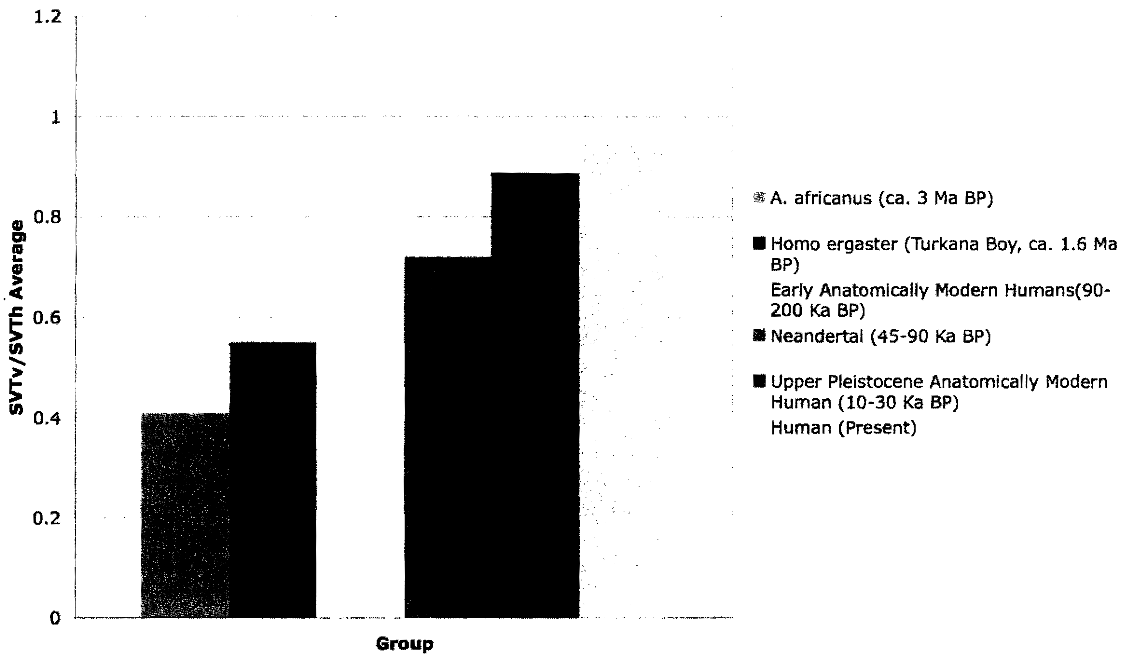

Figure 4. Average SVTv/SVTh Ratio by Group.

An examination of the average vertical vocal tract lengths of the same groups yields an interesting result. The average SVTv length dramatically increases sometime between 1.6 million and 200 thousand years before present and begins to gradually decline until the present. (Fig. 5)

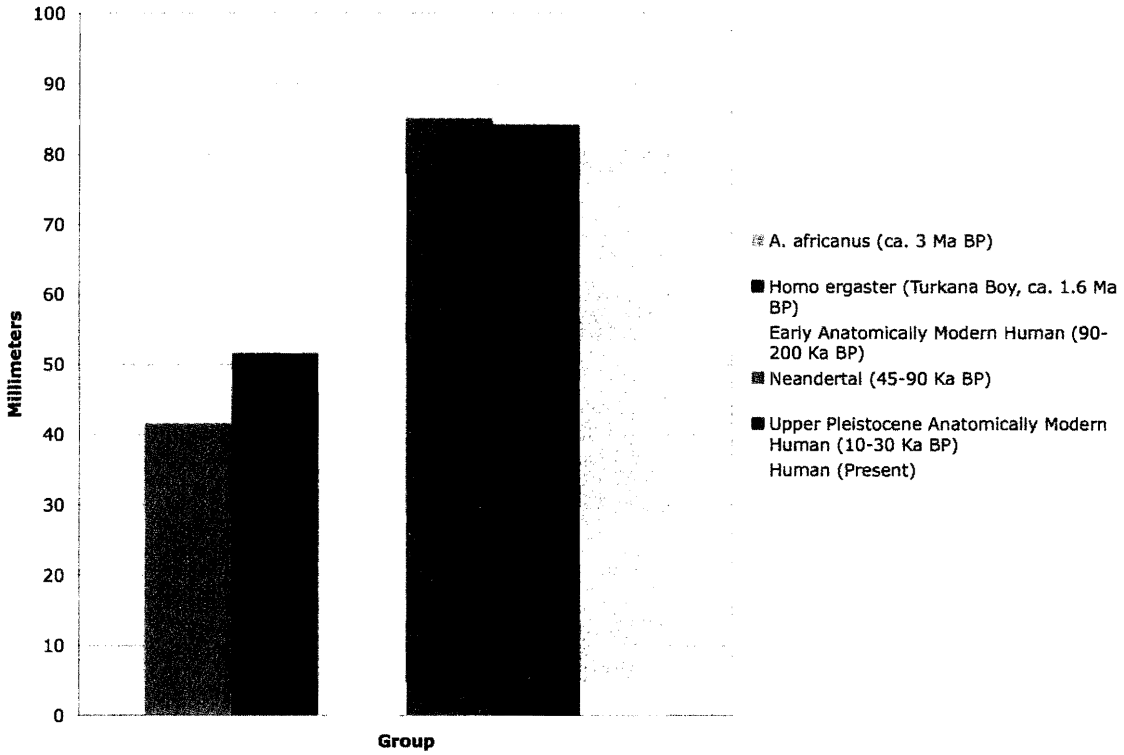

Figure 5. Average SVTv Lengths by Group.

However, an analysis of the average horizontal vocal tract lengths of the same groups yields markedly different results. Figure 6 shows an SVTh length of 102.4 mm for *A.africanus* at 3.3 Ma BP which decreases to 93.2 with the Turkana Boy specimen at 1.6 Ma BP. Specimens classified by Granat and colleagues (2007) as early anatomically modern humans from between 90 and 200 thousand years before present then show an increase in SVTh length to 108.7 mm. Neandertal specimens from between 45 and 90 thousand years before present show a further increase in average SVTh to 118.3mm. The average SVTh length then declines in Upper Pleistocene humans from between 10 and 30 thousand years before present to 94.7 mm and further declines in the modern population to around 84mm.

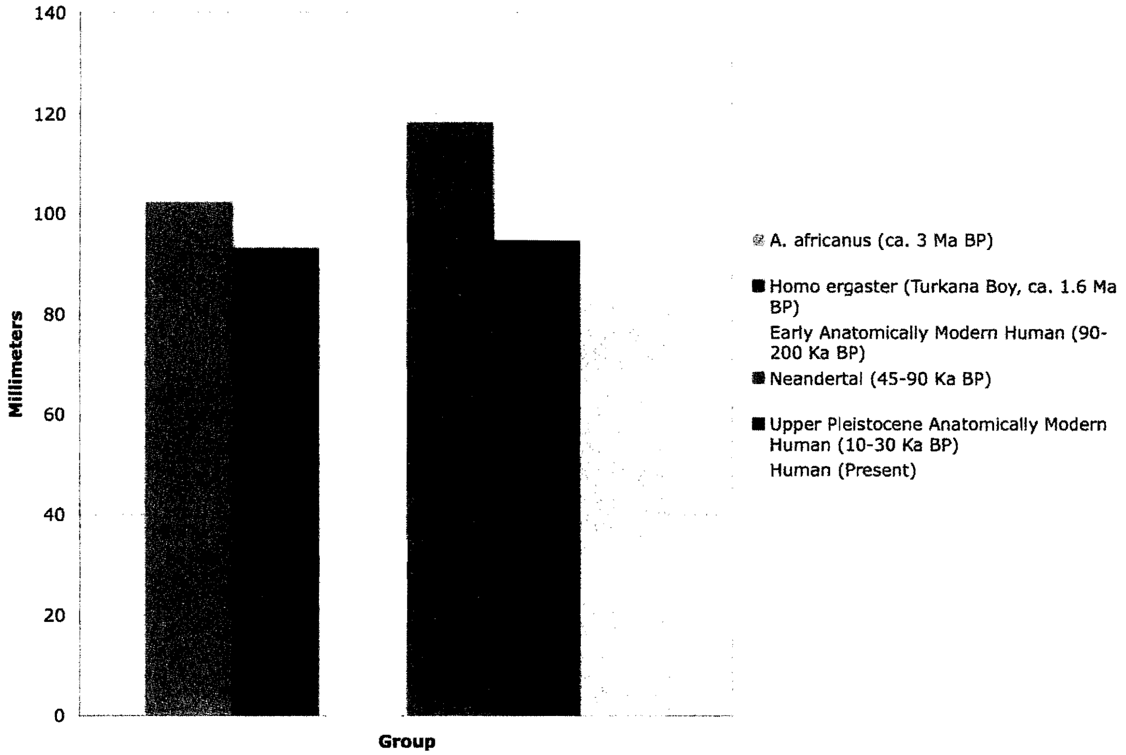

Figure 6. Average SVTh Lengths by Group.

4.2 Developmental Data

An analysis of the SVTv/SVTh ratio in chimpanzees (Fig. 7) shows that at birth their ratios are between .40 and .50, increase early during development, and peak at about 20 months. From this point their SVTv/SVTh ratios decrease until they reach the adult average between .40 and .55. It should also be noted that their adult ratio is similar to their birth ratio.

In contrast, the human development of the SVTv/SVTh ratio is quite different from that of chimpanzees (Fig. 8). The human ratio is near .60 at birth and increases to nearly .75 during the first year. From this point the human SVT ratio stays relatively constant until 60 months of age. After 60 months the human ratio increases steadily to the adult ratio of approximately 1.0 by 9 or 10 years of age.

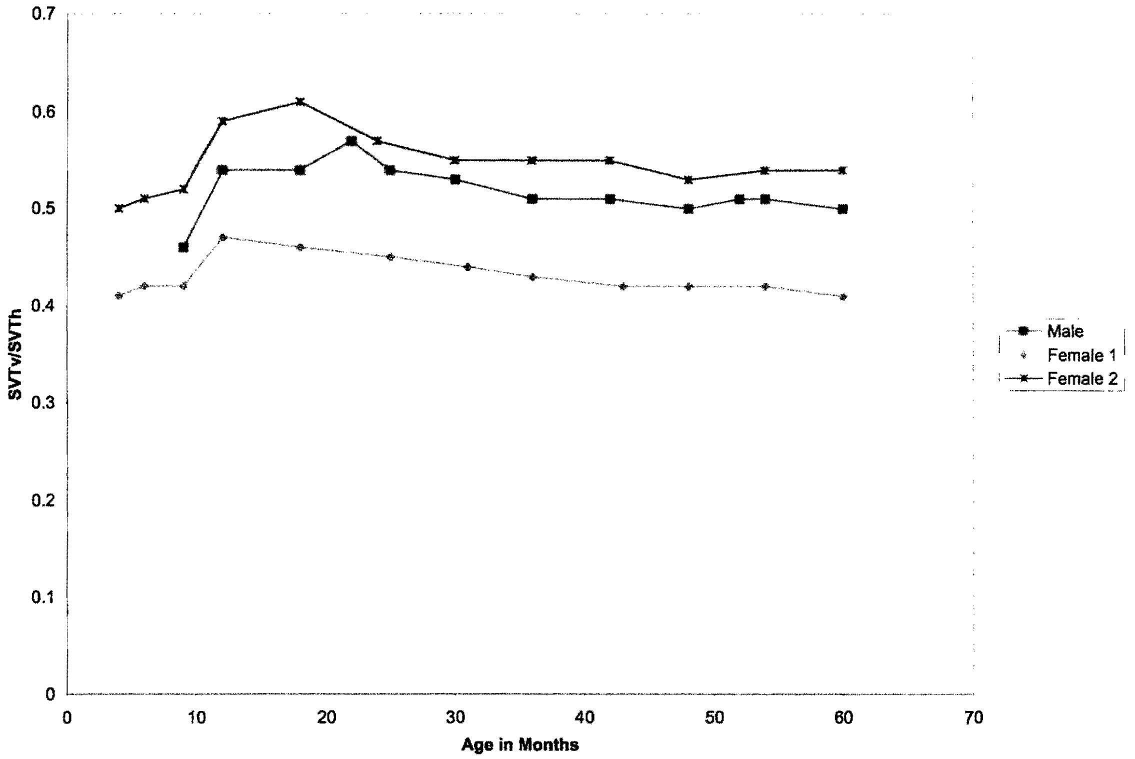

Figure 7. Chimpanzee SVTv/SVTh During Development.

Figure 9 compares the skeletal human and Neandertal data from Granat and colleagues (2007) to the radiograph human data from Lieberman and colleagues (2001). The skeletal human data shows a similar developmental trend as that of the radiograph human data. The Neandertal SVTv/SVTh ratios, however, are much lower. The two Neandertal specimens are estimated at 30 and 84 months of age and show relatively little change in the SVTv/SVTh ratio with a slight increase from 0.48 to 0.49. However, it should be noted that the Neandertal data seems to follow a similar developmental trend as the human data.

An analysis of the individual components of the Neandertal and Human SVT was also necessary for comparative purposes (Figs. 10 and 11). The SVTv length of the young skeletal humans shows an initial length of 26 mm at birth that increases to 38mm by 30 months of age. From this point the SVTv length steadily increases and approaches 50 mm by 120 months. A comparison of the Neandertal SVTv length between 30 and 84 months shows a similar increase to that of humans with average lengths only 4 mm shorter than those of modern humans from the present. The SVTh length of young humans shows an initial length of 44 mm at birth which steadily increases to approach 60 mm around 120 months of age. Similarly, the two SVTH values for the young Neandertals shows a steady increase in length between 30 and 84 months of age. However, in the Neandertals the average lengths are more than 20 mm longer than those of the modern human specimens.

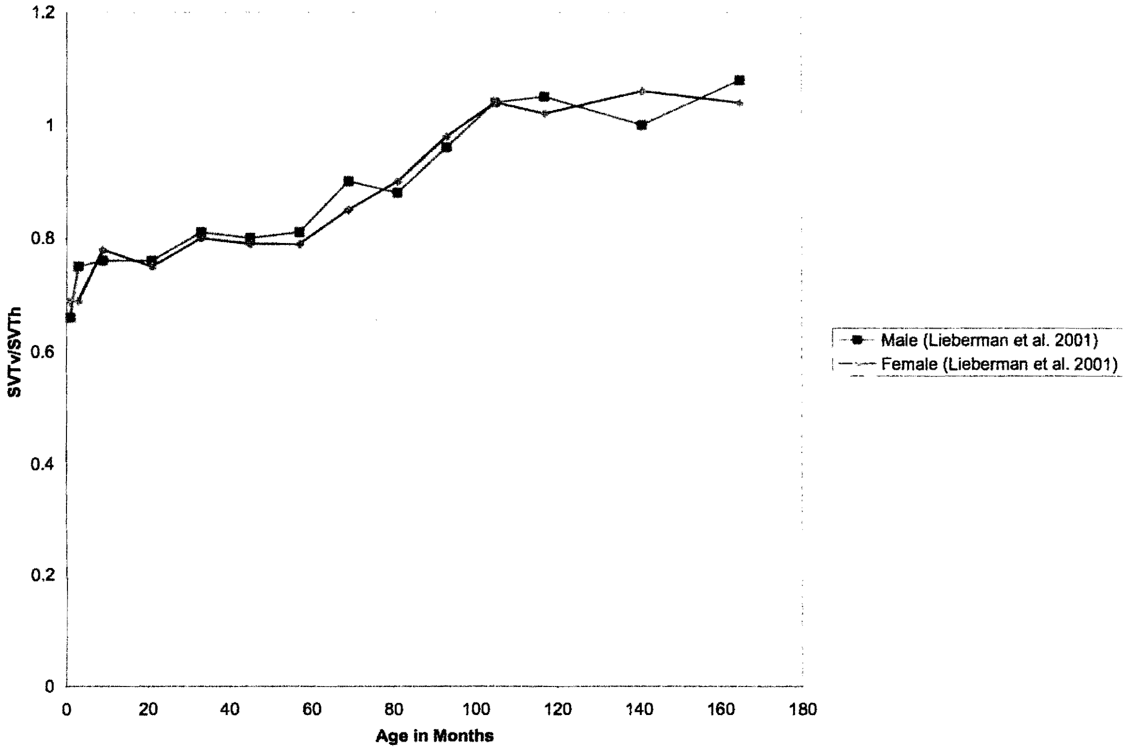

Figure 8. Human SVTv/SVTh During Development.

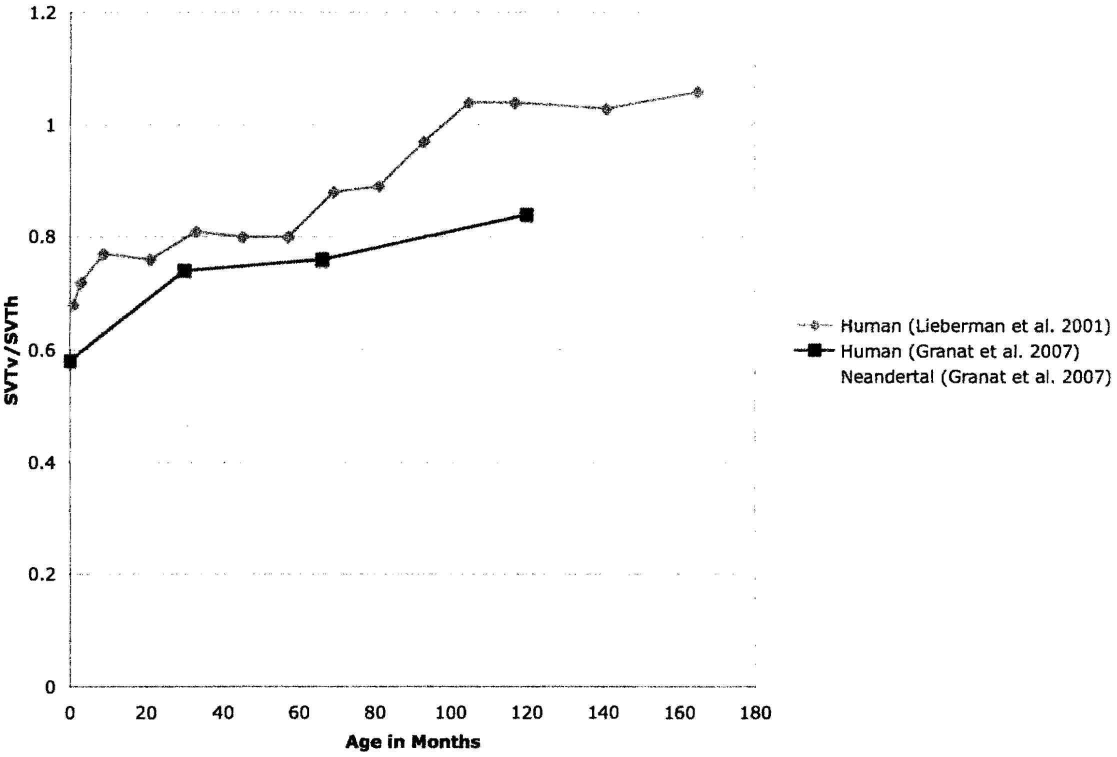

Figure 9. Human and Neandertal SVTv/SVTh Ratio.

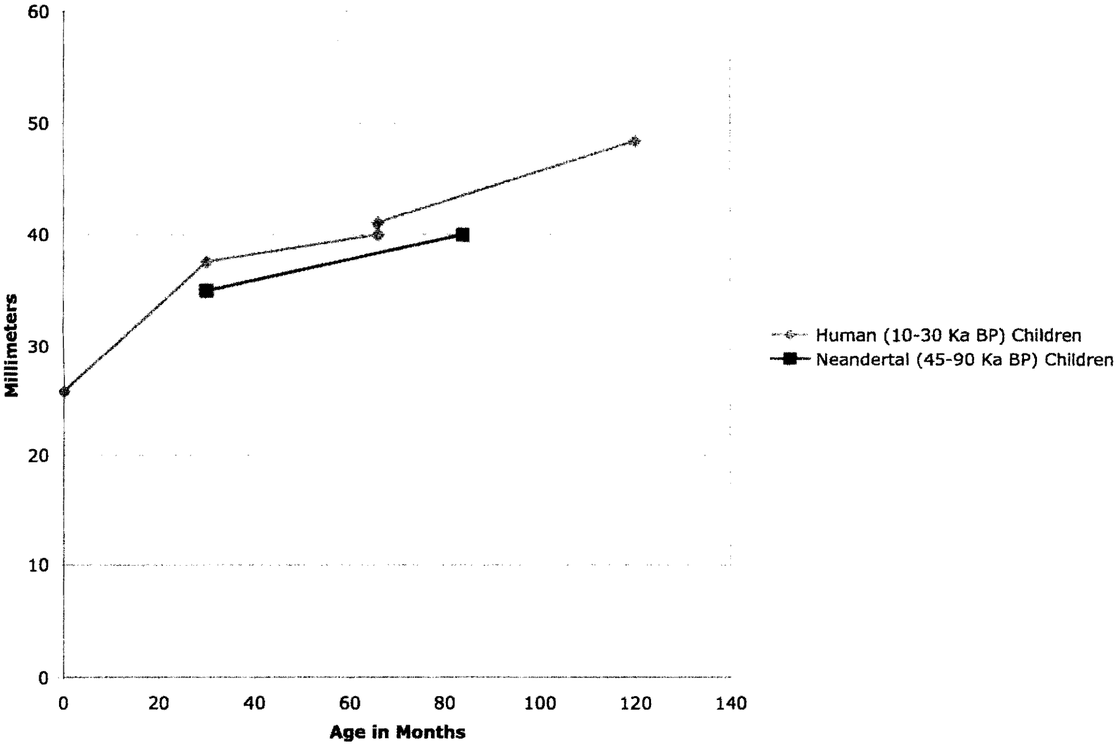

Figure 10. SVTv Length in Modern Human and Neandertal Children.

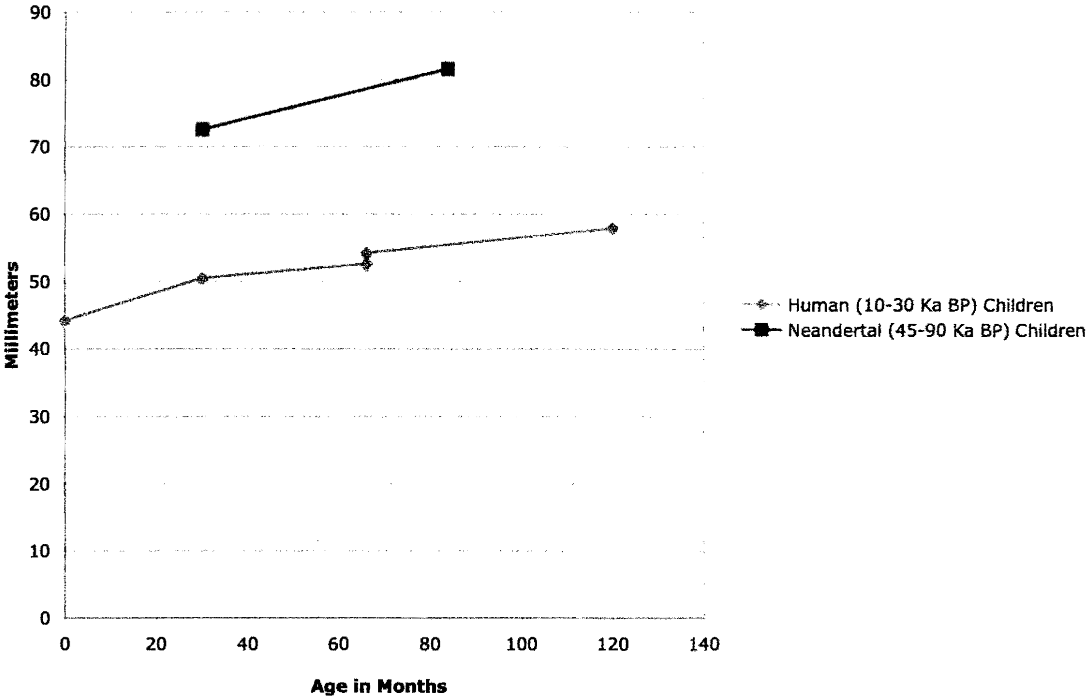

Figure 11. SVTh Length in Modern Human and Neandertal Children.

5. Discussion

5.1 Analysis of Developmental Data

A careful comparison of chimpanzee and human developmental data is necessary to characterize which developmental category best fits the Neandertals. Figures 7 and 8 show the major differences between chimpanzee and human SVT development and configuration. In chimpanzees, the vertical portion of the SVT lengthens at a faster rate than the horizontal portion until around 20 months of age, at which time the horizontal portion begins to lengthen at a faster rate than the vertical portion until the adult ratio is reached. In contrast, the human vertical SVT lengthens from birth at a faster rate than the horizontal SVT until the adult ratio of 1.0 is reached at about 108 months. The major difference between human and chimpanzee SVT development is the rapid growth of the SVTh relative to SVTv in chimps at about 20 months of age which does not occur in humans at any age. Thus, it seems that a lack of facial prognathism in humans, as indicated by their continuously slower SVTh growth rate, results in the SVT configuration conducive to modern speech as also noted by Nishimura and colleagues (2006).

Although the available data is minimal, a comparison of Neandertal developmental data to the human and chimpanzee data is possible. Figure 10 demonstrates that the young Neandertal SVTv/SVTh ratios are far outside the modern human range and more resemble the ratios of the chimpanzees in Figure 7. However, the Neandertal individuals display a gradual increase in the SVTv/SVTh ratio from age 30 to 84 months that matches the continually increasing developmental pattern for the human SVTv/SVTh ratio between the ages of birth and 108 months (Figure 8) and does not match that of the chimpanzees which displays an obvious decrease in SVTv/SVTh ratio between the ages of 18 and 60 months (Figure 7). Figures 10 and 11 represent the respective vertical and horizontal components of the SVT length of Neandertals and humans from the Granat and colleagues (2007) sample. Interestingly, the vertical SVT lengths of humans and Neandertals not only follow a similar pattern of growth but also have values within 4 mm of each other. The horizontal SVT lengths of the two samples also follow a similar pattern of growth, but the Neandertal SVTh length is more than 20 mm longer than the human on average. Although more data will be necessary to fully characterize Neandertal SVT development, an analysis of the available data seems to show that Neandertal SVT development follows a similar pattern as that of modern humans. The primary difference between the two is the elongated SVTh in Neandertals that seems to be consistently larger than modern humans at all ages. Arensburg (1994: 279) further supports this conclusion when he states that "Neandertals are more like modern humans than apes with regard to anatomy and development." However, this elongated SVTh is expected since Neandertals developed significant mid-facial prognathism due to environmental conditions in Upper Pleistocene Europe (Churchill, 1998)

5.2 Analysis of Adult Data

Before analyzing the data from Figures 4, 5, and 6, it is necessary to note that only one specimen each of *Homo ergaster* and *Australopithecus africanus* are represented in these figures. The young age of the Turkana Boy specimen might particularly influence the vertical and horizontal lengths representing the *ergaster* species, since the individual was most likely not fully grown. However, it can be assumed that the SVTv/SVTh ratio is fairly representative of the species since both humans and chimpanzees have reached their adult SVT ratios by the age of 11 years (Lieberman et al. 2001, Nishimura et al. 2006). Figure 5 shows average adult SVTv lengths for six groups. The significance of this data is that a stable vertical component of the SVT length in humans appears to have been in place as early as 200 thousand years ago, if not earlier. In contrast, Figure 6 shows strikingly different results for the horizontal SVT length. As noted by Nishimura and colleagues (2006), a decrease in facial prognathism is characteristic of the evolution of the human lineage. Since the SVTh is measured from the maxillary incisors, it can also be assumed that SVTh length would also decrease over time during the evolution of the human lineage. However, Figure 6 shows a decrease in SVTh length over time with the exception of Neandertals and the human groups immediately before and after them temporally. As already explained in the analysis of the developmental data, an increase in Neandertal SVTh length is expected due to their mid-facial prognathism. This does not, however, explain the increase in the SVTh length of the anatomically modern human specimens from between 90-200 thousand years ago and the humans from 10-30 thousand years ago. Figure 4 shows an increase in the SVTv/SVTh ratios of the six groups approaching the modern ratio of 1.0 over time. The primary exception in this case is again the Neandertals. The lower SVTv/SVTh ratio in Neandertals is, however, expected because of the longer average SVTh length. Thus, while the developmental data indicates that the Neandertals clearly follow a human pattern of development, it also places the SVTv/SVTh ratios of the young Neandertals outside the modern human range for speech even if we conservatively define that range as between .70 and 1.0 (greater than a modern human two year old). The adult data also show that the Neandertals differ from the other hominid groups due to their extended SVTh length. Despite this fact, the adult Neandertal SVTv/SVTh ratios are reasonably within the range for modern speech, unlike the children. Does this observation, however, mean that the Neandertals were capable of fully modern speech?

5.3 Neandertal Speech Capabilities

If an appropriate SVTv/SVTh ratio is considered an accurate prerequisite for the production of fully modern speech as has been proposed, then it appears that Neandertal children would have lacked the ability to produce modern speech while the adult Neandertals would have had the capacity for fully modern speech. If this observation is correct, then several possible scenarios for Neandertal communication are possible, all of which depend on the origin of the vocal capacity for modern speech/language, the development of the neurological capacity for modern speech/language, and the status of Neandertals as either *Homo sapiens* or a separate branch of the *Homo* lineage.

Archaeological and cultural evidence supports the case that some significant form of communication was necessary to maintain the Neandertal lifestyle (Aiello and Dunbar, 1993; Brace, 1999). It would have been necessary for adults to communicate with children, especially for safety reasons. "Language, then reinforces and transmits values and customs in a verbalized whole that constitutes 'culture,'" and "the survival value of being able to take advantage of what culture can provide is obvious" (Brace, 1999:258). It does not seem likely, therefore, that adult Neandertals would have been utilizing fully modern speech if their children could not. Thus, a holistic protolanguage might have been sufficient to maintain the integrity of Neandertal society if group size and culture remained stable (Mithen, 2005). Since modern speech is much more efficient and complex than other forms of communication (Lieberman, 2006), it also does not seem likely that Neandertals would have developed then lost the capacity for fully modern speech due to climactic adaptations. With this idea in mind, it appears that fully modern speech had probably not developed by the time the Neandertals began to significantly adapt to the Late Pleistocene ice age climate nearly 125 thousand years ago.

Anatomical evidence, however, supports the idea that the vocal tract configuration necessary for the production of fully modern speech was in place at least 200 thousand years ago, if not much earlier in the evolution of the *Homo* genus, as some have suggested (Aiello and Dunbar, 1993). Figure 5 shows that the SVTv has been relatively stable for the last 200 thousand years, while Figure 6 shows an overall decline in SVTh beginning atleast 3 million years ago and resulting in the increased facial flattening associated with the ability to produce the sounds necessary for modern vocalization as noted by Nishimura and coauthors (Nishimura et al, 2006). These observervations, thus, seem to support the case for a modern vocal tract as early as 200 thousand years ago. A better characterization of *Homo* specimens prior to 200 thousand years ago will be necessary to properly classify the vocal tracts of these groups with regard to modern speech production. However, if the vocal tract was in place this early but modern speech had not yet in developed, then it seems plausible that the final step toward fully modern speech might have been neurological in nature.

Kramer and colleagues (2001) argue that skeletal remains from the Levant during the Late Pleistocene represent evidence of admixture between Neandertals from Europe and "modern" humans from Africa. Specimens utilized in their study included those from Skhul and Qafzeh, which are typically classified as "modern" humans, and those from Amud and Tabun, which are typically classified as Neandertal. The horizontal SVT data presented in Figure 6 of this study also supports their conclusions because the anatomically modern human group, which includes the Skhul V individual, has a higher SVTh than expected. This higher SVTh might reflect the influence of admixture between "modern" humans and Neandertal groups in the Levant.

Given the likelihood of admixture between "modern" populations from Africa and Neandertals, it seems reasonable to propose that the neurological component necessary for modern speech might have arisen in and been selected for in Africa due to population pressure and the need for increased group size such as that described by Aiello and Dunbar (1993). The neurological capacity for the development of a more efficient form of communication may then have spread into the Levant and throughout other human populations across the old world. This model of speech acquisition would have primarily had a neurological basis and, therefore, would not have required native populations around the world to significantly lose their regional adaptations and, thus, fits well with the multi regional evolution model.

One exception to this model, however, may have been the 'classic' Neandertals of Western Europe. If the neurological capacity for language developed in Africa nearly 200 thousand years ago, it may have taken a significant amount of time for a holistic protolanguage to develop into fully modern speech. Therefore, the admixture of Neandertals in the Levant and "modern" humans from Africa with the neurological capacity for language may have occurred before modern speech had fully developed. This admixture, of which Skhul V seems to have been a product of, would have allowed the Neandertals in the Levant between 90 and 200 thousand years ago not only to acquire the neurological capacity for speech but also to develop a horizontal vocal tract configuration more conducive to speech production. However, by the time modern human groups possessing the neurological capacity for speech reached the Neandertal populations in Western Europe around 45 thousand years ago, modern speech had probably already developed within their groups. Thus, the odds of significant admixture between Neandertals armed only with a holistic protolanguage and modern humans with fully developed speech might have been greatly reduced. While limited admixture probably still occurred between these two groups, the anatomical and neurological limitations of these Neandertals may be an explanation for their rapid decline in Western Europe during the Late Pleistocene.

6. Conclusion

The results of this study comparing the vocal tract anatomies of various hominid groups and chimpanzees raise more questions rather than provide more answers regarding the development of the capacity for modern speech within the *Homo* lineage, in particular Neandertals. Available anatomical data and cultural evidence seem to indicate that the trend toward the development of the modern human vocal tract began as early as 3 million years ago and was in place at least 200 years ago. However, the elongated horizontal vocal tract length of Neandertals due to their development of mid facial prognathism represents a reversal of this trend. Such a reversal seems unlikely if modern human speech had also already developed, because it would have made it difficult, if not impossible, for Neandertal adults to communicate with their children. Thus, it seems more probable that both Neandertals and early modern humans were using some type of proto language for transmission of the information and knowledge necessary for maintaining social and cultural cohesion.

This conclusion suggests that the final step in the development of modern speech might have been neurological. The basis for the acquisition of the neurological component required for the development of modern speech might have been increased population pressure in Africa. Early modern humans, in whom this trait was present, probably moved out of Africa and interbred with existing human populations, and these populations eventually developed modern spoken language. Unlike Neandertal populations in the Levant, the Western European Neandertal populations might have been more isolated and might not have had the opportunity to lose the mid facial prognathism that would have made it more difficult for them to acquire the speech skills that were present in modern human populations about 45 thousand years ago.

Although the acquisition of the final adaptive trait for the development of modern speech most likely occurred in Africa, it was probably not a speciation event but spread out of Africa according to the principles supported by the multi regional evolution hypothesis into populations already possessing the supralaryngeal vocal tract configuration conducive to speech production. What questions, then, should future research be designed to address? The study of language development and speech production should be a multi disciplinary effort. Future studies on the neurological basis for speech and language and further characterization of the capacities of the supralaryngeal vocal tract, particularly of children and skeletal specimen, may be areas for continued exploration of this topic.

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