AN MRI STUDY ON THE RELATIONSHIP BETWEEN ORAL CAVITY SHAPE AND LARYNX POSITION

Kiyoshi HONDA and Mark K. TIEDE

ATR Human Information Processing Research Laboratories
2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0288 Japan

ABSTRACT

Individual variation of larynx position reflects human morphological differences and thus contributes to generating biological information in speech sounds. This study examines the factors of orofacial morphology that co-vary with larynx position based on MRI data collected for 12 Japanese and 12 English speakers. The materials are midsagittal craniofacial images, and the method is based on the measurement of angles and indices. Among all the measures examined, the aspect ratio of the oral cavity showed the highest correlation (r=0.87) with a larynx height index (ratio of arytenoid apex - palatal plane distance and anterior nasal spine - nasopharyngeal wall distance), and a facial angle (angle of maxillary incisor - nasion - nasopharyngeal wall) showed the second highest correlation (r=0.66) with the larynx height index. Since the facial angle is known to be an index of prognathism, the results suggest that larynx position co-varies with oral cavity shape, being higher when the oral cavity develops more forward. This tendency is parallel to the general relationship between the oral shape and larynx position among mammals, and provides a reliable basis for estimation of larynx position in fossil humans.

1. INTRODUCTION

The subject of this study is the interdependencies that control the morphological variation of human vocal tract organs. The size and shape of the vocal tract influence the quality of vocal sounds and comprise the source factors of biological information in speech. Vocal tract size increases with physical development and causes age-related variations in vocal quality. Vocal tract shape also varies with vocal tract development, and it supplements speaker-specific characteristics of speech sounds. The way the orofacial shape affects the sounds is not simple, but it seems to be a complex process involving various morphological factors. As an approach to quantifying these effects various possible shape indices can be examined, as for example the relative dimensions of the horizontal and vertical portions of the vocal tract, or the relative height of the palatal vault. It is likely that these indices are interrelated, and the relationship among the measures should reflect biological constraints determining the range of body shape variation. In this study, we focus on orofacial morphological factors that correlate with individual variation of larynx position measured in a non-phonating rest condition. Statistical analyses are performed to predict larynx height from the orofacial geometry based on midsagittal magnetic resonance imaging (MRI) data.

This study was set forward by a series of x-ray microbeam studies of the relationship between oral cavity shape and speaker characteristics of vowel sounds (Honda *et al*. 1996, Honda *et al*. 1997). Previous related work includes an EPG study (Perkell 1979), and a transverse MRI study (Tiede 1998). The results obtained by the x-ray studies for Japanese and English speakers can be summarized as follows: 1) the major variation of the oral cavity shape in lateral x-ray scans is represented by the aspect ratio of the antero-posterior and vertical dimensions of the bony framework of the oral cavity, and 2) averaged formant frequencies of the point vowels reflect the aspect ratio thus measured; i.e. the first formant is higher when the oral cavity is flat, and vice versa. The crucial piece of vocal tract shape information that was unavailable in the x-ray microbeam investigation was the position of the larynx. In this study, we aim at establishing a method for predicting larynx position from the orofacial geometry based on midsagittal craniofacial MRI data collected for the same language groups. In addition, we expect from this study to identify certain regularities of morphological variation in the orofacial structure as anthropological evidence that bridges the evolution of speech organs and the origin of human speech.

2. MATERIALS AND METHOD

The materials of the present study are midsagittal MRI data collected from 12 Japanese (mongoloid) and 12 English (caucasoid) speakers collected in a resting (non-phonating) condition. The instrument used is a Shimadzu clinical MRI scanner (1.0 Tesla) installed at Takanohara Chuo Hospital (Nara, Japan). The Japanese group includes two females and ten males, and the English group includes three females and nine males. The age of the subjects ranges from 23 to 48. The data were collected using a variety of scanning protocols, with resolution of approximately 1 mm/pixel and excited slice thickness ranging from 3 to 10 mm.

The digital images were displayed on a monitor screen to identify anatomical landmarks used to derive angular and linear measurements. Landmarks and measurements were made independently by the two authors and averaged for the results reported here. Figure 1 shows an example of landmark identification. The analysis method used in this study deviates slightly from standard cephalometric procedure (e.g. Rakosi 1982) in that the landmarks and lines were chosen to be compatible with those used in the previous x-ray microbeam studies. The standard plane is the palatal plane defined by a line through the anterior nasal spine (ANS) and posterior nasal spine (PNS). The intersection of this line and the posterior nasopharyngeal wall is a boundary of the oral cavity, referred to as NPW in this study. The distance between ANS and NPW is the reference measure for linear analyses. The reference line for measuring facial angles is the line from nasion (point of the frontal sinus wall near the soft tissue nasion) and the tip of the maxillary incisor. The landmark for larynx height was set at the apex of arytenoid tissue that could be recognized most reliably from midsagittal MRI data. The following measurements are derived from these landmarks.

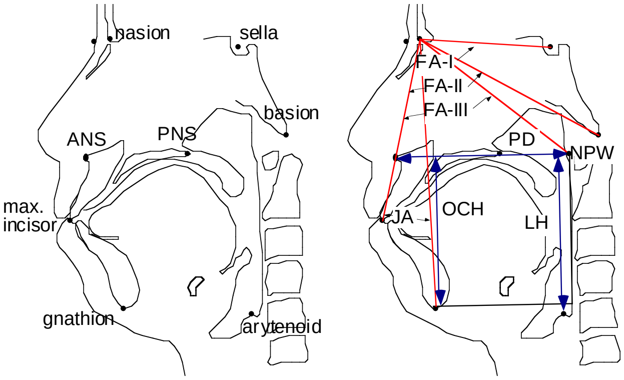

Figure 1: Anatomical landmarks (left) and line drawings for angular or linear measurements (right).

Three linear measurements were obtained:

- PD (palatal distance): ANS – NPW distance
- LH (laryngeal height): arytenoid apex – palatal plane distance
- OCH (oral cavity height): gnathion – palatal plane distance

Using these two linear indices were derived:

- LHI (larynx height index): LH / PD
- OCI (oral cavity index): OCH / PD

Five angular measures were obtained:

- FA-I (facial angle): max. incisor - nasion - sella
- FA-II: max. incisor - nasion - basion
- FA-III: max. incisor - nasion - NPW
- PA (pharyngeal angle): palatal plane / pharyngeal wall
- JA (jaw angle): max. incisor - nasion - gnathion

The present investigation employs 1) description of the range of variation, 2) correlation analysis for the relationship among the angular and linear measures, and 3) multiple regression analysis to predict LHI from other measures.

3. RESULTS

1. Range of Variation

Larynx Height Index (LHI)

The morphological correlates of this index are the target of this analysis. Roughly speaking, LHI gives the ratio of vertical to horizontal lengths of the vocal tract, and the value is greater when the larynx position is lower, or the oral cavity is shorter. The index ranges from 0.83 to 1.25 across all subjects, with female subjects tending to have smaller values. Figure 2 shows midsagittal images for two male subjects representing the range of LHI values.

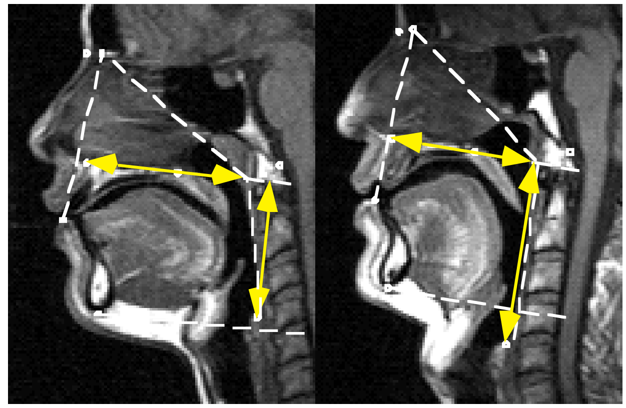

Figure 2: Two male subjects with contrasting Larynx Height Index (LHI) values (left: 0.86; right: 1.25).

Oral Cavity Index (OCI)

This index is the ratio of the vertical height of the oral cavity to the antero-posterior length of the oral cavity roof. It ranges from 0.78 to 1.09; smaller values indicate a flat oral cavity shape. The two subjects shown in Figure 2 also show contrasting OCI values.

Facial Angles (FA-I, FA-II, FA-III)

These three angles indicate the antero-posterior expansion of the skull base and provide an index of prognathism. Among these angles, FA-III is the one that can be obtained from x-ray microbeam data. It ranges from 52.5 to 68.0 degrees. Larger values indicate greater antero-posterior expansion of the facial cranium. Figure 3 shows images for two male subjects representing the range of FA-III values.

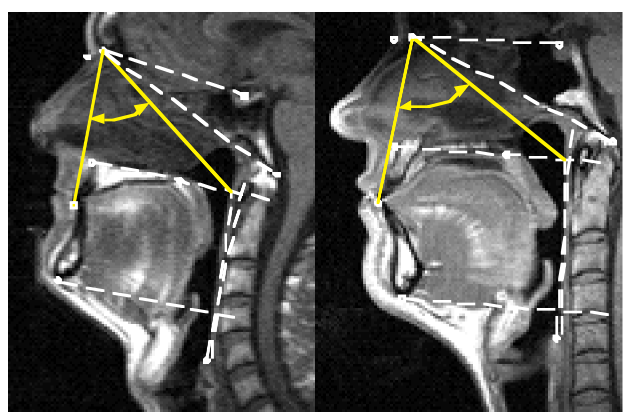

Figure 3: Two male subjects with contrasting Facial Angle (FA-III) values (left: 52.5; right: 62.5).

Pharyngeal Angle (PA)

This angle indicates the orientation of the cervical spine relative to the palatal plane. It ranges from 79.8 to 102.3 degrees. Smaller values indicate a sharper vocal tract angle. It also means that the vocal tract is longer if larynx position is at the same level. Figure 4 shows images for two male subjects representing the range of PA values.

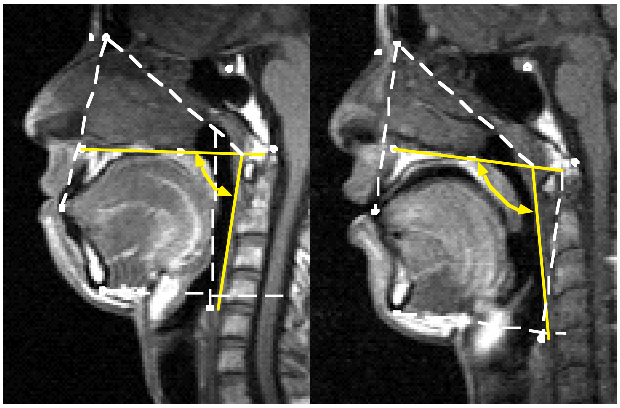

Figure 4: Two male subjects with contrasting Pharyngeal Angle (PA) values (left: 79.8; right: 100.0).

Jaw Angle (JA)

This angle indicates the orientation of the mandibular symphysis relative to the maxillary incisor - nasion line. It ranges from 0.1 to 15.0 degrees. Larger angles indicate mandibular retrognathism. Figure 5 shows images for two male subjects representing the range of JA values.

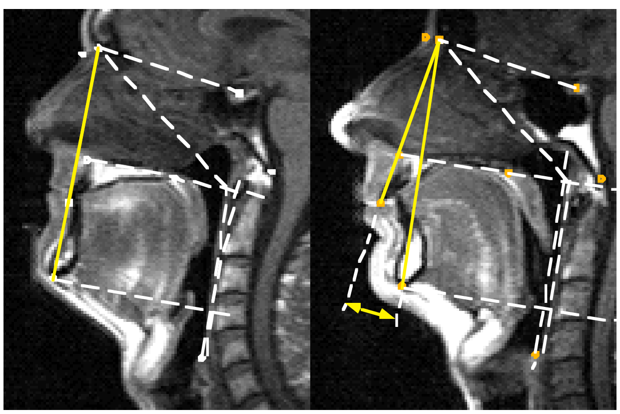

Figure 5: Two male subjects with contrasting Jaw Angle (JA) values (right:0.1; left: 11.5).

Summary of Derived Measures

The average values for the principal derived measures are summarized in Table 1 below:

	LHI	OCI	FA-III
Female	0.95	0.87	60.54
Male	1.05	0.93	60.32
Mongoloid	1.02	0.94	60.91
Caucasoid	1.03	0.89	59.82
All	1.03	0.92	60.37

Table 1: Summary of averaged derived measures

2. Single Correlation Analysis

A single correlation analysis was performed between LHI (Larynx Height Index) and other measures, with highlights shown in Table 2. OCI (Oral Cavity Index) and FA-III (max. incisor - nasion - NPW angle) showed the highest correlation with LHI.

	LHI	OCI	FA-II	FA-III	PA	JA
LHI	1					
OCI	0.87	1				
FA-II	-0.52	-0.33	1			
FA-III	-0.66	-0.72	0.73	1		
PA	0.33	0.45	-0.30	-0.61	1	
JA	-0.43	-0.46	0.58	0.72	-0.28	1

Table 2: Correlation matrix of derived measures.

Figures 6 and 7 illustrate these relationships graphically. Since both OCI and FA-III are good indices of prognathism, this result suggests that prognathic speakers tend to have a higher larynx position and/or a shorter oral cavity.

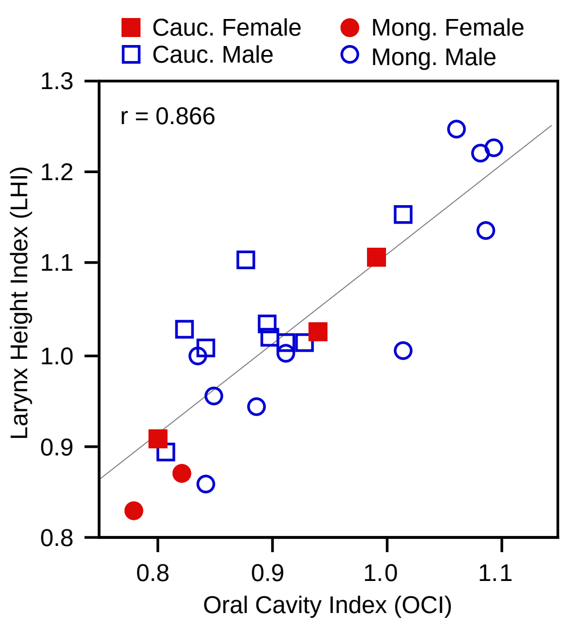

Figure 6: Positive correlation between LHI (Larynx Height Index) and OCI (Oral Cavity Index).

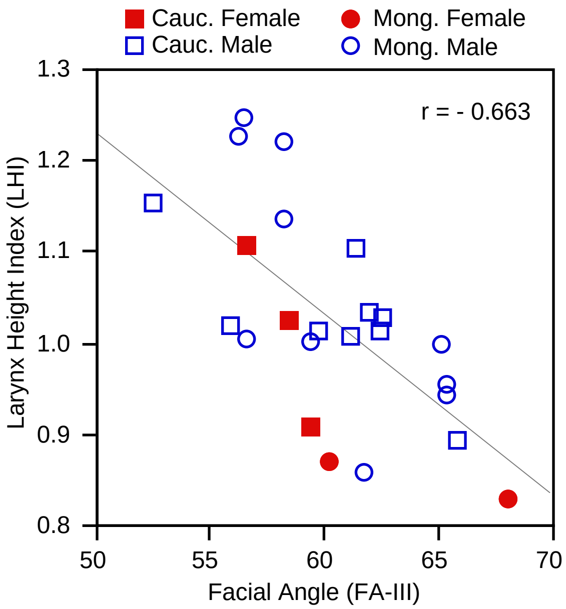

Figure 7: Negative correlation between LHI (Larynx Height Index) and FA-III (max. incisor-nasion-NPW angle).

3. Multiple Regression Analysis

A multiple regression analysis was performed to obtain a statistical model for predicting LHI from the other morphological measures and additional biological factors (age, sex, and ethnicity). Since the correlation among the independent variables is relatively high, a stepwise analysis was performed to include only two independent variables in two conditions with OCI and FA-III as forced variables. When OCI is the forced variable, FA-II was included in the model as the second independent variable, with $r^2 = 0.814$. When FA-III is the forced variable, subjects' sex was the second independent variable, with $r^2 = 0.551$. In both cases, the contribution of the second factor to the model was small. Ethnicity was not a significant factor.

4. DISCUSSION

The above results indicate that larynx height is dependent on the orofacial geometry, and that its individual variation can be predicted from linear or angular measurements on midsagittal cross-sectional images. The correlation analyses revealed that larynx height can be predicted either by the aspect ratio of the oral cavity (OCI) or the antero-posterior dimension of the facial cranium (FA-III). Since these parameters indicate the degree of retrognathism or prognathism, it may be concluded that the individual variation in larynx height reflects the variation of facial geometry between prognathic and retrognathic types.

OCI is a good predictor of larynx height, and this fact can be used to estimate larynx position of a speaker from the shape of the oral cavity. In this study, the measures of larynx height were obtained in supine position and thus they may differ from larynx position in a natural speaking condition. Despite this limitation, the estimate of larynx position can be used to obtain an approximate size of the vocal tract. It provides a useful supplement to the articulatory data from the x-ray microbeam system, since the oral cavity dimension can be measured from the lateral scan images.

FA-III is another predictor of larynx height, although less reliable than OCI. This measure can be used to estimate larynx position when the data for the mandible is not available, and is therefore a possible index for estimating larynx position for cranial samples in anthropological studies, as with fossil skulls of archaic humans. The correlation of facial protrusion and high larynx position is a general morphological tendency across mammalian species. It appears that this tendency also extends to humans as a causal factor of individual variation in vocal tract shape.

5. REFERENCES

1. Honda, K., Maeda, S., Hashi, M., Dembowski, J.S., and Westbury, J.R. "Human palate and related structures: their articulatory consequences," ICSLP96 Proceedings: 784-787, 1996.
2. Honda, K., Hashi, M., and Westbury, J.R. "Effect of the size and form of the orofacial structure on vowel production," J. Acoust. Soc. Am., 102, Pt. 2: 3133, 1997.
3. Perkell, J.S., "On the nature of distinctive features: implications of a preliminary vowel production study," in *Frontiers of Speech Communication*, B. Lindblom and S. Öhman, Eds., Academic Press, New York: 365-380, 1979.
4. Rakosi, T. *An Atlas and Manual of Cephalometric Radiography*. Wolfe Medical Publications, London, 1982.
5. Tiede, M., "Palate shape effects on characteristic vowel tongue postures," 16th ICA/135th ASA Joint Meeting Proceedings: 1285-1286, 1998.