Ann. Bull. RILP, No. 13, 43-51 (1979)

PHARYNGEAL WALL MOVEMENT DURING SPEECH

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Although the articulatory movement of the velum has been studied by many investigators, the significance of pharyngeal wall movement seems to have been overlooked. When we consider that the pharyngeal cavity behaves as a resonator, the movements of the cavity wall must be important in shaping the resonating cavity, and should be investigated. In this study, the articulatory gestures of two different parts of the pharyngeal wall, i.e., the lateral wall of the epipharynx and that of the mesopharynx were investigated. The main question was whether the movement pattern of the mesopharyngeal wall is the same as that of the epipharyngeal wall. If not, what is the main role of the mesopharyngeal wall from the viewpoint of speech production?

It is well known that sphincteric velopharyngeal closure during oral articulation is performed by the combination of the medial movement of the lateral wall of the epipharynx and superoposterior movement of the velum. Recently, we have reported [1] that these two movements, although in different directions, are identical in time course and induced mainly by the levator veli palatini muscle. In other words, velopharyngeal closure is achieved almost solely by the contraction of the levator veli palatini muscle. We have also reported that the constrictor muscle, which moves the mesopharyngeal wall, does not contribute to velopharyngeal closure during speech. These results are in agreement with the anatomical studies of Honjo [2] and Dickson [3]. Since the constrictor muscle runs semicircularly forming the posterior and lateral walls of the mesopharynx, the contraction of this muscle causes narrowing of the cavity. It is reasonable then, to hypothesize that the constrictor muscle has some effects on vowel production.

Experiment

In order to test the above hypothesis, it was necessary to monitor the movement of the lateral wall of the epipharynx (LWE) and the lateral wall of the mesopharynx (LWM) simultaneously. For this purpose, a specially designed fiberscope [4] having two image guides connected to one eye piece was used. By using this special fiberscope, two different articulators can be observed simultaneously and taken on the same frame of the movie film. For this particular study, one of the two image guides was inserted into the subject's nostril and positioned with its objective lens tip near the posterior border of the hard palate, providing a view of the vertical excursion of the velum as well as the side-to-side movement of the LWE. The other image guide was fixed to a tongue depressor to stabilize it and inserted into the subject's oral cavity to provide the side-to-side movement of the LWM.

A cinefilm was taken at the rate of 25 frames per second during speech production. Synchronizing pulses were generated frame-by-frame from the camera and recorded on a multi-channel data recorder along with the speech sounds. Using this pulse train, we were able to relate each frame to its corresponding speech sound accurately and easily.

To identify the muscle activity which may induce these articulatory movements, electromyographic (EMG) recordings were obtained by means of the hooked-wire technique from two different levels of the superior constrictor muscle (at the level of the velopharyngeal closure and at the level of the mesopharynx) and from the levator veli palatini muscle. Electrode placements were verified by observing the increasing activity when the subject performed some extreme, non-speech gestures (for example, Valsalva maneuver, swallowing, etc.).

A small laboratory computer was used to calculate the average EMG pattern. The subjects for this study were two native speakers of standard Japanese who had no apparent pathology.

The utterances used in this experiment were:

1. Sustained Japanese vowels

   /a/, /i/, and /u/

2. Nonsense CVC syllable strings

   /pan pan pan/, /pin pin pin/, /pun pun pun/

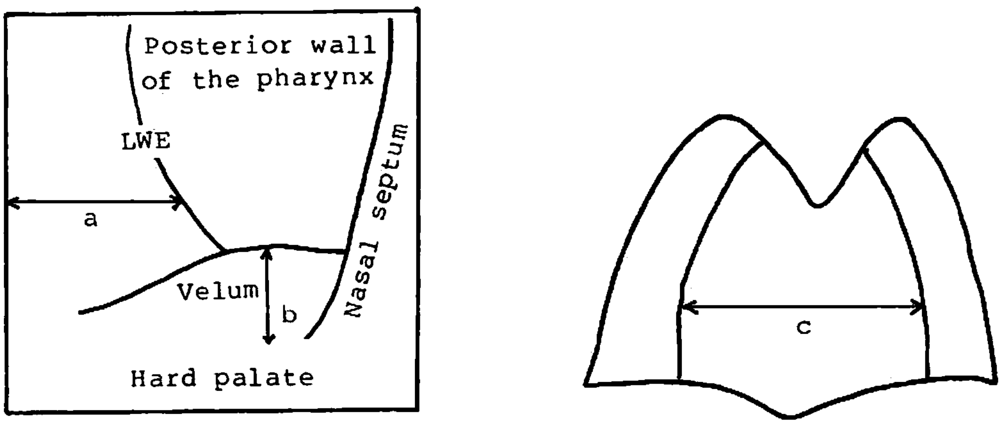
   /han han han/, /hin hin hin/, /hun hun hun/

These speech samples were uttered twice for filming and ten times for EMG recordings.

Results

1. Movement patterns of the lateral pharyngeal wall

In order to describe lateral wall movement, the medial displacement of the LWE and LWM were measured frame-by-frame. In addition, the vertical displacement of the highest observed point of the velum was also measured frame-by-frame. The parameters used for measuring the displacement of each articulator are shown in Figure 1.



a: Distance between the reference line and the LWE along the 50% level line of the full excursion of the velum.
b: Distance between the highest observed point on the velum and the level of the hard palate.
c: Distance between the right and left posterior fauces.

Fig. 1 : Schematic drawing of a frame.

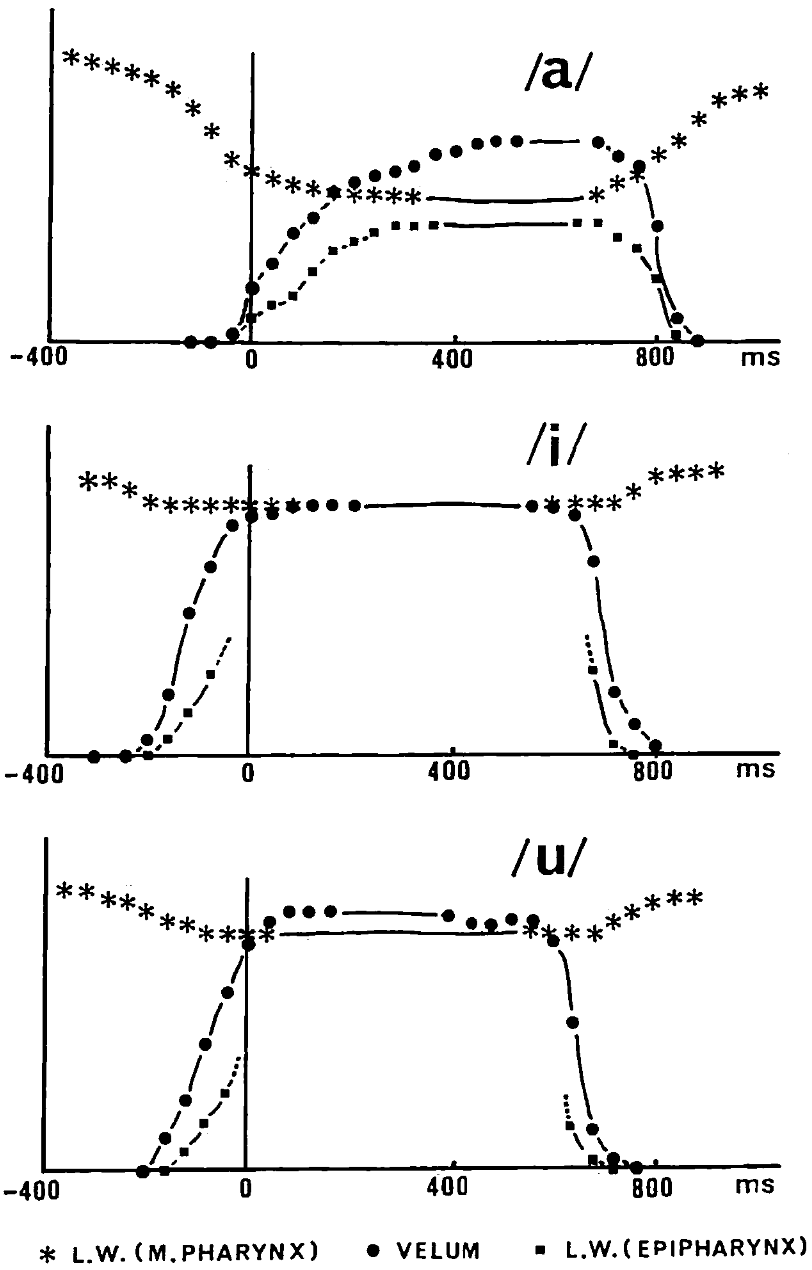


Fig. 2: Movement patterns of the velum, mesopharyngeal wall and epipharyngeal wall for sustained vowels.

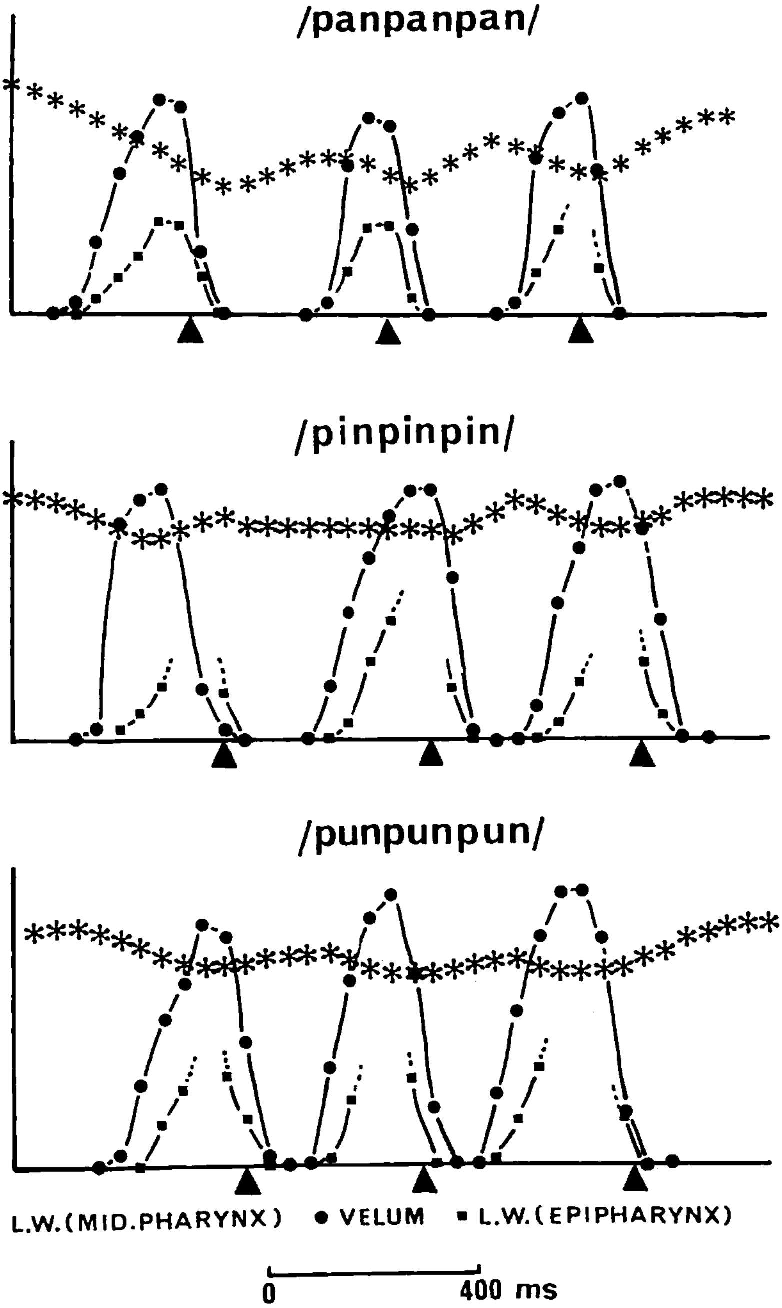


Fig. 3: Movement patterns of the velum, mesopharyngeal wall and epipharyngeal wall for nonsense syllables.

Figure 2 shows the displacements of each articulator for the three different sustained vowels /a/, /i/ and /u/ from top to bottom. The medial displacement (downward in the figure, indicated by *) of the LWM is greater for /a/ than for /i/ and /u/. Conversely, the medial movement of the LWE (upward in the figure, indicated by ■) and the elevation of the velum (indicated by ●) are smaller for /a/ than for /i/ and /u/. The missing data points for the LWE indicate that the measurement point on the LWE was hidden behind the highly elevated velum. Since the movement patterns of the LWE and the velum are identical [1)] we may interpret the vertical movement of the velum as a substitutive parameter for the horizontal movement of the LSW.

Figure 3 shows the movement patterns for the CVN syllable strings. The vowel onset in each syllable is indicated by ▲ on the abscissa. The LWE and the velum start simultaneously to close the velopharyngeal port for the stop /p/ and open it for the nasal /N/. On the other hand, the LWM moves medially at the initiation of the utterance (downward in the graphs) and keeps that position with little fluctuation throughout the utterance. The overall medial excursion of the LWM is greater for the syllable string with vowel /a/ than for those with vowels /i/ and /u/, which parallels the data for the sustained vowels /a/, /i/ and /u/. The observed differences in the degree of excursion for the different vowels are assumed to reflect the various sizes of the pharyngeal cavity for vowel productions, i. e, , /a/ must have a narrowed back cavity, and /i/ and /u/ must not.

The medial displacement of the LWM (indicated as troughs in the graph) reaches the maximum immediately after the peaks of the vertical displacement of the velum. This also suggests that the medial movement of the LWM corresponds to the vowel articualtion. For /pin pin pin/ and /pun pun pun/ cases, the timing relationship between LWM and the velar movement is not as consistent as for the /pan pan pan/ case. This might be due to the tongue-depressor's interference with articulatory movement.

2. EMG findings

Since the muscle layer of the posterior pharyngeal wall consists of only the superior constrictor muscle, the EMG signals from the electrodes in the posterior pharyngeal wall could not be anything other than the superior constrictor muscle. In other words, there is no possibility of contamination from any other muscle EMG .

Figure 4 shows the EMG activity for swallowing which requires the strong constriction of the velopharyngeal port. The superior constrictor muscle became active at both levels, i. e., at the mesopharynx and at the velopharyngeal closure. This indicates that the electrode positioning was correctly done.

For sustained vowels, the superior constrictor muscle is active at the mesopharyngeal level and not at the level of the velopharyngeal port. The level of EMG activity is greater for /a/ than for /i/ and /u/ (Figure 5). This EMG data parallels the movement data of the LWE.

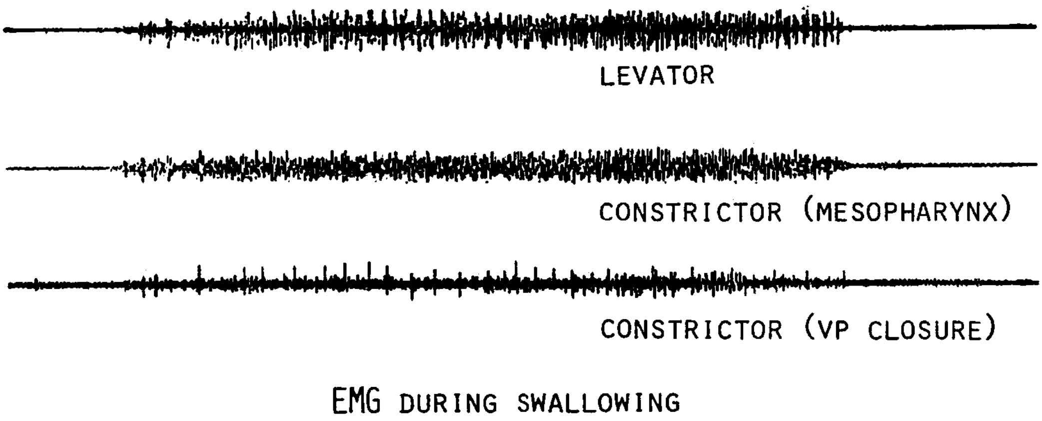


Fig. 4: EMG from the levator veli palatini muscle and two different levels of the superior constrictor muscle.

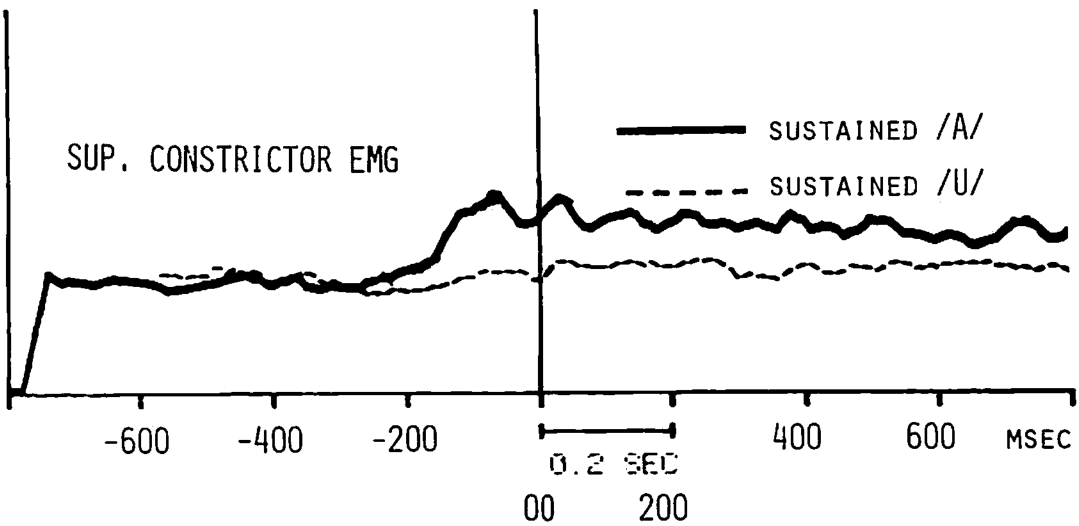


Fig. 5 : Averaged EMG patterns for different vowels.

Figure 6 shows the EMG activity for the CVN strings. Since the electrodes to the pharyngeal muscles necessarily pass through the oral cavity, syllable strings beginning with /h/ were used to avoid mechanical artifacts in the EMG signals for the CVN syllable strings.

It is clear that the superior constrictor EMG does not show the segmental pattern for each syllable.

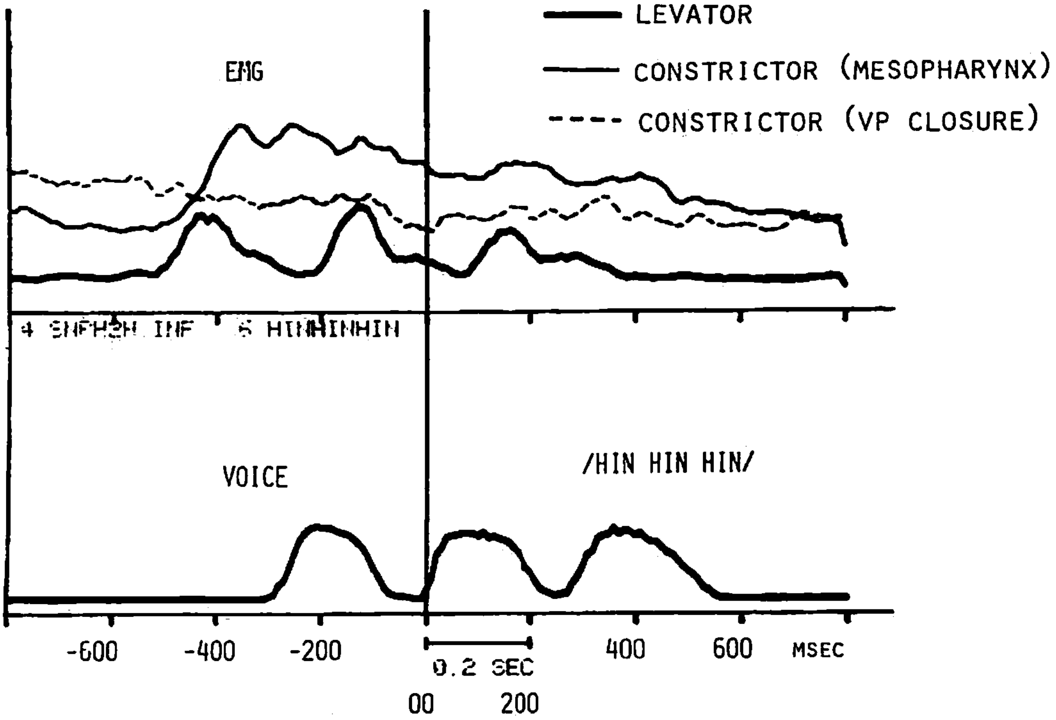


Fig. 6: Averaged EMG pattenns for a nonsense syllable and audio-envelope.

Discussion

It has been known that velar elevation varies depending upon the oral cavity constriction of an oral segment [6, 7, 8, 9, 10, 11, 12, 13]. Velar elevation is higher for obstruents than for high vowels, and also higher for high vowels than for low vowels. The present data also supports the observation that the velum is higher for /i/ and /u/ than for /a/. In addition, the LWE shows greater medial excursion for /i/ and /u/ than for /a/. We conclude that both velar elevation and medial displacement of the LWEare cuased by the contraction of the levator veli palatini muscle and result in the tight closure of the velopharyngeal port. For high vowels such as /i/, tight closure of the velopharyngeal port is required to prevent nasalization, while the LWM moves less medially for /i/ than for /a/. Thus, we have demonstrated that the LWE and LWM behave differently during speech and conclude that the LWE is directly related to velopharyngeal port function and that the LWM has a role in characterizing the vowels.

The movement pattern of the LWM for /pan pan pan/ (the top curve in Figure 3) indicates the vowel dependency of this structure most clearly, i. e., the peaks of the velar elevation and the LWE movement correspond to the /p/ gesture and the peaks of the LWM movement (shown as a trough in the graph) correspond to the vowel segments.

Electromyography from the superior constrictor muscle also indicates the vowel dependency (Figure 5). For CVN syllable strings, the levator veli palatini muscle shows stronger activities for oral segments than for the nasals. However, the superior constrictor muscle at the level of the mesopharynx is active throughout the utterance (Figure 6), because the pharyngeal wall is displaced medially for vowel production and is indifferent to the nasal-oral distinction.

Summary

1. The lateral wall of the epipharynx and that of the mesopharynx behave differently during speech articulation.
2. The articulatory adjustment of the lateral wall of the mesopharynx is related to vowel distinctions, and unrelated to the velopharyngeal closure mechanism.
3. The function of the superior constrictor muscle during speech articulation is vowel dependent.

References

1) Niimi, S. and F. Bell-Berti: An EMG - air pressure - movement study of velopharyngeal closure in speech. 3rd International Congress on Cleft Palate and Related Craniofacial Anomalies. 1977 Toronto, Canada.

2) Honjo, I. et al: Role of the levator veli palatini muscle in movement of the lateral pharyngeal wall. Arch. ORL. 212: 93-98, 1976.

3) Dickson, D. R.: Anatomy of the normal velopharyngeal mechanism. Clin. Plast. Surg. 2: 234-248, 1975.

4) Niimi, S. et al: Stereo-fiberscopic investigation of the larynx. JASA, 60, suppl. 1, 1976.

5) Hirose, H.: Electromyography of the articulatory muscles: Current instrumentation and technique. Haskins Laboratories Status Report on Speech Research, SR 25/26, 73-85, 1971.

6) Czermak, J. N.: Wesen und Bildung der Stimm und Sprachlaut: Czermak's gesammlelte Schriften, Vol. 2. Leipzig, Wilhelm Engelman 1869.

7) Moll, K. L.: Velopharyngeal closure on vowels. JSHR : 5: 30-77, 1962.

8) Bzoch, K. R.: Variations in velopharyngeal valving: The factor of vowel changes. Cleft Palata Jour. 5:211-218, 1968.

9) Lubker, J. F.: An electromyographic-cineradiographic investigation on velar function during normal speech production. Cleft Palate J. : 5: 1-18, 1965.

10) Fritzell, B.: The velopharyngeal muscles in speech: An electromyographic and cineradiographic study. Acta Otolaryngologica Supple. 250, 1969.

11) Isshiki, N. et al: Cineradiographic analysis of movement of the lateral pharyngeal wall. Plastic Reconstr. Sug. 44; 357-363, 1969.

12) Sawashima, M. and T. Ushijima: Use of the fiberscope in speech research. RILP, No. 5; 25-34, 1971.
13) Bell-Berti, F. and H. Hirose: Palatal activity in voicing distinctions: A simultaneous fiberoptic and electromyographic study. J. Phonetica, 3: 69-74, 1975.