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AN ELECTROMYOGRAPHIC STUDY ON LARYNGEAL ADJUSTMENT FOR WHISPERING

Koichi Tsunoda, Seiji Niimi, Hajime Hirose,
**Katherine S.Harris and ***Thomas Baer

*Department of Otolaryngology. University of Tokyo, Tokyo, Japan.
** Haskins Laboratories.New Haven, U.S.A.
*** Cambridge University. Cambridge. U.K.

ABSTRACT

In order to clarify the laryngeal adjustments for whispering, an electromyographic study of the intrinsic laryngeal muscles was conducted. Subjects were two native Japanese speakers.

The posterior cricoarytenoid muscle (PCA) showed a higher background activity during whispering than during ordinary phonation. Furthermore, there were additional segmental activities which seemed to contribute not only to keeping the glottis open. but also to performing the necessary gestures for relevant phonemes. The activity patterns of the other intrinsic laryngeal muscles are also discussed.

1. INTRODUCTION

It has been said that whispering is an aphonic laryngeal action[1], meaning that there it entails no vocal fold vibration. However, even during whispered speech. one can distinguish between "voiced" and "voiceless" segments as well as between accent patterns[2]. There have been some reports dealing with the activity of the intrinsic laryngeal muscles during whispering[3,4]. The first report of whispered phonation dealing with the EMG activity of the cricothyroid muscle (CT) and the vocalis muscle (VOC) was performed by Faaborg-Andersen[3]. According to his results, electrical activity was less in whispered than in ordinary speech, but not due to intensity alone. With changes in intensity, the amplitude of the action potential pattern remained unaltered. Sawashima and Hirose[4] suggested that for whispering, the intrinsic laryngeal muscles show an unique activity pattern.

Weitzman et al.[5] studied laryngeal gestures during whispering using another approach, then performing a fiberoptic observation of the laryngeal gestures in whispering. They showed that an adduction of the false vocal folds takes place with a decrease in the size of the anterior-posterior dimension of the laryngeal cavity. They assumed that this particular laryngeal gesture for whispering was to prevent the vocal fold vibration caused by the transglottal air flow.

From our experience, we can identify voiced and voiceless segments even in whispered speech. This fact suggests that laryngeal gestures must be different in the production of voiced and voiceless segments during whispering.

The purpose of our study is to elucidate these laryngeal adjustments objectively. An electromyographic (EMG) study was performed. But before this EMG study, we performed a listening test as a perceptual study in order to estimate how accurately we can distinguish "voiced" and "voiceless" segments during whispering.

2.Perceptual study

2-1 Method

The speaker of the stimuli was a native speaker of Japanese who also served as a subject for the EMG experiment. He was required to whisper nonsense words of /CVCV/ form.

The test words were: /tete/. /dede/, /sese/. /zeze/.

These test words were also used in the EMG study. Each test word which we recorded was embedded in the carrier sentence /ii CVCV desu/ (It is a good CVCV). and whisperd more than fifteen times. We edited the stimuli into three different random orders to obtain a total of 180 acoustical samples.

The listeners were eleven native adult Japanese volunteers with normal hearing. They were instructed that the presented stimuli consisted of /te/. /de/. /se/. /ze/. The task of the listeners was to judge the consonants to be /t/,/d/,/s/,or /z/.

2-2 Results

The results of this study are shown in Table-1. As shown in Table-1, there was no confusion between plosive consonants and fricative consonants.

The overall accuracy of the judgments for each syllable are shown on Table-2. The consonant identification in this study was excellent. The accuracy for each plosive consonant was around 75%, and for each fricative consonant was around 95%.

3. EMG study

3-1 Method

The subjects were two native speakers of the Tokyo dialect of Japanese, one of whom was the speaker for the perceptual test.

The EMG activity was recorded from the posterior cricoarytenoid muscle (PCA), the cricothyroid muscle (CT), the lateral cricoarytenoid muscle (LCA), the vocalis muscle (VOC) and the interarytenoid muscle (INT). For the EMG recordings, hooked wire electrodes were used. The electrodes were inserted perorally to PCA and INT, and inserted transcutaneously in the other muscles. The method of verification of the electrodes' location is described elsewhere[6].

The experimental conditions are shown on Table-3. We obteined PCA, LCA and CT from subject K.T, and PCA, INT and VOC from subject S.N.

As an indication of the articulatory gestures, the intraoral pressure was also recorded on an FM data recorder together with the EMG signals.

The subjects were required to utter nonsense words of /CVCV/ form in whispered and in ordinary speech with different accent patterns.

The test words were the folloring.
/tēte/, /tetē/, /tete/
/dēde/, /dedē/, /dede/
/sēse/, /sesē/, /sese/
/zēze/, /zezē/, /zeze/.

Each test word was embedded in the carrier sentence /ii CVCV desu/ (It is a good /CVCV/), and uttered more than ten times in whispered and in ordinary speech.

After the recordings, the EMG signals were rectified and computer-processed in order to obtain the average pattern of each muscle activity. As the line-up point for averaging the EMG signals, the moment of the abrupt drop of the intraoral pressure was taken as an indication of the oral release.

3-2 Results

3-2-1 Ordinary and Whispered Speech (Figure 1)

Figure 1 shows the averaged EMG patterns for whispered(dotted line) and ordinary phonation (solid line) in subject KT. The ordinate represents the EMG potential and the abscissa represents time. Zero on the abscissa indicates the line-up point. In this particular data set, the line-up was chosen as the release of the first /t/. In ordinary phonation, PCA activity (top panel of the Fig.1) decreases 700ms prior to the line-up point for the adduction of the vocal folds for phonation from the higher activity level for inspiration. On the other hand, in whispering, there is no suppression of PCA activity, but rather an increment in this activity at the initiation of the utterance (-550ms). Furthermore, in addition to the elevated activity level, PCA showed a segmental pattern related to each phoneme. The EMG peak around the line-up point corresponds to the first /te/ in the test word /tete/. The PCA activity for the second /te/ is seen at 50ms after the line-up point (+50ms).

On the other hand, the amplitude of each peak is higher than that in ordinary phonation. Although there are segmental activities in LCA (second panel) and CT (third panel), the amplitude is smaller than that in ordinary phonation. Hence the perturbation patterns of CT and LCA are similar in both modes of phonation.

Another difference between the two speech modes is the base line activity on the PCA trace. It is clear that there is no suppression at all throughout the period from -550ms to +750ms.

3-2-2. Voiced and Voiceless Segment (Figure 2)

Figure 2 shows the difference in EMG patterns for the production of voiceless /tete/ (solid line) and voiced /dede/ (dotted line) segments. We can see a higher increment rate and peak activity of the abductor muscle (PCA:upper lines of the top panel of Fig.2) for voiceless consonant /t/ than for voiced consonant /d/ just before the line-up point. On the other hand, in the activity of the adductor muscle (LCA:bottom lines of the top panel of Fig.2), we can recognize a higher activity for the voiced consonant /d/ than for the voiceless consonant /t/.

4. DISCUSSION

During whispered speech, one can distinguish between "voiced" and "voiceless" segments[2]. The result of our perceptual study suggested and supported that we could identify the difference between "voiced" and "voiceless" segments even in whispering to an accuracy of more than 80%.

Whispering has been defined as "aphonic laryngeal gesture". From this point of view, several studies have been conducted to describe laryngeal gestures during whispering mainly by using a fiberscope[5]. These studies conclude that during whispering, the glottis is kept open to prevent vocal fold vibration. But this was not clear because of the constriction of the supererior-laryngeal structure which shades the actual view of the vocal fold movements in fiberscope studies.

However, the results of our EMG experiments showed an increased PCA activity throughout the utterance as the upward shift of the baseline which may represent the force applied to open the glottis.

Furthermore, the PCA activity showed segmental patterns which corresponded to each phoneme. In other words, during whispering the PCA showed EMG patterns compatible with ordinary speech, except for higher baseline activity. In addition, the other intrinsic laryngeal muscles (CT and LCA) were suppressed in whispered speech compared to with ordinary speech. This supports the previous report of Faaborg-Andersen and the previous suggestion of Sawashima and Hirose.

Interestingly, the pattern of the perturbation of CT and LCA is similar in both modes of phonation, which means that the segmental activity pattern of the EMG remains as in ordinary speech even in whispering.

Hence the higher baseline activity of the PCA may contribute to changing the speaking mode from ordinary phonation to the whispered mode. Even in the whispeed mode, the general laryngeal attitude to distinguish each phoneme would be preserved. This hypothesis can explain the difference in EMG patterns for the production of "voiced" and "voiceless" segments uttered in whispered speech.

On the other hand, there is a high PCA activity at the beginning of utterances around 300 msec before the line-up point which is supposed to be related to the first syllable of the carrier sentence /ii/. This observation is contradictory to an previous finding, that is, that PCA becomes active for "voiceless" segments and less active for "voiced" segments. To explain this contradictory phenomenon, we have to take into consideration that this segment /ii/ is located at the begining of the utterance. This particular phonetic environment may cause a different laryngeal gesture from the whispered mode. We can speculate that the higher EMG activity of the PCA corresponding to /ii/ in utterance initial position is a kind of resistance against strong glottal adduction.

5.Conclusion

For the production of whispering, PCA activity level becomes higher to prevent vocal fold vibration. In general, the intrinsic laryngeal muscles, including PCA, still have segmental activity patterns which are compatible with the laryngeal gestures observed in ordinary phonation. At the very begining of an utterance, the laryngeal gesture for whispering may be special.

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Table-1 **Responses** (from 11 subjects)

		te	de	se	ze
Stimuli	te	**71.7%**	28.3%	0%	0%
	de	23.6%	**76.4%**	0%	0%
	se	0%	0%	**99.2%**	0.8%
	ze	0%	0%	12.5%	**87.5%**

Table-2 **Accuracy**

te	355/495	71.7%
de	378/495	76.4%
se	491/495	99.2%
ze	433/495	93.2%
total	1657/1980	83.7%

Table-3 **Conditions of Electrodes**

Subject	PCA	INT	CT	VOC	LCA
K.T 28M	+	/	+	/	+
S.N 48M	+-	+	/	+	/

(+: good, +-: noisy, /:not obtained)