Physiological Study of the Supraglottal Structure

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Abstract

The supraglottal structure of the human larynx was examined using physiological methods. In normal phonations, the supraglottal region is abducted and no significant vibrations are observed. However, in certain pressed-type phonations, vibration of the supraglottal structure, as well as that of the vocal folds, contributes to regulate their special voice quality. The EMG study of the supraglottal constriction shows that adductions of the vocal and ventricular folds are caused by the activations of different laryngeal muscles.

1. Introduction

In the human larynx, there is a three-tiered sphincter comprising the vocal folds, the ventricular folds (false vocal folds), and the aryepiglottic sphincter [12] (Fig. 1).

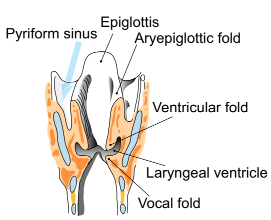

Figure 1: *Coronal view of the larynx, as seen from behind.*

The ventricular folds are incapable of becoming tense, since they contain very few muscle fibres. However, the ventricular folds can be constricted by the action of certain intrinsic laryngeal muscles (e.g. the thyroarytenoid and thyroepiglottic muscles). In the aryepiglottic region, the constriction is also approximation of the tubercle of the epiglottis (anterior), aryepiglottic folds (lateral), and arytenoids (posterior) by the action of certain intrinsic laryngeal muscles. In normal phonation, the vibration of the ventricular and aryepiglottic folds is not observed.

In our previous studies, both vocal-ventricular and vocal-aryepiglottic vibrations were observed in special singing techniques. In throat singing, the ventricular folds laterally constrict and vibrate as do the vocal folds. The ventricular fold vibration plays an essential role in the generation of throat singing's unique pressed-type voice quality. In growl phonation, the aryepiglottic folds antero-posteriorly constrict and vibrate as do the vocal folds. The aryepiglottic vibration plays an essential role in the generation of the growl's unique voice quality.

Recent studies have shown that the constriction of the two-tiered supraglottal structure occurs as both pathological and normal phonetic gestures [16, 17].

In this paper, we summarize the supraglottal vibratory phenomena and examine them from the physiological viewpoint. We also investigate the mechanism of the supraglottal adduction using electromyography.

2. Vocal-ventricular vibration

In some singing styles, ventricular fold vibration is observed. Throat singing is very representative of singing with this vibration. Throat singing is a traditional singing style found around the Altai mountains. Khöömei in Tyva, Khöömij in Mongolia, and Kai in Altai are its representatives. In throat singing, two different laryngeal sources are commonly observed: (i) a *drone voice*, which is a basic voice for singing with whistle-like high overtones, and (ii) a *kargyraa voice*, which is perceptually one octave lower than the modal register. A similar techniques are also found in Tibetan Buddists' chants.

In what follows, we summarize the results of physiological observations of the laryngeal movements from simultaneous recordings of high-speed digital images, EGG, and sound waveforms [4, 10, 15].

In the drone voice, the ventricular folds are strongly adducted and vibrated. The strong ventricular fold adduction makes direct observation of vocal fold vibrations difficult. However, by comparing EGG waveforms and high-speed digital images from the coronal image of the larynx reported in [11], we can reasonably state that both the vocal and ventricular folds vibrate. The period of the ventricular fold vibration was equal to that of the vocal fold vibration detected from the EGG waveform. There is a phase difference between vibrations of the vocal and ventricular folds. (Figs. 2 and 3).

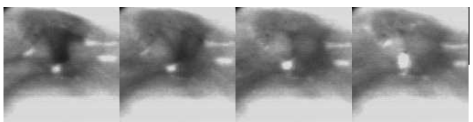

Figure 2: *High-speed images in drone, by male Khöömei singer. Frame rate:* $4/4500$ *s.*

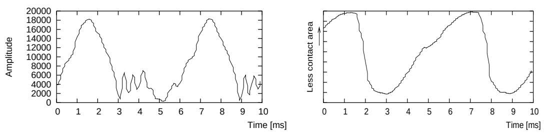

Figure 3: *Laryngeal flow obtained by inverse-filtering (left) and EGG waveform (right) for* 10 *ms in drone, by male throat singer. Y-axis of EGG represents less contact area.*

In the kargyraa voice, the ventricular folds are strongly adducted but looser than that in the case of the drone voice. The ventricular folds vibrate at half the frequency of the vocal folds (subharmonic). The period of the ventricular fold vibration estimated from the high-speed images and EGG are equal to the period of the sound waveform (Figs. 4 and 5).

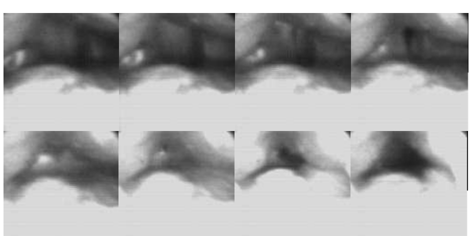

Figure 4: *High-speed images in kargyraa, by male Khöömei singer. Frame rate:* $4/4500$ *s.*

The vibratory pattens observed were confirmed by physical simulation using a 2×2-mass model. The 2×2-mass was obtained by improving the two-mass model [7]. In the 2×2-mass model, the ventricular folds are described in a self-oscillating model as are the vocal folds [14, 15] (Fig. 6).

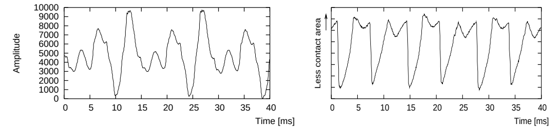

Figure 5: *Laryngeal flow obtained by inverse-filtering (left) and EGG waveform (right) for* 40 *ms in kargyraa, by male throat singer. Y-axis of EGG represents less contact area.*

As stated above, the ventricular folds are not equipped with a mechanism to change its physical properties, but they can be adducted by the action of certain laryngeal muscles. Their physical properties, such as mass and stiffness, and how those properties are changed by the adduction are still unclear. To take account of the changing shapes of the ventricular folds and, we introduced an *adduction parameter* into the model, as one possible parameterization. Along with a narrowing of the rest area between the ventricular folds in the 2×2-mass model, various phonations—pressed without distinguishable ventricular vibration (e.g., Min-yoh, Japanese singing, [9]), kargyraa (triple- and double-periodic), and drone—appear consecutively (Fig. 7). These results are supported by physiological observations [14]. The simulated laryngeal flow includes the laryngeal ventricle resonance.

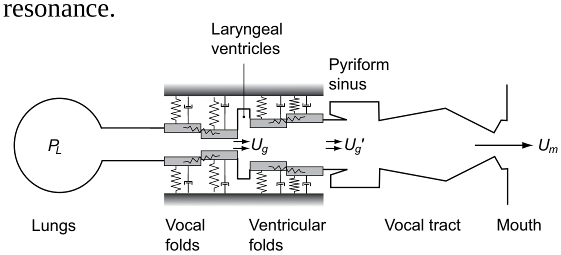

Figure 6: *Physical model for synthesis of singing voices.*

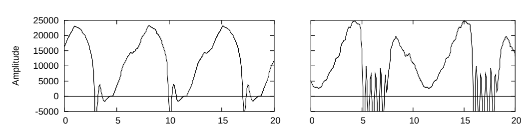

Figure 7: *Synthesized laryngeal flows using the 2×2-mass model with the vocal tract in /e/. Drone (left) and kargyraa (right) for* 20 *ms.*

3. Vocal-aryepiglottic vibration

The term *growl* originally referred to low-pitched sounds uttered by animals, such as dogs, or similar sounds by humans, and therefore is mainly described in terms of auditory-perceptual impression. Growl is widely observed in singing as well as in shouting and aroused speech. The growl phonation is a rather common effect in some ethnic musics (e.g. the music of the Xhosa people in South Africa, the beginning of Kakegoe used by Noh percussionists) and pop styles (e.g. jazz, blues, gospel, Enka in Japan, samba in Brazil) [1, 2, 3, 13]. Some singers use growl extensively through a song, while others use it as a vocal effect for expressive emphasis.

In terms of phonetics, growl is sometimes described as the voiced aryepiglottic trill [3]. Recently, the aryepiglottic fold vibrations during the growl phonation were observed using the high-speed images [13]. In the growl phonation, the aryepglottic region is compressed antero-posteriorly, and the tubercle of the epiglottis and the arytenoid cartilages come into contact (Fig. 8). Lateral views of the larynx during the growl phonation using X-ray videofluoroscpy has shown that the larynx is raised to about the level of the fourth cervical vertebrae, and the epiglottis is depressed [1, 13]. In some cases, both aryepiglottic folds vibrate with almost the same phase. In other cases, the phases of both seem to be slightly different. Further in some cases, the vibration of the aryepiglottic folds is unstable and seems to be aperiodic.

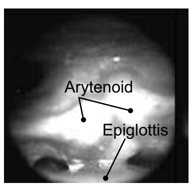

Figure 8: *Aryepiglottic region in growl, as seen from above. Upper part is posterior*

From the EGG and sound waveforms (Fig. 9), it is reasonable to conclude that the vocal folds vibrate half-periodically to the aryepiglottic fold vibration. The period-double vibration of the aryepiglottic folds generates subharmonics. This vibratory pattern is similar to the vocal-ventricular vibratory pattern in kargyraa. Neither the vocal nor ventricular folds were directly observed because the aryepiglottic folds were strongly constricted. However, we conclude that the vocal and aryepiglottic folds vibrate and the ventricular folds do not, because smooth transition from modal to growl is frequently achieved by various singers. This conclusion is also supported by EGG waveform, and aerodynamic constraint.

Just what growl is seems to still be controversial. However, at least, it is obvious that the there is a phonation in which the aryepiglottic folds vibrate and the vibration contributes to the generation of its special timbre. At least, it is reasonable to define growl in this phonatory manner.

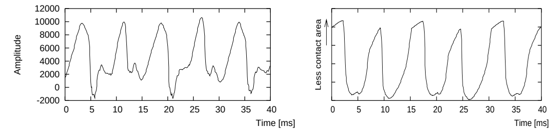

Figure 9: *Laryngeal flow obtained by inverse-filtering (left) and EGG waveform (right) for* 40 *ms in growl. Y-axis of EGG represents less contact area.*

4. EMG study of supraglottal structure

The intrinsic laryngeal muscles involved in the adduction of the vocal folds has been discussed in the literature. The thyroarytenoid, lateral cricoarytenoid, and interarytenoid muscles are known adductors. However, there are only a few speculations about which intrinsic laryngeal muscles adduct the ventricular folds. The vocal fold adductors may induce the ventricular fold adduction by approximation of the arytenoids. However, the vocal and ventricular fold adductions does not always occur simultaneously. We may speculate that the three-dimensional geometry of the arytenoid cartilage and certain intrinsic laryngeal muscles would bring about the ventricular fold adduction.

The *thyroepiglottic muscle* (or more precisely, the *ventricularis*) courses antero-posteriorly and is directed upward from the angle of the thyroid cartilage to the aryepiglottic folds. Some fibres of the thyroepiglottic muscle course along the lateral margin of the ventricle and enter the lateral margin of the epiglottis [18]. Recent histological studies on the supraglottal structure have shown that the fibres of the thyroepiglottic muscles course inside the ventricular folds [8].

The activation of the *aryepiglottic muscle* is considered to induce the aryepiglottic constriction by approximating the arytenoids and epiglottis. The aryepiglottic muscle includes very few muscle fibres as does the thyroepiglottic muscle.

To examine the actions of the thyroepiglottic, aryepiglottic, and thyroarytenoid muscles, which can be considered to induce supraglottic constriction, we performed an electromyographic investigation.

4.1. Procedure

In our procedure, the vocalis, thyroepiglottic muscle, and aryepiglottic muscles were reached perorally. An anesthesia procedure utilizing 2% Xylocaine spray was employed to desentisize the pharyngeal and laryngeal areas.

Hooked wire electrodes were used for all insertions. A pair of thin wires (platinum-iridium alloy (90%-10%), outer diameters of 0.09 mm, and teflon coated) were threaded through an L-shaped rod with a carrier needle (25-gauge, i.e. inner and outer diameters of 0.32 mm and 0.5 mm, respectively), and the exposed ends of the wires were bent back over the needle to form hooks [5]. The insertion was performed under endoscopic observation (Fig. 10).

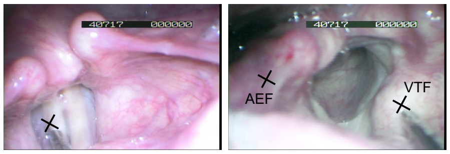

Figure 10: *Insertion positions of hooked wire. Left: Vocal fold. Right: Ventricular (VTF) and aryepiglottic folds (AEF). Upper part is posterior*

One male, who can distinguishably produce drone and kargyraa in throat singing and growl, was the subject. The phonation tasks employed here were six different sustained phonations: modal, falsetto, vocal fry, drone, kargyraa, and growl. Physiological tasks, such as swallowing and breath holding (pseudo-valsalva. i.e. accompanied with glottal closure), were also employed.

4.2. Results

The EMG of the aryepiglottic muscle was very difficult to record because of some technical problems with the procedure. During the experiments, the laryngeal reflections were inevitable and the aryepiglottic folds sometimes moved very widely because of coughing. Therefore, the insertion placement of the hooked wires was very unstable and easily moved out of the muscles fibres. In our experiments, the EMG of the aryepiglottic muscle was very unstable. We therefore discuss only activities of the vocalis and thyroepiglottic muscle in this paper.

Fig. 11 shows sound waveforms, and activities of the vocalis and thyroepiglottic muscle for the six different sustained phonations. Fig. 12 shows the average voltage of the segmental integrals of the absolute values of the EMG signals (integral for each 50 ms) [6].

The thyroepiglottic muscle tended to be more active during pressed-type phonations (drone, kargyraa, and growl) with the supraglottal constriction than during modal and falsetto. Furthermore, the thyroepiglottic muscle tended to be more active during drone than during kargyraa. This result is very consistent with fact that the ventricular fold is constricted during drone more than during kargyraa. The vocalis also tended to be more active during the three pressed-type phonations than during modal and falsetto. During vocal fry, both the vocalis and thyroepiglottic muscle tended to be active as well as during the pressed-type phonations. The fibrescopic observation shows the slight ventricular fold constriction in vocal fry, which agrees with that he thyroepiglottic muscle tended to be active during vocal fry.

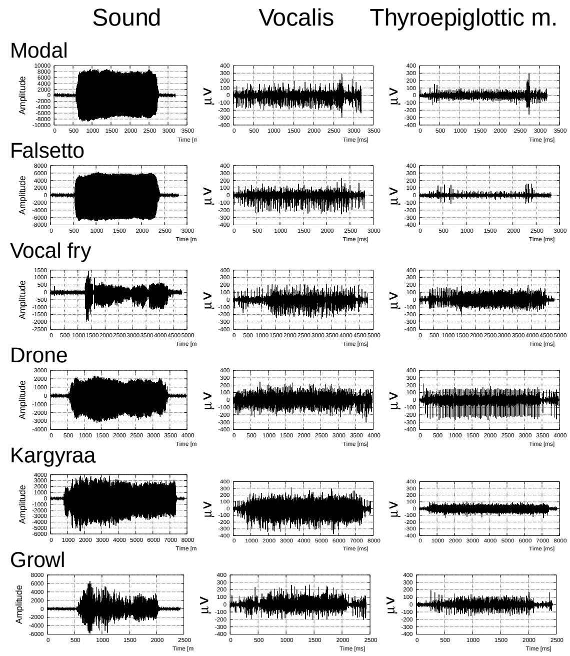

Figure 11: *Activity of the vocalis and thyroepiglottic muscles.*

During swallowing and breath holding, both the vocalis and thyroepiglottic muscle tended to be very active.

We have discussed our results of the EMG experiment under the assumption that the measured muscle in the ventricular fold is the thyroepiglottic muscle. However, the lateral cricoarytenoid muscle courses very closely to the thyroepiglottic muscle. Therefore, we cannot neglect the possibility that the EMG, which is considered of the thyroepiglottic muscle, was contaminated by the activity of the lateral cricoarytenoid muscle. In addition, our results are not contradictory to the geometry of the arytenoid cartilage and the function of the lateral cricoarytenoid muscle, if the EMG at the ventricular folds came from the lateral cricoarytenoid muscles. However, from the histological evidence, together with the gesture of the ventricular fold adduction and the insertion position of the ventricular fold, it may be possible that the wires were inserted into the thyroepiglottic muscle (ventricularis).

5. Discussions and conclusions

In this paper, we summarized previous research on supraglottal structure vibration in special phonations. We also observed the activities of the muscles which are considered to induce the supraglottic constriction to clarify the mechanism of the supraglottal constriction which induces these vibrations.

Our results show that the activity of the thy-

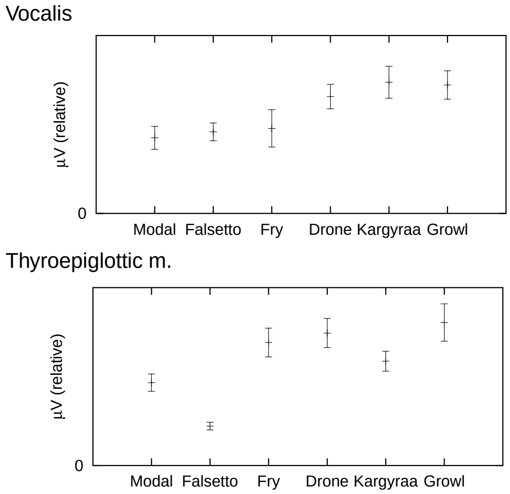

Figure 12: *Mean voltage of segmental integrals of absolute values of the EMG for six phonations*

roepiglottic muscle increases when the ventricular folds are constricted. Moreover, as in some phonations (kargyraa), the strength of the vocalis and thyroepiglottic muscle activation is not always synchronized. The mechanism of the ventricular fold constriction has been investigated very little and is unclear. However, our results imply that the thyroepiglottic muscle may cause the ventricular fold constriction.

To verify the contamination between the thyroepiglottic and lateral cricoarytenoid muscle, it is necessary to simultaneously record the activity of the lateral cricoarytenoid muscle by percutaneously inserting hooked wire. We were unable to record the EMG of the aryepiglottic muscle. However, it is still necessary to determine the depression of the epiglottis and the aryepiglottic constriction. These remain as future work.

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