Ann.Bull.RILP(1987)No.21, 153-164

ELECTROMYOGRAPHIC STUDY OF VIBRATO AND TREMOLO IN SINGING

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Introduction

It is well known that in the singing voice there are regular noticeable changes of tone quality. Acoustically, these quality changes can be considered as characterized either by frequency changes, intensity changes, formant changes or a combination of these. Singers claim that quality differences occur either intentionally or unintentionally.

At present, there are various proposals about how one produces and regulates vocal vibrato, for example, but these proposals are described rather subjectively and lack acoustic and physiological evidence[1,2]. Moreover, the terminology for singing techniques has also been based on subjective impression. Many terms seem to cause confusion among singers, voice trainers and voice researchers when singing techniques are discussed. In order to obtain a common basis for discussion of singing techniques, it is preferable to understand the physiological mechanisms involved.

The mechanisms of voice production can be divided into three levels, the subglottic system, that supplies the energy, the larynx, that serves as a sound generator, and the supraglottic system that acts as a resonator. Although we realize that the supraglottic and subglottic systems can contribute to these changes, in this study we focus on the laryngeal mechanisms of control as a first step in clarifying the control mechanisms of the singing voice.

Method

A professional tenor singer (54 years of age, male) served as the subject. Electromyography (EMG) was recorded from the vocalis muscle (VOC), cricothyroid muscle (CT), lateral cricoarytenoid muscle (LCA) and sternothyroid muscle (ST) using bipolar hooked wire electrodes inserted percutaneously in the neck[3]. The acoustic signals were recorded simultaneously with EMG signals. The subject was asked to phonate /a:/ at a comfortable pitch (G3), a higher pitch (C4) and a lower pitch (C3) with "normal vibrato", "rapid vibrato", "trilla" and "tremolo". These terms were defined by the subject. According to the subject's definition, can the singer control the pitch fluctuation volitionally only for the trilla.

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In the present study, the trilla had two kinds of pitch changes, one labeled a 2-semitone leap and the other a 4-semitone leap. These tasks were performed in the sitting position.

The locations of the electrodes were verified by various non singing tasks such as swallowing, jaw opening, tilting of the head, elevation of the larynx and so forth. These verification maneuvers were performed several times during the recording session. The intensity of the voice was not controlled, allowing the subject to sing the tasks quite naturally.

Fundamental frequency variations were extracted from the microphone signal by means of a laboratory computer.

Results

I Acoustics

1) Normal vibrato

The vibrato rate was 4.5Hz. The observed excursions of the pitch fluctuations were 12Hz, 7Hz and 8Hz at high pitch (C4), medium pitch (G3) and low pitch (C4), respectively (Figure 1).

2) Rapid vibrato

The rate of the rapid vibrato (5Hz) was slightly faster than that of the normal vibrato . Besides the faster rate of the vibrato, pitch fluctuations were greater than for the normal vibrato (Figure 1).

3) Trilla

The rate of frequency modulation was 4.5 - 5 Hz for both the 2-semitone leap and the 4-semitone leap (Figure 2).

However, the trajectories of the fundamental frequency showed different patterns for high pitch and low pitch. At high pitch, the trajectory was steeper during the increasing phase than the decreasing phase of the fundamental frequency. On the other hand, at low pitch, the trajectories were steeper during declination. This difference of between the increasing and the decreasing phases of the pitch was more or less observed in other maneuvers.

4) Tremolo

The acoustic characteristics of the tremolo were quite different from the other maneuvers. The rate of the modulation was the highest of all cases, as high as 10.5Hz. Frequency excursions were rather small, and the trajectories were irregular. On the other hand, the amplitude modulation was marked and regular. The sound could be perceived as a glottal stop.

II EMG

1) Normal vibrato (Figure 4)

i. Vocalis muscle: The activity of this muscle was, in general, pitch dependent. The higher the pitch was, the greater the activity was. Intensity dependency was not consistent in this study, however. The modulation pattern of the muscle activity was observed to correspond to the frequency modulation pattern at high and medium pitch. At low pitch, the modulation pattern was unclear because of the slight activity of the muscle.

ii. Lateral cricoarytenoid muscle: The modulation pattern was as in the case of the vocalis muscle. However, the activity of the muscle was not pitch dependent.

iii. Cricothyroid muscle: As expected this muscle was more active for high pitch. There was no modulation pattern observable at any pitch.

iv. Sternothyroid muscle: Contrary to what we expected, this muscle was less active for low pitch than for high pitch in this particular subject. No modulation pattern was observed at any pitch.

2) Rapid vibrato (Figure 5)

The activity patterns of the vocalis and lateral cricoarytenoid muscles were almost the same as those seen in the case of normal vibrato. In addition, the cricothyroid muscle and the sternothyroid muscle showed modulation patterns similar to those of the vocalis muscle and the lateral cricoarytenoid muscle. In other words, these two muscles were recruited for the greater degree of modulation.

Interestingly, these two muscles somehow showed some reciprocity in their patterns. When one increased in activity, the other decreased.

3) Trilla (Figure 6)

i. Vocalis muscle: Pitch dependency was observed in this maneuver. In addition, modulation patterns in the muscle activity were observed at all pitch levels. These patterns were more prominent in the 4-semitone leap than the 2-semitone leap.

ii. Lateral cricoarytenoid muscle: The modulation patterns were more prominently seen in this muscle than in either the normal vibrato or the rapid vibrato. Pitch dependency was not clearly seen, however. There was no significant difference in muscle activity between the trillas with the 2-semitone leap and those with the 4-semitone leap.

iii. Cricothyroid muscle: Modulation patterns were present in all tasks and were marked for the low pitch because of the small background EMG activity. The overall activity of this muscle depended on the pitch level, as expected.

iv. Sternothyroid muscle: As far as modulation patterns were concerned, the EMG activity was similar to that of the cricothyroid muscle. A reciprocal relationship was again observed between the sternothyroid muscle and the other three muscles. This reciprocity was clearly seen at high pitch. Although at low pitch the reciprocal relationship was maintained, the initiation of the sternothyroid muscle activity occurred earlier than in the case of the high pitch. In other words, the sternothyroid muscle became active immediately after the cessation of the cricothyroid muscle activity.

4)Tremolo (Figure 7)

Prominent modulation patterns were observed in the vocalis and lateral cricoarytenoid muscles at all pitches. These patterns were very similar to those observed in the production of glottal stops[4]. There was no specific patterns seen in the other muscles.

Discussion

A variety of research has been conducted on the control mechanism of pitch, intensity and voice quality in singing[5,6,7]. However, little attention has been paid to the fine regular changes in tone quality of the singing voice, such as vibrato, trilla and tremolo.

The present study focused on these tone quality changes and their underlying control mechanisms. The control mechanism of "normal vibrato" is based upon changes in activity patterns of the vocalis and lateral cricoarytenoid muscles. This conclusion is derived from the finding that these two muscles showed modulation patterns in their activities that corresponded to the changes in the acoustic signal.

The cricothyroid and sternothyroid muscles do not contribute to the modulation patterns of normal vibrato, although these two muscles seemed responsible for maintaining certain pitch levels. It can be suggested that the cricothyroid muscle regulates a steady pitch level, and that the vocalis and lateral cricoarytenoid muscles modulate this pitch level and add changes to the perceived tone quality.

Since in our experiment the basic activity levels of the lateral cricoarytenoid muscle were constant at any pitch level, it can be assumed that this muscle participates in controlling acoustic parameters other than pitch fluctuations, or that it has an indirect role in pitch fluctuation, as reported by Hirano et al[5].

When large pitch leaps were required (as in the case of the "trilla") or when quick pitch changes were required (as in the case of the "rapid vibrato"), the activities of other muscles, such as the cricothyroid and sternothyroid muscle observed in this experiment, may be needed.

Contrary to what we expected, the sternothyroid muscle was less active for low pitch than for high pitch in the particular subject studied.

It has been reported that the sternothyroid muscle lowers the fundamental frequency, or at least becomes active during low-pitched phonation [8, 9].

Our findings are in disagreement with previous reports in which phonation was made in the speech mode. In operatic singing, which was used in this study, the singer tries to maintain the larynx in a low position to produce the so-called "covered voice". For the production of high-pitched covered voice, it is necessary to stabilize the larynx (by the contraction of the strap muscles) and prevent its rising, which is naturally observed in the production of a high-pitched voice. This study has shown that the sternothyroid muscle and the cricothyroid muscle have a reciprocal relationship for pitch control. This relationship is shown schematically in Figure 8.

It is interesting that this reciprocity shows a phase difference between high and low pitch. At low pitch the initiation of the sternothyroid muscle activity occurs earlier than in the case of high pitch, even though the reciprocal relationship is maintained. In other words, the sternothyroid muscle becomes active immediately after the cessation of the cricothyroid muscle's activity.

Fundamental frequency trajectories differ according to pitch. At high pitch, the trajectories are steeper during the rising phase than during the falling phase. On the other hand, at low pitch the trajectories are steeper during the falling phase than during the rising phase (Figure 8).

For an explanation of the different inclination and declination patterns between high and low pitch, we propose the hypothesis that these pitch contours are regulated by the phase and amplitude differences between the activities of the pitch raising and pitch lowering muscles. We speculate that boundaries may be set for different maneuvers in the singing mode, and that these boundaries may be different from those in the speech mode.

Since at high pitch the cricothyroid muscle contributes more to pitch changes than the sternothyroid muscle, rises in pitch seem to be controlled mainly by the activity of the cricothyroid muscle, resulting in a steep pitch rise. On the other hand, at low pitch the sternothyroid muscle contributes more than the cricothyroid muscle, and this results in a steep pitch declination.

Conclusion

Physiological mechanisms controlling vibrato and vibrato-like productions in the singing voice were investigated using the electromyographic technique. In this study, we focused on the laryngeal mechanisms of control as a first step in clarifying the controlling mechanisms of the fine fundamental frequency changes in the singing voice.

The results of the present study suggest that the laryngeal muscles show a unique coordination pattern for the production of different types of singing maneuvers. Although this finding provides a possible explanation of the pitch and intensity variations in vibrato, trilla and tremolo, other acoustic parameters that could contribute to these qualities have not been studied yet. Further acoustic analysis of the singing voice, therefore, is required. We also hope to determine how the acoustic parameters affect listeners' perception of the singing voice.

The present study suggests that the acoustic parameters and physiological mechanisms have a good correlation, providing some objective measures for the quality of the singing voice and performance technique.

We believe that this kind of study will help to avoiding confusion in future discussions among people from various fields, as long as a clear specification of the bases of the discussion is given. In other words, it should always be made clear whether the data are perceptual, acoustic or physiological.

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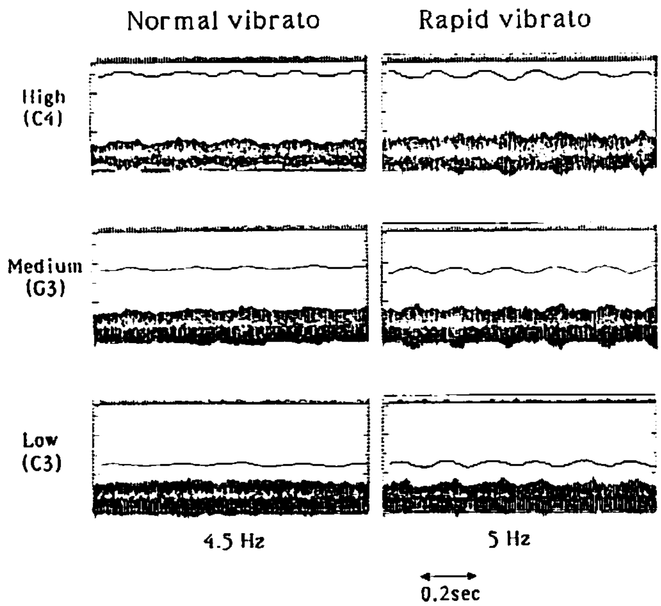

Figure 1. Acoustic waveforms and pitch curves of normal vibrato and rapid vibrato at three pitch levels.

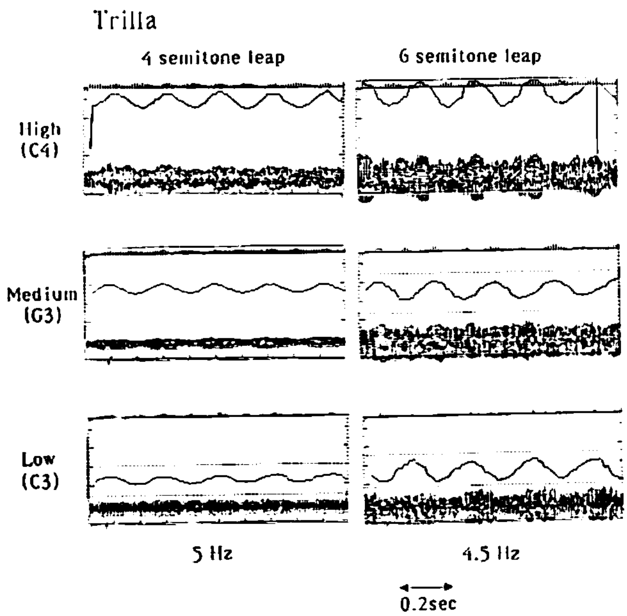

Figure 2. Acoustic waveforms and pitch curves of trilla with 2 semitone leap and 4 semitone leap at three pitch levels.

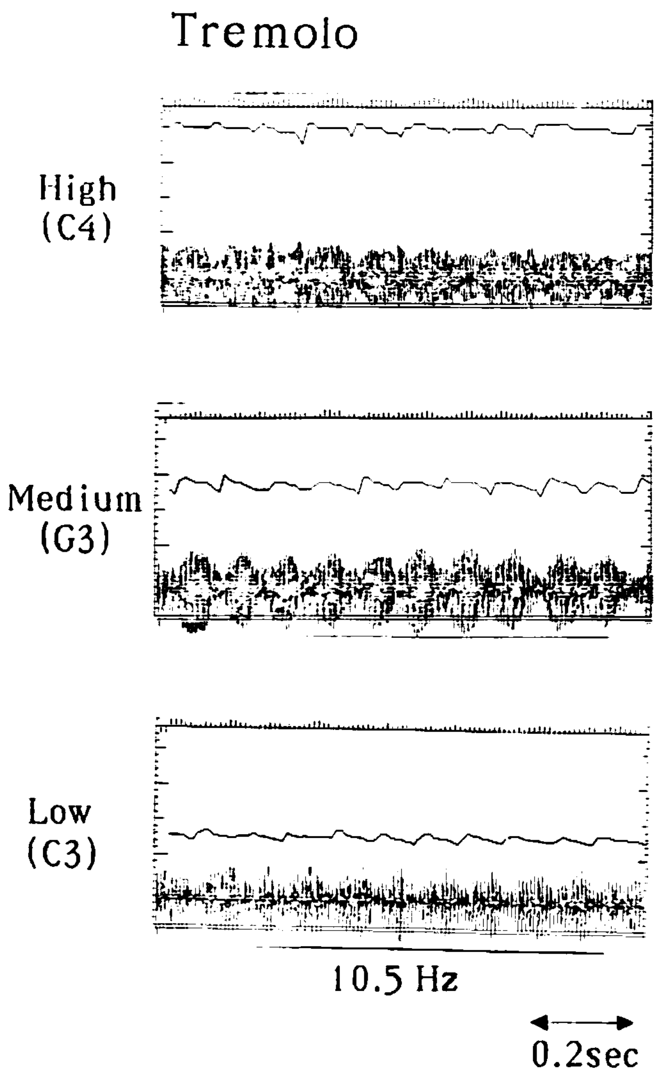

Figure 3. Acoustic waveforms and pitch curves of the tremolo at three pitch levels.

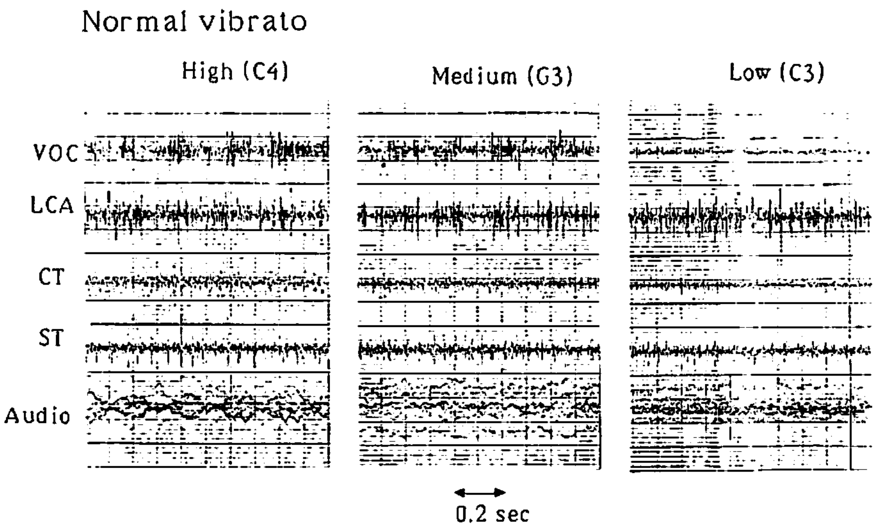

Figure 4. EMG and audio signals of normal vibrato at three pitch levels.

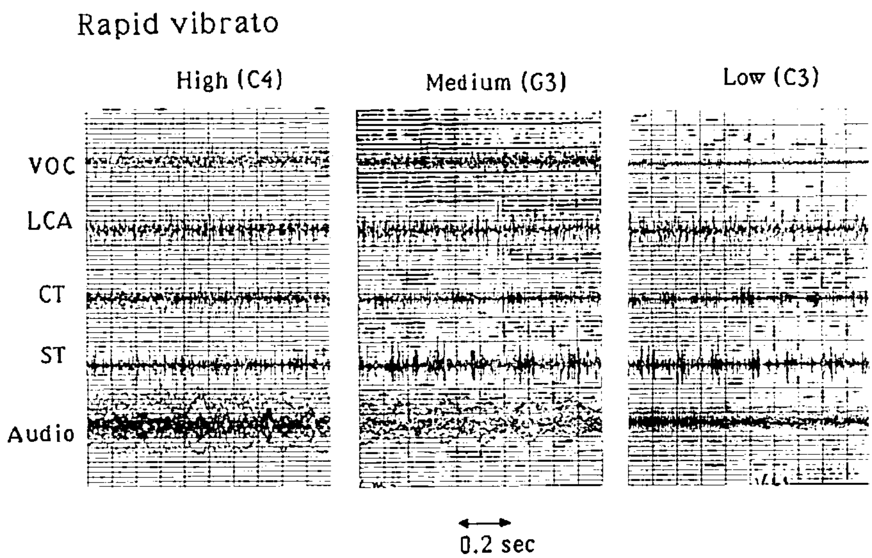

Figure 5. EMG and audio signals of rapid vibrato at the three pitch levels.

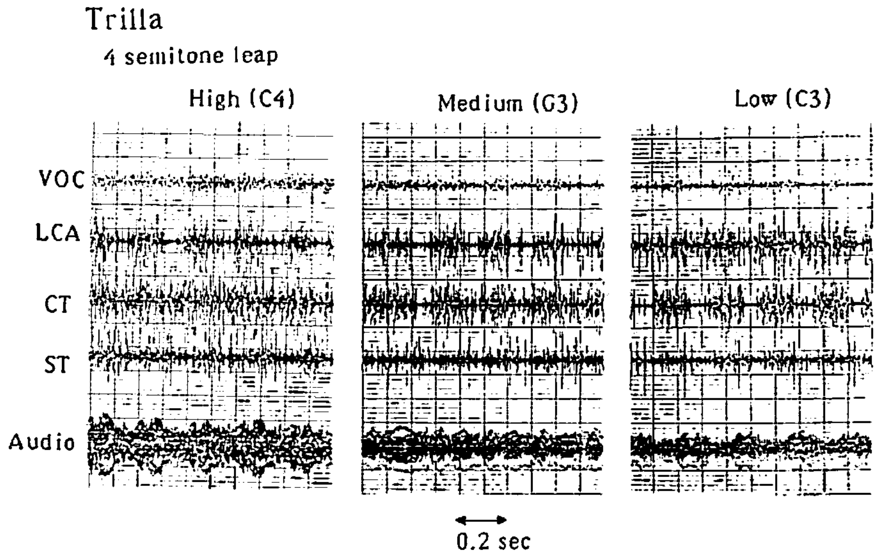

Figure 6. EMG and audio signals of trilla with 4 semitone leap.

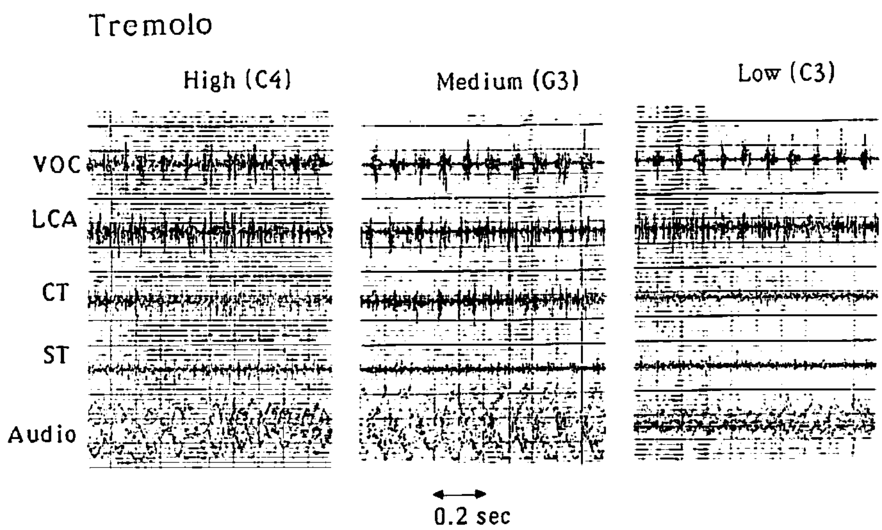

Figure 7. EMG and audio signals of tremolo at three pitch levels.

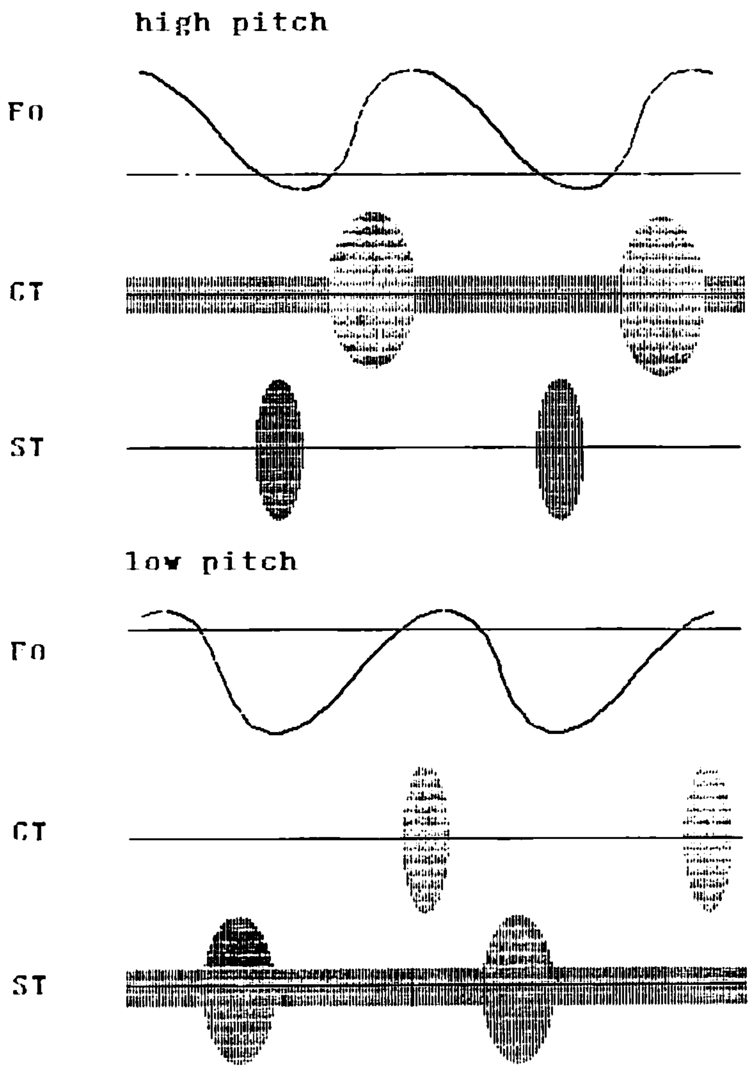

Figure 8. Schematic representsation of the phase relationship between the cricothyroid muscle and the corresponding pitch curves.