Dept. for Speech, Music and Hearing

Quarterly Progress and Status Report

Activity relationship between diaphragm and cricothyroid muscles

Sundberg, J. and Leanderson, R. and von Euler, C.

KTH Computer Science and Communication

journal: STL-QPSR
volume: 29
number: 2-3
year: 1988
pages: 083-091

III. MUSIC ACOUSTICS

A. ACTIVITY RELATIONSHIP BETWEEN DIAPHRAGM AND CRICOTHYROID MUSCLES

J. Sundberg, R. Leanderson, and Curt von Euler***

Abstract

The relevance of breathing behavior to phonation is notoriously experienced in voice pedagogy. A factor of possible relevance is the fact that the trachea is pulling down on the larynx, thus affecting the operation condition of the larynx. An experiment was carried out in order to investigate the relationship between diaphragmatic coactivation during singing and the EMG activity in the cricothyroid (CT) muscles. In three well-trained baritone singers, a higher CT EMG activity was observed during phonation under conditions of a low diaphragm, induced either by a high lung volume or a coactivation of the diaphragm during singing. The cause of this relationship is discussed.

Introduction

There seems to be close relationships between breathing activity and laryngeal adjustments. For instance, during inhalation the larynx is generally assumed to descend (Kirshner, 1970; Luchsinger, 1970; and Seidner & Wendler, 1982). The reason may be an increased tracheal pull on the larynx when the diaphragm is lowered during inhalation. Thus, Macklin (1925) found that the carina descended during inhalation. Since the tracheal rings are interconnected only by a fibroelastic membrane, this descent implies an increased tracheal pull on the larynx.

This type of interrelation between inhalation and larynx position has not been unanimously accepted. Thus, Mitchinson & Yoffey (1947) found that during inhalation the larynx dropped only in four subjects out of 23; in five subjects it actually raised, and in the remaining 14 subjects the larynx height remained unaffected. A constant larynx position may be due to compensatory activations of extrinsic laryngeal muscles, as suggested by EMG experiments on rats performed by Andrew (1955).

Even if a larynx descent does not always accompany inhalation, the varying tracheal pull with diaphragmatic activation may be relevant to phonation. According to Zenker & Zenker (1960), the tracheal tension itself pulls the arch of the cricoid cartilage downward, thereby increasing the anterior distance to the thyroid cartilage, and hence shortening the vocal folds. In this way, the tracheal pull acts as an antagonist to the pitch-raising cricothyroid (CT) muscles. On the other hand, Shipp, Morrissey, & Haglund (1985) found that the EMG activity in the CT muscles for a constant pitch was *higher* at low than at high lung volumes in three singers and three nonsingers.

In previous investigations we have studied the use of diaphragmatic coactivation during phonation (e.g., Leanderson, Sundberg, & von Euler (1987). Different behaviors

*Phoniatric Dept., Karolinska Institutet, Stockholm
**Neurophysiological Dept., Karolinska Institutet, Stockholm

were observed among professional singers. Some activated their diaphragm not only during inhalation but also for sudden reductions of the subglottal pressure at high lung volumes. Others showed a varying diaphragmatic activation throughout the phrase. Taking into consideration the great emphasis laid on breathing technique in voice pedagogy, this suggests that the use of the diaphragm has a phonatory relevance which is used differently among singers.

For a given lung volume, a diaphragmatic activation, affecting the tracheal tension, must coincide with a decrease of the rib cage circumference and an expansion of the abdominal wall. The above suggests the possibility of a mechanical connection between diaphragmatic activation, tracheal pull, and phonation.

In summary, two conflicting views exist regarding the relationship between the activity of the pitch-raising CT muscles and the tracheal pull resulting from an activation of the diaphragm. According to Zenker & Zenker (1960), an increased tracheal pull should be associated with an increased CT activity, while according to Shipp, Morrissey, & Haglund (1985), the opposite should apply.

The purpose of the present investigation was to collect some more information on the relationship between CT activity and diaphragmatic coactivation during singing at different lung volumes.

Method and material

Three baritone singers, between 35 and 55 years, served as subjects. They all had considerable experience of solo singing and sang with a diaphragmatic coactivation increasing with subglottal pressure as previously described by Leanderson, Sundberg, & von Euler (1987).

Standing in an upright position, the subjects performed identical singing tasks at least three times in succession under conditions of passive and active diaphragm. First, the phonation was initiated after a deep inhalation and then after a deep inhalation followed by a relaxation of the inhalatory muscles with open airways, so that a clear difference in lung volume was obtained.

The transdiaphragmatic pressure was used as an indication of diaphragmatic activation. It was measured by two pressure transducers (GAELTEC) placed above and below the diaphragm. The difference between these two pressures was displayed to the subject on an oscilloscope screen so as to provide a visual feedback. The rib cage and abdominal circumference, and the lung volume was derived from inductive spirometry (RESPITRACE). The EMG activity in the right CT muscle was recorded by a bipolar needle electrode placed in this muscle.

All these signals plus an audio signal were simultaneously recorded on a multi-track AMPEX FM tape recorder and a 10 track Mingograph ink writer. Thereafter, using the same ink writer, the tape recorded signals were plotted once more, this time together with the integrated and smoothed (LP at 13 Hz) EMG signal, the fundamental frequency, and the sound level. The fundamental frequency was derived from the low-pass filtered audio signal by means of a double-peak-picking pitch extractor (FONEMA). The sound level of the same signal was obtained from a sound level meter (Brüel & Kjær). From this recording, the total integrated EMG activity was calculated by means of a planimeter.

Results

The three subjects showed similar behaviors. Fig. 1 displays the various signals recorded when subject RL sang a sustained high pitched tone at high lung volume with active and passive diaphragm. The CT EMG activity is clearly greater under conditions of diaphragmatic activation, even though sound level and pitch were identical. Both transdiaphragmatic pressure and CT EMG activity decreased with decreasing lung volume. For passive diaphragm, the CT EMG is more constant.

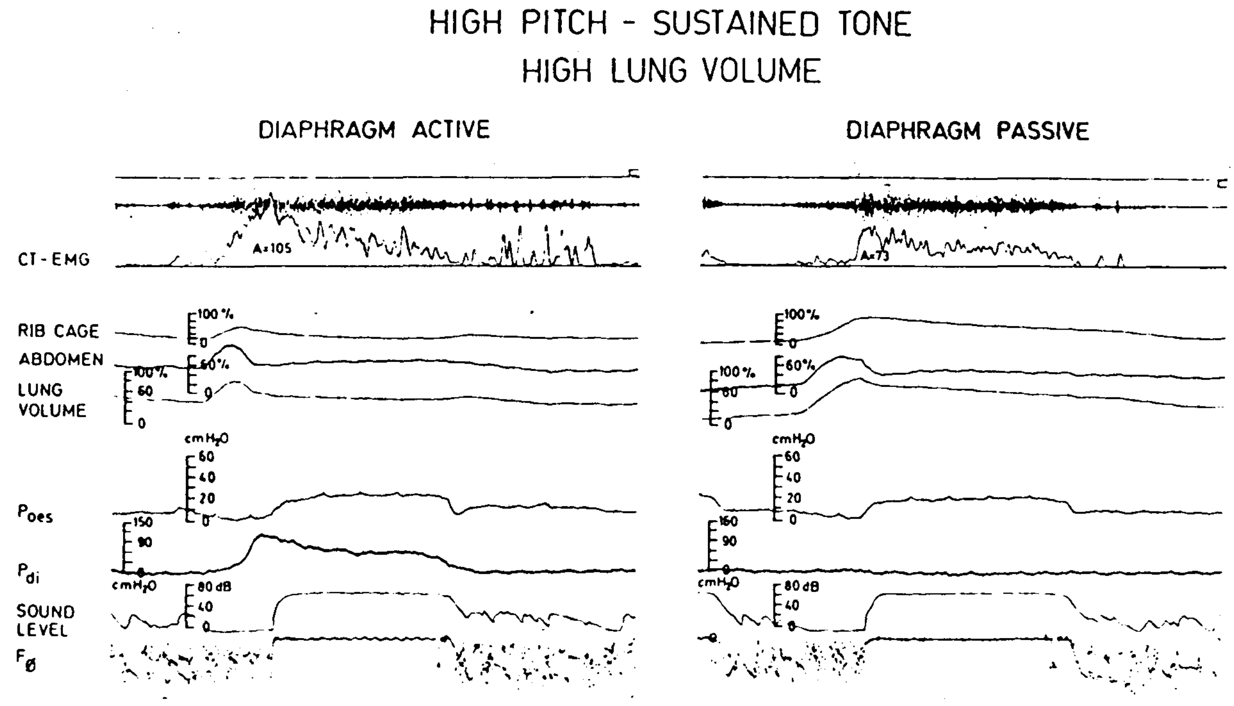

Fig. 1. Simultaneous recordings of various phonatory parameters from a baritone RL, singing a sustained tone at about 300 Hz fundamental frequency with (left) and without (right) coactivation of his diaphragm starting at a high lung volume. From top bottom the curves represent: a) raw EMG signal, b) integrated and smoothed EMG of the right cricothyroid muscle, where A represents the total integrated EMG activity; c) rib cage and abdominal circumference, and total lung volume; d) oesophageal pressure; e) transdiaphragmatic pressure; f) sound level; g) fundamental frequency.

Similar observations can be made in Fig. 2, showing the same comparison for the same subject under condition of low lung volume. The CT EMG activity is lower than at high lung volume, and it was lower with a passive diaphragm. Also, both CT EMG amplitude and transdiaphragmatic pressure decreased with lung volume.

Fig. 3 shows a similar difference observed when subject SH sang a series of octave intervals at high lung volume with and without diaphragmatic activation. The CT EMG activity is greater during the high note, as expected. Also, it is greater with an activated diaphragm. In this case, however, it does not decrease with decreasing lung volume.

Fig. 4 shows the same comparison for low lung volume. The same observations can be made; the CT EMG activity was clearly higher with activated diaphragm and remained the same for each of the pitches throughout the phrase. Note also that there was a CT EMG activity during the diaphragmatic inhalation in this case.

In the figures it can be barely observed that a coactivation of the diaphragm is associated with a reduction of the rib cage circumference, while the abdominal circumference remains more constant. This suggests that this activity resulted in a *descent* of the diaphragm. This interpretation was corroborated by a complementary experiment in which two of the subjects participated. Using inductive spirometry, the subjects phonated with and without a voluntary coactivation of the diaphragm. The resulting registrations shown in Fig. 5 demonstrate clearly that in these subjects, phonation with a co-contraction of the diaphragm was associated with a reduction of the rib cage circumference, while phonation with a flaccid diaphragm was associated with a reduction of the abdominal circumference.

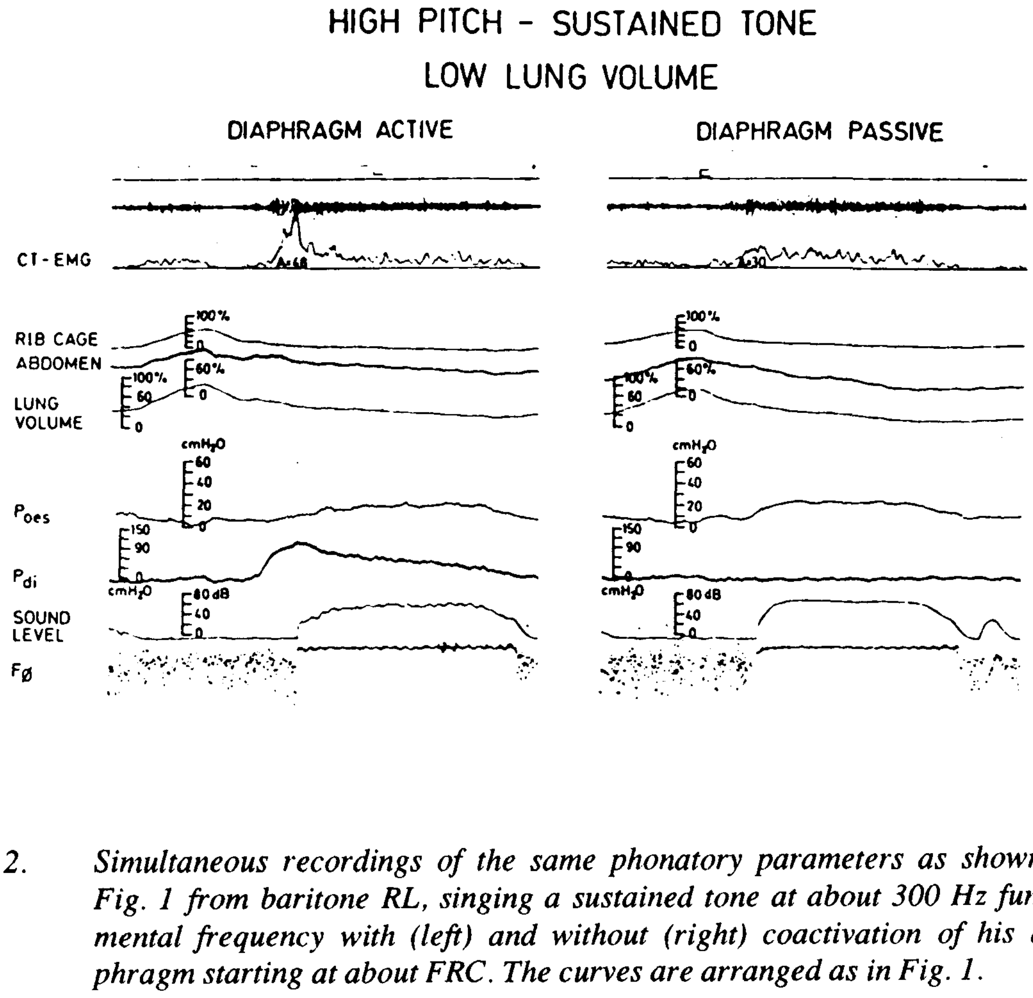

Fig. 2. *Simultaneous recordings of the same phonatory parameters as shown in Fig. 1 from baritone RL, singing a sustained tone at about 300 Hz fundamental frequency with (left) and without (right) coactivation of his diaphragm starting at about FRC. The curves are arranged as in Fig. 1.*

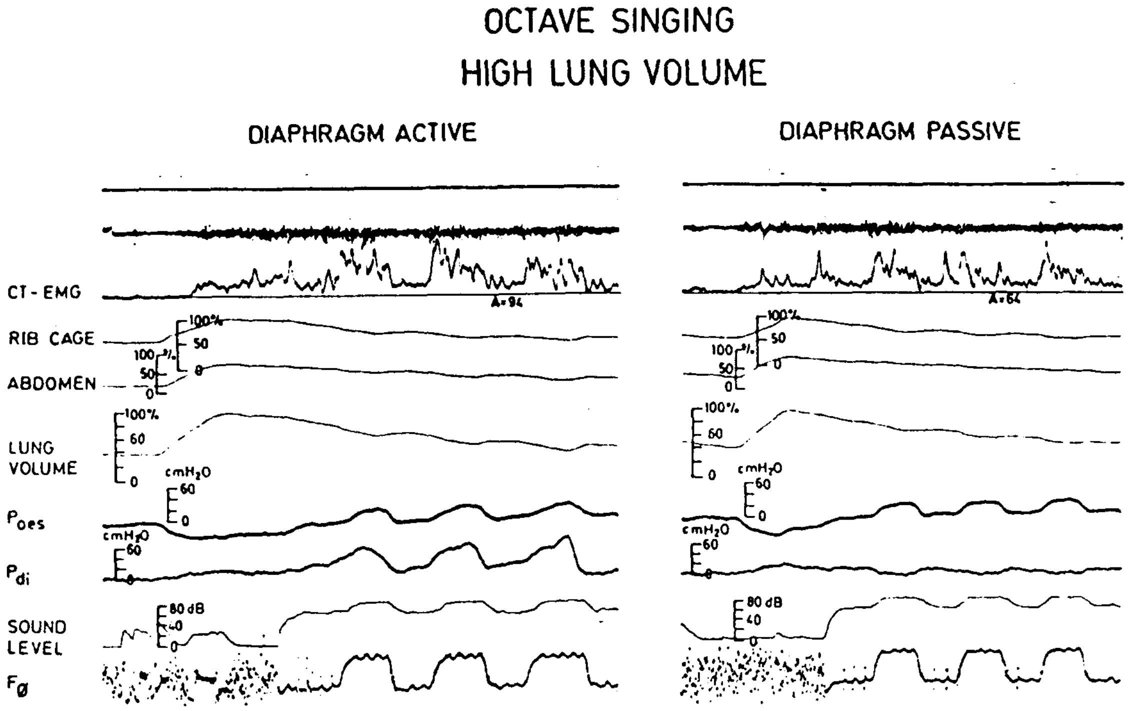

Fig. 3. *Simultaneous recordings of the same phonatory parameters as shown in Fig. 1 from baritone SH, singing a sequence of alternately rising and falling octave intervals with (left) and without (right) coactivation of his diaphragm starting at a high lung volume. The fundamental frequency of the higher tone was about 300 Hz. The curves are arranged as in Fig. 1.*

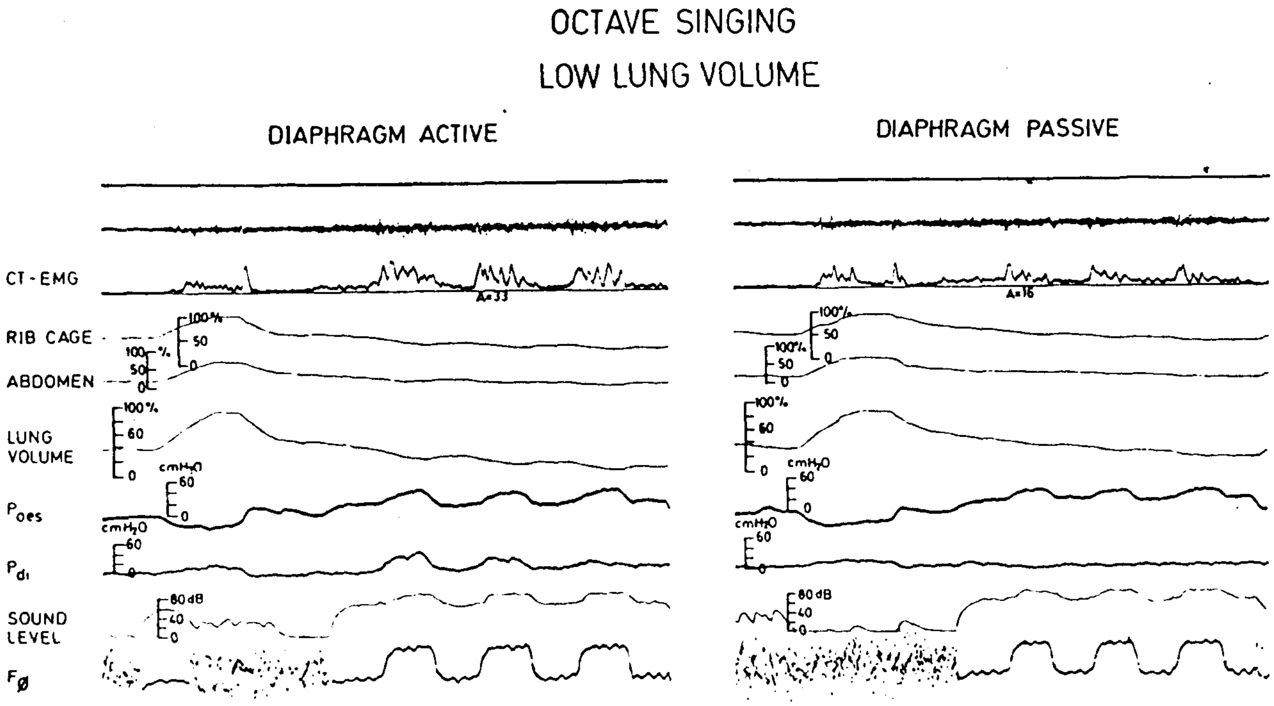

Fig. 4. *Simultaneous recordings of the same phonatory parameters as shown in Fig. 1 from baritone SH, singing a sequence of alternately rising and falling octave intervals with (left) and without (right) coactivation of his diaphragm starting at about FRC. The fundamental frequency of the higher tone was about 300 Hz. The curves are arranged as in Fig. 1.*

Discussion

Our results suggest that a descent of the diaphragm induced a need for increased CT activity in order to sustain a constant pitch and loudness. In our three singers, the EMG activity of the CT was found to be greater at high lung volumes than at low lung volumes. Also, irrespective of lung volume, it increased when the diaphragm was coactivated during singing. Indeed, in no case an increase in diaphragmatic activation was observed without an accompanying increase in CT EMG.

These results agree with those of Zenker (1964). A tracheal pull tends to increase the anterior distance between the lower margin of the thyroid cartilage, stabilized by the hyoid, and the arch of the cricoid. Such a widening of the thyroid-cricoid distance is the typical gesture accompanying a pitch lowering. A descent of the diaphragm cupolas implies an increased tracheal pull on the cricoid cartilage, requiring a compensatory recruitment of the CT muscle activity in order to maintain the pitch. Conversely, a reduced lung volume implies raised diaphragm cupolas, decreased tracheal pull, and hence less need for CT activity.

Our results do not seem to agree with the results found by Shipp, Morrissey, & Haglund (1985). They observed a clearly higher CT activity at low lung volumes. This disagreement is not well understood. However, it may be relevant that their investigation concerned extremely low lung volumes, while our subjects started phonation close to FRC. It does not seem likely that their subjects activated their diaphragms at these lung volumes. Rather, findings by Rubin, LeCover, & Vennard (1967) seem relevant; at extremely low lung volumes, they found a rise in subglottal pressure in combination with an unchanged transglottal air flow, thus indicating an increased adduction activity. It seems possible that such a change in the laryngeal conditions may affect the roles of the glottal muscles.

As pointed out by many authors, e.g., Vennard (1967) and Shipp, Morrissey, & Haglund (1985), a low laryngeal position is favorable, at least in male singing. In our previous work (Sundberg, Leanderson, & von Euler, 1986) we observed that an activation of the diaphragm during phonation was typically associated with certain effects on the operation of the vocal folds, which generated acoustical consequences in the voice source. These effects involved a greater transglottal peak air flow.

According to Zenker (1964) and Zenker & Glaninger (1959), the form of the larynx cavity and the arrangements of the connective tissue in its walls imply that a tracheal pull can be effective as a glottis opener. As the larynx is suspended in the hyoid bone, a tracheal pull generated, e.g., by a coactivation of the diaphragm will produce an abductory component. This effect would increase if the larynx-raising hyoid musculature is compensatorily activated in order to maintain larynx position. This would agree with the increase in air flow that we observed under conditions of diaphragmatic coactivation. Also, it seems to agree with observations of Shipp, Morrissey, & Haglund (1985), that a low diaphragm (high lung volume) is combined with a greater adduction activity in internal laryngeal muscles, required as a compensation of the abducting force induced by the tracheal pull. Such an abductory effect would counteract pressed phonation, according to Gauffin & Sundberg (1980). It may very well be that this effect is the phonatory essence of the coactivation of the diaphragm during singing.

Interestingly, this abduction effect would not arise unless the larynx is pulled downward from below, because if the larynx is pressed downward from above, the abducting effect will not be generated. Thus, the way in which the larynx is lowered may be highly relevant to its phonatory effects. This might be a rewarding topic to pursue in future research.

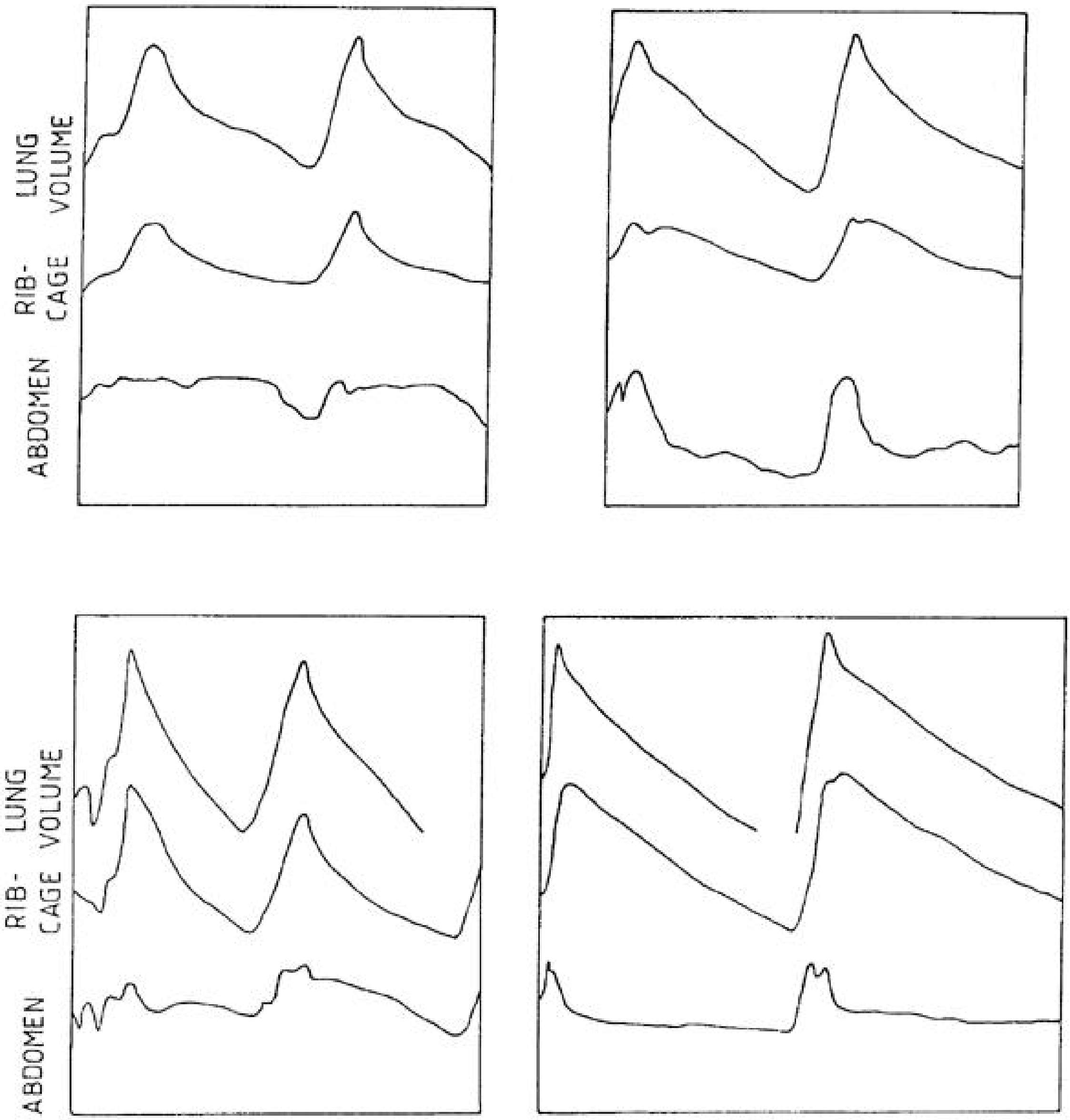

Fig. 5. *Simultaneous recordings of lung volume, rib cage and abdominal circumference in subjects RL (upper panels) and JS (lower panels) phonating with (left panels) and without (right panels) coactivation of the diaphragm.*

The functioning of the laryngeal apparatus is obviously extremely complicated. For instance, the role of one single muscle may change depending on the activity in other muscles. We have observed a relationship between a contraction of the diaphragm and the CT muscles. This relationship may arise for various reasons.

One is an undue activation of several muscles resulting as a response to an unusual task, such as deliberately contracting the diaphragm. This alternative seems unlikely as our three subjects habitually sang with a diaphragmatic coactivation.

Another is a direct reflectory connection. The lack of a precise phase agreement between the transdiaphragmatic pressure and the CT EMG seen in Figs. 3 and 4 does not support this alternative.

A third alternative is a mechanical effect; changes of the tracheal pull have consequences for the laryngeal conditioning which requires changes of the CT activity.

The existence of tracheal pull on the larynx cannot be doubted. The dependence of this pull on the positioning of the diaphragm seems obvious from the fact that Macklin (1925) found the carina to descend during full inhalation, a gesture which cannot be performed without a lowering of the diaphragm. Therefore, we find no reasons to doubt the existence of a mechanical connection between the diaphragm position and the CT activation.

The degree of tracheal pull must depend on the posture of the trunc. For example, a straight trachea would lead to a maximal tracheal pull, while a curved trachea would result in a reduced tracheal pull. Moreover, the tracheal pull depends on the positioning of the diaphragm, which, in turn, also is influenced by the body posture. According to the experience of singing teachers and voice therapists, the body posturing is of great importance to phonation. A mechanical connection between the diaphragm position and the laryngeal conditioning would explain this experience.

Our experiment raises a number of interesting questions. Are the increased demands on CT activity, resulting from a coactivation of the diaphragm, beneficial from some point of view? For instance, what are the acoustical implications of this increased activity? What are the details of relationships between tracheal pull, phonation, and posture of the trunc? These questions should be investigated in future research. Also, a more detailed analysis of the relationship between diaphragm contraction and displacement should be carried out on a greater number of subjects.

Conclusions

This investigation has revealed a relationship between the position of the diaphragm cupolas and the electrical activity in the CT muscles. An increased tracheal pull, resulting from a coactivation of the diaphragm or from an increase in lung volume, seems to induce not only an increased glottal abduction but also an increase of the CT EMG activity during phonation at high and moderately low lung volumes. This may be a neural compensation to a mechanical effect: As the diaphragmatic pull on the trachea, transmitted to the larynx, is likely to widen the anterior gap between the cricoid and thyroid cartilages and thus slacken the vocal folds, an increased CT activity is required for sustained pitch and loudness.

Acknowledgements

The experiments of the present investigation, initially arising from an informal discussion with Dr. Thomas Hixon, were carried out at the Department of Linguistics at the Stockholm University. Dr. Per Åke Lindestad, Huddinge Hospital, kindly assisted with placing the EMG electrodes, and technical help was offered by Sten Ternström, Dr. Bob McAllister, and others. All these persons are gratefully acknowledged.

References

Andrew, B. (1955): "The respiratory displacement of the larynx: a study of the innervation of accessory respiratory muscles", J.Physiol. **130**, pp. 474-487.

Gauffin, J. & Sundberg, J. (1980): "Data on the glottal voice source behavior in vowel production", STL-QPSR 2-3/1980, pp. 61-70.

Kirschner, J. (1970): *Pressman & Kelemen's Physiology of the Larynx,* (2nd ed.), Am.Acad.Ophtal.Otolaryng., Rochester, Minnesota.

Leanderson, R., Sundberg, J., & von Euler, C. (1987): "Role of diaphragmatic activity during singing: a study of transdiaphragmatic pressures". J.Appl.Physiol. **62**(1), pp. 259-270.

Luchsinger, R. (1970): *Die Stimme und ihre Störungen, Vol. I* of *Handbuch der Stimm- und Sprachheilkunde*, Springer, New York.

Macklin, C. (1925): "X-Ray studies on bronchial movements", Am.J.Anat. **35**(2), pp. 303-320.

Mitchinson, A. & Yoffey, J. (1947): "Respiratory displacement of larynx, hyoid bone, and tongue", J.Anat.Lond. **81**, pp. 118-120.

Rubin, H., LeCover, M., & Vennard, W. (1967): "Vocal intensity, subglottal pressure, and airflow relationships in singers", Fol.Phoniat. **19**, pp. 393-413.

Seidner, W. & Wendler, J. (1982): *Die Sängerstimme*, Hänschelverlag, Berlin.

Shipp, T., Morrissey, P., & Haglund, S. (1985): "Laryngeal muscle adjustments for sustained phonation at lung volume extremes", pp. 269-277 in (A. Askenfelt, S. Felicetti, E. Jansson & J. Sundberg, eds.) *Proc. Stockholm Music Acoustic Conf. 1983 (SMAC 83), Vol. II*, Publ. issued by the Royal Swedish Academy of Music No. 46:2, Stockholm.

Sundberg, J., Leanderson, R., & von Euler, C. (1986): "Voice source effects of diaphragmatic activity in singing", J.Phonetics **14**, pp. 351-357.

Vennard, W. (1967): *Singing, the Mechanism and the Technique*, Carl Fischer, New York.

Zenker, W. (1964): "Questions regarding the function of external pharyngeal muscles", pp. 20-29 in (D. Brewer, ed.) *Research Potentials in Voice Physiology*, Proc.Int.Conf., Syracuse, 1961.

Zenker, W. & Glaninger, J. (1959): "Die Stärke des Trachealzuges beim lebenden Menschen und seine Bedeutung für die Kehlkopfmechanik", Z.Biol. **111**, pp. 154-166.

Zenker, W. & Zenker, A. (1960): "Über die Regelung der Stimmlippenspannung durch von aussen eingreifende Mechanismen", Fol.Phoniat. **12**, pp. 1-36.