USE OF HOOKED-WIRE ELECTRODES FOR ELECTROMYOGRAPHY OF THE INTRINSIC LARYNGEAL MUSCLES

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A new technique for electromyography of the intrinsic laryngeal muscles with bipolar hooked-wire electrodes is described in detail. This technique has the following important advantages for investigating speech activity: (1) it offers minimum discomfort to the subject, and consequently does not interfere with natural speech; (2) the electrodes stay in place regardless of rapid movements of the vocal cords or of the entire larynx during speech; and (3) it permits considerable localization of the area from which electrical activity is picked up.

Successful electromyographic investigation of the muscle activity during speech requires that the electrodes and their leads not interfere with natural phonation and articulation and that the electrodes not shift in the muscle. Almost all previous electromyographic studies of the intrinsic laryngeal muscles have employed concentric needle electrodes inserted through the mouth. Only in the case of the cricothyroid muscle has the electrode always been inserted through the skin. The pain and discomfort caused by the needle and the presence of the electrode leads in the vocal tract make natural speech difficult or even impossible. Furthermore, movement artefacts contaminate the signal frequently due to the rapid movements of the vocal cords or of the entire larynx. In the past, therefore, electromyographic investigations of the intrinsic laryngeal muscles related to phonation were limited mostly to some vowels.

Recently, Hiroto, Hirano, Toyozumi, and Shin (1962) described transcutaneous methods for approaching all the intrinsic laryngeal muscles. This technique avoids the disruption of natural articulation from electrode leads passing through the length of the vocal tract. Hiroto et al. later (1967) obtained and reported electromyographic records from the intrinsic laryngeal muscles during the production of Japanese monosyllables and simple disyllables. Their technique, however, does not eliminate the slight pain or discomfort which may affect natural speech, nor does it avoid possible movement artefacts due to electrode slippage.

Wire electrodes have great advantages over the needle electrodes due to their flexibility and lightness. Such wire electrodes have been used successfully for the pharyngeal and palatal muscles (Basmajian, 1962; Basmajian and Dutta, 1961a and 1961b; Fritzell, personal communication; Shipp, Wayne, and

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Robertson, 1968), muscles in the extremities (Bigland and Lippold, 1954; Close, Nickel, and Todd, 1960; Long, Eleanor, and Weiss, 1960 and 1961), and diaphragm (Basmajian, 1962). Especially, the bipolar wire electrodes with a hooked tip which were described by Basmajian and Stecko (1962) appear profitable for electromyographic study of speech production.

This paper describes our current technique for using hooked-tip wire electrodes in the intrinsic laryngeal muscles, giving an account of the necessary anatomical and physiological features of these muscles.

Preparation of the Electrodes

The electrodes are made in a way similar to that described by Basmajian and Stecko (1962), though the wire and needles we use are different. A single length of wire (40 gauge copper magnet wire, Belden No. 8072, 0.087 mm in diameter) long enough to serve as two electrodes (approximately 50 to 60 cm) is cut out. The free ends of the wire are twisted together and inserted into the beveled end of a No. 25 hypodermic needle. The wire is pulled through the needle until a small loop remains. The loop is bent back carefully and cut leaving two ends approximately 1 mm and 1.5 mm or less, respectively, out of the beveled tip of the needle (Figure 1). We do not remove the insulation from these ends, so that the wires will not short out during insertion by both touching the needle, and so that we can get greater localization of the area from which the electrical activity is picked up. At the other ends of the wires the insulation is scraped off for connection to a differential amplifier.

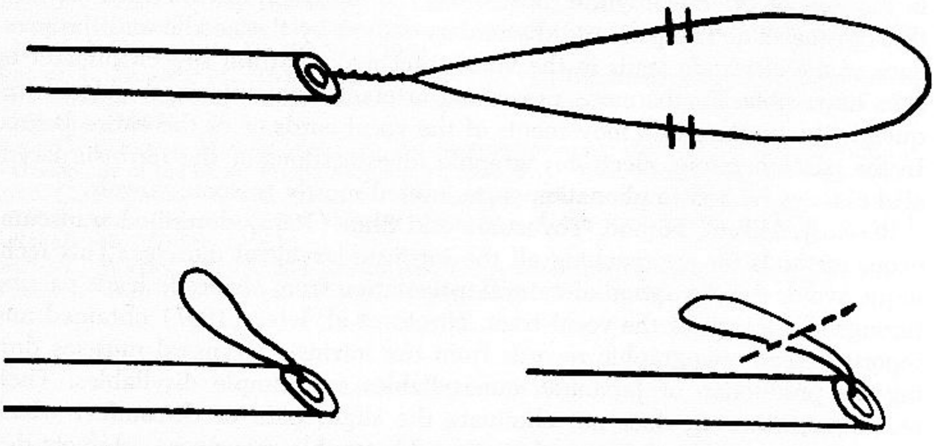

FIGURE 1. Technique for making the bipolar hooked-wire electrodes.

Advantages and Disadvantages

The type of wire electrodes described here has some significant advantages in investigations of speech production, when compared with concentric needle electrodes. Hooked-wire electrodes stay in place much better than rigid needles. They cause little discomfort to the subject once they are in place, and they do not interfere with natural speech at all. Indeed, after the hypodermic needle has been removed, the subject is often unaware that the wires are there. Furthermore, there is the usual advantage of a bipolar over a monopolar electrode system in that one can obtain greater localization of the area from which the electrical activity is registered and greater freedom from ambient noise.

On the other hand, this type of electrode is more difficult to implant correctly. With a concentric needle electrode one can retract and reposition it when it has been incorrectly placed. Using hooked-wire electrodes, however, one cannot tolerate retraction of the needle until the active tips of the wires are located precisely in the target muscle. Should this happen, further insertion of the needle could catch the wire at a vulnerable angle and cut it. The experimenter must be very familiar with the anatomical environment of the muscles being studied. Repeated practices with cadavers or excised larynges are essential. Accidental and premature separation of the tips of the wires and the tip of the needle might occur during violent movements of the larynx, e.g., swallowing. This can be guarded against by putting a mark on the wires at their point of emergence from the base end of the needle and making sure that this mark never moves forward or disappears into the needle (white ink or a tiny piece of self-sticking paper will suffice for this purpose). If the mark does disappear into the shaft of the needle further insertion must be stopped.

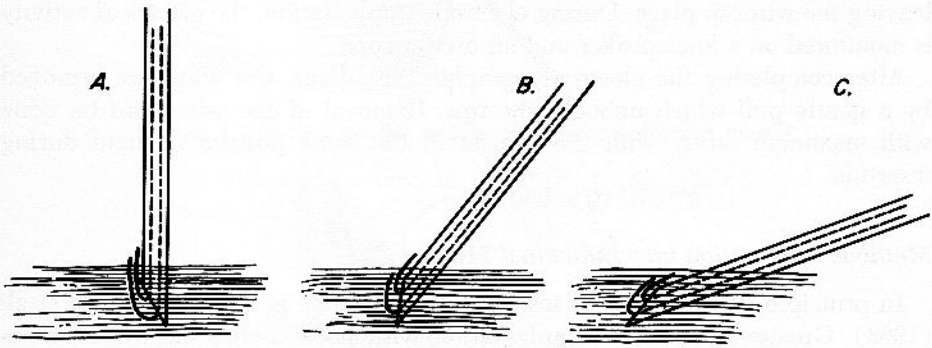

FIGURE 2. A, B. Possible faulty insertions of hooked-wire electrodes. C. Correct method of insertion.

Also, with this type of electrode there is a distance of approximately 2 to 4 mm between the tip of the hypodermic needle and the active tips of the wires. As the intrinsic laryngeal muscles are small in size, it is possible that the active tips of the wires may not be located in the target muscle even though the tip of the needle is (Figure 2A and B). When the tips of both wires are out of the target muscle, one cannot get any activity or one may get activity of the neighboring muscle (if there is one nearby). When the tip of one wire is located in the target muscle and that of the other is out of the muscle, one may get increased background noises or contamination with the neighboring muscle. This trouble is not infrequently encountered, especially in the cricothyroid and posterior cricoarytenoid muscles. In order to minimize it, the needle should be inserted into the muscle at the sharpest possible angle to the muscle fibers (Figure 2C). An occasional short circuit between the tips of two wires may occur along the hypodermic needle during implantation.

This is, however, easily remedied by rotating the needle gently a few degrees. Extreme rotation should be avoided, as this may possibly damage or weaken the wires.

General Procedure

The electrodes are sterilized by usual means, such as heat or antiseptics. The subject lies on his back with his head tilted back. For the vocalis and the interarytenoid muscles, he may take a sitting position, in which case a laryngeal mirror may be used for monitoring the insertion. The skin of the neck is disinfected with alcohol. Surface anesthesia to the mucosa of the larynx is required when the vocalis or interarytenoid muscle is aimed at, whereas no anesthesia is necessary for the cricothyroid, lateral cricoarytenoid, or posterior cricoarytenoid muscle. We prefer to inject anesthetics (usually Xylocain) via the cricothyroid membrane.

A ground lead is placed on the ear lobe of the subject. The electrodes are inserted into the muscle with the hypodermic needle, which is later removed leaving the wires in place. During electrode implantation, the electrical activity is monitored on a loudspeaker and an oscilloscope.

After completing the electromyographic recordings, the wires are removed by a gentle pull which unhooks the tips. Removal of the wires can be done with maximum safety with the subject in the same posture he held during insertion.

Methods of Insertion into Individual Muscles

In principle, our methods of insertion are the same as those of Hiroto et al. (1962). Greater difficulty in implantation with hooked-wire electrodes, mentioned above, however, has caused partial modifications of their original techniques.

1. The Crico-Thyroid Muscle (*Figure 3*). Pierce the skin at a point above the lower edge of the cricoid cartilage and lateral to the midline. Direct the needle posterolaterally and upwards along the long axis of the pars obliqua aiming at the lower surface of the thyroid cartilage posterior to the inferior tuberculum of that cartilage. If the electrodes extend too deep beyond the inner surface of the thyroid cartilage they may be placed in the lateral cricoarytenoid muscle. If the penetration is not deep enough, one may get activity from the sternohyoid muscle (Figure 4).

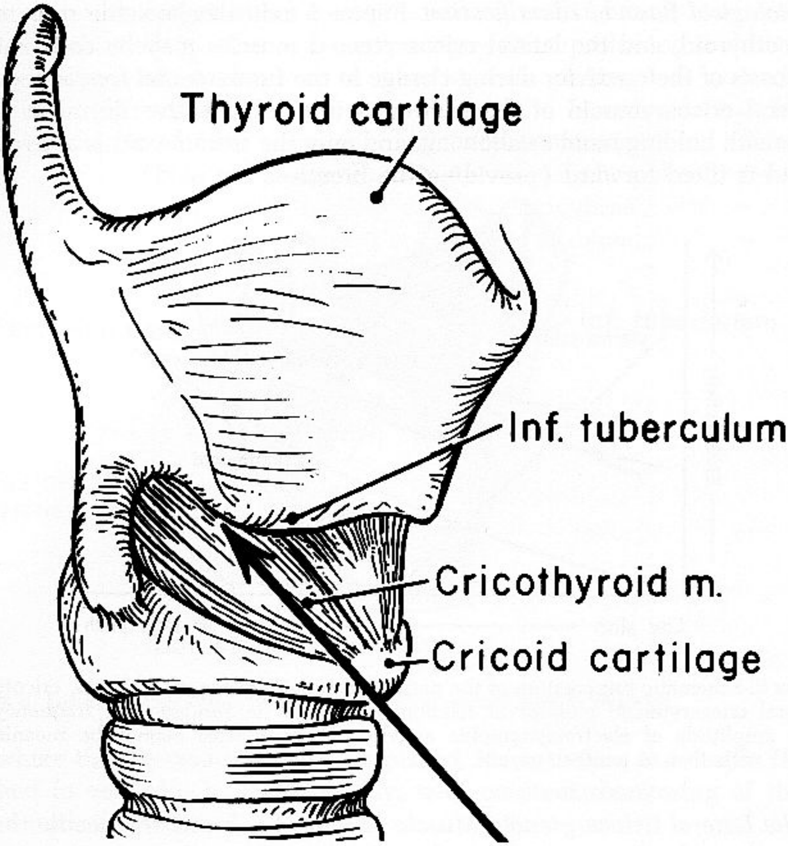

FIGURE 3. Insertion of the needle into the cricothyroid muscle.

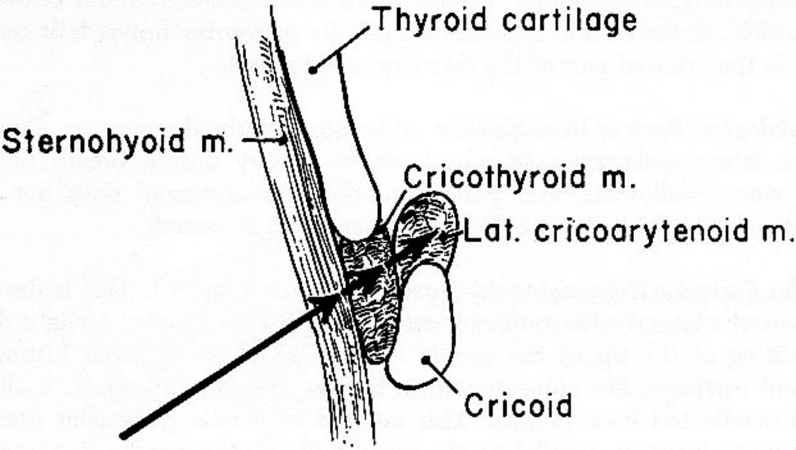

FIGURE 4. Oblique cut along the needle in Figure 3. Note that the electrodes can be placed in any of the sternohyoid, cricothyroid, or lateral cricoarytenoid muscles depending on the depth of insertion.

Physiological Basis of Identification. Figure 5 indicates how the sternohyoid, the cricothyroid, and the lateral cricoarytenoid muscles may be differentiated on the basis of their activity during change in the fundamental frequency. Only the lateral cricoarytenoid of these three is invariably active during a glottal stop (breath holding) and swallowing, and only the sternohyoid is active when the head is tilted forward (providing the breath is not held).

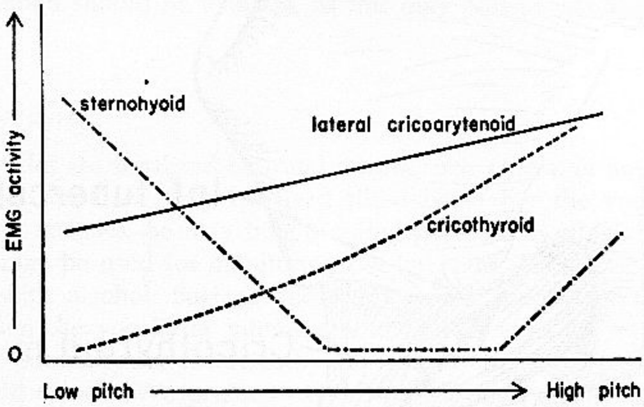

FIGURE 5. Schematic presentation of the pattern of activity of the sternohyoid, cricothyroid, and lateral cricoarytenoid muscles in relation to changes in fundamental frequency. The absolute amplitude of electromyographic activity of one muscle cannot be meaningfully compared with that of another muscle.

2. *The Lateral Cricoarytenoid Muscle (Figure 6).* Insert the needle through the cricothyroid space penetrating the cricothyroid membrane anterior to the inferior tuberculum of the thyroid cartilage. Push the needle posteriorly, slightly laterally, and slightly upwards, until it reaches the lateral cricoarytenoid muscle. If the needle is directed medially or too far upwards it may be placed in the external part of the thyroarytenoid muscle.

Physiological Basis of Identification. Although both the thyroarytenoid muscle and the lateral cricoarytenoid muscle show activity during breath holding, glottal stop, swallowing, and phonation, the thyroarytenoid does not show much change in the amount of activity when pitch is varied.

3. *The Posterior Cricoarytenoid Muscle (Figures 6 and 7).* This is the same path as to the lateral cricoarytenoid, except 5 to 10 mm deeper. A slight downward tilting of the tip of the needle is often required to avoid hitting the arytenoid cartilage. For subjects with a narrow cricothyroid space, a slightly curved needle has been helpful. This method of needle placement does not permit us to insert it parallel to the muscle fibers; the needle is necessarily inserted at a right angle to the long axis of the muscle. Fortunately, the posterior cricoarytenoid muscle is thickest near its insertion to the arytenoid car-

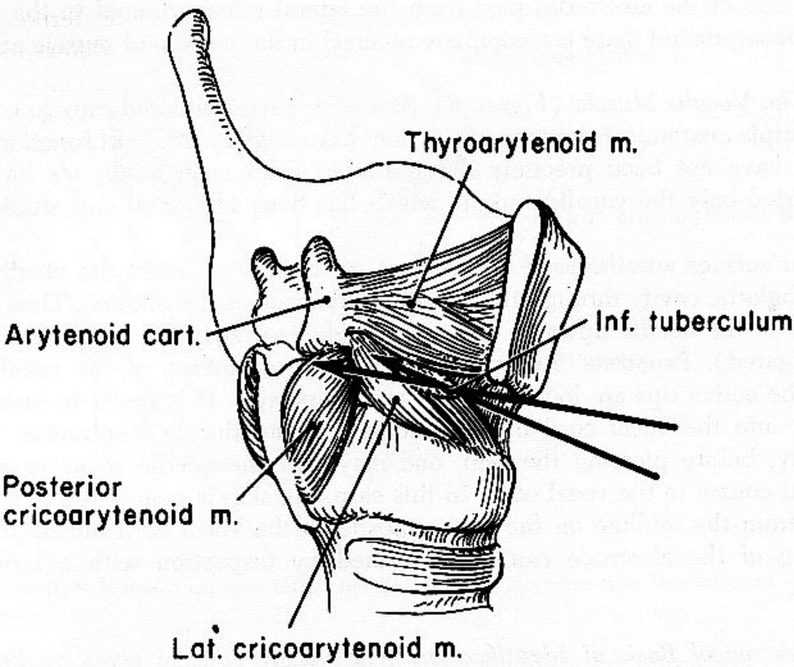

FIGURE 6. Insertion into the lateral and posterior cricoarytenoid muscles.

tilage, where the electrodes usually are placed. Nevertheless, the needle should be pushed in very slowly and carefully, with constant monitoring of the resultant muscle activity.

Physiological Basis of Identification. The posterior cricoarytenoid muscle gives marked activity during inspiration and little or no activity during phonation or swallowing. This pattern is unique to this particular muscle. When the

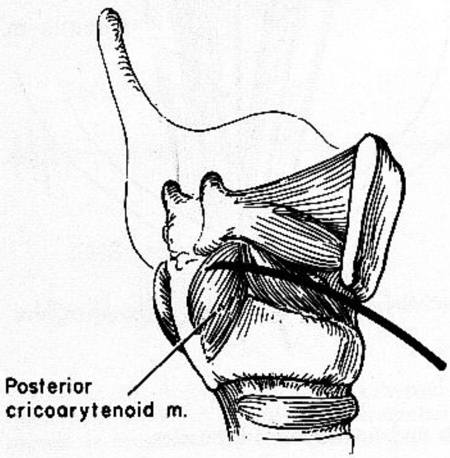

FIGURE 7. Insertion into the posterior cricoarytenoid muscle using a curved needle.

active tips of the electrodes pass from the lateral cricoarytenoid to the posterior cricoarytenoid there is a complete reversal in the pattern of muscle activity.

4. The Vocalis Muscle (*Figure 8*). Since the thyroarytenoid muscle consists of multiple anatomical portions which may have slightly different functions and which have not been precisely differentiated from each other, we have investigated only the vocalis muscle, which has been identified and studied by others.

After surface anesthesia of the mucosa of the larynx, insert the needle into the subglottic cavity through the cricothyroid space at the midline. Then angle the tip of the needle upwards and to the side (towards the vocal cord to be investigated). Penetrate the mucosa of the lower surface of the vocal cord until the active tips are located in the vocalis muscle. It is easier to insert the needle into the vocal cord during phonation than during respiration. Alternatively, before piercing the skin, one may aim the needle so as to take a straight course to the vocal cord. In this case, the skin is penetrated at a point away from the midline on the side opposite to the vocal cord aimed at. The location of the electrode can be confirmed by inspection with a laryngeal mirror.

Physiological Basis of Identification. The vocalis muscle gives marked ac-

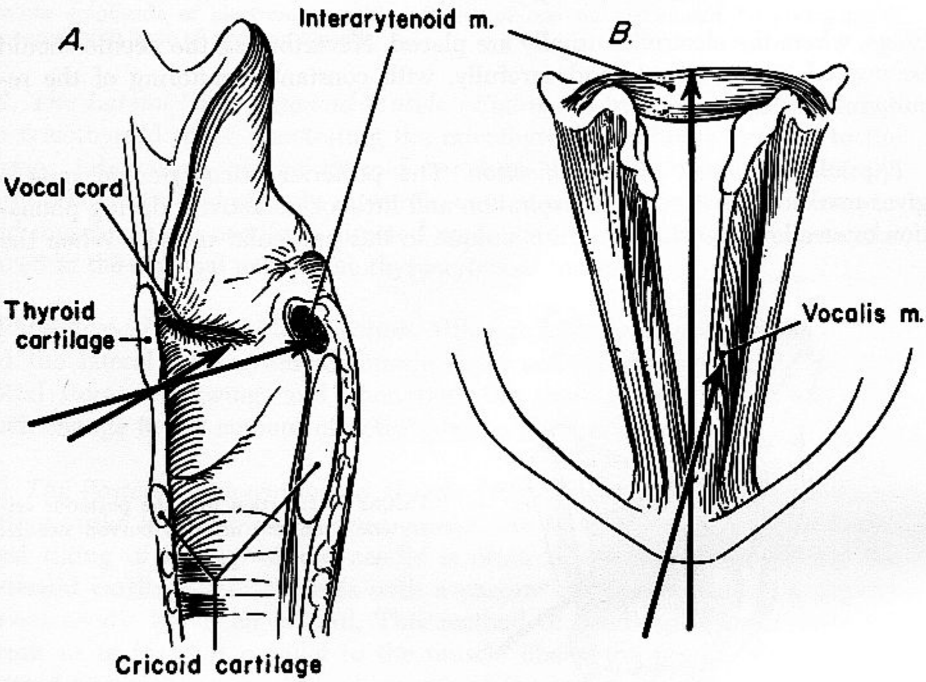

FIGURE 8. Insertion into the vocalis and interarytenoid muscles.

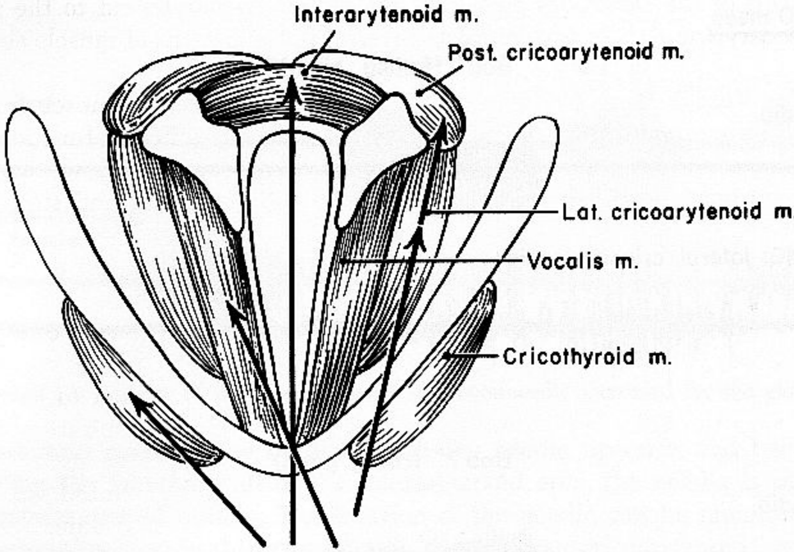

FIGURE 9. Schematic representation of the ways of insertion into the intrinsic laryngeal muscles.

tivity for breath holding, glottal stop, swallowing, and phonation. There is little chance of contamination with any other muscle.

5. *The Interarytenoid Muscle* (*Figure* 8). Following local anesthesia to the mucosa of the larynx, insert the needle in the subglottic space through the

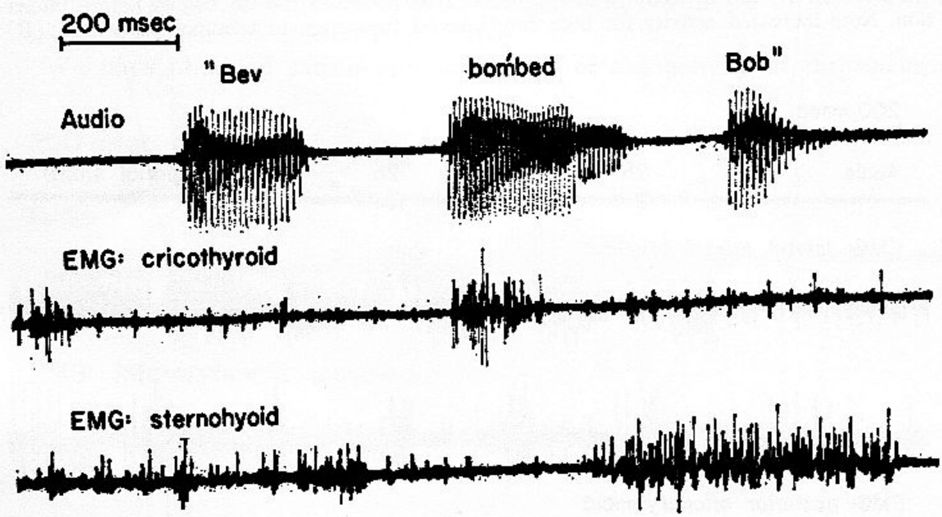

FIGURE 10. Activity of the cricothyroid muscle is increased for high fundamental frequency on the word *bombed*, which contains the nuclear accent. Activity of the sternohyoid muscle is increased for low fundamental frequency after the nuclear accent.

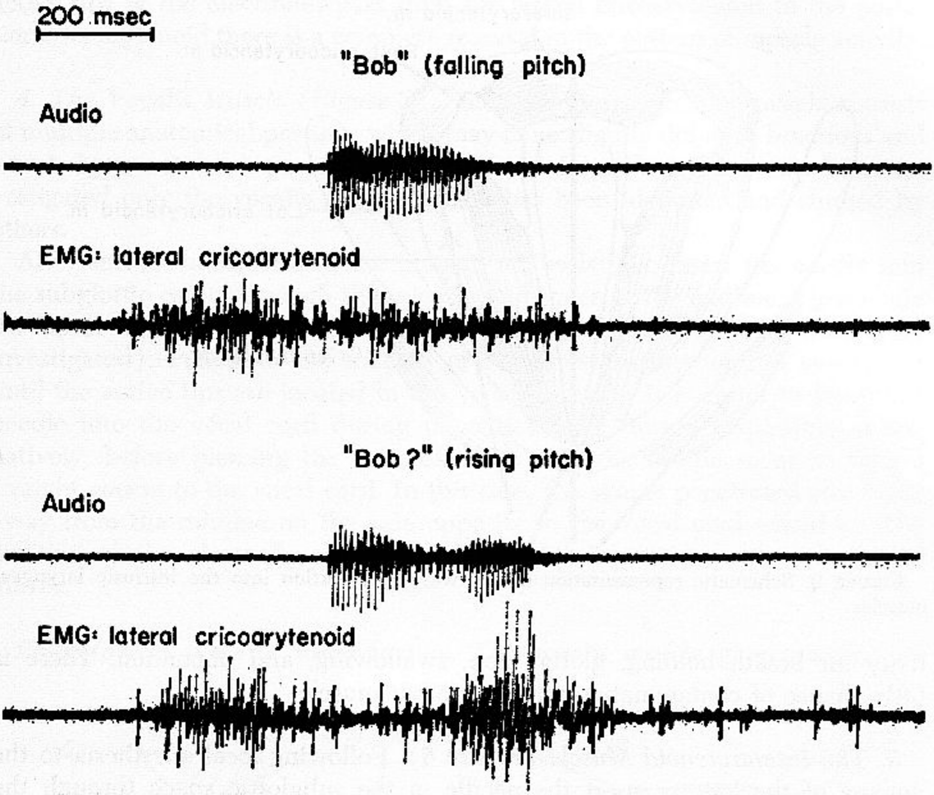

FIGURE 11 A, and B. Activity of the lateral cricoarytenoid muscle begins before phonation. Note increased activity for high fundamental frequency in terminal portion of (B).

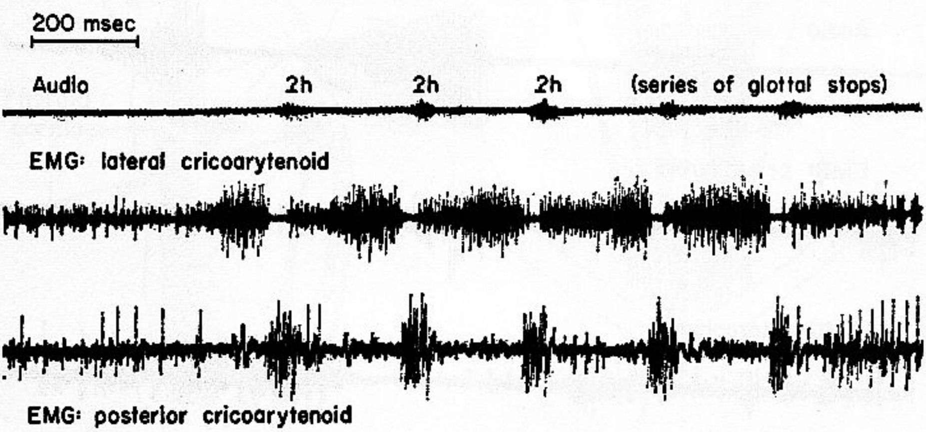

FIGURE 12. The lateral cricoarytenoid and the posterior cricoarytenoid muscles are antagonistic; the alternate excitation/inhibition pattern shown here suggests that the two muscles are reciprocally innervated.

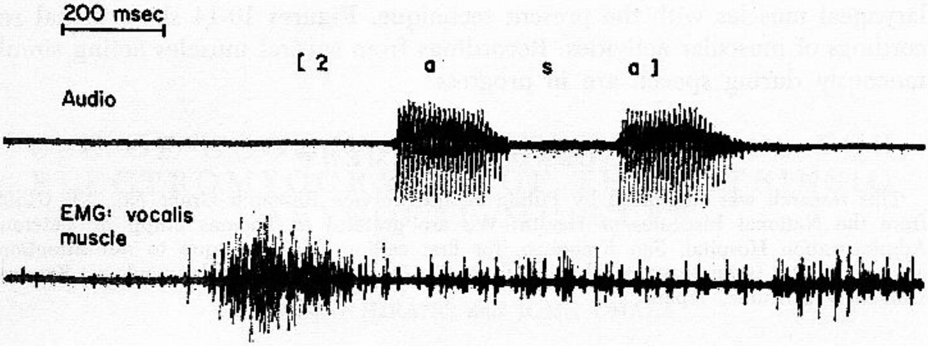

FIGURE 13. Activity of the vocalis muscle is pronouncedly increased for the glottal stop.

cricothyroid space at the midline. Push the needle upwards and backwards. Piercing the anterior wall of the interarytenoid area, the needle is placed in the interarytenoid muscle. The location of the needle can be monitored with a laryngeal mirror. In this muscle, as in the posterior cricoarytenoid, we cannot insert the needle parallel to the muscle fibers. Luckily the interarytenoid muscle is rather thick and can be located quite easily. There are no neighboring muscles which the electrodes could be placed in by mistake.

Physiological Basis of Identification. The basic patterns of the action of the interarytenoid muscle are the same as those of the vocalis muscle. A simple visual inspection of the placement of the electrodes in the larynx can prevent any confusion between them.

Figure 9 shows, schematically, the approach of the needles for all five intrinsic laryngeal muscles as viewed from above.

We have obtained satisfactory recordings of the activity of the intrinsic

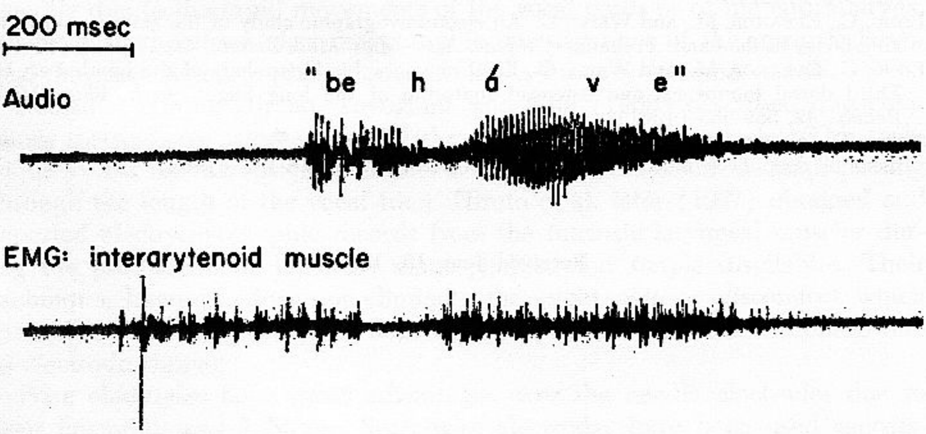

FIGURE 14. The interarytenoid muscle is activated for phonation; it is inhibited for [h], which requires some abduction of the vocal cords.

laryngeal muscles with the present technique. Figures 10-14 show actual recordings of muscular activities. Recordings from several muscles acting simultaneously during speech are in progress.

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REFERENCES

BASMAJIAN, J. V., *Muscles Alive. Their Functions Revealed by Electromyography.* Baltimore: Williams and Wilkins (1962).

BASMAJIAN, J. V., and DUTTA, C. R., Electromyography of the pharyngeal constrictors and soft palate in rabbits. *Anat. Record,* 139, 443-449 (1961a).

BASMAJIAN, J. V., and DUTTA, C. R., Electromyography of the pharyngeal constrictors and levator palatini in man. *Anat. Record,* 139, 561-563 (1961b).

BASMAJIAN, J. V., and STECKO, G., A new bipolar electrode for electromyography. *J. Appl. Physiol.,* 17, 849 (1962).

BIGLAND, D., and LIPPOLD, O. C. J., Motor unit activity in the voluntary contraction of human muscle. *J. Physiol.,* 125, 322-335 (1954).

CLOSE, J. R., NICKEL, E. D., and TODD, F. N., Motor-units action-potential counts. *J. Bone Joint Surg.,* 42A, 1207-1222 (1960).

DEDO, H. H., and BURN, H. F., Reliability of laryngeal electromyography in the human: A preliminary study. *1967 Conference on Speech Communication and Processing,* 154-156 (1967).

HIRANO, M., KOIKE, Y., and VON LEDEN, H., The sternohyoid muscle during phonation. Electromyographic studies, *Acta Oto-laryngol.,* 64, 500-507 (1967).

HIROTO, I., HIRANO, M., TOYOZUMI, Y., and SHIN, T., A new method of placement of a needle electrode in the intrinsic laryngeal muscles for electromyography. *Oto-rhino-laryngol. Clinic Kyoto,* 55, 499-504 (1962).

HIROTO, I., HIRANO, M., TOYOZUMI, Y., and SHIN, T., Electromyographic investigation of the intrinsic laryngeal muscles related to speech sounds. *Ann. Otol.-Rhinol.-Laryngol.,* 76, 861-872 (1967).

LONG, C., ELEANOR, M., and WEISS, G., An electromyographic study of the extrinsic-intrinsic kinesiology of the hand: Preliminary report. *Arch. Phys. Med. Rehab.,* 41, 175-181 (1960).

LONG, C., ELEANOR, M., and WEISS, G., Electromyographic kinesiology of the hand: Part II. Third dorsal interosseus and extensor digitorum of the long finger. *Arch. Phys. Med. Rehab.,* 42, 559-565 (1961).

SHIPP, T., WAYNE, W. D., and ROBERTSON, C., A technique for electromyographic assessment of deep neck muscle activity. *Laryngoscope,* 78, 418-432 (1968).

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