The Stuttering Larynx: An EMG, Fiberoptic Study of Laryngeal Activity Accompanying the Moment of Stuttering

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Over a century ago Arnott (1828) wrote, "the most common cause of stuttering is in the glottis." Other writers, including Müller (1857), Hunt (1861), and Kenyon (1943), proposed models of the stuttering block incorporating a primary laryngeal component. The present research sought to test this century-old hypothesis through two methodologies. The first approach utilized a fiberoptic endoscope for direct observation of the glottis, while the second utilized multichannel electromyography to investigate the motor commands that resulted in the observed laryngeal dysfunction.

Comments on the fiberoptic studies will be brief for two reasons: first, because a film of work is currently available;1 and second because of overlap with recent work of Contour, Brewer, and McCall (1974).

When Chevrie-Muller (1963) utilized the glottalograph to study 27 stutterers, she reported: (1) arhythmic vocal-fold vibrations, (2) unpredictable glottal openings, and (3) partial or complete absence of voicing during rapid glottal activity. Fujita (1966) took anterior-posterior X-rays of a Japanese stutterer and reported: (1) irregular or inconsistent opening and closing of the pharyngo-laryngeal cavity and (2) asymmetric tight closure of the glottis, which extended upward and included closure of the pharyngeal cavity. Our own fiberoptic observations found: (1) irregular, unpredictable glottal openings and (2) very tight closure of the laryngeal aperture.

Figure 1 shows individual frames from the motion picture, illustrating the sequence typical of the tight laryngeal closure in some moments of stuttering. Each frame is shown in its original form, and in a tracing of the tissue outline. Frame 1 shows the true folds in phonatory position. In frame 2 the ventricular folds can be seen as they are adducted and partially occlude the

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1This film (Kamiyama, Hirose, Ushijima, and Niimi, 1965) was included, with subtitles, in the American Speech and Hearing Association 1974 film theater offerings. Inquiries should be addressed to Dr. Seiji Niimi, Haskins Laboratories, New Haven, Conn.

[HASKINS LABORATORIES: Status Report on Speech Research SR-41 (1975)]
glottis. In frame 3 the adduction of the ventricular folds is almost complete. Frame 4 shows anterior-posterior closure at the level of the arytenoids and the tuberculum of the epiglottis. Even with this tight closure of the larynx, the subject is still attempting to phonate through the stricture, as the sound track accompanying the film shows. Other fiberoptic studies show that blocking also includes depression of the epiglottis.

The electromyographic (EMG) techniques used in the second phase of our work have been developed in a series of experiments investigating the normal laryngeal muscle activity in phonation and speech (Faaborg-Anderson, 1957; Hirano and Ohala, 1969; Hirano, Ohala, and Vennard, 1970; Hirose, 1971; Shipp and McGlone, 1971; Gay, Strome, Hirose, and Sawashima, 1972; Hirose and Gay, 1972, 1973). Experimental procedures are described in Hirose (1971) and data collection and processing are discussed in Port (1971, 1973, 1974).

Data were collected on three subjects. Attempts were made to record simultaneously from all five intrinsic laryngeal muscles and from three upper-tract articulatory muscles. In each case, acceptable recordings were obtained from four of the five intrinsic laryngeals (though the set varies from subject to subject) and three upper-tract articulators. Repeat recordings were made in a second session with one subject.

The first stage of data processing yielded oscillographic tracings of the muscle action potentials and the acoustic signal. Inspection of these "raw" EMG tracings yielded findings relevant to the "Wingate hypothesis." Wingate (1969, 1970) reevaluated the speaking conditions under which most stutterers are fluent. These conditions included whispering, choral speaking, speaking in rhythm, or speaking under delayed auditory feedback (DAF), or auditory masking. He hypothesized that, "in these circumstances which improve fluency, the stutterer is induced, in one way or another, to do something with his voice that he does not ordinarily do" (Wingate, 1969:684-685).

Each subject read the same material under three or more of these conditions: white noise, DAF, rhythm, choral speaking, and whispering. These conditions had the anticipated effect of reducing stuttering in the three subjects. The following data samples allow a comparison of EMG recordings taken during a stuttered reading of a sentence with those taken during the reading of the same sentence under a fluency-evoking condition.

Figure 2 shows three laryngeal muscle recordings for subject PN reading the phrase "and the origin of all false science and imposture is in the desire to accept false causes rather than none." The upper graph shows a stuttered reading and the lower shows a fluent reading under white noise. The overall activity levels are higher for the stuttered reading and lower for the fluent condition.

Figure 3 shows recordings for subject GG from the same three muscles for the same sentence. Here the fluency-inducing condition is rhythm reading. Again, the fluent condition shows activity levels that are lower than those recorded in the disfluent reading.

Figure 4 shows data from subject DM for posterior cricoarytenoid (PCA), vocalis (VOC), and lateral cricoarytenoid (LCA). The effects of choral reading on the activity levels of these muscles are particularly dramatic.
These data appear to support the Wingate hypothesis. The three subjects do indeed use laryngeal activity patterns that differ from their stuttering modes when they speak under these three fluency-evoking conditions.

Further processing of the data allows us to examine the details of laryngeal articulation of individual words. However, interpretation of data on the stuttering subjects is based on analysis of laryngeal articulatory activity in normals. Therefore, a brief summary of these studies is necessary. Current research indicates that the posterior cricoarytenoid is responsible for abduction of the vocal folds with increasing levels of PCA activity correlating with width of glottal opening (Hirose and Gay, 1972; Hirose and Ushijima, 1974). Segmentally it is active for voicelessness and aspiration. The interarytenoids, lateral cricoarytenoid, and thyroarytenoid, while generally grouped together as vocal-fold adductors, exhibit activity patterns indicative of functional differentiation (Hirose and Gay, 1972; Hirose, 1974). The interarytenoids are active for all voiced sounds, vocalic and consonantal, with sharp drops in activity for voicelessness. The thyroarytenoid (vocalis) and the lateral cricoarytenoid show increasing activity for vowel segments with decreases in activity for consonant segments. The lateral cricoarytenoid applies medial compression and is very active for tight glottal closure, as in glottal stop or swallow (Hirose and Gay, 1973). The thyroarytenoid increases anterior-posterior vocal-fold tension and interacts with the cricothyroid in control of fundamental frequency (Shipp and McGlone, 1971; Gay et al., 1972).

Within this framework stuttered and fluent utterances may be compared.

Figure 5 shows data on subject DM. He repeated the word "ancient" with progressive adaptation from a strong prolongation to a mild block and finally to a fluent utterance. In the first stuttered utterance, the period of prolongation is characterized by activity of the glottal abductor, the PCA, with the two adductors, the VOC and the LCA. Disruption of the normal reciprocity between adductors and adductors appears to be a critical factor. Unfortunately, this subject is the only one on whom a successful PCA recording was secured. The stuttered utterances are also marked by higher levels of activity in the adductors.

For subject PN, Figure 6 shows the word "causes," first a stuttered utterance and then a fluent utterance spoken under white noise. The first three channels are the laryngeal adductors and the fourth is the genioglossus. The peaks in the genioglossus tracing represent activity for raising the dorsum of the tongue for the /k/. Activity levels in the adductors are greater for the stuttered contrasted with the fluent utterance. It is interesting that the activity levels for the genioglossus do not show such large differences.

Figure 7 shows the same word produced nonfluently and then fluently by subject GG. The fluent utterance is spoken in rhythm. The subject repeated the

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2 The data showing suppression of thyroarytenoid and lateral cricoarytenoid for voiced consonants were obtained mainly on English and Japanese samples. Recent recordings of Danish and Dutch speakers show some cases of VOC activity for voiced consonants. There may be some individual or language differences that require further investigation.
Figure 5
initial sound only once, paused, then uttered the word. This is typical of his pattern, which contains many "silent" blocks. The fluent utterance of the first syllable shows a synchrony of adductive activity between the interarytenoid (IA) and the LCA. In the stuttered utterance, the LCA does not act in synchrony with the IA for the vowel production. The contrast in activity in this muscle between the fluent and stuttered utterance is readily apparent. The lower graph traces the inferior longitudinal (IL), an intrinsic tongue muscle, active here for raising the tongue tip for the devoiced [z]. Note that although the [z] is not uttered in the first abortive attempt, the tongue is obviously moving into position during the stuttered utterance. This evidence of articulatory coarticulation in a stuttering block contradicts Van Riper's (1971) hypothesis concerning the absence of coarticulation in moments of stuttering, but supports the work of Hutchinson and Watkin (1974).

In conclusion, we find that moments of stuttering are characterized by patterns of laryngeal muscle activity that are not characteristic of fluent utterance and that indeed may be incompatible with normal fluent utterance. These abnormal patterns include (1) disruption of the normal reciprocity between abductors and adductors, (2) disruption of the normal synchrony between adductors, and (3) generally higher levels of activity in four of the intrinsic laryngeal muscles.

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