

LARYNGEAL MUSCLE ACTIVITY DURING STUTTERING

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Laryngeal muscle activity during fluent and stuttered utterances was investigated via electromyography. Analysis revealed that stuttering was accompanied by high levels of laryngeal muscle activity and disruption of normal reciprocity between abductor and adductor muscle groups. Results are interpreted as demonstrating the existence of a laryngeal component in stuttering and showing a strong correlation between abnormal laryngeal muscle activity and moments of stuttering.

For almost a century and a half writers have proposed models of stuttering that incorporate a laryngeal component (Arnott, 1828; Muller, 1833; Hunt, 1861; Kenyon, 1943; Moravsek and Langova, 1967; Wyke, 1971; Schwartz, 1974). Recently, a number of studies have indirectly implicated the phonatory mechanism in stuttering (Stromstra, 1965; Wingate, 1969, 1970; Adams and Reis, 1971, 1974; Agnello, 1971; Brenner, Perkins, and Soderberg, 1972).

Evidence of laryngeal involvement in stuttering has emerged from several physiological studies. Chevrie-Muller (1963) used a glottograph to study 27 stutterers and reported abnormal laryngeal activity that included arrhythmic vocal-fold vibration and unpredictable glottal openings. Fujita (1966) studied posterior-anterior laryngeal X rays of a stutterer and found abnormal activity that included irregular and inconsistent opening and closing of the pharyngo-laryngeal cavity and asymmetric tight closure of the larynx. Ushijima et al. (1965), and Conture, Brewer, and McCall (1974) used the fiberoptic endoscope to view the larynx during stuttering and reported abnormal activity similar to that described by Chevrie-Müller and Fujita. Conture et al. (1974) reported that the abnormal laryngeal activity they observed was suggestive of a disturbance in the smooth, reciprocal interplay between agonistic and antagonistic laryngeal muscles.

The present research used electromyography (EMG) to investigate patterns of muscle activity that accompany stuttering. Although emphasis was placed on laryngeal muscles, data from selected upper-airway muscles were gathered to aid in the interpretation of the laryngeal observations.

METHOD

The EMG techniques used were developed in a series of investigations of normal laryngeal muscle activity in phonation and speech (Faaborg-Anders-

son, 1957; Hirano, Ohala, and Vennard, 1970; Hirose, 1971a; Gay, et al., 1972; Hirose and Gay, 1972, 1973). Specific procedures are described by Hirose (1971a), and data processing is discussed by Port (1971) and Kewley-Port (1973, 1974).

Subjects

Subjects were four adult males. Two subjects (G.G. and C.D.) were mild-to-moderate stutterers, and two (D.M. and P.N.) were severe stutterers. Participants ranged in age from 22 to 47 years. All had begun to stutter in childhood and had received some form of therapy.

Procedure

The objective was to obtain simultaneous recordings from the five intrinsic laryngeal muscles (posterior cricoarytenoid, PCA; interarytenoid, INT; cricothyroid, CT; thyroarytenoid, TA; and lateral cricoarytenoid, LCA) and at least three upper-airway articulatory muscles (inferior longitudinal, IL; superior longitudinal, SL; genioglossus, GG; and orbicularis oris, OO). Recordings were obtained from the sternohyoid, SH, in Subject G.G.

With one exception (OO for Subject G.G.), bipolar, indwelling hook-wire electrodes (Basmajian and Stecko, 1962) were used. Detailed descriptions of each insertion are given in Hirose (1971a), Hirose, Gay, and Strome (1971), and Freeman (1977).

The wire employed was an 0.005-cm (0.002-in) diameter platinum- (90%) iridium (10%) alloy with isonel polyester coating. Electrodes were prepared in essentially the same manner described by Basmajian and Stecko (1962). For the peroral insertions to the PCA and INT a specially designed probe was used (Hirose, 1971a; Freeman, 1977). To decrease salivation, seven to 10 drops of belladonna were administered by mouth. For the two peroral laryngeal insertions, Cetacaine Spray (Gaskil and Gillies, 1966) was applied to the pharynx and larynx. Percutaneous insertions were preceded by a topical administration of 2% Xylocaine without epinephrine through a Panjet-70 air jet at the site of the needle insertion. After insertion the electrode-bearing needle was withdrawn, leaving the electrodes hooked in the target muscle. Recordings were made with subjects sitting upright. Insertion procedures were as follows for specific muscles.

Posterior Cricothyroid (PCA). Insertion (perorally by indirect laryngoscopy) was parallel to the alignment of the muscle fibers into the belly of the muscle on the cricoid cartilage through the hypopharyngeal mucosa.

Interarytenoid (INT). Insertion (perorally by indirect laryngoscopy) was made at the midline between the two arytenoid prominences.

Cricothyroid (CT). Insertion (percutaneous) was made at a point above the cricoid ring, and approximately 1 cm lateral to the midline.

Thyroarytenoid (TA). Insertion (percutaneous) was made at a point close

to the midline at the level of the cricothyroid space. The needle was directed cranially and slightly laterally, penetrating the cricothyroid membrane and reaching the muscle from its inferior surface.

Lateral Cricoarytenoid (LCA). Insertion (percutaneous) was made at almost the same point as the CT insertion. The needle was directed laterally and slightly cranially, penetrating the cricothyroid membrane at a point anterior to the inferior tuberculum of the thyroid cartilage.

Inferior Longitudinal (IL). Insertion into the lower surface of the anterior third of the tongue (about 1 cm from the lateral edge) was directed superficially to place the electrode close to the mucosal surface.

Superior Longitudinal (SL). Insertion to the upper surface of the anterior quarter of the tongue (approximately 2 cm from the tip and 1 cm lateral to the midline) was obliquely directed to the surface so that the electrode was left immediately underneath the surface of the tongue.

Genioglossus (GG). Insertion (percutaneous) was perpendicular to the skin surface at the midpoint between the hyoid bone and the mandibular ridge in the paramedian line.

Orbicularis Oris (OO). Insertion was made at the vermilion border of the upper lip about 1 cm lateral to the midline (Leanderson and Lindblom, 1972). A paint-on electrode (Subject C.D.) was applied at the same point (Allen and Lubker, 1972).

Sternohyoid (SH). Insertion (percutaneous) was made at the level of the thyroid lamina lateral to the midline and parallel to the alignment of the muscle fibers.

Correct placement of an electrode in a muscle was verified in a two-step procedure. First, after each insertion, oscilloscope and amplifier-speaker systems were used to monitor muscle activity during performance of a series of maneuvers. If activity patterns from the insertion site differed from the patterns previously found to be typical for a given target muscle (Freeman, 1977), the electrode was removed and a new insertion was made for the muscle. Second, recordings were made as the subject performed the series of maneuvers. Using the recordings, final verification was based on examination of the simultaneous activity patterns from different insertion sites. In cases where spatial proximity made contamination from adjacent muscles possible, verification was based on demonstrable functional differentiation between the two muscles in question. Functional differentiation is possible between any pair of laryngeal muscles except the LCA and the TA. For these two muscles the patterns are very similar, differing only in degree (relative level of activity) for some maneuvers.

The structure of the tongue is such that it is difficult to specify a given electrode as recording from only the fibers of a selected muscle. The insertions described for the SL and IL have been used in other studies of tongue muscle function (Borden and Gay, 1975; Borden, Harris, and Catena, 1973; Raphael and Bell-Berti, 1975). The superficial placement is anatomically appropriate to assure recordings from IL and SL fibers (Miyawaki, 1974) but

these recordings may admittedly be contaminated by electrical activity from other intrinsic tongue muscles. For the subjects of this study, electrode placements at the sites specified as SL and IL showed activity for tongue-tip consonant production, specifically for [r], [l], [t], [d], [s], [z], [tʃ], [dʒ], and to a lesser extent for [θ] and [ð]. Table 1 summarizes the insertions attempted and reports the success rate in achieving verifiable recordings from each muscle for each subject. For a variety of technical reasons only those insertions indicated by the X were accepted.

TABLE 1. Verified insertions for each subject and for each muscle over the series of experiments.

Subject	Laryngeal Muscles						Upper Airway Articulators				Totals		
	PCA	INT	LCA	TA	CT	SH	IL	SL	GG	OO	Laryngeal	Upper Airway	Combined
D.M.	X		X	X			X	X	X	X	3	4	7
P.N.		X	X	X					X	X	3	2	5
G.G.		X	X	X	X	X		X		X	5	2	7
C.D.	X	X		X				X		X	3	2	5
Totals	2	3	3	4	1	1	1	3	2	4	14	10	24

Data Collection and Processing

The design of the study required that comparable fluent and stuttered tokens be obtained from each subject. Subjects P.N., G.G., and D.M., an adequate number of stuttered tokens were obtained by having them read a selected prose passage (see the Appendix). Fluent samples were secured by repeated readings and by use of selected fluency-evoking conditions including choral reading, rhythm reading, reading in the presence of white noise, and reading under delayed auditory feedback (DAF) (Wingate, 1969, 1970).

Subject C.D. did not have perceivable blocks while reading the prose passage. Therefore, he engaged in conversation, making frequent use of feared "difficult" words. In a choral reading condition, the investigator and C.D. read a list of sentences transcribed from C.D.'s spontaneous conversation. The recordings made under the other fluency-evoking conditions consisted of spontaneous conversation and repetitions of sentences in which blocks had occurred previously.

Data were collected and processed using the Haskins Laboratories EMG system (Port, 1971; Kewley-Port, 1973). Electrodes were connected to differential preamplifiers. Signals from the preamplifiers were fed to distribution amplifiers having 80-Hz high-pass filters, with 24-dB/octave rolloffs. Filtering was intended to reject noise and movement artifacts. Signals were FM tape-recorded. Speech was recorded with an air microphone, and appropriate clock and code pulses for data processing were recorded.

Recorded signals were played back through the distribution amplifiers and routed through sections of the 80-Hz high-pass filters, resulting in a 36-dB/octave total rolloff. Overall frequency response for the FM channels was es-

serentially flat for the 80–1250 Hz range, with a signal-to-noise ratio of about 40 dB.

After recording, the electromyographic, voice, and code tracks were input to a Honeywell Visicorder, whose oscillographic records were used in visual editing of the signals for identification and lineup for computer processing.

The EMG data tape was played back on the same tape recorder under computer control. Analog EMG signals were full-wave rectified and passed through an RC circuit that performed a running integration with a time constant of 35 msec. Signals were sampled at 5-msec intervals. Stored digital sample values were converted to microvolt values by comparison with a 300 μ v calibration signal. The integrated EMG data in this study were single tokens of individual utterances. A slightly modified version of the E\$MGSUMS program (Bell-Berti, 1973) was used to compute the activity in each channel averaged over a speech segment of two seconds. E\$MGSUMS first computed the sums and sums of squares at 5-msec intervals over the 2-sec sample window for each utterance. It then calculated the means and standard deviations in microvolts for each 5-msec interval. Finally, it calculated the means and standard deviations in microvolts for each 2-sec speech segment. The correlation program E\$MGCORL (Kewley-Port, 1973) was used to calculate the correlation between the activity in the PCA and the activity in the INT for subject C.D. E\$MGCORL computed a Pearson Product-Moment Correlation coefficient, r , for two EMG signals at 5-msec intervals.

RESULTS

The patterns of successful insertion and the procedures used in eliciting fluent and stuttered speech samples yielded results that were not parallel for all four subjects. For two subjects (C.D. and D.M.) recordings were obtained for the laryngeal abductor (PCA) and for laryngeal adductors. It was possible with these two subjects to study the coordination of the reciprocal activity of the antagonist muscles in fluent and stuttered utterances.

With Subject C.D., both PCA and INT recordings were obtained for 49 utterances of the same consonant-vowel sequence, allowing a correlation study of abductor-adductor reciprocity in fluent and stuttered utterances.

For the three subjects (D.M., G.G., and P.N.) who stuttered on the oral readings of the passage, it was possible to compare the averaged levels of muscle activity for selected sentences in the stuttered and fluent readings. For C.D. (who did not stutter while reading), the average of the peak values for stuttered and fluent utterances of the same word were compared. Procedures used in the investigation yielded information on two aspects of muscle activity in stuttering: levels of muscle activity and coordination.

Findings Related to Levels of Muscle Activity

In the tracings of the "raw" (unrectified) EMG signal, intensity of muscle

Figure 1 consists of two vertically stacked line graphs showing raw rectified EMG recordings for three laryngeal muscles (PCA, TA, LCA) and an audio recording of Subject D.M. The top graph is titled "First Reading (stuttered)" and the bottom graph is titled "Choral Reading (fluent)". Both graphs share a common y-axis scale for "Peak Value μV " on the right side. The x-axis represents time in seconds, with labels for specific syllables and words: "and", "scr", "im", "not", "s", "s", "s", "s", "s", "s", "at", "is", "and", "i", "i", "um", "pa", "pa", "pa", "a", "stutter".

First Reading (stuttered) Peak Values:

Muscle	Peak Value (μV)
PCA	154
TA	200
LCA	253

Choral Reading (fluent) Peak Values:

Muscle	Peak Value (μV)
PCA	101
TA	52
LCA	180

The audio recording in both graphs shows a clear difference in the duration and intensity of the vocalizations between the stuttered and fluent readings. The x-axis for the top graph is labeled "13.5 sec" and for the bottom graph is labeled "6.6 sec".

FIGURE 1. Comparison of raw (unrectified) EMG recordings from three intrinsic laryngeal muscles—posterior cricoarytenoid (PCA), thyroarytenoid (TA), and lateral cricoarytenoid (LCA)—for Subject D.M.'s stuttered and fluent readings of the same phrase.

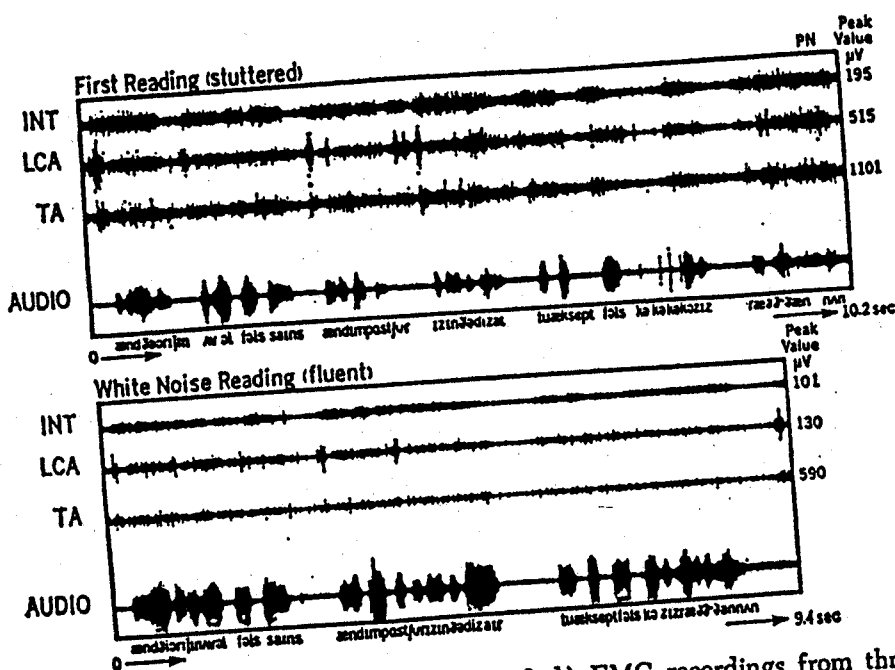


FIGURE 2. Comparison of raw (unrectified) EMC recordings from three intrinsic laryngeal muscles—interarytenoid (INT), lateral cricoarytenoid (LCA), and thyroarytenoid (TA)—for Subject P.N.'s stuttered and fluent readings of the same phrase.

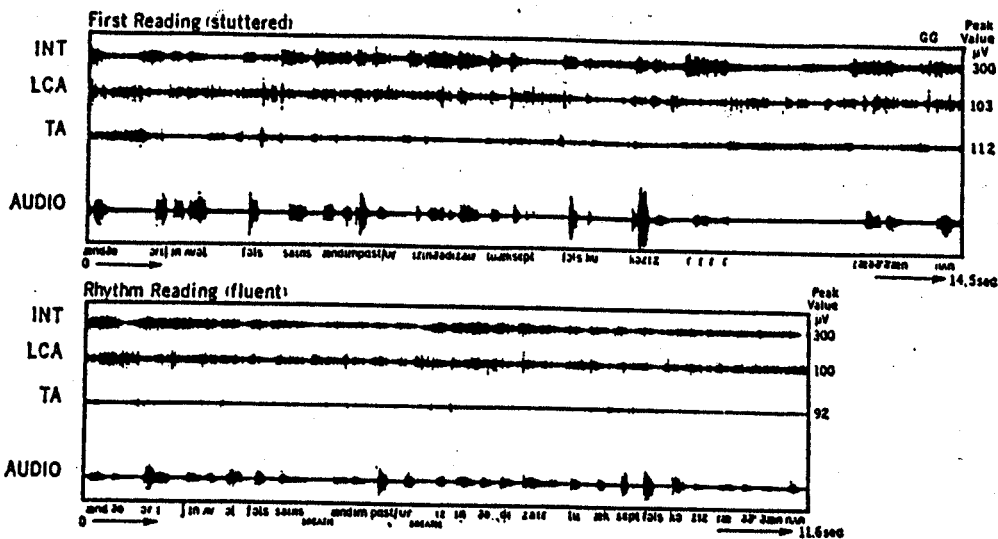


FIGURE 3. Comparison of raw (unrectified) EMG recordings from three intrinsic laryngeal muscles—interarytenoid (INT), lateral cricoarytenoid (LCA), and thyroarytenoid (TA)—for Subject G.G.'s stuttered and fluent readings of the same phrase.

the muscles maintained higher levels of activity during the first (stuttered) reading than during the evoked (fluent) reading.

Differences observed in the raw tracings were apparent in the processed (integrated) EMG. Figure 4 shows recordings from four muscles for Subject P.N. The graphs on the left of the illustration trace the course of the EMG activity for these muscles during a stuttered utterance of the word *causes*, which occurred in the first (stuttered) reading. The fluent utterance is from the subject's reading under white noise. The raw EMG for these utterances is shown in Figure 2. Figure 5 shows the activity of a single muscle, the LCA, for three utterances of the word *effect*. Subject D.M. repeated the word three times, with progressive adaptation from a severe block to a mild block, to a fluent utterance. The reduction of activity in the LCA (Figure 5) correlated with the reduction in degree of dysfluency.

To quantify these differences in levels of muscle activity, selected speech samples (consisting in each case of readings of the first paragraph of our passage; see the Appendix) were divided into segments of 2-sec duration. The 2-sec interval was selected as most appropriate for use with the E\$MG\$SUMS program for calculation of average level of activity. A single number representing the average level of activity in microvolts was calculated for each muscle for each 2-sec segment. The mean values for the 2-sec segments constituting one speech sample were then averaged, yielding a single mean value for each muscle for each speech sample.

For each speech sample, utterance content was held constant, but the total length of the sample (number of 2-sec segments) varied with utterance rate. For each subject, the first (stuttered) reading was compared with each of the readings under the fluency-evoking conditions. Figures 6, 7, and 8 illustrate the differences derived from this comparison, by converting the microvolt

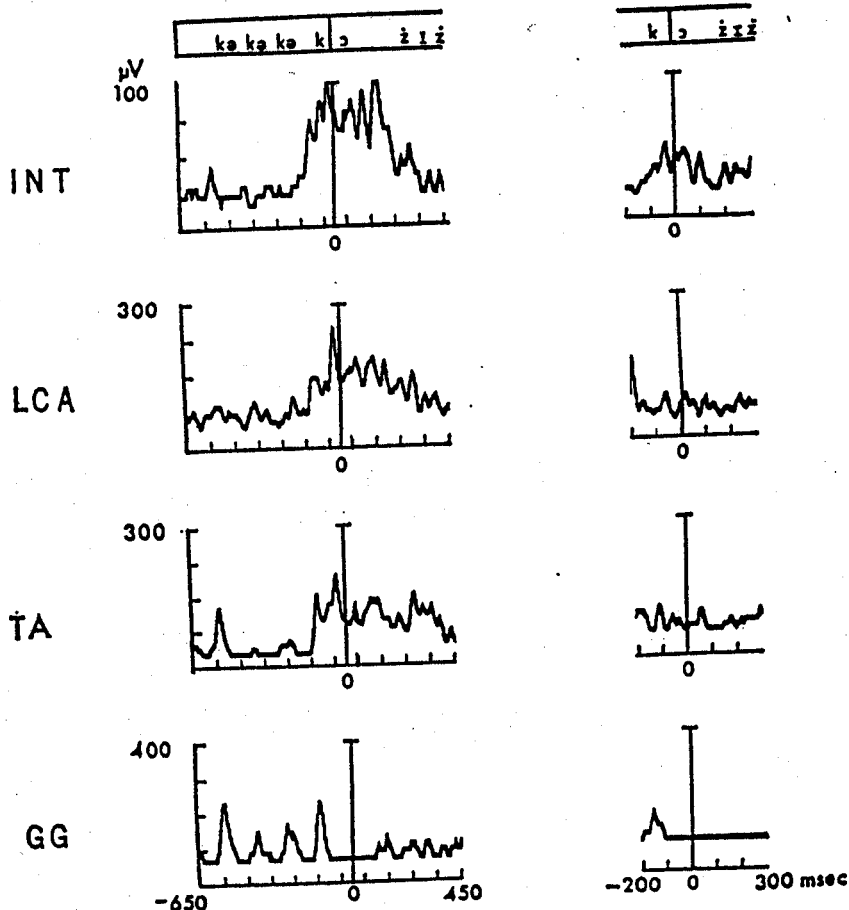


FIGURE 4. Comparison of muscle activity—interarytenoid (INT), lateral cricoarytenoid (LCA), thyroarytenoid (TA), and genioglossus (GG)—for Subject P.N.'s fluent and stuttered utterances of the word *causes*.

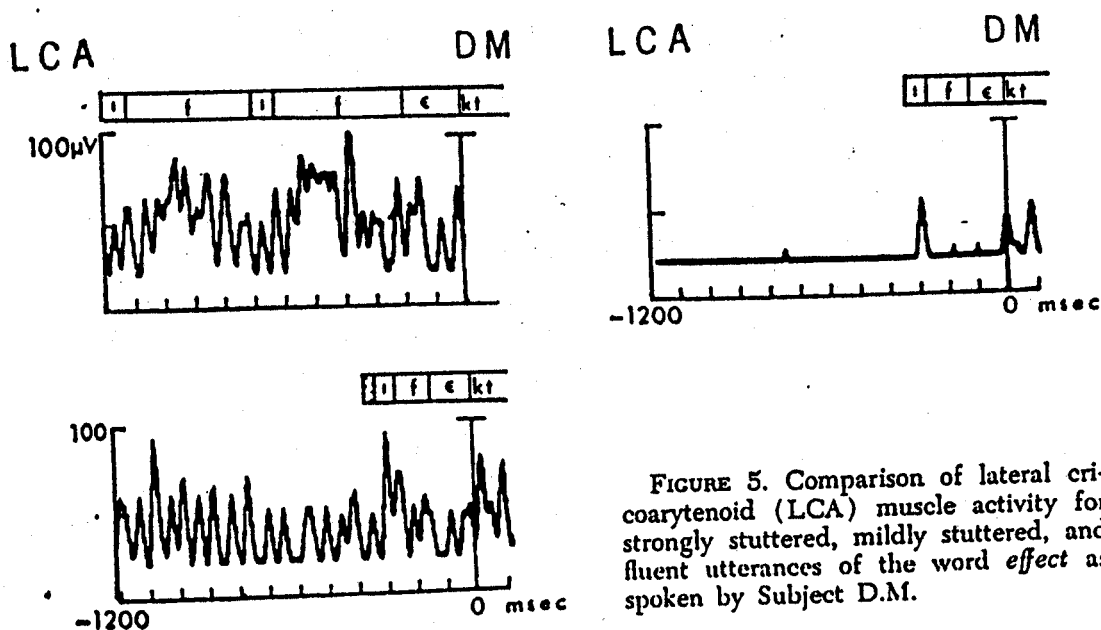


FIGURE 5. Comparison of lateral cricoarytenoid (LCA) muscle activity for strongly stuttered, mildly stuttered, and fluent utterances of the word *effect* as spoken by Subject D.M.

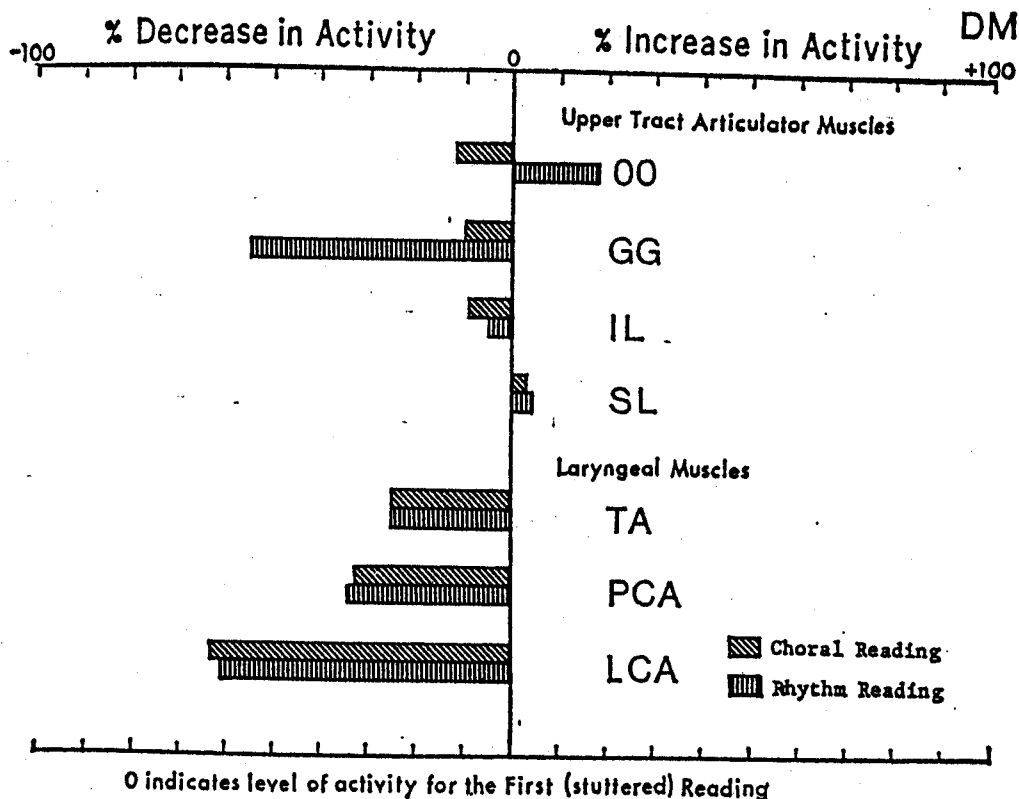


FIGURE 6. Comparison of average levels of muscle activity per 2-sec segment for Subject D.M.

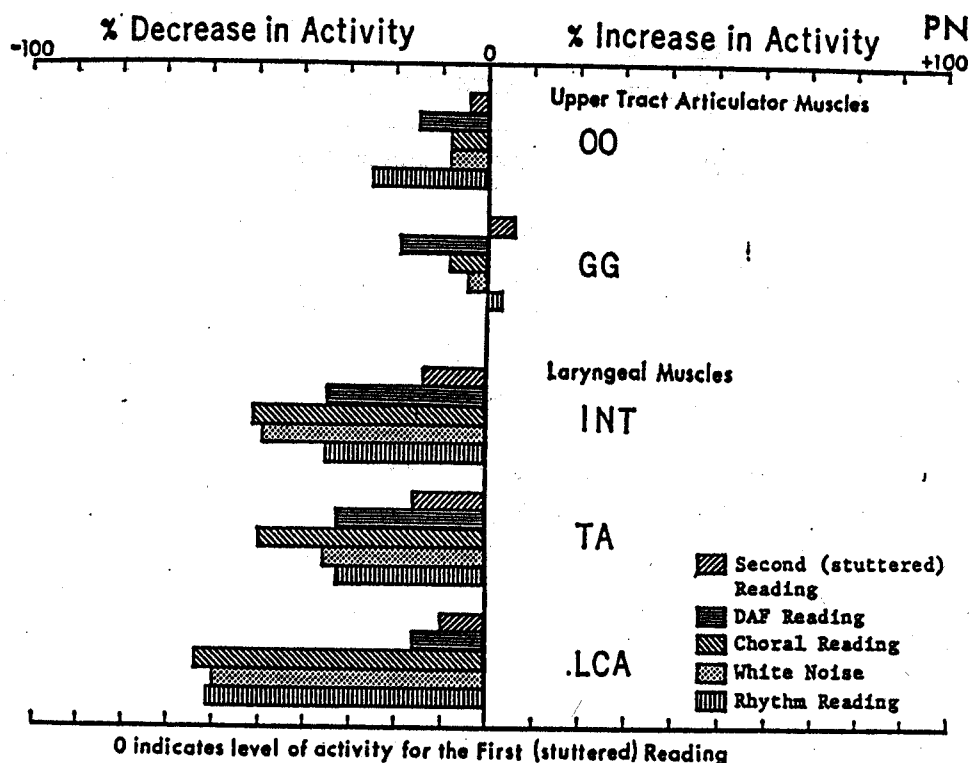
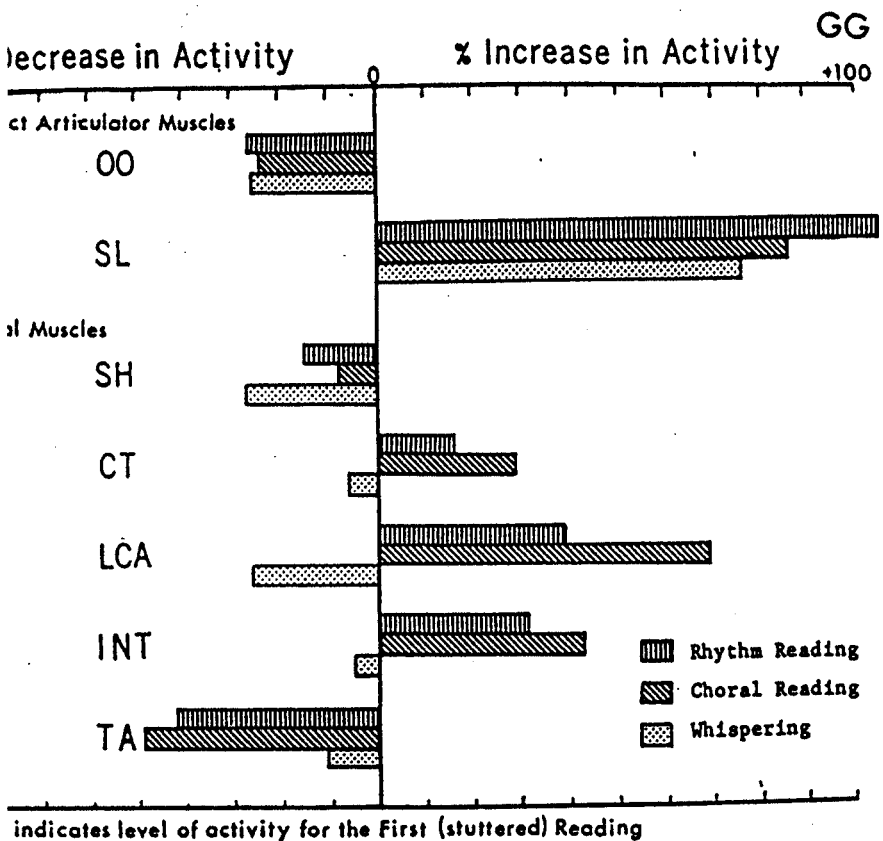


FIGURE 7. Comparison of average levels of muscle activity per 2-sec segment for Subject P.N.



Comparison of average levels of muscle activity per 2-sec segment for

percentages, using the mean level of the first reading as a reference. s in levels of activity evident in the comparison shown in Figures are directly related to the two effects of the fluency-evoking con- ne production of the subjects. In each case, the fluency-evoking resulted in (1) a decrease in the frequency of disfluencies (mea- centage of syllables stuttered), and (2) an increase in utterance (red as syllables per second). Figure 9 graphically illustrates these the three subjects. These results, which relate decrease in dis- crease in rate, are in agreement with a number of other studies of cy (Adams and Hutchinson, 1974; Conture, 1974). However, the change in the utterance would generate contradictory hypotheses changes in levels of muscle activity. That is, taken alone (without changes in utterance rate), a marked decrease in stuttering anticipated to be accompanied by decrease in average level of ity. On the other hand, increases in utterance rate will be accom- an increase in average level of muscle activity for two reasons. rease in syllables per second results in an increase in the number estures per second, and hence an increase in the average level of ity per 2-sec segment. Second, an increase in rate results in a ity of articulator movement, which may require a higher level of

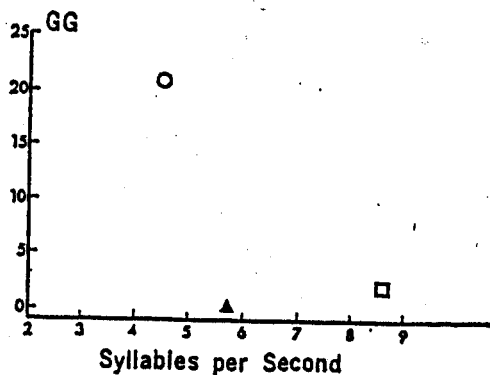
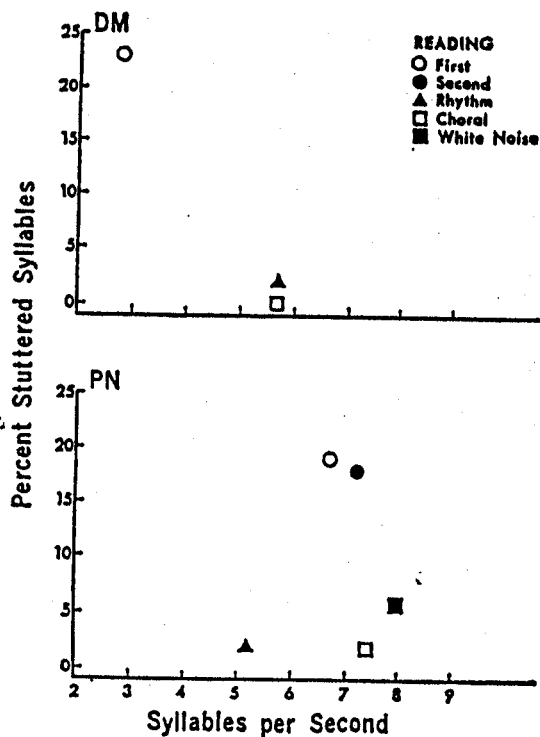


FIGURE 9. Interaction between utterance rate (measured as syllables per second) and frequency of disfluencies (measured as percent stuttered syllables).

muscle activity (Bigland and Lippold, 1954; Gay and Hirose, 1973; Kuehn, 1973). Clearly, two opposite and potentially canceling effects were operative.

To neutralize the effects of the increases in utterance rate, the syllables in each 2-sec segment were counted, and the average level of muscle activity in each segment was divided by the number of syllables uttered in that segment. The resulting means were used to calculate an average level per syllable for each muscle for each speech sample. This procedure could accentuate any effects of nonphysiological noise in the system. Results for this calculation are illustrated graphically in Figures 10, 11, and 12.

Figure 13 summarizes the results relating to decreases in activity. The broken line labeled 100% indicates the reference level of the first (stuttered) reading, while the vertically striated bars are the average of all the upper-airway articulatory muscles for all the fluency-evoking conditions. The horizontally striated bars are the average of all the laryngeal muscles for all conditions.

The increase in rate (syllables per second) had a pronounced effect on the levels of muscle activity. The finding that the rate effect is not uniform for all muscles nor for all subjects is consistent with speaking rate studies on normals (Gay and Hirose, 1973; Gay et al., 1974). In general, the effects of rate change were more pronounced for the upper-airway articulatory muscles (particularly OO, SL, and IL) than for the laryngeal muscles. However, this finding may be related to the muscles selected, since the GG (an upper-airway muscle) also shows only small changes related to rate. Subjects D.M. and G.G. show pronounced changes related to rate, while P.N. demonstrates a smaller

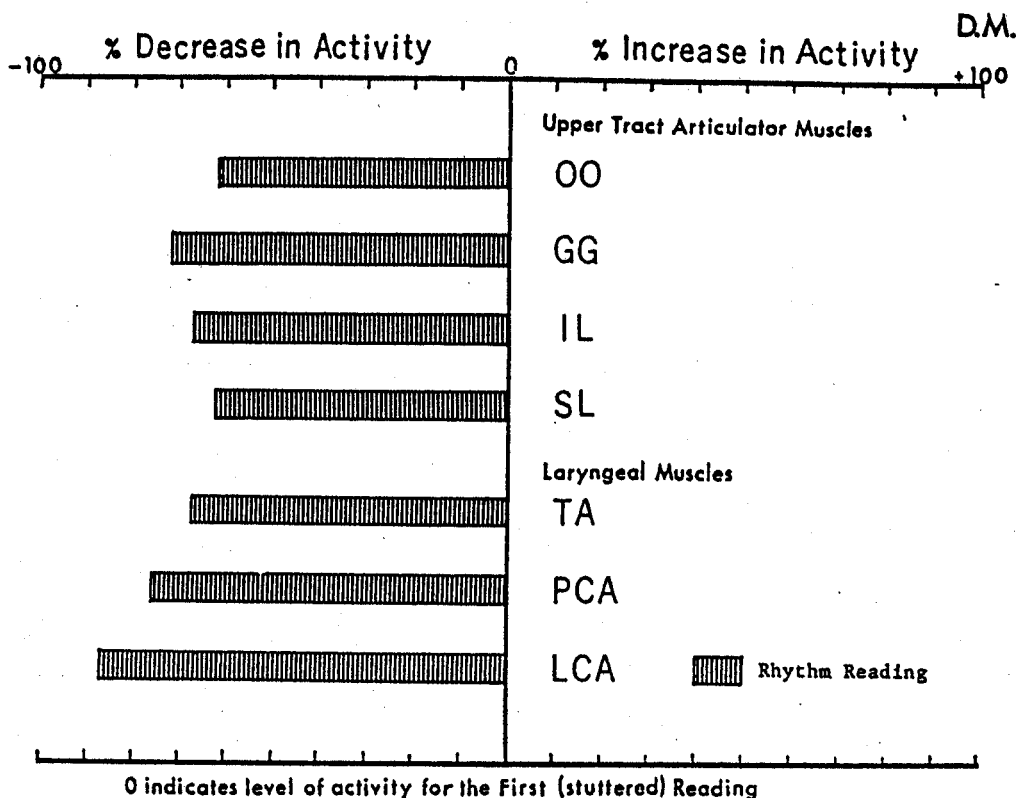


FIGURE 10. Comparison of average levels of muscle activity per syllable for Subject D.M. (The choral reading condition of Figure 6 is omitted because the two voices on the audio recording prevented an accurate syllable count.)

effect. The possibilities of misleading results if rate effects are not considered are illustrated by the dramatic differences between Figures 8 and 12 for Subject G.G.

The data collected on the fourth subject's (C.D.) 49 utterances of the words *syllable* and *syllables* were used to learn whether the peak levels of muscle activity were different for fluent and stuttered utterances. In each utterance, the time period between the initial muscle activity for the production of the voiceless fricative [s] (indicated by activity in the superior longitudinal for raising the tongue tip and activity in the PCA for opening the glottis) and the point in the audio track that indicated the onset of voicing for the vowel [i] was identified. Within this time period, the highest peak of activity was identified for each muscle. The level (in microvolts) for this peak of activity was computed for each muscle for each utterance. The investigator, after listening to audio recordings, identified 23 utterances as stuttered and 26 as fluent. The peak values for the 23 utterances judged as stuttered were averaged for each muscle and the results compared with similarly derived averages from the 26 utterances judged fluent. Means and standard deviations were calculated and a *t*-test applied. Results are graphically illustrated in Figure 14, where the average peak value for the stuttered utterances serves as the reference, and the average peak value for the fluent utterances is ex-

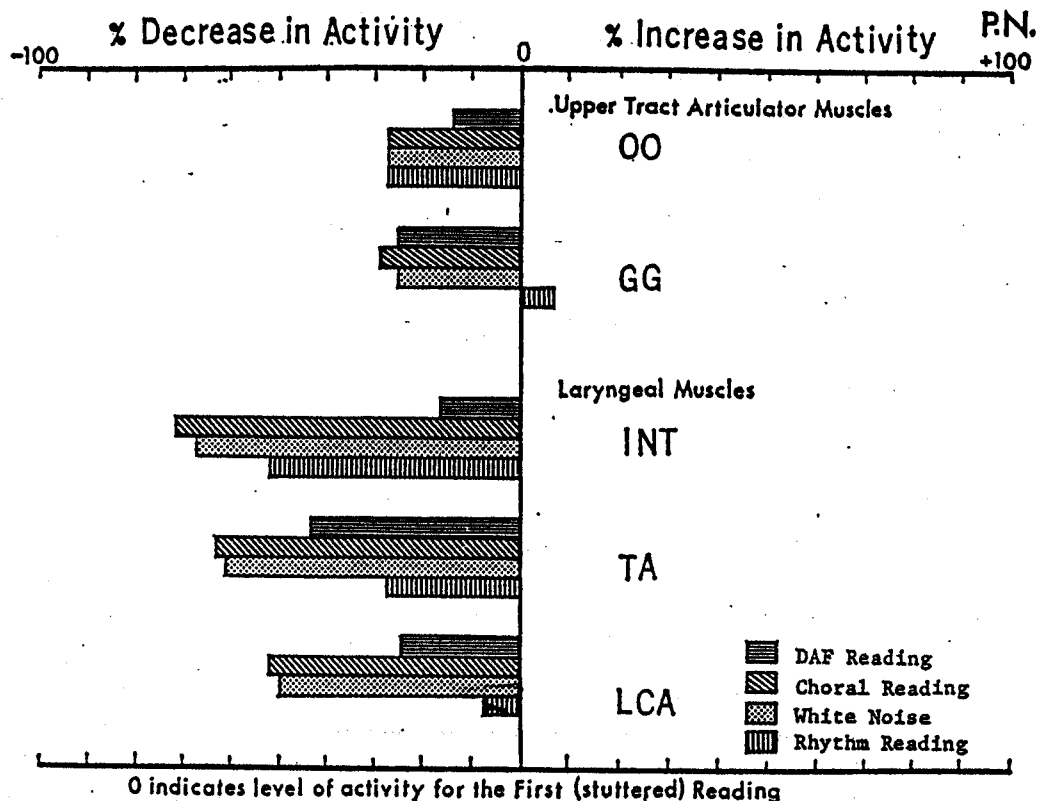


FIGURE 11. Comparison of average levels of muscle activity per syllable for Subject P.N. (The second stuttered reading is omitted because it was not significantly different from the first stuttered reading.)

pressed as a percentage. Computed t -values were INT (5.76), PCA (5.37), and TA (4.75). With 48 degrees of freedom, these differences were found to be significant at the 0.001 level of confidence.

The pattern of level differences between stuttered and fluent speech was different for each subject. However, it may be noted that for all four subjects the muscle that showed the greatest level differences was a laryngeal adductor muscle.

Findings Related to Coordination

The study of disruption of coordination in stuttered speech is restricted to some extent by our imprecise knowledge of many aspects of coordination in normal speech. On one point, however, studies of normal laryngeal articulations have provided relatively clear and consistent findings. These studies indicate that the abductor and adductor muscles in the larynx normally act with reciprocity. When the glottal abductor (the PCA) is strongly active, the adductors (INT, TA, and LCA) are suppressed, and conversely (Suzuki and Kirchner, 1969; Hirose, 1971b; Shipp and McGlone, 1971; Hirose and Gay, 1972, 1973; Hirose, 1974; Hirose, Lee, and Ushijima, 1974; Hirose and Ushi-

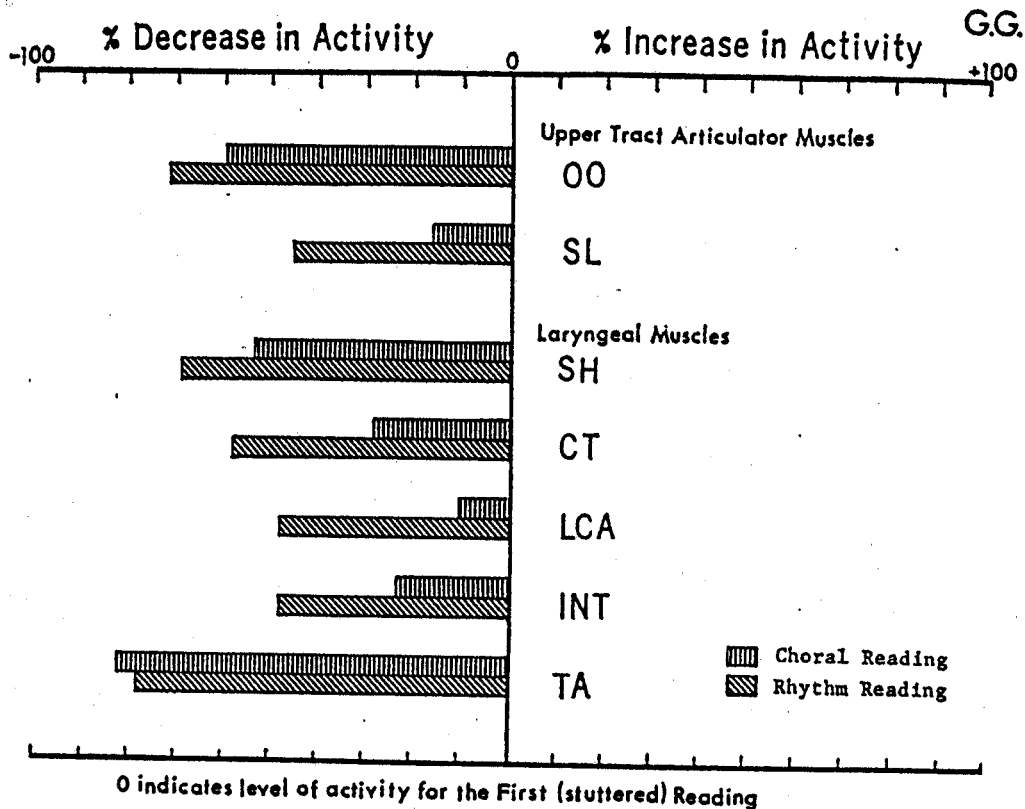


FIGURE 12. Comparison of average levels of muscle activity per syllable for Subject G.G.

ma, 1974; Shipp¹). Because recordings from the abductor were secured for two subjects (D.M. and C.D.), it was possible to investigate the reciprocal activity of the antagonist muscles.

Figure 15 shows recordings from three muscles for Subject D.M. The graph on the left-hand side is from a stuttered utterance of the word *less*, while the graph on the right-hand side is from a fluent utterance of the same word.

The boxes at the top of the graph contain phonetic symbols and represent the relative length of each segment as measured in oscillographic tracings. The lineup, or 0 point, on each graph represents the end of voicing for the vowel. In the bottom graph, the peaks of activity for the SL relate to tongue-raising for the [l] and the [s]. During the prolongation of the [l] the PCA (laryngeal abductor) and the TA (a laryngeal adductor) were both active. During the fluent utterance these two muscles showed reciprocal activity.

Figure 16 shows three utterances of the word *ancient*, with progressive adaptation from a strong block to a mild block to a fluent utterance. During the prolongation of the [e] in the strong block, the PCA (laryngeal abductor) and the TA and the LCA (laryngeal adductors) were all active. During the fluent utterance the antagonist muscles acted reciprocally.

Figure 17 shows recordings from three muscles for Subject C.D. for con-

¹T. Shipp, personal communication (1975).

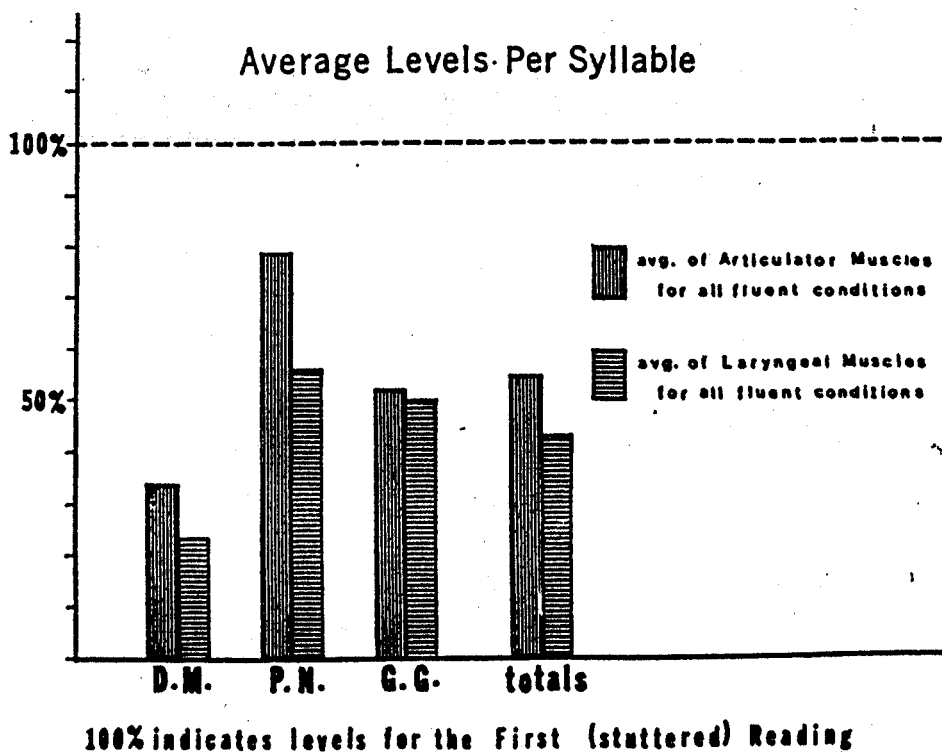
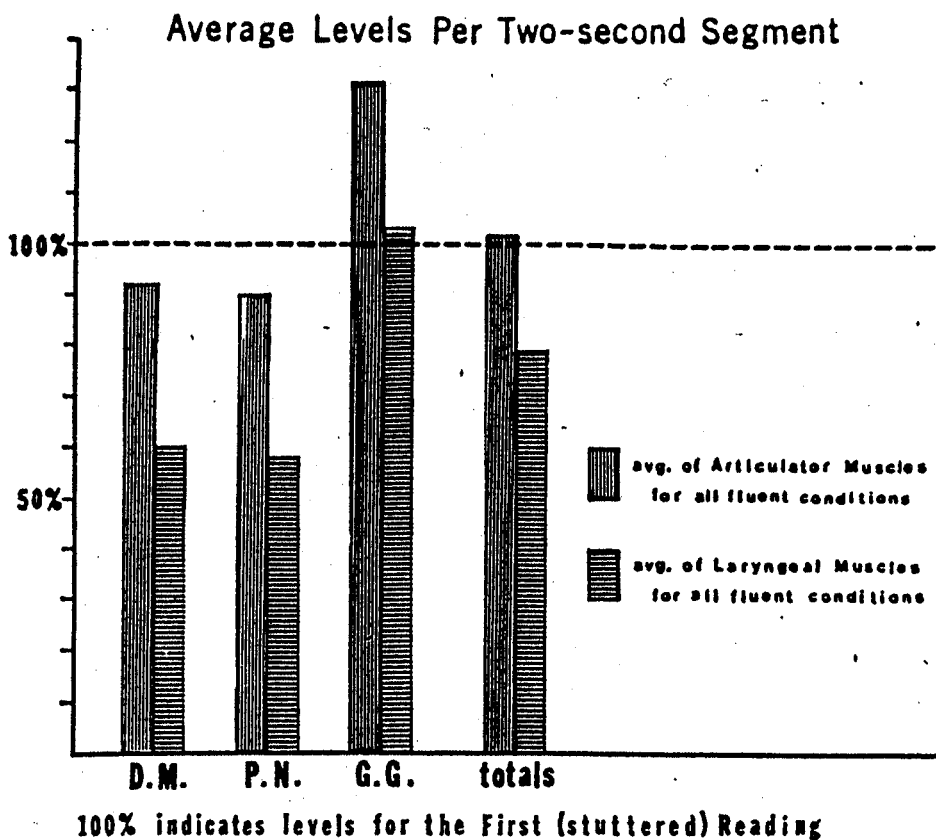


FIGURE 13. Comparisons of average levels per 2-sec segment and of average levels per syllable for upper tract articulator muscles and for laryngeal muscles for Subjects D.M., P.N., and G.G.

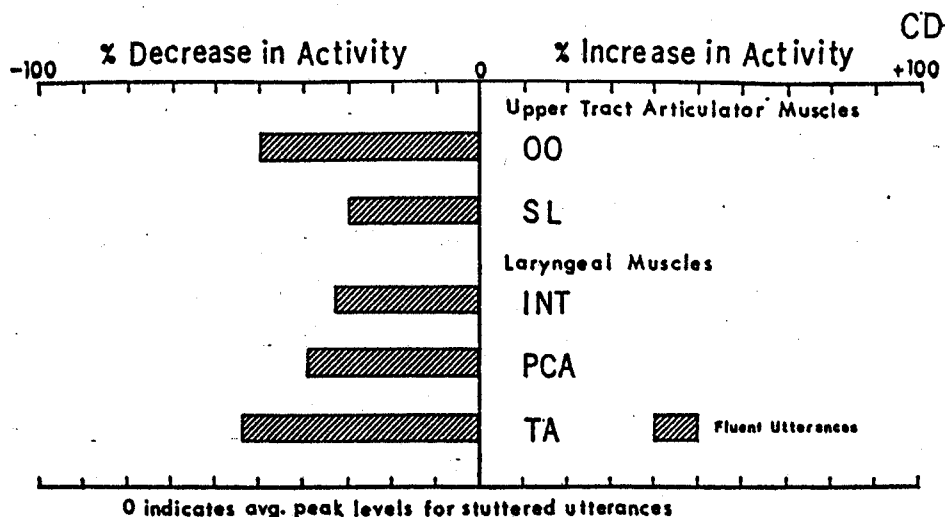


FIGURE 14. Comparison of average peak levels of muscle activity for Subject C.D.'s 23 stuttered and 26 fluent utterances of the words *syllable* and *syllables*.

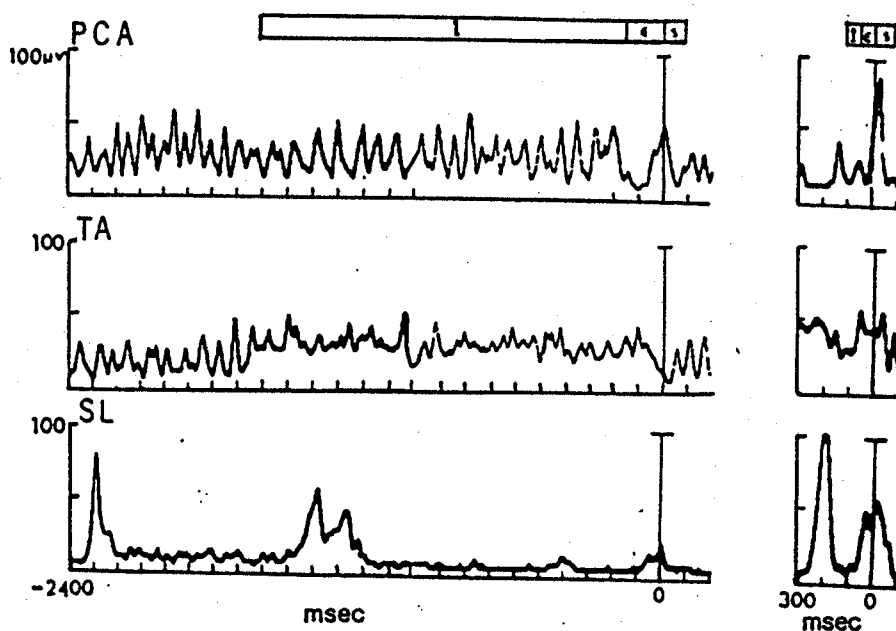


FIGURE 15. Comparison of muscle activity—posterior cricoarytenoid (PCA), thyroarytenoid (TA), and superior longitudinal (SL)—for Subject D.M.'s stuttered and fluent utterances of the word *less*.

trasting stuttered and fluent utterances of the word *syllable*. The lineup point for both utterances was on the onset of voicing for the first vowel. In the top graph, the peaks of activity in the SL were related to tongue-tip raising. During the stuttered prolongation of the initial voiceless fricative, the PCA (laryngeal abductor) and the INT (laryngeal adductor) were both active. During the fluent utterance the antagonist muscles acted reciprocally.

The first syllable of the words *syllable* and *syllables* have phonetic context suitable for a correlation study of PCA-INT activity. During the first segment

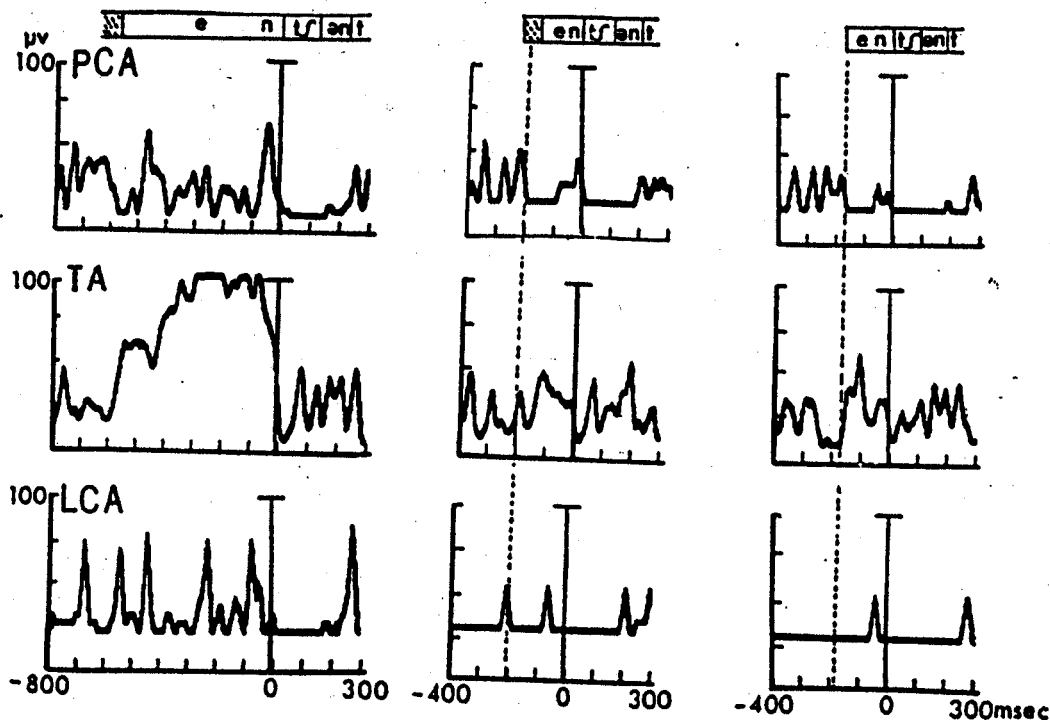


FIGURE 16. Comparison of muscle activity—posterior cricoarytenoid (PCA), thyroarytenoid (TA), and lateral cricoarytenoid (LCA)—for strongly stuttered, mildly stuttered, and fluent utterances of the word *ancient* as spoken by Subject D.M.

of the syllable, the PCA is active and the INT is suppressed for the production of the voiceless fricative. The INT is then active while the PCA is suppressed for the production of the vowel. This pattern is shown in the fluent utterance of Figure 17. If the normal activity of these antagonist muscles were to be correlated over time, a negative correlation should result. And, indeed, the plotting of such a correlation for the fluent utterance in Figure 17 yielded an r of -0.83 . Conversely, the plotting of the correlation between the INT and the PCA for the stuttered utterance in Figure 17 yielded an r of $+0.80$.

The program, E\$MGCORL (Kewley-Port, 1973), used for these calculations, plotted and correlated points at 5-msec intervals. Correlations were plotted for the time period between the first activity of the SL and PCA for the [s] and the onset of voicing for the vowel [ɪ]. Coefficients of correlation were calculated for 49 utterances of the words *syllable* and *syllables*. As previously discussed, the investigator had judged 23 of these utterances to be stuttered and 26 to be fluent.

Of the 23 utterances judged stuttered, 20 yielded positive correlations and three yielded negative correlations; while of the 26 utterances judged fluent, 19 yielded negative correlations and seven yielded positive correlations. These findings are graphically illustrated in Figure 18.

In Figure 18 the 23 stuttered utterances are shown on the upper half of the graph, while the 26 fluent utterances are shown on the lower half. All positive correlations are shown to the right of center, and negative correlations to the

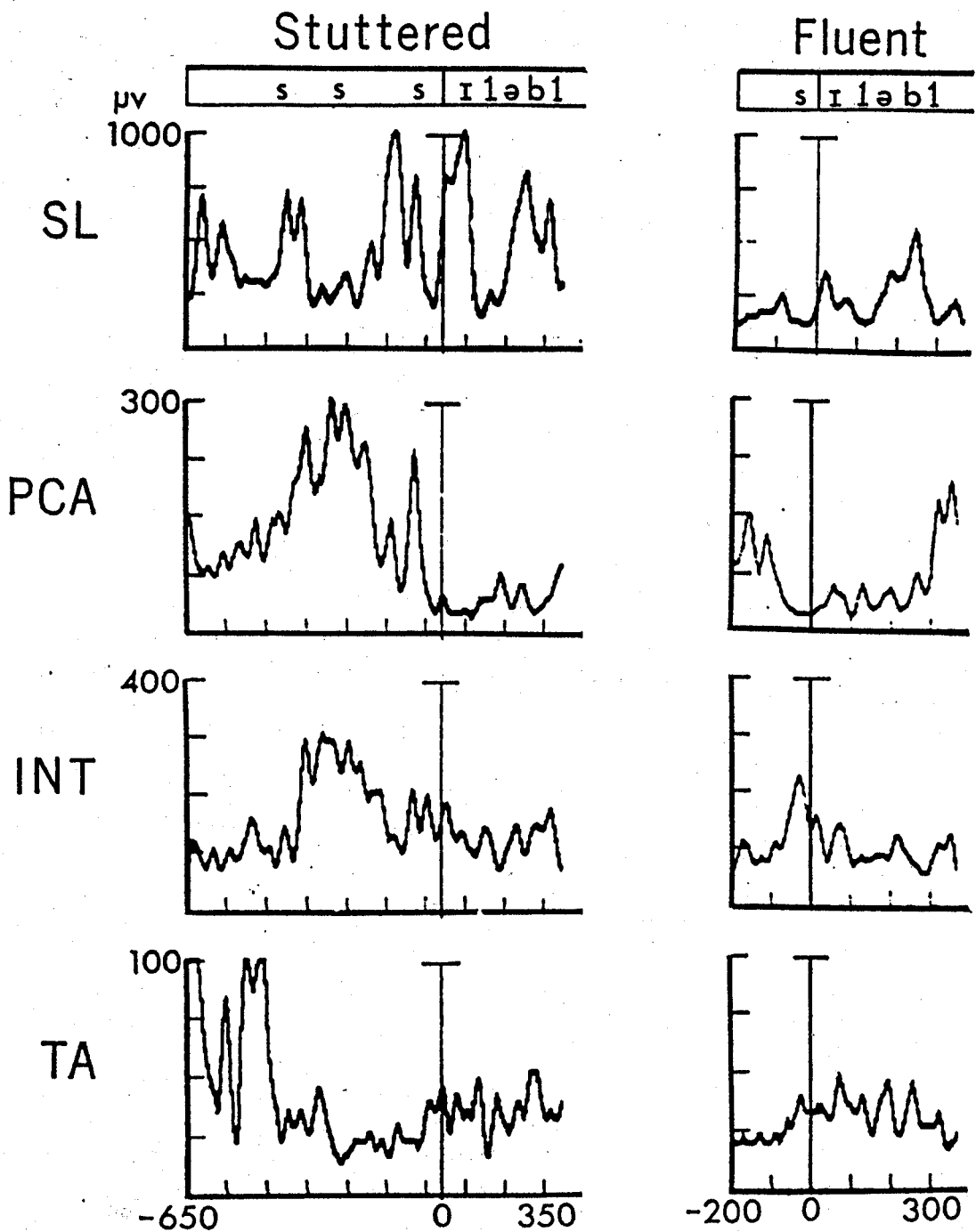


FIGURE 17. Comparison of muscle activity—superior longitudinal (SL), posterior cricoarytenoid (PCA), interarytenoid (INT), and thyroarytenoid (TA)—for Subject C.D.'s stuttered and fluent utterances of the word syllable.

left. There is a significant positive correlation between abductor and adductor activity for the stuttered utterances ($p < 0.01$, sign test) and a significant negative correlation between abductor and adductor activity for the fluent utterances ($p < 0.05$, sign test).

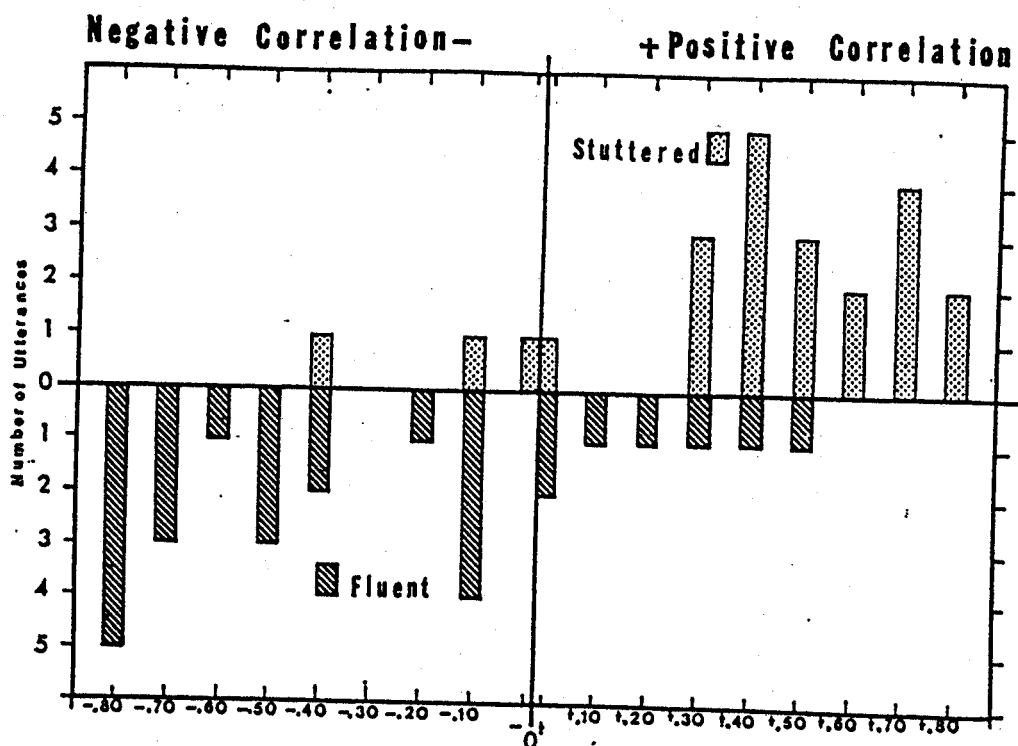


FIGURE 18. Comparison of abductor-adductor correlations for Subject C.D.'s 26 fluent and 23 stuttered utterances of the first syllable of the words *syllable* and *syllables*.

DISCUSSION

When considering the question of "cause" in relation to stuttering, it is possible to distinguish between the basic etiology of the disorder (the distal cause) and the abnormal vocal tract behaviors that generate the disrupted speech (the proximal cause). The present research was undertaken in the belief that understanding the proximal cause or causes of stuttering would (1) facilitate development of efficient, effective therapy procedures or (2) provide valuable insights regarding the distal cause or causes, or both.

Normal phonation involves a delicate balance of laryngeal muscle tensions. Further, segmental speech articulation requires rapid and continuous adjustments in the fine balance of these muscle tensions. Any factor that interferes with the delicate balance of laryngeal muscle tensions, or with their rapid adjustments during ongoing speech, has the potential for disrupting fluent utterance.

Both abnormally high levels of laryngeal muscle activity and disrupted coordination of abductor-adductor muscles have the potential for inhibiting phonation. High levels of muscle activity have long been considered counter-productive to the performance of skilled motor tasks. Those concerned with teaching and performance of such acts (singers, dancers, athletes, musicians, typists) have sought to improve performance through reduction of "tensions." The levels of laryngeal muscle activity recorded during stuttering were significantly higher than those levels necessary to produce the desired phonatory

adjustments and vocal tract shape changes for the segmental content of the experimental passage. Because the lower levels recorded in the fluent utterances were adequate to produce clearly intelligible, adequately loud speech, these levels may be considered representative of the necessary activity for phonation and articulation. Further, for each of the four subjects, levels of activity during moments of stuttering equaled the levels recorded for that subject during protective laryngeal closure. If a given level of adductive muscle activity is sufficient for the tight glottal closure of swallowing or coughing, it is almost certainly excessive for normal phonation.

At the level of the larynx, phonation may be arrested in at least three ways.

1. The vocal folds may be too tightly closed.
2. The vocal folds may be too far apart.
3. The vocal folds may be properly approximated, but so rigid (tense) as to prevent normal interaction with subglottal and supraglottal air pressures.

Strong adduction and high levels of vocal-fold tension are produced by high levels of laryngeal muscle activity. It follows, therefore, that excessively high levels of laryngeal muscle activity may lead to the prevention or interruption of normal phonation.

We offer three hypotheses regarding the relation of high levels of laryngeal muscle activity to disrupted abductor-adductor reciprocity. High levels of muscle activity may lead to cocontraction; the high levels of activity may be generated as the system attempts to overcome the disruptive effects of cocontraction; or both may result from unknown causal factors.

Regardless of the precipitating factor, the effects of simultaneous strong contractions of the abductor and adductor muscles are clearly counterproductive to normal phonation. As described by Sherrington (1909), "reciprocal inhibition" facilitates coordinated movement by agonist muscles through relaxation of antagonist muscles. As demonstrated by Travill and Basmajian (1961), the antagonist in a muscle pair usually relaxes completely while the agonist is active. Studies of normal subjects, and indeed, recordings of the induced fluent readings of the stuttering subjects, show highly consistent reciprocity between the abductor (PCA) and the adductor group, particularly the INT. It is possible that some whispered speech may be produced by simultaneous contraction of the PCA and some adductor muscles² but in normal phonation, the laryngeal abductor and adductors act with reciprocity. From the data collected on D.M. and C.D., strong cocontraction of the laryngeal antagonists appears incompatible with normal phonation. In many instances cocontraction occurred during a silent period just before an utterance. When cocontraction occurred during sound production, audible disruptions accompanied the event. For both subjects, the termination of cocontraction was almost invariably followed (50 to 150) by a fluent-sounding utterance.

²T. Shipp, personal communication (1975).

The abnormal laryngeal muscle activity demonstrated by the subjects of this investigation is sufficient to produce interruption of normal phonation, breaks in phonation, temporary inhibition of phonation, or inability to initiate phonation. If we accept the essentials of stuttering recently offered by Bloodstein (1974) and Van Riper (1971), it follows that a laryngeal component may be sufficient to account for the critical behaviors of stuttering. Bloodstein describes the "deeper level" of the stutterer's behavior as consisting of "tensions and fragmentations;" while Van Riper "finds the essence of the disorder in this fracturing and disruption of the motor sequence of the word," or in the "broken word." Bloodstein's tension component is clearly supported by EMG investigations. Further, the obvious outcome of interrupted phonation or inability to initiate phonation promptly would be fragmentation, fracturing, or breaking of words.

Whether abnormal laryngeal muscle activity does indeed produce the fragmentations and fractured words of most or all stutterers is of course another matter. The laryngeal component may be sufficient, without being primary or necessary. Data on a larger number of subjects will be necessary before generalizations can be substantiated. However, the EMG results derived from these four subjects take on additional significance when viewed in relation to the other physiological studies of laryngeal functioning in stuttering (Chevrie-Muller, 1963; Ushijima et al., 1965; Fujita, 1966; Conture, Brewer, and McCall, 1974). The picture emerging from these experiments (which were conducted independently, used a variety of instrumentations, and studied stutterers of three "racial" stocks who spoke three different languages) is consistent. This consistency supports the view that laryngeal involvement is not an idiosyncratic phenomenon.

Comments on Past and Future Studies

Although electromyography has been used in a number of studies of stuttering, it is difficult to draw parallels between previous studies and the present work for two reasons. First, most of the early studies were designed to investigate hypothesized neurophysiological differences between stutterers and non-stutterers (Travis, 1934; Morley, 1937), while the present study was designed to investigate the differences between what the stutterer does when he speaks fluently and when he stutters. Second, technical differences, including types of electrodes, data processing, experimental procedures, and utterance types make comparisons difficult.

Some selective comments are possible, however. First, the finding of Sheehand and Voas (1954) that the peak of maximum muscle activity occurs "late in the block, near the release" appears generally to be true for most of the muscles and most of the subjects of the present study. It was not true consistently for Subject G.G., and it was not true for the TA for Subject C.D. This study strongly supports Williams's (1955) finding that "moments of stuttering characteristically involve muscular tension in excess of that characteristic of normal speech."

The data also support Wingate's (1969, 1970) hypothesis that the fluency-evoking conditions affect changes in manner of vocalization. When the experimental subjects spoke under the four selected fluency-evoking conditions, the levels of laryngeal muscle activity were generally lower, and fewer instances of abductor-adductor cocontraction occurred. These results raise the question of why the fluency-evoking conditions produce changes in manner of phonation. There is preliminary evidence that the fluency-evoking conditions also produce changes in laryngeal muscle activity in normal speakers (Dorman, Freeman, and Borden, 1975). Further research related to fluency-evoking conditions is indicated.

In most cases, this study has also verified hypotheses of other investigators who have studied phonation in stuttering. Adams and Reis (1971, 1974), Adams and Hayden (1974), Adams et al. (1974), all described the initiation of phonation problem demonstrated by Subject C.D. and correlated with disrupted abductor-adductor reciprocity.

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APPENDIX

Prose Passage—

Quotations on Science

The origin of science is in the desire to know causes; and the origin of all false science and imposture is in the desire to accept false causes rather than none; or which is the same thing, in the unwillingness to acknowledge our own ignorance.

Science, like life, feeds on its own decay. New facts burst old rules; then newly divined conceptions bind old and new together into a reconciling law.

The aim of science is to seek the simplest explanation of complex facts. We are apt to fall into the error of thinking that the facts are simple because simplicity is the goal of our quest. The guiding motto in the life of every natural philosopher should be, "Seek simplicity and distrust it."

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