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Electromyographic changes with delayed auditory feedback of speech

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Abstract: EMG recordings from selected laryngeal and supralaryngeal muscles of normal speakers were obtained during normal auditory feedback and delayed auditory feedback (DAF) conditions. The changes in muscle function were analyzed and compared to EMG recordings previously obtained from subjects who stutter. The main effect of DAF was to alter the timing of muscle activity. Prolongations and repetitions were sometimes manifest directly in prolonged and repeated peaks of activity while in other instances the changes were indirectly reflected in increased time between peaks and fragmentation of normally coherent peaks of activity. The amplitude of EMG activity was also altered by DAF but the direction of amplitude change varied with muscles and subjects. Similarities and differences were found between EMG patterns of normal speakers under DAF and EMG patterns of stutterers.

Introduction

Speakers normally hear their own speech by air and bone conduction of the sound. It has been observed that if the auditory feedback is intensified and delayed by about 200 ms, speakers become dysfluent (Lee, 1951). The effect has been compared to stuttering because syllables are repeated and sounds prolonged (Fairbanks, 1955). Somewhat paradoxically, stutterers are often more fluent under delayed auditory feedback (DAF) than under normal auditory feedback. They report that those dysfluencies experienced under DAF differ in kind and in degree from those experienced during stuttering (Neelley, 1961).

The present study is part of a series of experiments designed to study control mechanisms used in normal speech production (Borden, Harris & Oliver 1973; Borden, Harris & Catena, 1973). Subjects with normal speech and hearing read sentences under both normal and delayed auditory feedback. The purpose of the study was to investigate the effects of DAF on muscle activity during speech and to compare these effects with data on muscle activity during stuttering (Freeman, 1975; Freeman, Ushijima, Dorman & Borden, 1975).

Procedures

Two male subjects read sentences designed to be of moderate complexity phonemically (frequent consonant clusters), syntactically (prepositional phrases and subordinate clauses), and semantically (unexpected word combinations). The sentences were as follows:

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‡Also Adelphi University, Garden City, New York
§Also Herbert H. Lehman College of the City Univ. of N.Y.

(1) A wasp sting can be fixed to some extent by the application of wet mud, a sympathetic friend, and some smelling salts.
(2) School becomes increasingly difficult and tedious when spring arrives with its temptations of balmy weather and late evening light.
(3) The squirrel repeatedly scampered down the elm to fetch pieces of spidery string from my workbox in order to soften his nest.
(4) A cat's scratch should be washed immediately and sprayed with an antiseptic solution if possible.
(5) The thirsty rooster was splashing in the water bowl and crowed with such excitement that he surely woke any neighbors who might have been sleeping.
(6) The taxi was bombarded by snowballs when it attempted to park in such a way that it effectively blocked the stickball game.
(7) The whiskers of the sweaty chef were covered with flour, but he stood over the stove oblivious of that fact, dropping grapes into the sauce.

An Ampex PR 10 tape recorder was used to produce the delay of auditory feedback. The playback head was 1·5 in from the recording head. Tape recording at a speed of 7·5 ips provided a 200 ms delay. The delayed sidetone was heard through matched and calibrated Grayston Stadler headphones. The intensity of the signal was further amplified and adjusted until it interfered with fluent speech. The list of sentences was read three times under each condition: first under DAF and then under normal feedback.

Muscle activity was recorded from hooked wire electrodes inserted into selected laryngeal muscles: the posterior cricoarytenoid (PCA), interarytenoid (INT), lateral cricoarytenoid (LCA), vocalis (VOC), and cricothyroid (CT) and into selected supralaryngeal muscles: the genioglossus (GG), superior longitudinal (SL), and orbicularis oris (OO). The insertion techniques used in this study are described further in Hirose (1971).

The data were collected and processed using the Haskins Laboratories EMG system described by Port (1971) and Kewley-Port (1973). In the present study, however, the individual tokens of the speech sample were not averaged but were simply rectified and integrated with a time constant of 25 ms. The signals from each muscle were sampled at 5-ms intervals and, by computer comparison of each sample with a 300-μV calibration signal, were converted to microvolt values. It was then possible to compare the acoustic and EMG data under normal and DAF conditions for each utterance.

Results

In addressing the first question, the matter of how the dysfluent speech is manifest in EMG recordings, the most striking difference in the data is a change in the timing of motor activity. Figure 1 shows EMG activity from the genioglossus (GG) during three fluent productions of the phrase "the application of wet mud". The EMG activity precedes each tongue raising event, and the signals for a given gesture evidence very similar patterns of activity for the three repetitions.

Figure 2 shows GG activity during the phrase "application of wet mud" spoken under DAF. The normal timing of motor activity has been disrupted—there are longer delays between the peaks of EMG activity, and the consistency of the intervals between the peaks is altered. Morever, the amplitude envelopes of EMG activity for a given gesture, across repetitions of an utterance, are rather dissimilar.

A comparison of the EMG signals in Figs 1 and 2 suggests that peak amplitude of the EMG signal changes under DAF relative to that found under normal feedback. Muscle

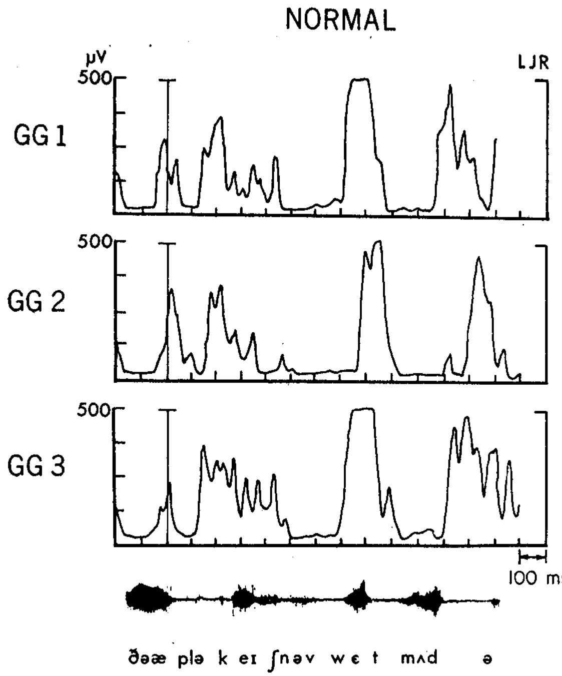

Figure 1 Electromyographic recordings from the genioglossus muscle for three productions of "the application of wet mud" under normal auditory feedback.

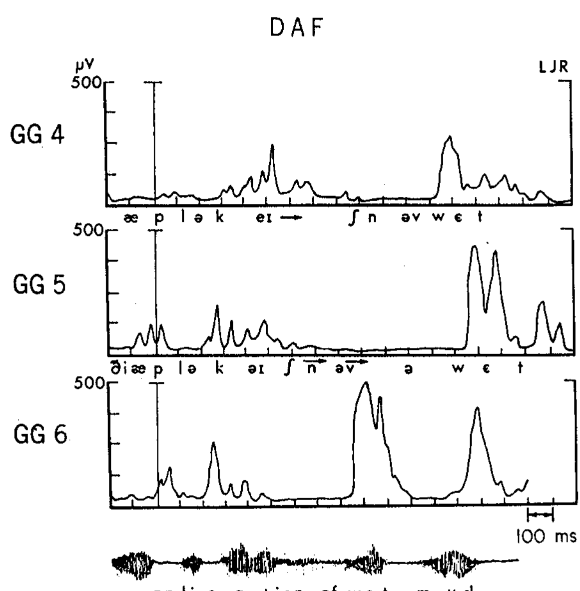

Figure 2 Electromyographic recordings from the genioglossus muscle for three productions of "application of wet mud" under delayed auditory feedback.

activity in this example generally decreases, especially when the speech is most disrupted, as in the first two repetitions of the utterance. It is of interest that the third production of the utterance was the most fluent and most similar in amplitude to the utterances under normal auditory feedback.

The disruption of the normal temporal pattern of muscle activity under DAF is correlated with two prominent aspects of dysfluency: (i) increased duration of voiced continuants (prolongations) and (ii) sound repetitions.

Prolongations

Figure 3 shows the EMG correlates of vowel prolongation under DAF. The recordings are from the posterior cricoarytenoid (PCA), vocalis (VOC), and orbicularis oris (OO) muscles during the utterance "wasp sting".

With normal auditory feedback, the PCA is active for vocal fold abduction for the voiceless consonants /sp/. The VOC is normally active for voicing of /wa/ and /ɪŋ/, and the OO is active for lip rounding or closure, in this case the /w/ and /p/. Under DAF, this subject prolonged both vowels in the utterance especially the /ɪ/, as can be seen in the acoustic trace. Under DAF the utterance was 200 ms longer than normal.

The increased vowel durations appear to be accompanied by increased duration of VOC activity and there is a change in the timing between periods of activity. Most interesting perhaps is the activity of the OO. With normal feedback, the peak of activity that corresponded to lip closure for /p/ followed the PCA activity for vocal fold opening by approximately 100 ms. With DAF, the OO activity again begins to peak after PCA action but shows three peaks before the lips closed for /p/. In the case of prolongations, then, the EMG activity is not always simply extended in time but rather the timing between peaks may change or there may be aborted bursts of activity preceding an effective burst.

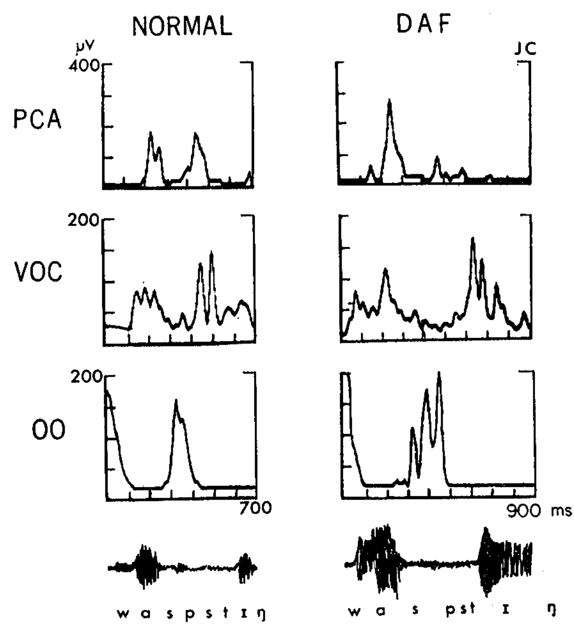

Figure 3 Electromyographic recordings from the posterior cricoarytenoid (PCA), vocalis (VOC), and orbicularis oris (OO) muscles during the production of "wasp sting" under DAF.

Repetitions

A second effect of DAF is to cause repetition of segments within the utterance. Figure 4 shows tongue and laryngeal activity during the utterance "balmy weather".

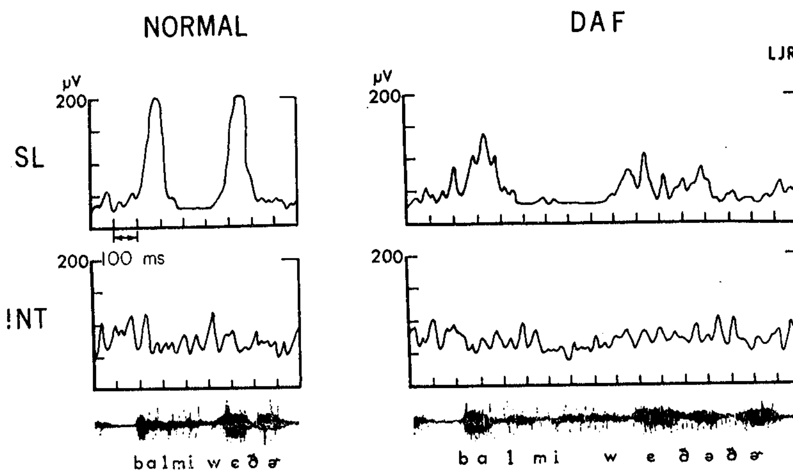

Figure 4 Electromyographic recordings from the superior longitudinal (SL) and interarytenoid (INT) muscles during the production of "balmy weather" under DAF.

Normally, this subject shows activity of the SL muscle for /l/ in "balmy" and /ð/ in "weather". With DAF the utterance was rendered as "balmy weatherther". The SL does not evidence two "normal" coherent peaks for each repetition of /ð/, but rather the muscle activity is characterized by rapid oscillations. There is a marked decrease in amplitude of the SL under DAF. Conversely, the INT muscle does not show a significant level difference between speaking conditions. Only an increse in duration marks the difficulty resulting from the feedback delay.

DAF and stuttering

Are the EMG correlates of dysfluencies under DAF similar to the EMG correlates of dysfluencies in stutterers? Freeman and her colleagues (Freeman, 1975; Freeman *et al.* 1975) have investigated laryngeal muscle activity in stuttering. In general, EMG activity recorded from laryngeal muscles during a stuttering block was of higher amplitude than for the same muscle during the same utterance spoken fluently. In addition, the normal reciprocal relationship between the laryngeal abductor and adductor muscles was disrupted during a stuttering block. For example, Fig. 5 shows EMG recordings from the abductor of the vocal folds, the PCA, and the primary adductor of the vocal folds, the INT.

Normally, when the INT is active, the PCA is inhibited, as evidenced just before the lineup point of the fluent rendering of the word "syllable". During the stuttered version, however, the PCA and INT were active simultaneously as the subject repeated the /s/. This loss of reciprocity impedes normal phonation, and initiation of voicing is difficult. The amplitude differences between the fluent and stuttered samples are readily apparent.

The dysfluencies in the speech of normal speakers under DAF are like stuttering in that the EMG signals change in amplitude when disorganized and there is a loss of normal

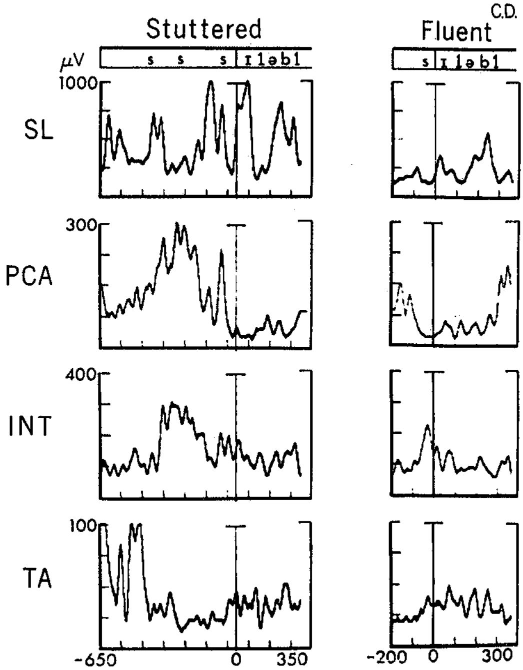

Figure 5

Electromyographic recordings from stuttered and fluent samples of the word "syllable". During stuttering the EMG signals are more intense and the normal reciprocity is disrupted.

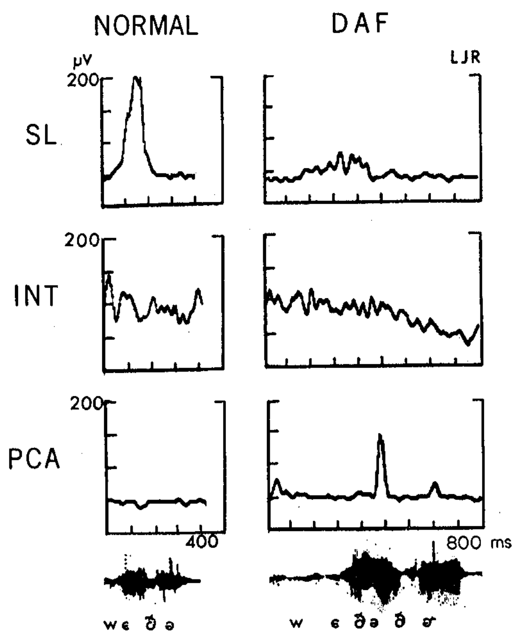

Figure 6

Change of amplitude of EMG signals during speech of normal speakers under DAF.

reciprocity in agonist–antagonist muscles. They differ, however, in two respects. First, with DAF there are changes in the amplitude of the EMG signal, but the direction of change varies for different subjects and different muscles. Figure 6, for example, shows one muscle increasing activity (PCA), one remaining similar (INT), and one decreasing activity (SL) under DAF.

The second difference between EMG recordings of normal speakers under DAF and of stutterers is in terms of muscle coordination and timing: although DAF does disrupt the timing of muscle activity, the DAF disruptions differ from those of stuttering. The disruption of reciprocity between adductor and abductor muscles of the larynx characteristic of the moment of stuttering typically occurs before the onset of voicing. For normal speakers under DAF, however, voicing starts but is either prolonged or started again, presumably to stall for the delayed voice to catch up. It often happens during DAF that the abductor (PCA) fires during voicing, as was illustrated in Fig. 6.

Summary

The main effect of delaying auditory feedback on the muscle activity of normal speakers was to change the timing of the EMG signal. Acoustic prolongations and repetitions were sometimes reflected directly in EMG duration changes and multiple peaks and sometimes only indirectly by increased time between peaks. With DAF, intensity levels of muscle activity changed, but in no discernably predictable manner. Finally, EMG recordings of normal speakers under DAF differ from those of stutterers in terms of the direction of amplitude changes and in the relationship between voicing and muscle contraction. Part of the problem exhibited by stutterers is difficulty in making the transitional adjustments necessary to go from voiceless to voiced states and vice versa. Normal speakers under DAF, however, demonstrate little difficulty in initiating voicing but rather prolong the voiced state or repeat it. Indeed, it is this stretching of the speech signal that probably accounts for the decrease in blocks observed in the speech of stutterers under DAF. As a continuation of this series of studies on speech control, we plan to investigate the EMG correlates of the speech of stutterers under DAF to see if they differ from normal speakers under DAF and from recordings of their own stuttering episodes.

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