The Effect of Delayed Auditory Feedback on Phonation: An Electromyographic Study*

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ABSTRACT

Delayed auditory feedback (DAF) alters the temporal pattern of laryngeal and supralaryngeal muscle activity. In some instances, the alterations are manifest simply in terms of prolonged muscle activity, while in other instances, the normal coherent pattern of muscle contraction is fragmented by rapid oscillations in muscle activity. The amplitude of electromyographic activity is also altered by DAF but changes in activity vary considerably between muscles and speakers. The patterns of EMG activity correlated with dysfluencies under DAF appear substantially different from those patterns found in stuttering.

It is well-known that most normal speakers who hear their speech delayed by about 200 msec become dysfluent (Lee, 1951). The dysfluencies, sometimes termed "artificial stutter," are manifest in increased vocal intensity, prolonged vowels and syllable repetition (Fairbanks, 1955). Individuals who stutter, however, become more fluent when speaking under delayed auditory feedback (DAF) (Neelley, 1961). In this paper, which reports a portion of a long-range study of feedback mechanisms used in the control of speech production, we consider two questions: (1) What is the effect of DAF on the laryngeal and supralaryngeal muscle activity of normal speakers? and (2) How does the disruption of electromyographic (EMG) activity under DAF compare with the disruption of EMG activity found during stuttering?

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With respect to the first question, the most striking effect of DAF 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." Note that the EMG activity precedes each tongue raising event, and that the EMG signals for the three repetitions of a given gesture evidence similar patterns of activity. In contrast, Figure 2 shows GG activity during the phrase "the application of wet mud," spoken under DAF. The normal timing of motor commands has been disrupted: there are longer delays between the peaks of EMG activity. Moreover, the patterns of EMG activity for each repetition of a given gesture are rather dissimilar.

A comparison of Figure 1 and 2 suggests that the amplitude of the EMG signal changes under DAF. Muscle activity 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 the closest in amplitude to the utterance under normal auditory feedback.

The disruption of the normal temporal pattern of muscle activity under DAF is correlated with two prominent aspects of dysfluency: (1) increased vowel duration and (2) syllable repetition. Therefore, we turn now specifically to the EMG correlates of these two phenomena.

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." Under normal feedback, the VOC, acting in concert with other vocal fold adductors to produce closure for /a/, was active for approximately 200 msec. The PCA was active to open the folds for the voiceless /sp/. The PCA activity was followed 100 msec later by OO activity for /p/ closure. Under DAF, the /p/ closure and the vowels in both "wasp" and "sting" were prolonged. The VOC activity mirrored the vowel prolongation showing—for example, for /a/—100 msec more activity. For the /p/ closure, the OO evidences three peaks of activity over a 200-msec period, in contrast to the single peak of activity over a 100-msec period under normal feedback. Note that the EMG activity under DAF, for the OO, did not evidence a normal, but simply prolonged, pattern of muscle contraction. Rather, the pattern of activity was altered, evidencing rapid oscillations in muscle contraction.

Let me now turn to an example of syllable repetition under DAF. As shown in Figure 4, under normal feedback the superior longitudinal (SL) peaks, for this subject, for the /l/ in "balmy" and the /β/ in "weather." Under DAF the utterance was rendered as "balmy weathether." The SL did not evidence two "normal" coherent peaks for each repetition of /β/, but rather the muscle activity was characterized by rapid oscillations.

We turn now to the question of the relationship between the EMG correlates of dysfluency under DAF and the EMG correlates of dysfluency during stuttering. Freeman and her colleagues (e.g., Freeman et al., 1975) have found generally increased EMG activity, especially for the laryngeal muscles, during stuttering. More important, perhaps, is that the normal reciprocity of laryngeal abductor and adductors was found to be disrupted.
Figure 1: Muscle activity recorded from the genioglossis (GG) during three productions of the utterance "the application of wet mud" under normal auditory feedback.
Figure 2: Muscle activity recorded from the genioglossis (GG) during three productions of the utterance "application of wet mud" under DAF.
Figure 3: Muscle activity recorded from the posterior cricoarytenoid (PCA), vocalis (VOC), and orbicularis oris (OO) during the production of the utterance "wasp sting" under normal and delayed auditory feedback.
Figure 4: Muscle activity recorded from the superior longitudinal (SL) and interarytenoid (INT) during the production of the utterance "balmy weather" under normal and delayed auditory feedback.
Figure 5: Muscle activity recorded from the tongue (SL), laryngeal adductors (INT and TA), and the laryngeal abductor (PCA) during fluent and stuttered speech.
Figure 6: Muscle activity recorded from the tongue (SL), a laryngeal adductor (INT), and the laryngeal abductor (PCA) during the production of "weather" under normal and delayed auditory feedback.
For example, Figure 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 one is active, the other is inhibited, but during the stuttering block, for example, on the /s/ of the word "syllable," both are active simultaneously. This loss of reciprocity disrupts normal phonation. Amplitude differences between the fluent and stuttered utterances are readily apparent.

Muscle activity, then, for stutterers is generally of higher amplitude during stuttered than during fluent speech, and there is evidence that the normal reciprocal relationship of the abductor and adductor laryngeal muscles is disrupted during stuttering blocks.

The dysfluencies in the speech of normal speakers under DAF are not like stuttering in these two respects. First, under DAF there are amplitude changes in the EMG signal, but the direction of change varies for different subjects and different muscles. For example, Figure 3 indicates an increase in the level of VOC and 00 activity under DAF. In Figure 6, however, the SL shows a decrease, the INT shows only minimal changes, and the PCA shows an increase.

The second difference in EMG activity between normal speakers under DAF and stutterers is that during a stuttering block the disruption of reciprocity between abductor-adductor muscles of the larynx prevents or delays normal initiation of voicing while for normally fluent individuals speaking under DAF, voicing usually starts but is either prolonged or "restarted." Typically, in dysfluencies caused by DAF, breakdown of reciprocity occurs after the initiation of voicing. To illustrate, for the fluent production of "weather" shown in Figure 6, the adductor (INT) is active through the utterance because all the segments are voiced. The abductor (PCA) is suppressed throughout the utterance. However, under DAF the abductor fires during the period in which the INT is still strongly active.

To summarize, the main effect of DAF is to alter the temporal pattern of laryngeal and supralaryngeal muscle activity. In some instances the alterations are manifest simply in terms of prolonged muscle activity, while in other instances the normal coherent pattern of muscle contraction is fragmented by rapid oscillations in muscle activity. The amplitude of EMG activity is also altered by DAF but changes in activity vary considerably between muscles and speakers. Finally, the patterns of EMG activity correlated with dysfluencies under DAF appear substantially different from those patterns found in stuttering.

REFERENCES
