Stress and Syllable Duration Change*

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It is generally assumed that underlying each phoneme there is an invariant articulatory target. At a surface level, this statement is, of course, untrue. There is no moment when the articulators assume a position for a given speech sound—a position that is invariant over changes in the phonemic context and supra-segmental structure. Much of the effort of traditional articulatory phonetics was directed towards writing rules to describe observed differences in articulatory target as a change in allophone selection. Modern physiological research searches for simple rewrite rules to derive observed positional variants from some presumed underlying single articulatory target.

A carefully worked out theory of this sort is Lindblom's (1963) theory of vowel reduction, which was developed to account for the changes in vowel color that accompany changes in stress. If a vowel is destressed, it will tend to be of shorter duration, and to move in vowel color towards the neutral schwa; the latter phenomenon is called vowel neutralization. Lindblom's proposal is that the neutralization is a consequence of the accompanying shortening. Briefly, in a consonant-vowel-consonant (CVC) sequence, although the signals sent to the articulators are constant, the response of the articulators is sluggish. If signals arrive at the muscles too fast, the articulators will start towards the vowel target but will be deflected towards the subsequent consonant target—that is, there will be undershoot. Lindblom tested his theory by having subjects produce sentences containing CVC monosyllables. The effect of rearranging the sentences was to change the stress on one "word" and consequently to change the vowel duration. He made careful measurements of the most extreme positions of the first and second formants, as a function of the vowel length. He found that as vowels lengthened, the formants tended towards asymptotic values which could be described as targets. Equations could be written describing the relation of vowel duration to the departure of formant position from target.

Lindblom's theory seems to be elegant and testable, if one substitutes for "signals" the more specific "muscle contractions." A reformulation in electromyographic (EMG) terms would then perhaps be: "Under conditions of changing stress the EMG signals associated with a CVC sequence will remain constant in amplitude. Only the relative timing of vowel and consonant signals will change."


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Lindblom goes further than this. He assumes that changes in duration operate in the same manner whether they are due to stress or to speaking rate. Gay (1973) has been investigating some aspects of this formulation with respect to speaking rate. I will talk about stress.

As our model for changing stress, we constructed some two-syllable nonsense words, of the form /pVCP/. The two middle vowels were always /i/, /a/, or /u/, and were always different. The first and last consonants were always /p/, and the middle consonant was /p/ or /k/. There was a neutral carrier on each end. Using this format, we examined EMG signals from several muscles involved in the articulation.

The genioglossus muscle will be discussed first. This is a large muscle making up a great part of the body of the tongue, acting to bunch it. Consequently, activity is always seen for the vowel /i/, usually is seen for /u/, and none is seen for /a/. No activity is seen for the consonants.

The effect of the change in stress is shown in Figure 1. (Time runs along the abscissa; each unit is 100 msec. Averaged energy is on the ordinate. The vertical line shows the point when the voicing for the first syllable ends.) The two curves in each graph show the two conditions of stress. In each graph the thin line shows the utterance with the first syllable stressed and the thick line shows the utterance with the second syllable stressed. The line rows show two different electrode insertions, both into the genioglossus. The curves show the two effects of stress usually found. First, there is a small difference in peak height between stressed and unstressed vowels (Harris, 1971).

The second effect is the "lineup" effect. Notice in the left column, that when the /i/ is stressed, the genioglossus curve begins earlier, but ends at the same time with respect to the offset of voicing. The effect is almost symmetrical when the /i/ is in the second syllable. In other words, the vowel activity lengthens, but dies off in a constant relationship to the offset of voicing.

Figure 2 illustrates the activity of the orbicularis oris muscle, which shows a burst of activity for the first, middle, and last /p/ in these utterances since it acts to close the lips. Note that the middle /p/ peaks over the offset of voicing, indicated by the vertical line. Again, the first /p/ moves leftwards, as the vowel lengthens, when the first syllable is stressed. The last /p/ moves rightwards, as the vowel lengthens, when the last syllable is stressed.

What does this mean? First, the activity for the vowel lengthens. Second, the time between consonant peaks changes systematically. Combining these facts, we get a picture of stress change illustrated by Figure 3.

This figure shows the relationship between orbicularis oris and genioglossus activity, for four disyllables. In all cases, the vocal activity begins as the initial consonant activity wanes. If the vowel is stressed, its activity continues for a longer period than if it is not stressed. The middle or terminal consonant begins as the vocal activity wanes. The vowel seems to lengthen literally—that is, associated muscle activity lasts longer. The temporal relationship of consonant and vowel activity seems to be fixed.

Lindblom's model, then, is wrong on two counts—it posits, first, that under conditions of changing stress the signals to the muscles will remain constant,
Figure 2
and second, that the temporal relationship between consonant and vowel signals will change. What is found is a difference in the peak amplitude of the signals to the relevant muscles while the relationship between consonant and vowel signals remains constant.

A closely parallel observation has been made by Kent and Netsell (1971) in a cinefluorographic study of stress contrast effects on various aspects of upper articulator movement in noun and verb forms of various words. They note that in words like "escort," articulator adjustments for the second vowel occur at the same time relative to the intervocalic consonant adjustments regardless of lexical stress. Our observations show that the EMG signals underlying the articulator movement are organic in a way that parallels the output articulator movement.

A second proposal for the stress contrast mechanism is Ohman's (1967) suggestion that stress is manifested by "extra energy" of articulation of the stressed member of a contrasting pair. The results described above are consonant with such a description. However, Ohman's proposal is obviously incomplete. If all muscles reacted to extra stress with more vigorous activity, the effects on antagonistic muscles would cancel each other. There must be uneven effects of stress on various muscles.

The left side of Figure 4 shows some examples from another subject. As before, genioglossus activity clearly lengthens with vowel lengthening as stress changes. There is also somewhat more activity with stress. However, the difference is not huge. The right side shows sample records taken simultaneously from the geniohyoid muscle. The activity appears to be correlated with jaw opening, at least in part. The important point is that stress effects here are very much larger. Apparently, then, the effects of stress are not evenly distributed to all muscles. Perhaps the effects of stress change are greater on jaw muscles than on tongue muscles; I should say, however, that we have a poor understanding of the opening and closing movements of the jaw.

What about Lindblom's (1963) hypothesis about the homogeneity of all duration change mechanisms? He discusses only stress and speaking rate contrasts specifically. A third type of vowel duration change is the well-known effect of voicing status in the terminal consonant. We have scattered information on all three problems. Gay, Ushijima, Hirose, and Cooper (1973) have shown that the effects of speaking rate change are not uniform on all articulatory components. Some gestures show more forceful articulation when rate increases, while others show less activity.

Raphael (1970) has collected some data on terminal consonant effects on vowel duration. The data are similar to what we have just seen—that is, the vowel gesture lengthens before the voiced consonant, but the timing relationship between consonant and vowel is fixed.

Let me conclude by summarizing. First, interrelationship of the consonant and vowel is surprisingly constant over stress lengthening, a finding not predicted by a previous model of the process. Second, stress effects can be considered as "more energetic" enunciation, but the effects of increased energy are distributed unevenly, according to a pattern we do not now understand, over the relevant articulatory muscles. Third, the mechanism of duration change is not uniform for all suprasegmental manipulations.
Figure 4
REFERENCES


