LARYNGEAL CONTROL OF SWEDISH WORD TONES *

- A Preliminary Report on an EMG Study -

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Swedish, like most Scandinavian languages, has word tones, in the sense that stressed words are characterized by one of two types of prosodic patterns, usually called the acute and grave accents.

The fundamental frequency patterns (the pitch contours) manifesting the accents vary a great deal among the different dialects of Swedish.[1] The acute accent in the Stockholm dialect, for instance, is somewhat similar in the pitch contour to the grave accent in the south, and the converse is also true.

In traditional handbooks and dictionaries the acute and grave accented words are analysed as having different phonetic stress patterns; for instance, acute: $\overset{4}{\text{a}}\text{nd}\overset{0}{\text{e}}\text{n}$ and grave: $\overset{3}{\text{a}}\text{nd}\overset{2}{\text{e}}\text{n}$.[2] Since similar stress differences were observed for most dialects whereas the pitch contour varied from dialect to dialect, it was generally assumed that stress or "dynamic accent" as it was called at that time was the determining feature in the accent distinction. Malmberg conducted experiments with synthetic speech at Haskins Laboratories and showed that he could simulate the accent distinction by using the pitch distinction only.[3] He also varied intensity and found that intensity was not efficient as a cue to the accents. Hadding in connection with her investigation of Southern Swedish intonation, tested the accent distinction in whispered words.[4] Her results indicated that the acoustic difference for the distinction of the two accent patterns could be maintained in whispered speech.

Öhman tried to incorporate the word tones in his general quantitative model for intonation.[5],[6],[7] He postulated that the observed fundamental

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** Phonetics Institute, University of Lund, Sweden frequency curve for a stressed syllable could be described as a consequence of passing a positive step function and a negative pulse through a fixed passive network, and tried to interpret the apparent variability of the pitch contours in terms of the pertinent timings of the muscle commands. This is a particularly interesting hypothesis, and it is thus quite worthwhile to examine activities of different laryngeal muscles involved in actualizing the different accent patterns: Öhman et al.6) made a pilot study in this direction.

EXPERIMENTAL PROCEDURES

Our test material consisted of some 20 sentences each containing a test word that had one of the two tones associated with various phonetic conditions (Table 1). The test words were embedded in semantically neutral carrier sentences in a rising-falling statement intonation and they were uttered by one female speaker (E) of the Skåne dialect and a male speaker (L) of standard Swedish. Some of the test words had a variation in syllable boundary as their minimal distinction, a few items had glottal stops and a couple of sentences were whispered. Each test sentence was uttered fifteen times in repetition. The study to be reported on here concerns only a part of the material.

Table 1.

Test sentences for EMG investigation of Swedish word tones.

1. deva mó:nen han sa.
2. deva mò:nen han sa.
3. deva mő:nen han sa.
4. deva mȍ:nen han sa.
5. deva pá:men ja sa.
6. deva pà:men ja sa.
7. deva mámma han sa.
8. deva màmma han sa.
9. deva mò:no:r han sa.
10. deva mò:n+o:r han sa.
11. deva mò:+no:r han sa.
12. deva mȍ:n+o:r han sa.
13. deva mò:+nó:r han sa.
14. deva mò:+o:r han sa.

We selected the vocalis and the cricothyroid muscles as the targets of our EMG study, since they are known to be active in laryngeal control of voicing and pitch changes. In addition the sternohyoid was also examined. This muscle has been reported to be active for pitch-lowering in certain data of English and Japanese.[8),9)]

The experimental method for the EMG data acquistion is similar to that described elsewhere.[10)] In this experiment, the mucosa of the larynx was given a light anesthesia before the electrodes were inserted. Once the electrodes had been fixed in the right position the subject could talk in a natural voice without feeling their presence.

The electromyographic signals were amplified by DC preamplifiers with high gains. Three EMG signals from different muscles and the speech signal were simultaneously recorded on magnetic tape by use of a four-channel FM tape recorder. The recorded signals were fed to a PDP-9 computer off line through an AD converter for data processings. In this process the EMG signals were sampled every 250 microseconds and digitized into 6-bit levels. The absolute values were taken for the samples and these were integrated over a range of 10 msec by use of a running window.[11)] The smoothed signals thus obtained for 10 selected utterances were summed up for every corresponding time samples. The sampling times were determined in reference to a time moment representing a selected speech event, e. g. , the explosion of [m] in the test word.

RESULTS

Each of the EMG curves in the Figures 1-3 represents an average of 10 utterances. They have been derived from the following muscles, from top to bottom in each figure: the vocalis, the cricothyroid, and the sternohyoid. The fundamental frequency curve shown as the lowest trace in the figure was taken from the sound spectrogram of one representative utterance. The reference point on the time axis for the summation process was selected for the samples in Figure 1 at the beginning of the voiced segment after the initial [p] and for those in Figure 2 at the release of the initial [m]. In what follows we shall discuss some of the findings (see Figures 1 and 2).

A. Muscle activity and segmental gestures.

The vocalis invariably shows a sharp fall for the articulatory occlusion of [p]. The moment of its minimum activity coincides or slightly precedes the apparent midpoint of the occlusion. A similar dip is also observed for the voiceless fricative [s] but the effect is less apparent perhaps due to the difference in stress.

The cricothyroid shows no apparent correlation with any articulatory gestures.

B. Muscle activity and prosodic gestures.

a. The fundamental frequency.

The vocalis shows a peak of activity near a peak in F_0 typically with some lead in time. Some intricate differences between the activity patterns of the vocalis and the cricothyroid muscles must be noted, however, particularly for Subject E (see infra). It must be noted also that in all of the data we have here, the vocalis muscle invariably becomes activated prior to the start of utterance, whereas the cricothyroid never shows this tendency.

The cricothyroid shows a clear and consistent correlation with the F_0 curve with some lead in time, except at the end of utterance for Subject E where the rising cricothyroid activity is combined with falling pitch.

The sternohyoid activity shows no simple correlation with the pitch value.

b. Stress.

Let us assume that the traditional interpretation of higher stress in the second syllable of the grave-accented word is correct and see if it correlates with some specific muscle activities. The vocalis activity is invariably stronger for the grave accent than for the acute in the second syllable of the test word. The same comparison between the accent patterns can be made for the cricothyroid only in the case of Subject L (standard Swedish), who shows a corresponding peak in the pitch contour (see Figure 2).

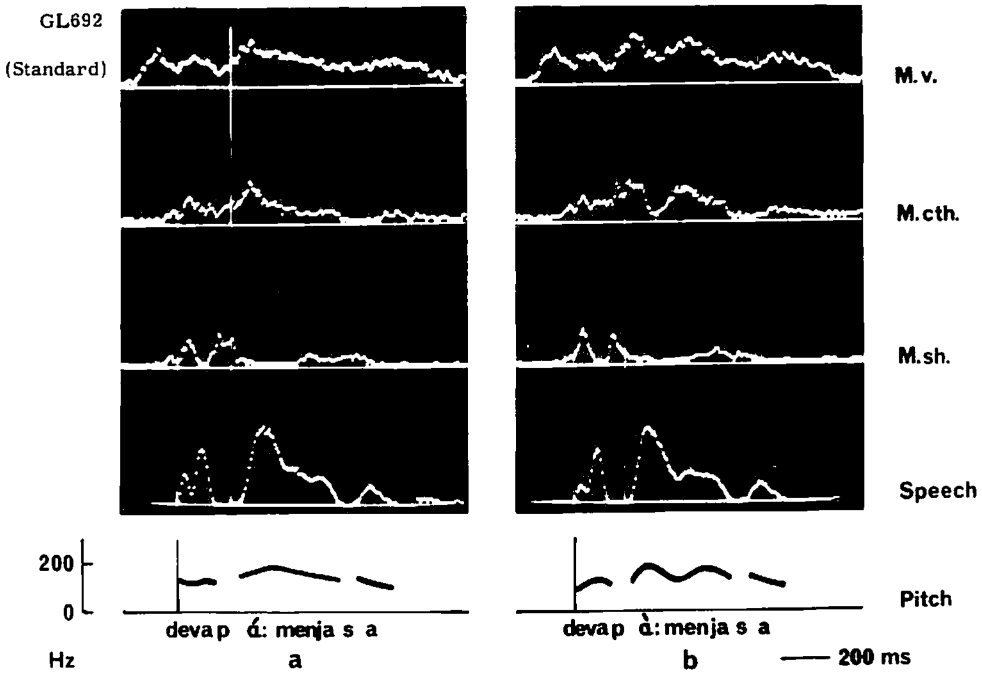

Figure 1. (Standard).

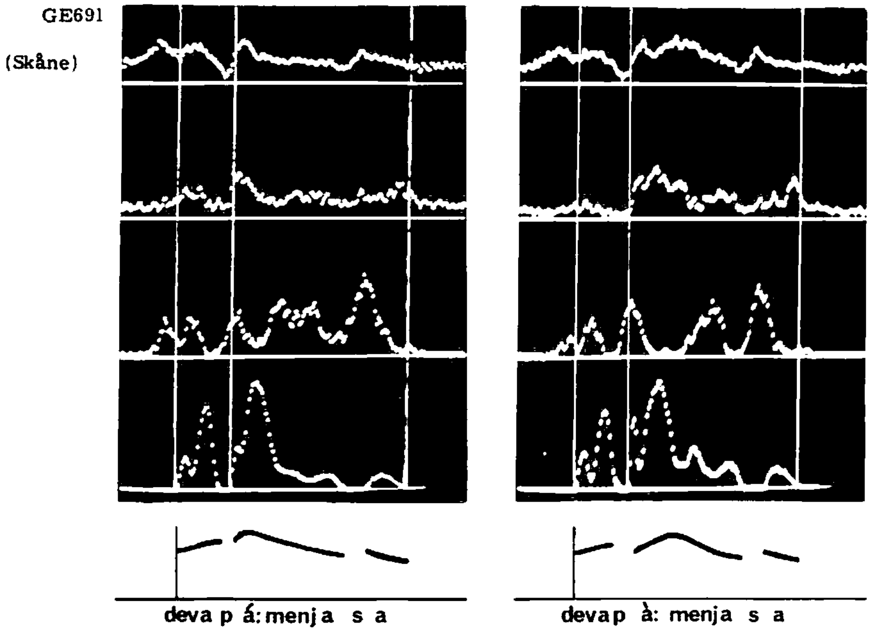

Figure 1. (Skåne).

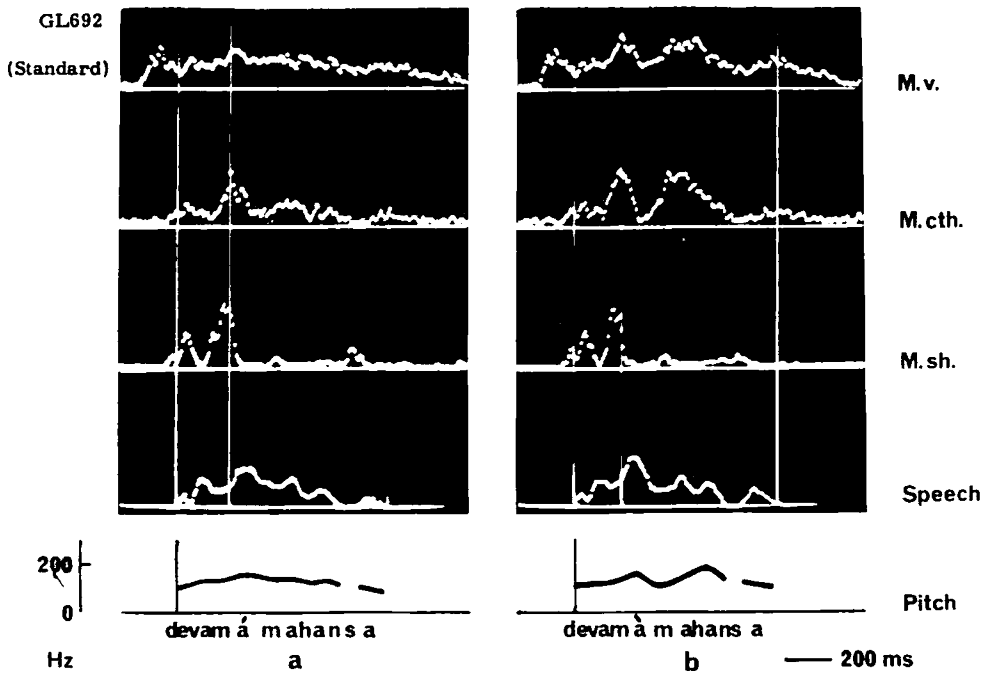

Figure 2. (Standard).

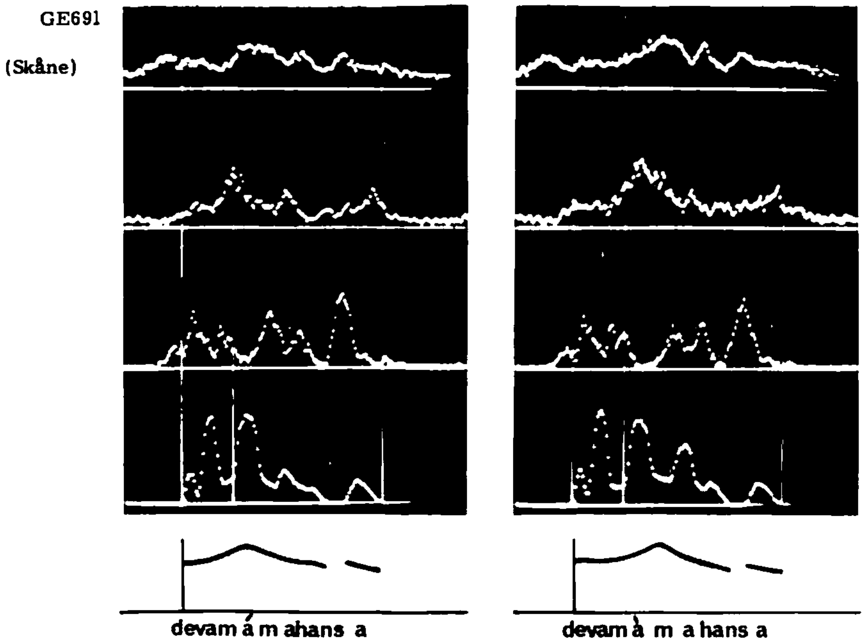

Figure 2. (Skåne).

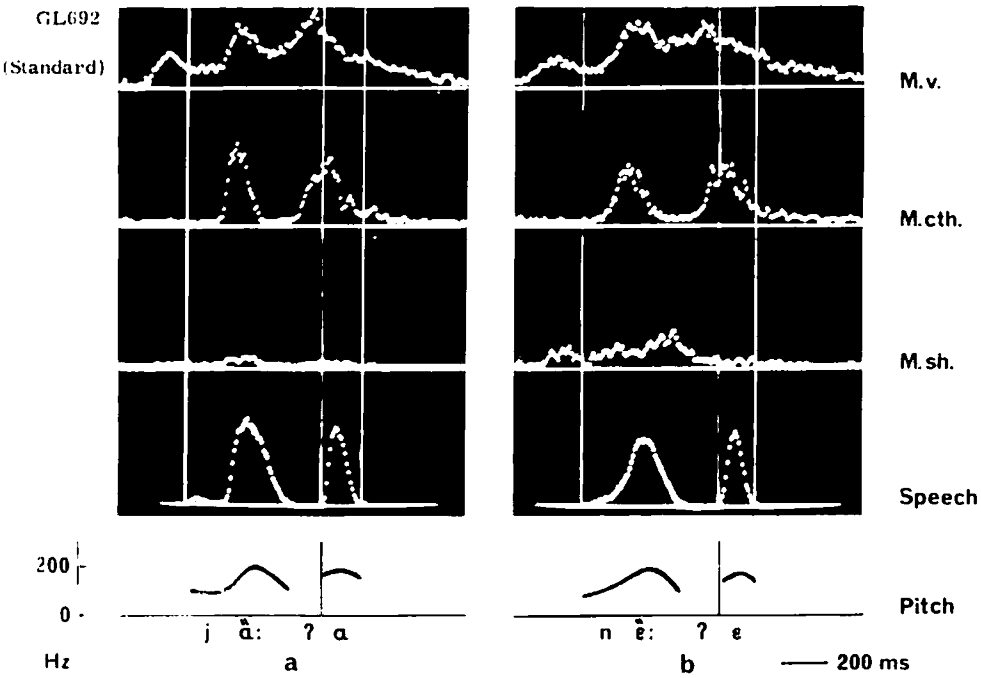

Figure 3. (Standard).

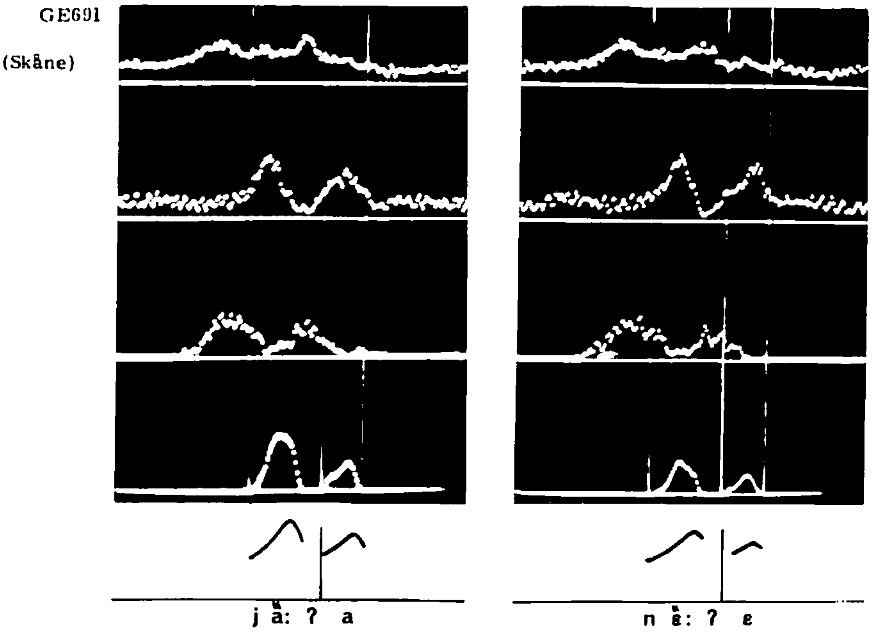

Figure 4. (Skåne).

COORDINATION OF THE MUSCLE ACTIVITIES

The tracings suggest that the interrelation between the vocalis and the cricothyroid muscle activity varies depending on the particular functions. Corresponding to the glottal adjustment for [h], in particular, there seems to be a sort of trading relation between the activities of the two muscles. For adduction in stressed syllables there is seen some general cooperation between the vocalis and the cricothyroid if we disregard the activities of the vocalis in articulations of voiceless fricatives and for initiation of voicing (see infra). There is, however, a marked disagreement between the two muscle activity patterns for the grave accent of the Skåne dialect.

The utterances represented in Figure 3 pertain to the Swedish highly expressive responses [jɑ̏: ʔɑ] and [nɛ̏: ʔɛ], to the left and right of the figure, respectively. They need a maximal use of laryngeal control because they have the grave accent, emphatic stress, and a glottal stop between the two syllables. They are also particularly well suited for the study of laryngeal control because the main portions of the utterances apparently use relatively constant tongue articulations.

It is noted in these samples that the pitch contours and the amplitude envelope correspond to each other almost perfectly with a slight delay of pitch peaks. The second peak in pitch invariably corresponds to the second peak in the cricothytoid activity. The first peak in the cricothyroid activity leads the corresponding peak in pitch by 60-80 msec. and coincides with the phase of maximum increase in pitch. It must be noted that around the glottal stop, either near the implosion (Subject E) or the explosion (Subject L), there is always a peak in the vocalis activity (cf. also the activity peak for [h] in Figure 2). At these moments of maximum activity of the vocalis, the cricothyroid seems to be suppressed, particularly in the case of Subject E (see supra). It seems clear that in this case, the activity of the cricothyroid for the glottal stop somehow interferes with the activity pattern for the second peak in pitch.

For all other samples, the cricothyroid activity shows peaks well corresponding to the peaks in pitch with a certain lead in time.

The sternohyoid, as well as the vocalis, shows an appreciable activity well in advance for the start of utterance. It also seems to show a peak at the moment of the first descent in pitch, but no such activity is observed for the second descent in pitch toward the end of utterance. The first peak may reflect an onset of a speech mode gesture in terms of an articulation (the mandible position), in parallel to an activity of the vocalis muscle prior to the onset of utterance. The second peak of Subject E may reflect a slight opening action of the mandible, but this remains to be studied further.

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