WORD TONES AND LARYNX MUSCLES

Eva Gårding

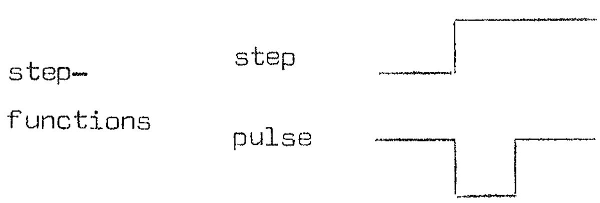
0. Outline

This is a slightly revised version at a seminar talk given in Lund, May 1970. In Section 1 I shall make a brief summary of Öhman's model for intonation (Öhman, 1967 a) and in Section 2 I shall discuss the results of an EMG study that was carried out by Öhman, Leandersson, and Persson to test Öhman's theory (Öhman *et al.* 1967 b). Section 3 is a preliminary report on an EMG investigation parallel to Öhman's (See also Gårding, Fujimura, Hirose, 1970). The implications of our own data are discussed in Section 4. They indicate that Öhman's model cannot be entirely correct. In Section 5, a revised version is suggested and in 6, Meyer's wordtone data for Swedish dialects (Meyer, 1937 and 1954) are interpreted in terms of the revised model. A correlation of our EMG data to the standard stress notation used for the word tones concludes the report (7).

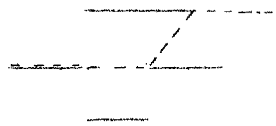
1. Summary of Öhman's model

Öhman tried to incorporate the Scandinavian word tones in a general quantitative model for intonation (Öhman, 1967 a). The first version of this model only concerns the stressed syllable of an utterance. He postulates that the observed fundamental frequency curve for such a syllable can be decomposed into a positive sentence intonation step and a negative word intonation pulse.

To give an example:



The stepfunctions represent the on and offset of the nerve signals. Each stepfunction passes through a filter which simulates the inertia of the anatomic structures. The filter has a smoothing effect on the stepfunction. When the two inputs above have been smoothed and added to each other, the output will be like the dotted line below:



By timing the pulse in various ways in relation to the step, Öhman obtains the configurations that he needs to approximate the word tones in different dialects. (Meyer, 1937 and 1954. The dialectal variation is shown in Figure 1, Öhman's figure II-B-3, op. cit. p. 23.)

Dialectal variation can then be explained as a difference in timing between the pulse and the step. The almost reversed patterns in Stockholm and Skåne (Numbers 1-5 and 90-93 in Figure 1) are interpreted in the following way: The time order of the step and the pulse is reversed (op. cit. p. 26). The acute and grave accents correspond in Danish to stød (a kind of glottal stop) and no stød. Smith (Smith, 1944) made acoustic and physiological measurements of this contrast. In an EMG investigation of the expiratory muscles he found that words with stød are characterized by a brief and intense innervation pattern compared to a more evenly distributed innervation in the words without stød. This innervation is followed by a sudden relaxation that (for reasons not well understood) brings about a momentary disturbance or inhibition in the vibration of the vocal cords. The effect of this inhibition is a segment with a glottal stop or in most cases a segment with creaky voice.

The fact that a glottal stop in Danish corresponds to the acute accent in Swedish gave Öhman the idea of interpreting all Scandinavian word tones as "glottal stops" in the sense that they all have some inhibitory effect on

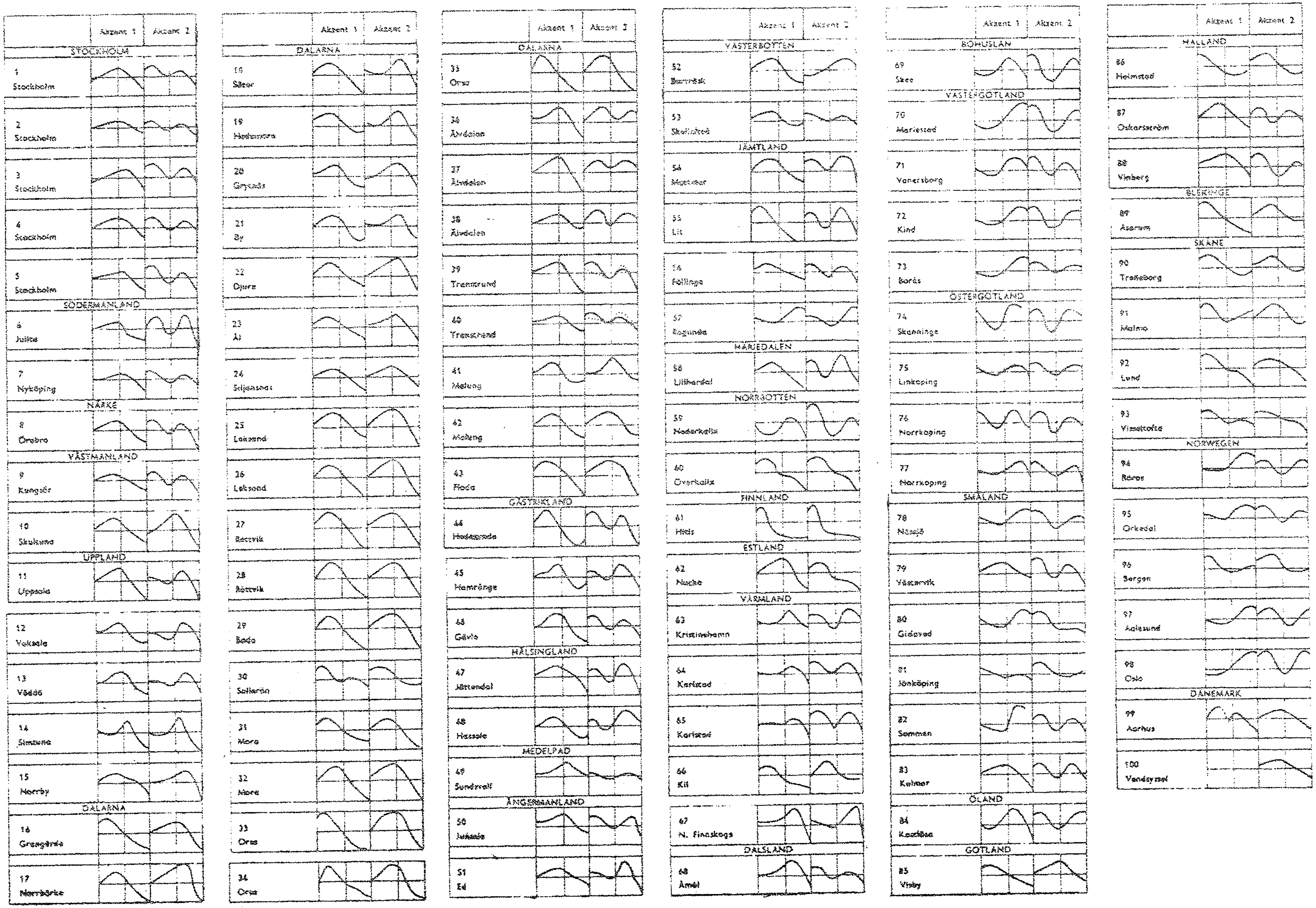


Figure 1.

Fig. II-B-3. Schematic acute and grave accent patterns of a hundred Scandinavian dialects according to E. A. Meyer: Die Intonation im Schwedischen, part II.

sentence intonation. This inhibitory effect is strongest in Danish: for the stød the vocal cords are adducted to such an extent that the vibratory pattern becomes irregular. In other Scandinavian dialects - according to the theory - the effect is much weaker: the vibrations are inhibited but they do not lose their periodicity.

This glottal stop theory motivates Öhman's choice of a negative pulse for the word accent.

2. Öhman's EMG study

Öhman then looked for some physiological mechanism that was likely to have a negative, that is pitch inhibiting effect on sentence intonation. In an EMG investigation Öhman and his co-workers studied the behavior of two of the intrinsic laryngeal muscles during the pronunciation of words with contrastive word tones and words with glottal stops. (Öhman et al., 1967 b.) The vocalis muscle was chosen as a representative of the adductory muscles. It is natural that this muscle should be active for glottal stops. That this is indeed the case has been shown in earlier EMG investigations, for instance by Faaborg-Andersen. (Faaborg-Andersen, 1957.) The cricothyroid was selected because this muscle is known as the main tensor muscle and therefore the muscle responsible for pitch control. When the cricothyroid contracts the cricoid arch is raised towards the anterior part of the thyroid cartilage. In this process the arytenoid cartilages which are mounted on top of the cricoid lamina are tilted backwards. The tilt lengthens the distance between the points of attachment of the vocal cords. (Sonesson, 1968, p. 51.) The vocal cords will therefore be stretched which means that during phonation the pitch will go up. The effect of the cricothyroid activity on pitch has been extensively studied. (Arnold 1961, Faaborg-Andersen 1957, Ohala et al. 1968 and 1969.) Expected electromyographic correlates to Öhman's theory would be a period of inhibition in the cricothyroid muscle combined with increased activity in the vocalis at the time when the negative word pulses are supposed to occur.

The results of the EMG experiment, which was performed with needle electrodes on a male subject speaking the Stockholm dialect, were inconclusive. The main finding according to Öhman was a brief interval of inactivity in the cricothyroid muscle which roughly coincided with the negative pulse. There was no corresponding increase in vocalis activity, at least not in the examples published by the authors. Figure 2 shows examples of the vocalis and cricothyroid activity implied by the word tones. The inhibition phases related to the word tones are marked by arrows.

To facilitate the interpretation of the electromyograms I have added the fundamental frequency curves that can be expected in this kind of dialect. The cricothyroid activity correlates very well with the fundamental frequency curve in general. With a low pitch as in the last part of the frame ja sa there is a concomitant low activity in the cricothyroid. In my view this correlation can also explain the arrow marked interval in the grave accented word in the figure and is not necessarily an indication of a negative pulse. Increased activity in the vocalis would have made the negative pulse interpretation more probable but the vocalis record does not change in connection with the pulse.

The electromyograms of the acute accented word do not give much support for the negative pulse either. It is true that the arrow points to an interval with reduced activity in the cricothyroid signal at a point in time tha fits the postulated pulse but it is not accompanied by increased activity i the vocalis muscle, rather the contrary. In my opinion the reduced activit in both the cricothyroid and vocalis muscles could be an effect of a phonation pause in connection with the syntactic boundary between the frame de v and the test word rather than a manifestation of a negative pulse. The gap

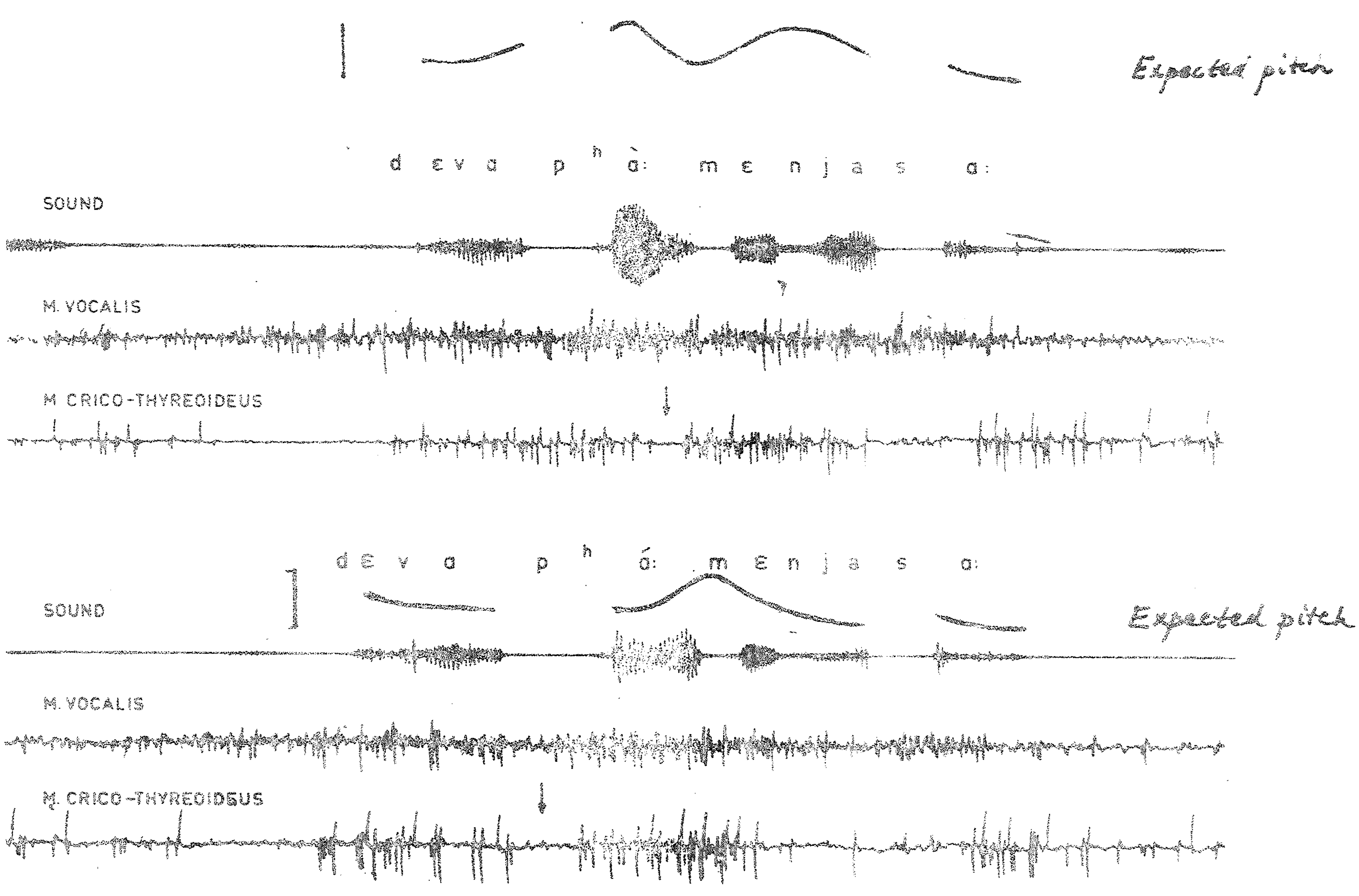


Figure 2. Expected fundamental frequency curves have been added.

Fig. II-C-1. **Examples of vocalis and crico-thyroid motor unit activity during the production of acute and grave accented words.** The crico-thyroid inhibition phase related in the oscillogram for the occlusion of the p of the acute word is longer than normal and certainly quite a bit longer than the occlusion for the corresponding p above in the grave accented word.

This experiment is the only attempt that Öhman has made so far to give a physiological basis to his theory.

In the following I shall discuss some results of an EMG investigation parallel to Öhman's. On the basis of our EMG data I shall propose an analysis of word tones in terms of positive pulses only. This analysis is well supported by the EMG data. It also fits the word tone data collected by Meyer.

My analysis may also be used to sketch the development of word tones in Scandinavian dialects from a common origin. I shall come back to this in another context.

3. EMG study (Gårding, Fujimura, Hirose, 1970)

Subjects

The two subjects are E (female) representing the Skåne dialect and L (male) speaking a dialect in which the word tones are manifested much the same as in the Stockholm dialect. His dialect may perhaps be descrited as Standard Middle Swedish.

Test material

Our test material consists of some 20 sentences with the two word tones in varying phonetic contest. The test words were put in neutral frames and the sentences were read with and without emphasis in a rising-falling sentence intonation. A typical test sentence is de va pamen ja se, i.e. it was pamen I said. The nonsense sequence pamen was given the acute and the grave accents respectively. A few items had glottal stops and a couple of sentences were whispered. Each test sentence was read fifteen times serially. So far only part of the material has been processed.

Muscles

Since the experiment was a parallel to Öhman's, it was natural to choose the same muscles: the vocalis and the cricothyroid. In addition the sternohyoid was selected. This muscle has been shown to be active for pitchlowering in both English and Japanese (Hirano *et al.* 1967 and Ohala *et al.* 1968) and it was expected to have a similar function in Swedish.

EMG equipment

Figure 3 shows the EMG equipment. The electrodes are bipolar and consist of thin wire threaded through the cannula of a hypodermic needle. The end of the wire is hooked. When the desired location has been reached the needle is withdrawn leaving the electrode hooked to the muscle. (The experimental procedures are described by Hirose *et al.*, 1970.)

The mucosa of the larynx is given a light anesthesia before the electrodes are inserted through the neck. The insertion is almost painless. Once the electrodes have been fixed in the right position the subject can talk in a natural voice without feeling their presence. After the session the wire is removed by a light tug.

The electromyographic signal was amplified by a DC preamplifier designed for EMG. It was recorded together with the microphone signal on magnetic tape. The recorded signals were fed to a PDP-9 computer through an AD (analogue to data) converter. In this process the EMG signal is sampled every 100 microsec and digitized into 6 bit levels. At first absolute values were taken of the samples and these were then smoothed over a range of 10 msec. (For a better description, see Simada *et al.* 1970.) The smoothed signals for 8-12

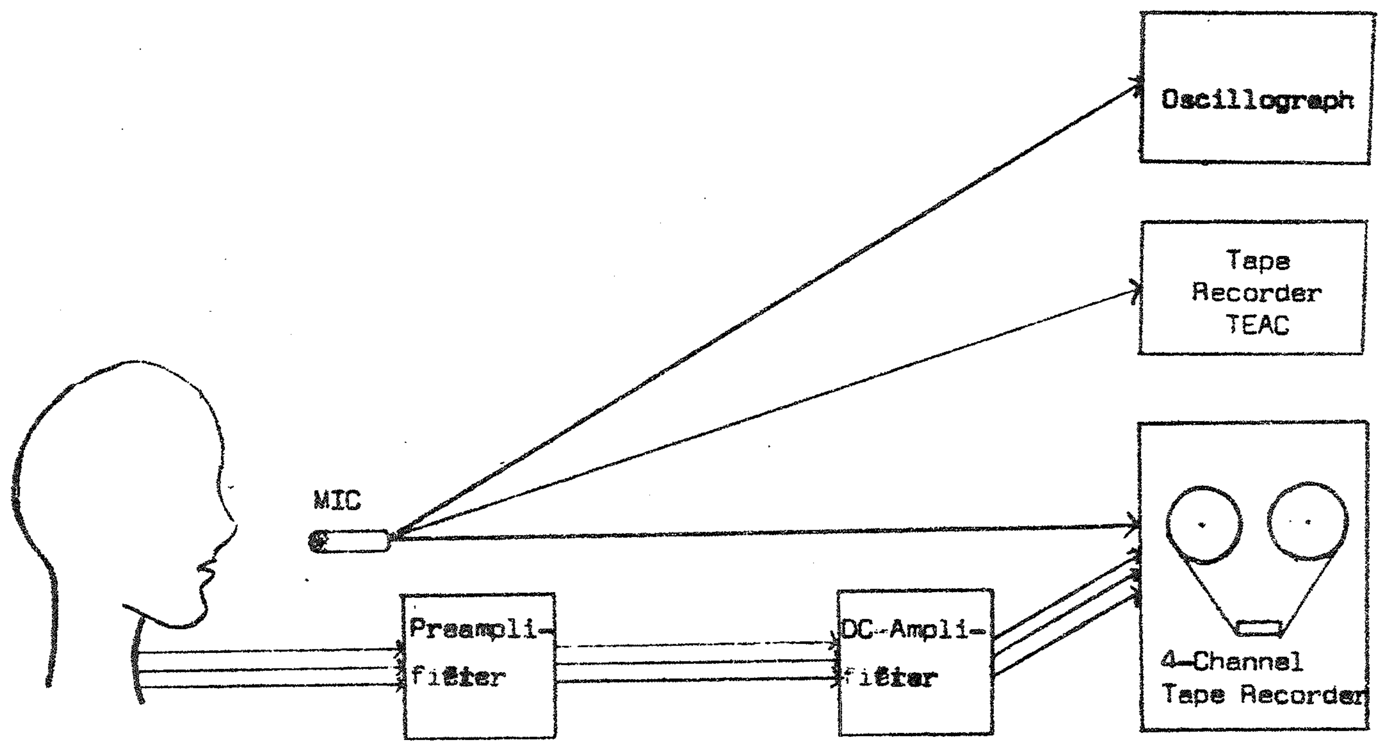


Figure 3. EMG equipment

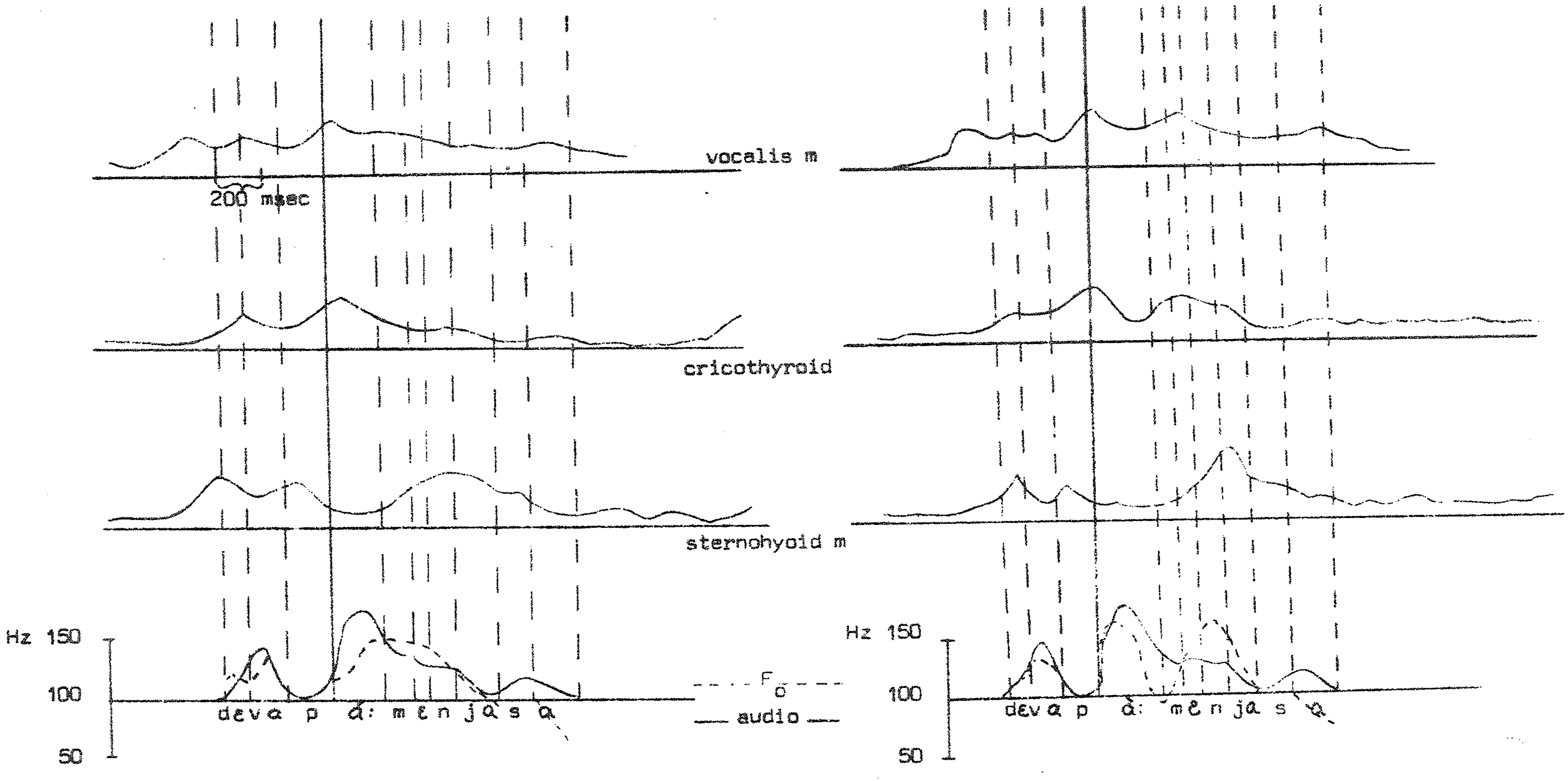


Figure 4. Speaker L. The EMG and Audio signals represent 12 rectified averaged and smoothed utterances. The F_o curve (dotted line superimposed on the audiosignal) is from one representative utterance.

ing the larynx back to its rest position after having been lowered for the low-pitched end of the frame? Or is it an effect of the inspiration? Buchthal (1959) thought that an increase of activity in this muscle during inspiration might serve to steady the vocal cords and prevent them from flapping during the influx of air.

The cricothyroid and the fundamental frequency curves are very similar. Every peak in F_0 has a corresponding peak in the cricothyroid curve. This confirms what is well known from a number of earlier investigations: the cricothyroid muscle is the main pitch controller. The articulatory gestures have little or no effect on this muscle.

The sternohyoid has peaks when the jaw opens for the most open and the most stressed vowels.

Figure 5 brings out the contrast between the acute and the grave accents, pá:mɛn, pàmɛn in 5 a and mámma, màmma in 5 b. The vowel segments of the acute words are marked by thick lines along the base line and the vertical lines show the borders of these segments. The corresponding lines for the vowel segments in the grave accented words have been left unmarked to avoid cluttering up the figure. They would in each case precede the existing lines by a few millimeters.

The most important difference between the word tones in the vocalis and cricothyroid behavior is two peaks for the grave accent compared to one for the acute, that is in principal the same difference as we find in the resulting fundamental frequency curves. The first peaks connected with the grave accent occur a little earlier than the acute peaks. The sternohyoid activity obviously is of no importance for the word tone contrast. The audio signal is similar for the two accents and refutes the traditional view of the grave accented words as having different energy distributions from the acute ones.

At the top of the figure Öhman's pulses have been inserted at the place on

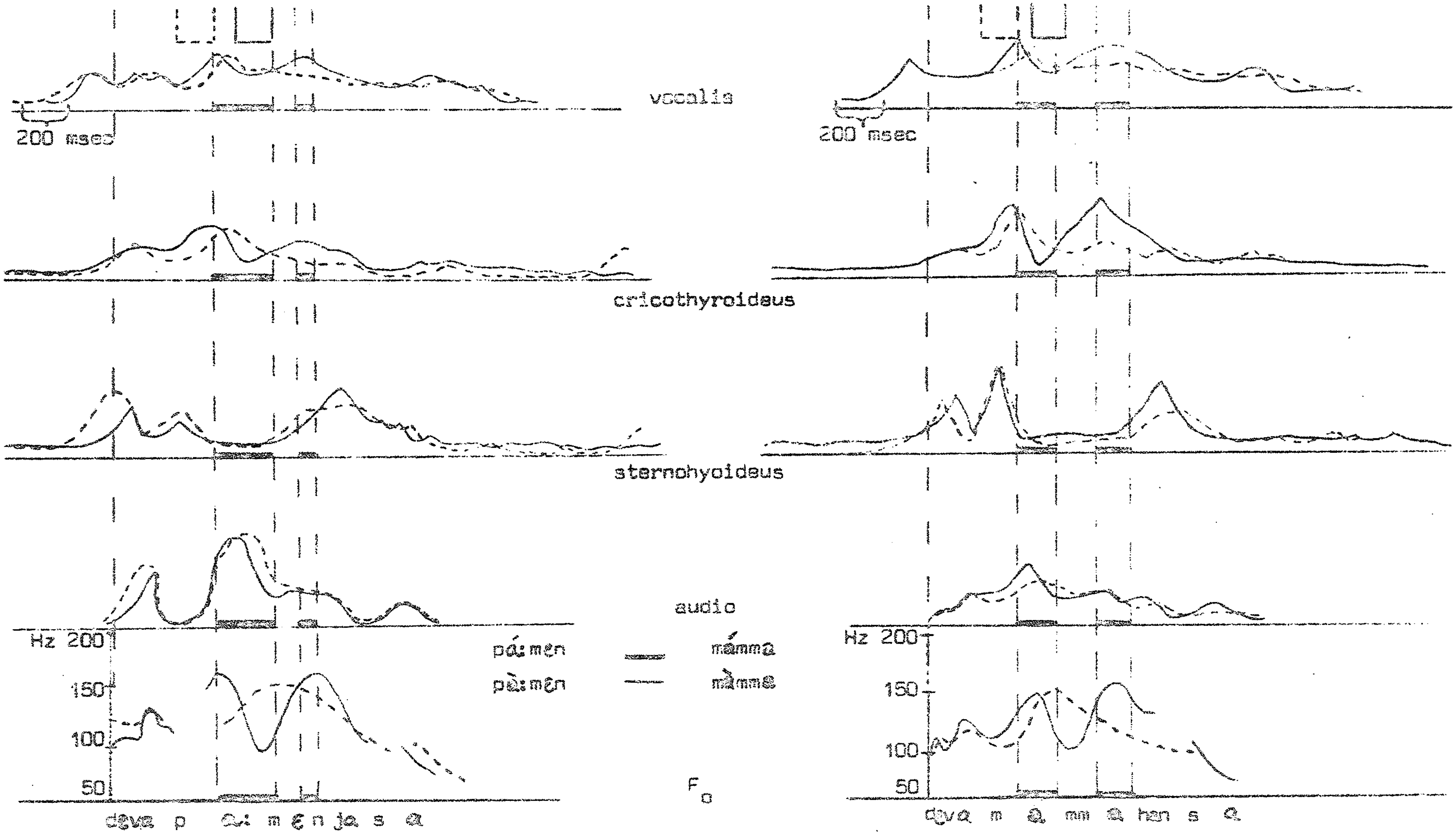


Figure 5. Speaker L. Rectified averaged and smoothed signals from two pairs of test sentences with contrastive wordtone. Tracings from utterances with the acute accent have dotted lines, the grave accent utterances have straight lines.
5 a: pá:mɛn, pà:mɛn
5 b: mámma, màmma.
Vowel segments of the acute words are marked by thick lines along the base line. Vertical lines show borders of these segments.
Öhmans pulses are inserted at the top of the figure at the place in time postulated for this dialect. Dotted pulse is the pulse of the acute accent, straight lined pulse is used for the grave accent pulse.

the time scale where they have been postulated for this dialect: early for the acute (dotted line) and late in the first syllable for the grave (straight line).

To support his theory the vocalis -- as an adductor -- would have to be active during the pulse whereas the cricothyroid - as a tensor - would have to be inhibited. The most convincing argument against Öhman's pulse theory in these records is that the vocalis and cricothyroid muscles work together.

Both muscles contract for the pitch peaks and they reduce their activity for the pitch fall in the accented words as well as for the lowpitched end of the frame.

There is - in these data - no resemblance between the muscle activity controlling word tones and the activity needed for the production of a stød or a glottal stop.

The utterances behind Figure 6 contain what can be regarded as extreme cases of glottal stops. On the whole these utterances need a maximal use of laryngeal control because they have, apart from a glottal stop between the two syllables, the grave accent and emphatic stress.

The utterances represented in these tracings are to the left [jàʔa] and to the right [nɛ̀:ʔɛ] pronounced by Speaker E in the Skåne dialect. The most striking feature in these tracings is perhaps that when the vocalis is active for the glottal stop, that is the closure of the glottis, the cricothyroid is completely relaxed.

What is the mechanism behind the opposed activity in the vocalis and cricothyroid muscles in this kind of glottal stop? Are these muscles opposed for adduction in general and working together for pitch control i.e. tensing? The data obtained so far speak in favour of such an interpretation. Notice again the pronounced peak in the vocalis muscle with a corresponding valley in the cricothyroid before the beginning of phonation. This event is similar

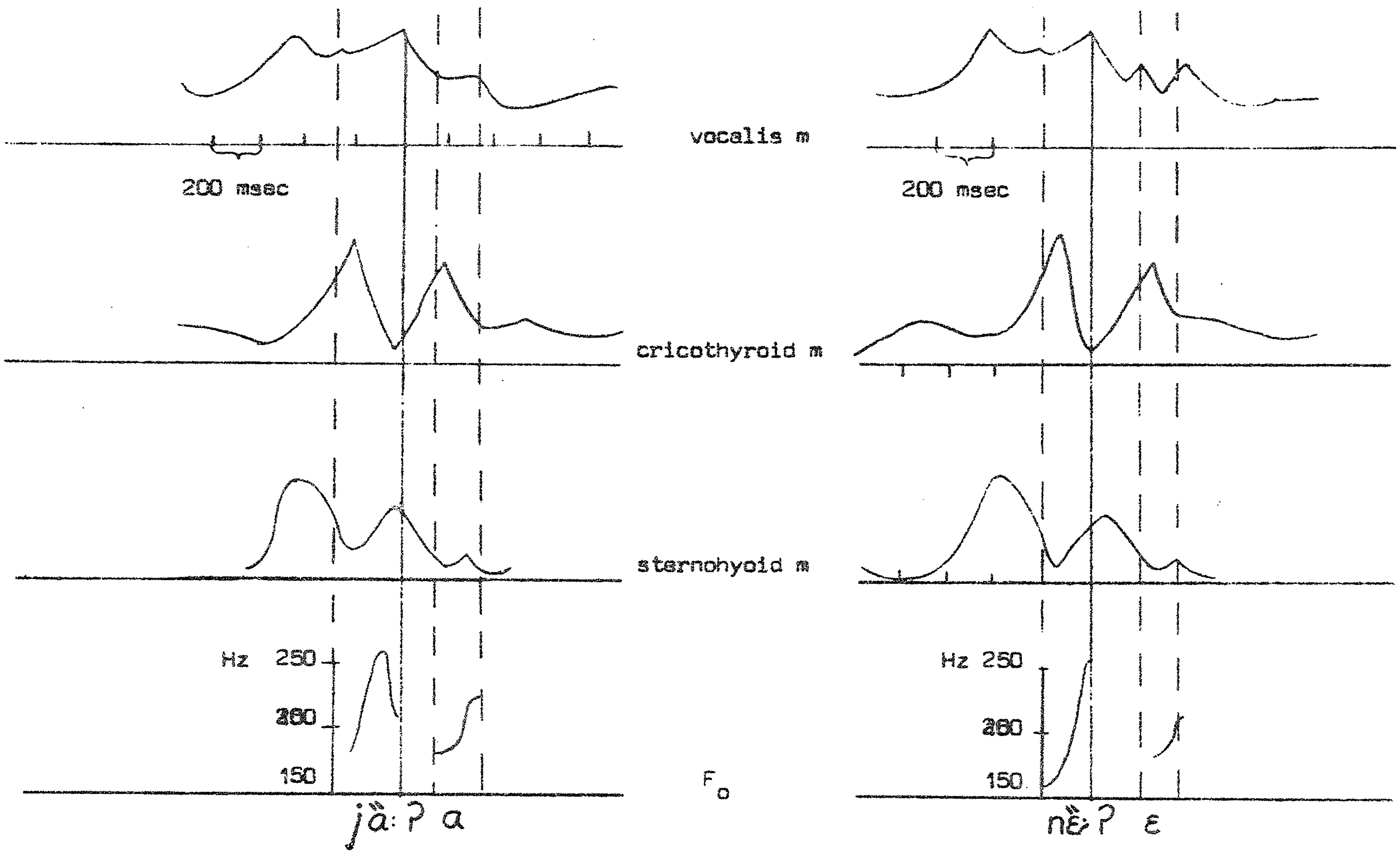


Figure 6. Speaker E. The signals represent 8 rectified, averaged and smoothed utterances of the test sentences [jȁ:ʔa] to the left and [nȅʔɛ] to the right. They are emphatic renderings of the words ja and nä (yes and no). The double grave accent symbols stand for the emphatic grave accent.

to the muscle activity for the glottal stop and may very well be a related adductory gesture.

In the corresponding test sentences for Speaker L, the glottal stop in most of the utterances is pronounced in a different way: no burst can be heard at the beginning of the second vowel. In the EMG tracings this performance of the glottal stop is parallelled by a less pronounced dip in the cricothyroid curve. It seems that the degree of relaxation in the cricothyroid is dependent on the degree of tension in the vocalis muscle.

Figure 7 presents some more data from Speaker E. You notice the typical Skåne accent patterns in the fundamental frequency curve: The acute accent is manifested by a rise and fall in the stressed syllable and the grave accent by a rise. As can be expected, this difference from Speaker L is accompanied by a difference in the EMG tracings.

The vocalis and cricothyroid muscles do not follow each other as closely as they did in Speaker L. They do have similar main peaks but the vocalis, apart from a deep valley for the occlusion of p, has a number of smaller dips that can be related to the other consonants. (Notice the opposed activity in the vocalis and cricothyroid muscles before the beginning of the audio signal.) The main peaks of the cricothyroid muscle coincide with peaks in the fundamental frequency curve.

The sternohyoid muscle has peaks when the jaw opens for the syllables. The highest peak is connected with the finishing syllable sa. This may be an indication of the extra activity needed to bring down the larynx in the appropriate position for the relaxed vocal cords needed for the low tone of the end of the frame.

Figure 8 shows the contrast between the acute and grave accents in Speaker E. Dotted lines represent the acute accent and the grave accent is marked by straight lines. Öhman's pulse is added as before. The difference between the

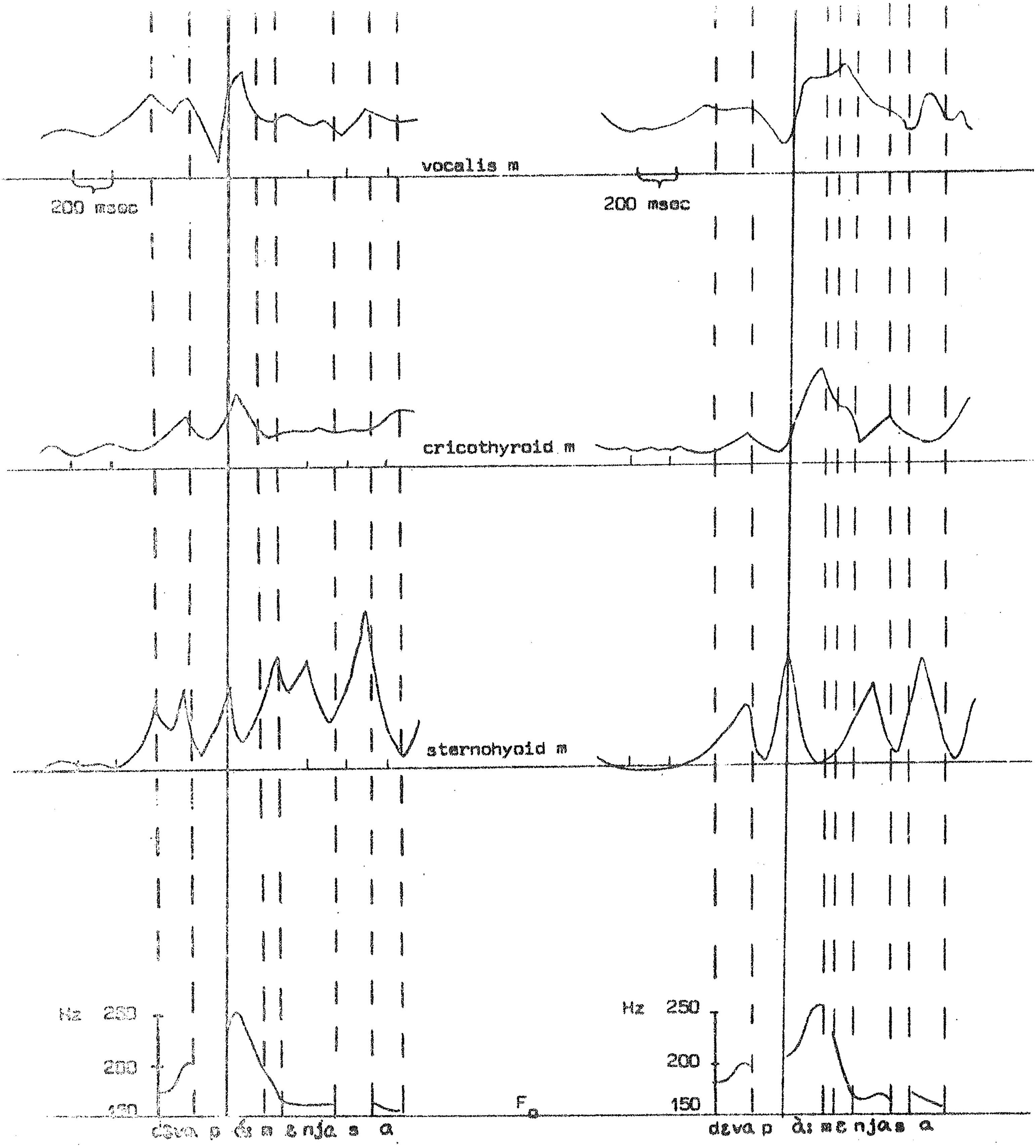


Figure 7. Speaker E. Arrangement of signals as in Figure 5.

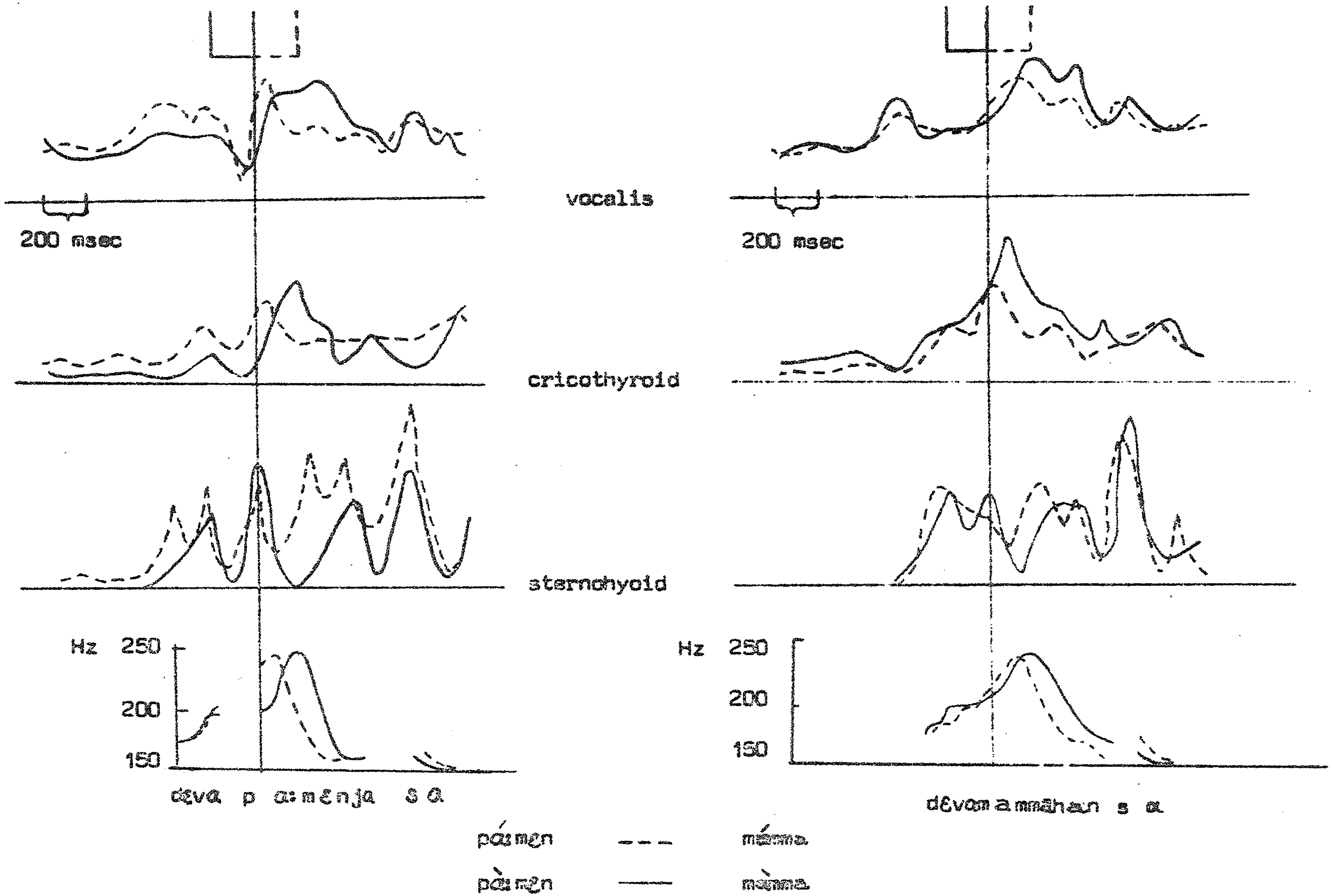


Figure 8. Speaker E. Word tone contrasts in pamen to the left and mamma to the right. Arrangement of signals as in Figure 5. The pulses have been added at the place in time postulated for this dialect, i.e. early for the grave (straight lines) and late for the acute (dotted lines).

word tones as they appear in these records is an early peak in the fundamental frequency, the vocalis and the cricothyroid curves for the acute accent as opposed to a later and plateau-formed obtrusion for the grave accent. According to the theory we should expect to find increased activity in the vocalis concomitant with reduced activity in the cricothyroid. As can be seen in the figure the muscles do not behave in this way. In three cases out of four the vocalis and the cricothyroid muscles cooperate. Only in mámma (acute) is there for a short period during the pulse opposed activity in the two muscles.

To sum up, our data do not provide any physiological basis for Öhman's negative pulse.

4. Discussion

Öhman was of course well aware that his EMG results were inconclusive, but he suggests that if the EMG investigation included other laryngeal muscles as well the pitch inhibiting muscle would perhaps be discovered.

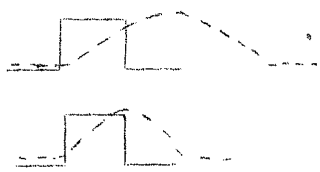
Is there any physiological justification for such a view?

It appears from the discussion on p.29 (op.cit.) that Öhman expects muscular activity for the word tone to be "ballistic" in nature just as Smith – using Stetson's terminology – regarded the stød as a ballistic stroke (Smith, 1944 b, p. 3). A typical innervation pattern behind such a movement would be an activation of an agonist muscle combined with a complete inhibition of its antagonist (reciprocal inhibition). In the EMG records from the test words pronounced with glottal stops (Figure 6) the opposed activity in the vocalis and the cricothyroid may perhaps be due to what is called reciprocal inhibition. But there is no similar effect in the data that can be associated with the word tones. Since there is no activity in the vocalis during the word tone pulses, Öhman's interpretation of the acute and grave accents as some kind of glottal stops is not very convincing.

5. Word tones and positive pulses

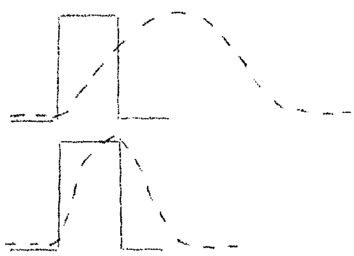
In the light of our data it seems natural to simulate word tones by one or two possitive pulses. To fit an actual fundamental frequency curve, these pulses must have appropriate amplitudes, onset times and durations and they must be exposed to a suitable smoothing procedure. I shall give a few examples of what can be achieved by such a process:

same pulse, different degrees of smoothing



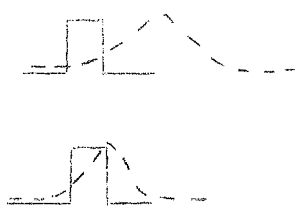
slow smoothing
fast "

pulse with high amplitude and different degrees of smoothing



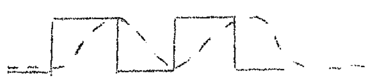
slow smoothing
fast "

pulse with short duration and different degrees of smoothing



slow smoothing
fast "

two pulses fast smoothing

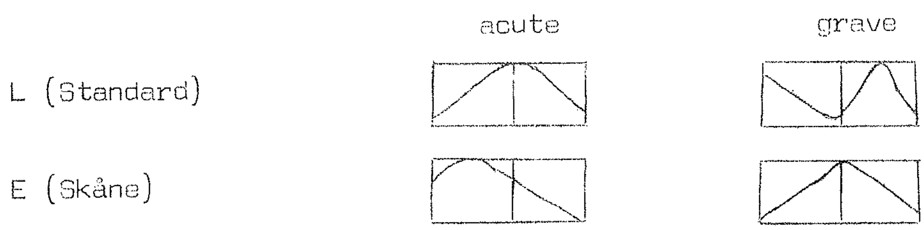


It seems clear that with one or two positive pulses we can simulate any pitch pattern implied by the word tones.[1] Actually in my examples above I may have more parameters than I need but we may safely say that a pitch curve with one peak corresponds to a step function with one pulse (or perhaps two very close pulses) and a pitch curve with two peaks corresponds to a step function with two pulses.

From now on we shall consider curves that are similar in shape to the obtrusions caused by the pulses in my examples as the output of positive step functions that I shall call positive pulses.

We have found earlier that the EMG curve derived from the cricothyroid muscle has about the same shape as F_0 with a time delay typical of an acoustic signal compared to a physiological one. The similarity between the F_0 and the cricothyroid curves makes it possible to interpret obtrusions in the fundamental frequency curve as the visible representatives of positive pulses.

Let us now go back to the word tones in the dialects of my speakers and interpret them as positive pulses.



The pitch curves have been stylized in the manner of Meyer with one square for each of the two syllables.

In terms of positive pulses the difference between the acute and grave accents in Speaker L is one pulse for the acute and two for the grave, whereas

---

1 According to Lars Gårding it is an established mathematical fact that any smooth curve can be simulated by a step curve provided that the step curve is subjected to a smoothing process with fixed parameters.

E has an early pulse in the acute as compared to a late pulse in the grave accent.

6. Interpretation of Meyer's data

If we interpret Meyer's data in the same manner (Figure 1) we shall find that there are mainly two types of dialects: dialects that like Skåne are characterized by an early pulse and a late pulse in the acute and grave accents respectively, and dialects that like Speaker L's have a late pulse in the acute and two pulses in the grave accent.

There is another striking feature about Meyer's curves: whatever the shape of the acute pitch curve the latter part of the grave curve is similar to it.

I can say with a certain amount of truthfulness: Give me your acute accent and I'll tell you what your grave is like. To perform this trick I do as follows: I squeeze in the acute accent in the latter part of the grave word. Then I extrapolate the curve to the earlier part of the word. Naturally a certain experience is needed to do it in the right way. I have to keep within a certain pitch range and I must follow a certain rule. The rule is that an early pulse in the acute accent brings on a late pulse in the grave one whereas a late pulse in the acute accent gives two pulses in the grave accent. Now we must ask: What is the linguistic implication of this procedure? I think it implies that in the acute accent we do not have a real word tone, only a sentence intonation pulse and it is this sentence intonation pulse that recurs in the second syllable of the grave accent.

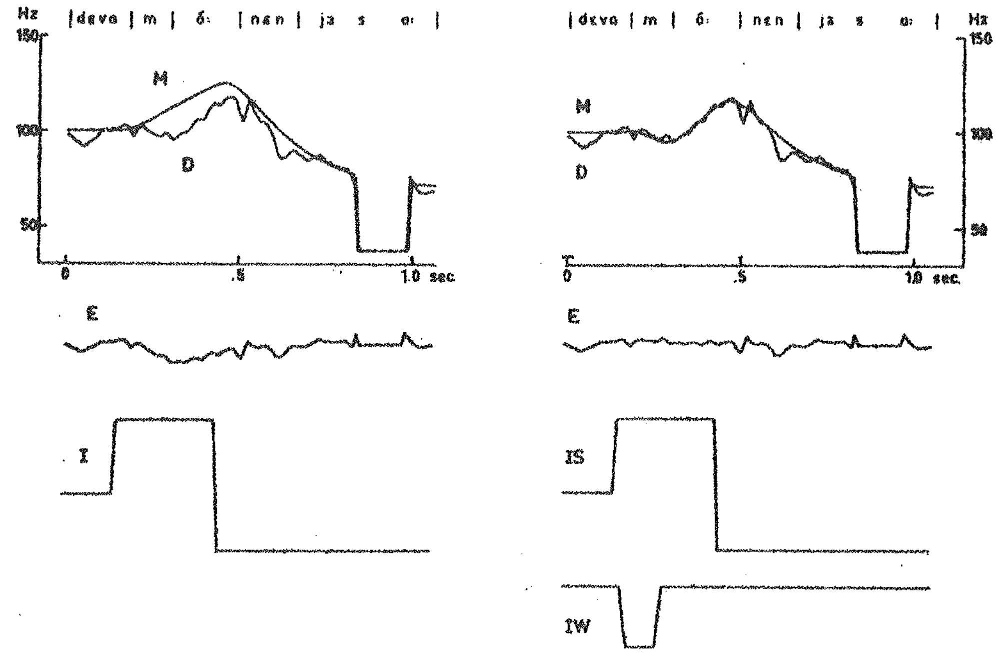
The idea that only the grave accent is a real word tone and the acute merely the manifestation of stress is not a new one. It was put forward in general terms by Henry Sweet as early as 1878. A similar position was taken by

Trubetzkoy (1939) who regarded the opposition between the two accents as a privative one, that is, one member of the opposition - the grave accent - is marked by a feature that is lacking in the other - the acute accent. Several other scholars have discussed the problem from various angles and have arrived at the same conclusion (Haugen & Joos 1956, 1962, Haugen 1963, 1967a, Malmberg and Elert 1963, Rischel 1963. For a summary of the discussion see Elert 1970).

According to this general analysis, Swedish intonation should be decomposable into sentence intonation and word intonation for the grave accent only. Öhman's model does not satisfy this requirement since he uses a negative pulse for both accents.

His use of negative pulses is open to many objections. We have seen earlier that it has no immediate physiological basis. It can be criticized also on other grounds. In the Stockholm acute accent, Figure 9 (Öhman, op. cit. Figure II-B-4), a negative pulse is superimposed on a sentence intonation step in order to produce a rather small dip in the pitch curve which may very well be caused by the oral closure for the initial consonant, in this case m. A look at the more schematic Figure 10 (Öhman op. cit. Figure II-B-8) reveals that, apart from minor effects, the main function of the negative pulse in Stockholm acute and Malmö grave is to delay the sentence intonation step. In view of these and earlier observations it seems more natural to assume that there is in Swedish just one tone, the grave accent. This word tone is manifested in all the dialects as a delayed sentence intonation pulse which in some dialects (for instance Stockholm but not Malmö) is preceded by an additional positive pulse.

ACUTE ACCENT: STOCKHOLM



GRAVE ACCENT: STOCKHOLM

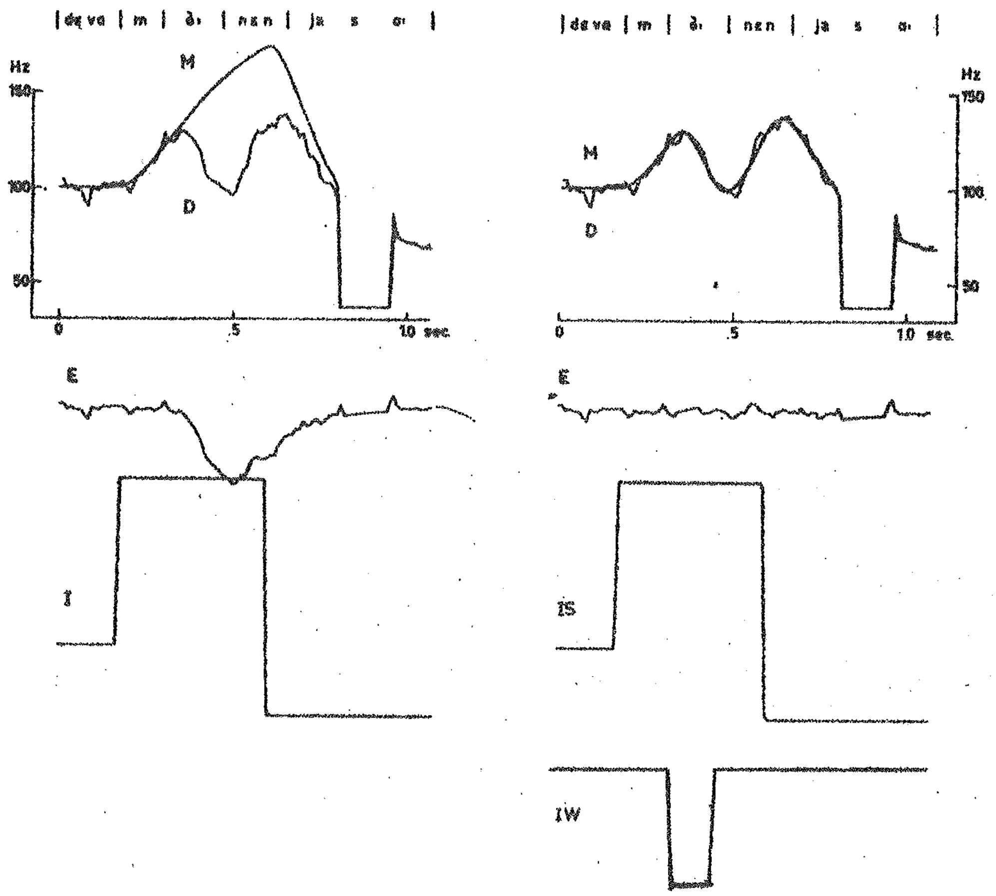


Figure 9.

Fig. II-B-4. Comparison of Stockholm accent patterns with curves calculated by means of intonation model. The pulses marked I, IS, and IW represent model outputs with the same input commands that were used to match the empirical data but with the model constants α and β both set to 1000.

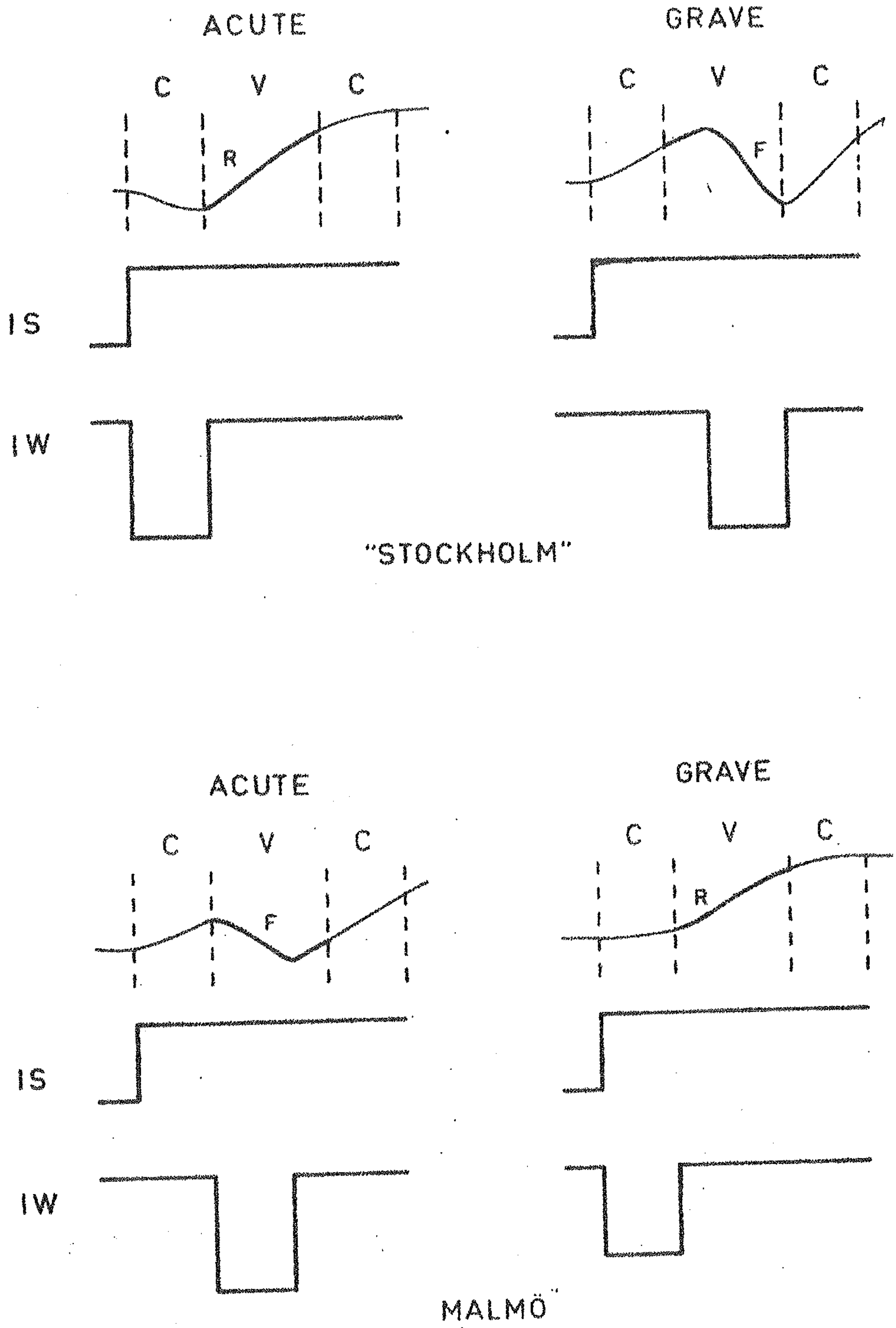


Figure 10.

Fig. II-B-8. Input commands suitable for Stockholm and Malmö accents. The pitch contour has been drawn with thick lines in the vowel segments.

7. Word tones and stress correlates

The dictionary of the Academy marks the accent contrast with numbers that indicates the difference in stress patterns that was supposed to be an invariable characteristic of these words quite independent of the dialectal variation in pitch. The acute accent is marked 4-0, and the grave 3-2, for example $\overset{4}{\text{an}}\overset{0}{\text{den}}$, $\overset{3}{\text{an}}\overset{2}{\text{den}}$. This marking system was introduced well before the time of acoustic measurements. Later, when such measurements could be made it was at first somewhat surprising that no consistent difference in the energy output of the acute and grave accented words could be found.[1]

Today it is well known that subjective impressions of stress are related to the total speech effort and only partly determined by the energy of the speech wave.[2] Increased pulmonary effort in connection with stressed syllables was demonstrated in EMG recordings by Ladefoged, Draper, and Whitteridge (1958), increased laryngeal effort is evident from Ohala's EMG work (Ohala 1970) and Harris and co-workers (Harris *et al*. 1968) showed that increased activity in some articulatory muscles is a constant correlate to stressed syllables.

Our EMG data may to a certain extent explain the difference in subjective stress attributed to the two accent patterns. Look again at Figures 5 and 8. For both speakers - notwithstanding the dialectal difference in their pitch curves - the second syllable of the grave words coincides with more activity in the vocalis and cricothyroid muscles than the corresponding syllable of the acute words. The second syllable of the grave accented words then seems to require a greater effort from these muscles.

---

1 In additional data, that I have received later, the averaged audio signals from Speaker E have a higher amplitude in the second syllable of the grave accented words than in the acute ones.

2 For a clarifying survey of the concept of stress and its acoustic and physiological correlates, see Lehiste, 1970.

The subjectively felt difference in stress connected with the acute and grave accents is perhaps a reflex of the difference in laryngeal activity that may be common to most dialects.

Acknowledgement

I wish to thank the Institute of Logopedics and Phoniatrics, Tokyo, for inspiring interest, skilful cooperation and generous help.

References

Arnold, G.E., Physiology and pathology of the cricothyroid muscle, Laryngoscope 71, pp. 687-753, 1961

Buchthal, F., Electromyography of intrinsic laryngeal muscles, Quaterly Journal of Experimental Physiology, Vol. XLIV, 1959

Buchthal, F. and Faaborg-Andersen, K., Electromyography of Laryngeal and Respiratory Muscles, Annals of Otology, Rhinology and Laryngology, Vol. 73, 1964

Elert, C.-C., Ljud och ord i svenskan, Stockholm, 1970

Elert, C.-C., Phonologic Studies of Quantity in Swedish, Stockholm, 1964

Faaborg-Andersen, K., Electromyographic investigation of intrinsic laryngeal muscles in humans, Copenhagen, 1957

Faaborg-Andersen, K., Electromyography of Laryngeal Muscles in Humans. Technics and Results, New York, 1965

Gårding, E., Fujimura, O., and Hirose, H., Laryngeal control of word tones, Annual Bulletin, No. 4. Research Institute of Logopedics and Phoniatrics. University of Tokyo, 1970

Harris, S., Gay, T., Sholes, G.N., and Lieberman, P., Some Stress Effects on Electromyographic Measures of Consonant Articulations, Haskins Laboratories, SR 13/14, pp. 137-151, 1968

Haugen. E. and Joos, M., Tone and intonation in East Norwegian, Acta Philologica Scandinavica 22, pp. 41-64, 1952

Haugen, E., On the rules of Norwegian tonality, Language 43, pp. 185-202, 1967

Hirano, M., Koike, , and von Leden, , The Sternohyoid Muscle during Phonation, Acta Oto-Laryngologica 64, pp. 500-507, 1967

Hirose, H., Forthcoming report. Annual Bulletin. No. 4. Research Institute of Logopedics and Phoniatrics. University of Tokyo, 1970

Ladefoged, P., Draper, M.H., and Whitteridge, D., Syllables and Stress, Miscellanea Phonetica 3, pp. 1-14, 1958

Lehiste, I., Suprasegmentals, Cambridge, Mass and London, 1970

Malmberg, B., Analyse instrumentale et structurale des faits d´ac ents. Proceedings of the Fourth International Congress of Phonetic Sciences, pp. 456-475, 1962

Meyer, E.A., Die Intonation im Schwedischen, Teil I, Stockholm, 1937

Meyer, E.A., Die Intonation im Schwedischen, Teil II, Stockholm, 1954

Ohala, J.J., Aspects of the control and preduction of speech, Working papers in phonetics 15, Los Angeles, 1970

Ohala, J.J., Hirano, M., and Vennard, W., An electromyographic study of laryngeal activity in speech and singing, Report of the 6th International Congress on Acoustics, B-1-2, Tokyo, 1968

Ohala, J.J. and Hirose, H., An electromyographic study of laryngeal activity in speech and singing, Fall meeting, Acoust. Soc. Japan, 1969

Rischel, J., Morphemic tone and word tone in Eastern Norwegian. Phonetica 10, pp. 154-164, 1963

Smith, S., Stødet i dansk rigssprog, København, 1944 a

Smith, S., The Danish Stød, Summary and curves, Copenhagen, 1944 b

Sonesson, B., The functional anatomy of the speech organs, Manual of Phonetics, ed. Malmberg, pp. 45-75, 1968

Simada et al., Forthcoming report. Annual Bulletin. No. 4. Research Institute of Logopedics and Phoniatrics. University of Tokyo, 1970

Sweet, H., Sounds and forms of spoken Swedish, Transactions of the Philological Society, pp. 478-543, 1878

Wessén, E., Svensk språkhistoria, Lund, 1968

Öhman, S.E.G., Word and sentence intonation: a quantitative model. Speech Transmission Laboratory, QPSR, 2-3, pp. 20-54, 1967 a

Öhman, S.E.G., Mårtensson, A., Leanderson, R., and Persson, A., Cricothyroid and vocalis muscle activity in the production of Swedish tonal accents: a pilot study, Speech Transmission Laboratory, QPSR, 2-3, pp. 55-57, 1967 b.