THE INTRINSIC FUNDAMENTAL FREQUENCY OF VOWELS AND THE ACTIVITY IN THE CRICOTHYROID MUSCLE

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ABSTRACT

The relationship between EMG activity from the CT muscle and IF_0 of Danish vowels was investigated. The results show a positive correlation: The CT activity rise in a vowel with a higher IF_0 starts earlier and has a higher overall amplitude than in a vowel with a lower IF_0. A subset of data was compared to data from an identical material recorded earlier from the same subjects. Both sets show the positive correlation described above. The following conclusions are drawn: The CT muscle is an important factor in controlling IF_0, and the reproducability of EMG data is high.

1. INTRODUCTION

It is well known that the fundamental frequency (F_0) of vowels is correlated with vowel quality: other things being equal, high vowels tend to have a higher F_0 than low vowels. This phenomenon, which is known as intrinsic fundamental frequency (IF_0), has been reported in numerous investigations. Various theories have been advanced to explain IF_0; for a detailed survey see Silverman [6]. The generally accepted theory is based on the assumption that an increased tongue pull during the articulation of high vowels may give rise to an increased vertical tension in the vocal folds, Ohala [3].

Most theories have explained IF_0 as a passive influence from articulation. Very recent data, however, point in the direction of a nervous control, more specifically that the cricothyroid (CT) muscle seems to be an important factor in the control of IF_0. Honda [2] and Vilkman et al. [7] found a positive correlation between peak values of CT activity and IF_0. Dyhr [1] observed an earlier and steeper CT activity rise in high vowels than in low vowels. It was impossible to determine whether the CT activity was the result of a synergistic relationship between CT and other muscles, or whether it was a planned control of IF_0.

The purpose of the present investigation is: 1) To look into the relationship between CT activity and IF_0 in a large set of Danish vowels, in both stressed and unstressed positions. 2) To compare a subset of data to data from an identical material recorded at an earlier session.

2. METHODS

2.1 Subjects and Material

The subjects were one female and four males, all phoneticians and native speakers of Danish.

The material consisted of the following Danish vowels: [i e ɛ u o ɔ ɑ] inserted in nonsense words of the type fVfVf'V, with identical vowels in each syllable, and [i: æ: u:] inserted in natural words of the type C'V:lə. The test words were embedded in carrier sentences and were read in four different randomizations.

2.2 Recordings

The electromyographic (EMG) recordings took place at the Dept. of Clinical Neurophysiology, Copenhagen University Hospital, Denmark, using Disa Electromedical Equipment. The EMG signals were collected from pars recta of the CT muscle, via concentric bipolar needle electrodes (Dantec Electronics, type 13L51, 20 mm). The insertion was performed by Dr. S. Fex, Lund University Hospital, Sweden, and was made percutaneously. The correct electrode position was controlled by a series of tests such as swallowing, high/low and gliding tones, and glottal closure. The acoustic signal was registered by an accelerometer (Brüel & Kjær, type 4375), taped directly to the skin above the larynx. The EMG and acoustic signals were recorded on an FM tape recorder, 30 ips. The recordings were monitored continuously via an oscilloscope.

2.3 Data Analysis

The EMG signals were rectified and integrated, with an integration time of 25 ms. The filtering was done in accordance with the results from Rischel & Hutters [5]. The F_0 analysis was carried out on an F-J. Electronics Fundamental Frequency Meter. Physiological and acoustic signals were sampled and averaged. Data were sampled through an eight-channel multiplexed analog-to-digital converter controlled by a real time clock. The sampling took place with a 1.25 sec. window at a sampling frequency of 200 Hz. Data and results were displayed on a graphic terminal.

3. RESULTS

The results are based on visual inspection of average EMG and F_0 curves. The average is based on at least six repetitions. The individual curves were carefully examined before averaging, and none of them were in disagreement with the final results shown in the average curves.

In order to correlate a muscle action with the resultant effect the muscle activity must be shifted forward in time compared to the actual event. This is because it takes some time for the muscle to contract after being innervated, primarily due to electrochemical transmission and inertia. In the present data this so-called time lag was measured from the EMG activity peak to the corresponding F_0 peak on the individual curves before averaging. The time lag varied between 60-110 ms. In the following description and discussion compensation has been made for this time lag.

3.1 IF_0

For all subjects there is a correlation between vowel height and IF_0, such that a higher vowel has a higher IF_0 than a lower vowel. This difference is most prominent among stressed vowels and least prominent among vowels in second pretonic position. The order of the vowels from high to low IF_0 is identical to data reported earlier for Danish, Reinholt Petersen [4]. In stressed position two subjects have [u] clearly higher than [i], whereas the rest of the subjects hardly have any difference between the two.

3.2 CT Muscle Activity

Two subjects show a positive correlation between CT activity and IF_0 for each step in vowel height in both stressed and unstressed vowels. Two subjects have the same results in stressed vowels, but for the unstressed vowels there is a positive correlation only between high and low vowels. The fifth subject shows a positive correlation in stressed vowels only, and only when the vowels are separated by two or more steps in vowel height. The observed IF_0 difference between [i] and [u] is clearly reflected in the CT activity. The general picture is that the CT activity rise related to a vowel with a higher IF_0 starts earlier and has a higher overall amplitude than in a vowel with a lower IF_0, see figure 1.

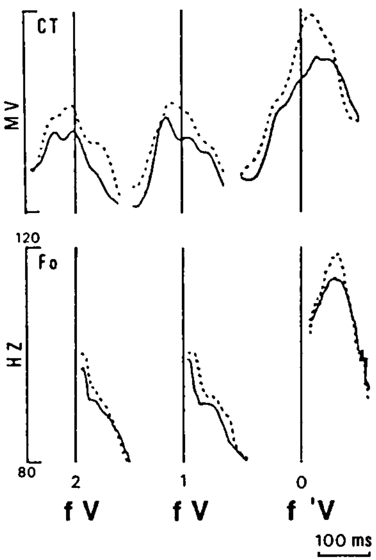

Figure 1. Comparison of extracts from superimposed average CT and F_0 curves from sentences containing the nonsense words [fifif'i] (broken lines) and [fefef'e] (solid lines) from the same subject. The line-up points (2,1,0) are the onset of the second pretonic (2), the first pretonic (1), and the stressed vowel (0). Notice that the IF_0 differences between [i] [e] are reflected in the CT curves in such a way that the CT activity rises earlier and has a higher overall amplitude in [i] than in [e].

Data from [i: æ: u:] are compared to data from an identical material recorded at an earlier session by the same subjects, Dyhr [1]. However, the EMG activity was then recorded from the pars obliqua of the CT muscle by means of bipolar hooked-wire electrodes. Both sets of data show the positive correlation between CT activity and IF_0 described above, see figure 2.

4 DISCUSSION

The results indicate that the CT muscle plays an important part in the control of IF_0 in vowels. Such a control can be explained in two ways: It may be the by-product of a synergistic relationship between the CT muscle and other larynx muscles and/or the muscles responsible for shaping the vocal tract for the different vowels, or it may be a specific, planned control of IF_0. A possible explanation of a planned control could be that IF_0 differences are important to speech perception, Silverman [6]. The results also imply that the pars recta and pars obliqua of the CT muscle are physiologically identical even if they are anatomically separated (at the moment further investigation is being carried out on this matter). Apart from some discomfort while swallowing, the use of bipolar concentric needle electrodes was a success. The insertion and adjustment of electrode position was easy. The fixation of the needle electrodes was surprisingly stable, and the EMG signals were less problematic than the ones collected via hooked-wire electrodes and were consequently less complicated to filtrate. Even with different registration methods the reproducability of the EMG data was high. This implies that EMG is also a reliable tool when applied to tiny muscles as found in the speech apparatus.

5 CONCLUSION

The following conclusions are drawn: 1) The CT muscle is an important factor in controlling the IF_0 in vowels. Whether this is the result of a synergistic relationship between larynx and other muscles or a planned control of IF_0 is impossible to determine from the present data. 2) The

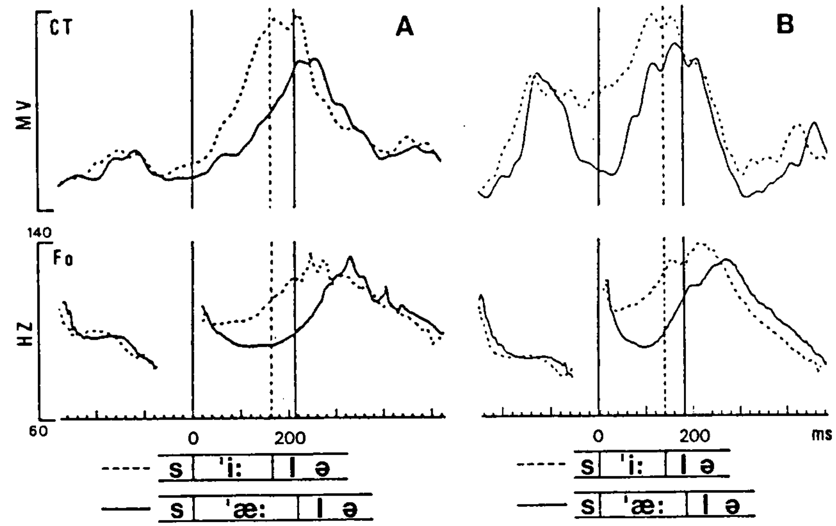

Figure 2. Comparison of superimposed average CT and F_0 curves from sentences containing the natural words [s'i:lə] (broken lines) and [s'æ:lə] (solid lines) from the same subject. The line-up point (0) is the onset of the stressed vowels, the offsets are marked with vertical broken/solid lines. A: The EMG signal is recorded from pars obliqua of the CT muscle via bipolar hooked-wire electrodes. B: The EMG signal is recorded from pars recta of the CT muscle via bipolar concentric needle electrodes. Notice that the IF_0 differences are reflected in the CT curves in such a way that the CT activity rise related to the high vowel starts earlier and has a higher overall amplitude than when related to the low vowel.

reproducability of EMG data is high, even when different registration methods are used.

5. REFERENCES

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