THE INTRINSIC FUNDAMENTAL FREQUENCY OF VOWELS AND THE ACTIVITY IN THE CRICO THYROID MUSCLE

N.-J. Dyhr

Department of General and Applied Linguistics, University of Copenhagen, Denmark.

ABSTRACT

The relationship between EMG activity from the cricothyroid muscle and $F_0$ of Danish vowels was investigated. The results show a positive correlation: The CT activity rise in a vowel with a higher $F_0$ starts earlier and has a higher overall amplitude than in a vowel with a lower $F_0$. 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 $F_0$, and the reproducibility 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, called $h$ [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 $IF_0$. Horta [2] and Vilkkan 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 a o u o:] inserted in nonsense words of the type $\text{feyv}$, with identical vowels in each syllable, and [i a o u:] inserted in natural words of the type $\text{fey}$. 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 parts of the CT muscle, via concentric bipolar needle electrodes (Dantec Electronics, type 131LS, 20 mm). The insertion was performed by Dr. S. Fex, Lund University Hospital, Sweden, and was made percutaneously. The contact 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 (Briel & 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 & Hatters [5]. The $F_0$ analysis was carried out on an F-3 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.

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 the 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 is the most prominent aspect of 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, Reinbold 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 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, called $h$ [3]. Most theories have explained $IF_0$ as a passive influence from articulation.
activity rise related to a vowel with a higher IF0 starts earlier and has a higher overall amplitude than in a vowel with a lower IF0, see figure 1.

4 DISCUSSION
The results indicate that the CT muscle plays an important part in the control of IF0 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 IF0. A possible explanation of a planned control could be that IF0 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 present further investigation is being carried out in 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 hook-wire electrodes and were consequently less complicated to filter. Even with different registration methods the reproducibility 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 IF0 in vowels. Whether this is the result of a synergistic relationship between larynx and other muscles or a planned control of IF0 is impossible to determine from the present data. 2) The reproducibility of EMG data is high, even when different registration methods are used.

5. REFERENCES