The Function of Muscles in Control of Stress and Intonation*

Katherine S. Harris,† Thomas Gay,
Philip Lieberman,†† and George Sholes

Haskins Laboratories, New York City

Recently, there has been a great deal of interest in understanding the physiologic aspects of the control of intonation and prominence in ordinary running speech. As is well known, several different types of linguistic events, such as questions and prominent words, are characteristically accompanied by rises in the accompanying fundamental frequency. We also know, from the work of Ladefoged, van den Berg, Lieberman and others, that there are two possible physiological mechanisms for this rise in frequency. If there is an increase in subglottal pressure, pitch will rise. Alternatively, adjustments of the laryngeal muscles will also cause a rise in frequency. The purpose of this paper is to study laryngeal muscles during some intonational maneuvers in order to better understand the relative contributions of their adjustment.

---

* Paper presented at the American Speech and Hearing Association Meeting, 12 November, 1969.

† Also, City University of New York.

†† Also, University of Connecticut, Storrs.

In the experiment to be described, we studied the laryngeal muscles, by observing their electromyographic behavior. Concentric needle electrodes were inserted in the vocalis, and/or cricothyroid, and the orbicularis oris muscles of four speakers. The speaker read a list of utterances about twenty times each, and the utterances were recorded on magnetic tape. A computer program was then used to average the electromyographic signals for each group of tokens for a given sentence. The details of this procedure have been described in various previous publications.

The subjects spoke a number of sentences of the following four forms:

It is pattering. As a simple statement.

Is it pattering? A simple question.

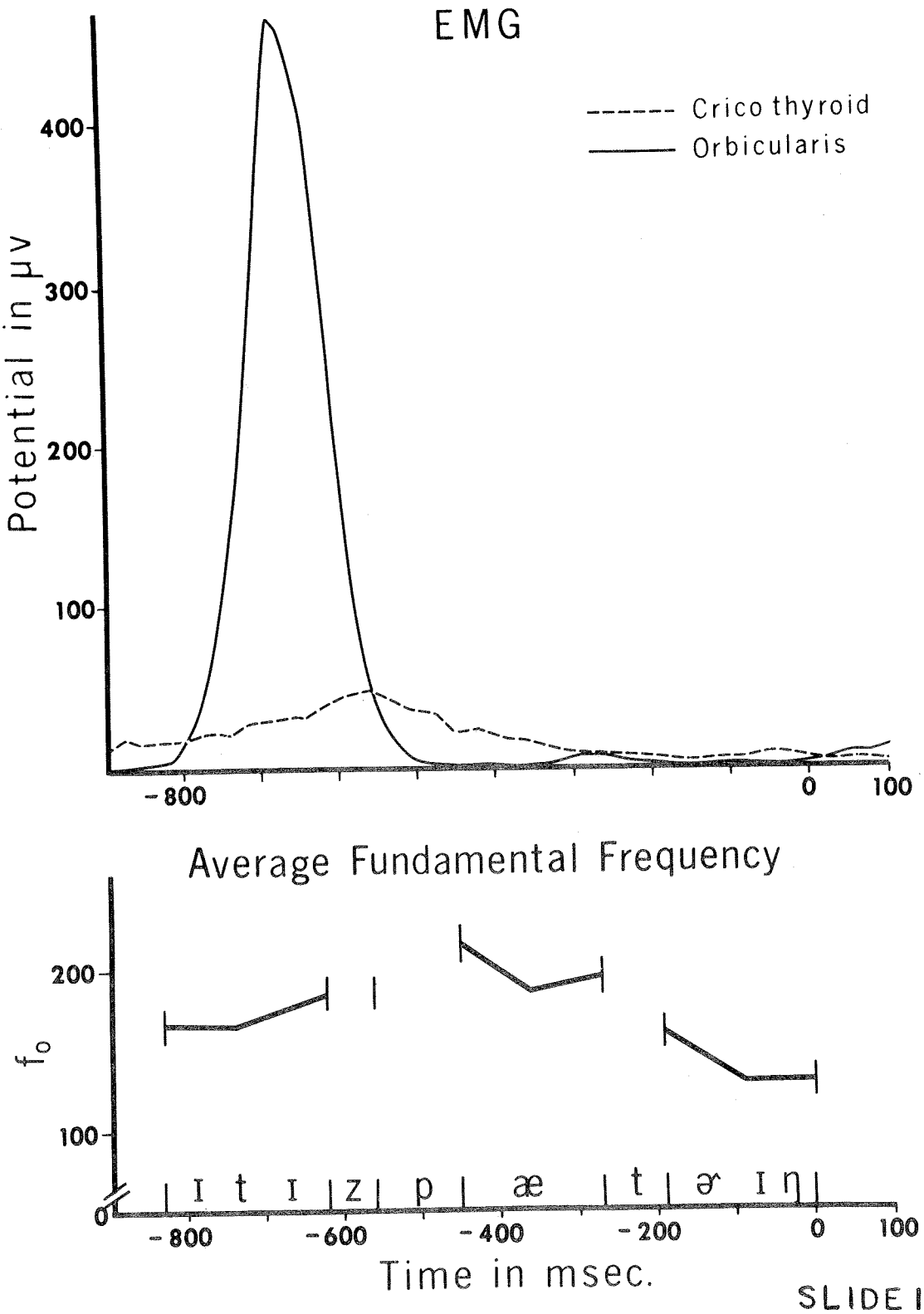
It is <u>pattering</u>. A statement with a word made prominent.

Is it <u>pattering</u>? A question with a word made prominent.

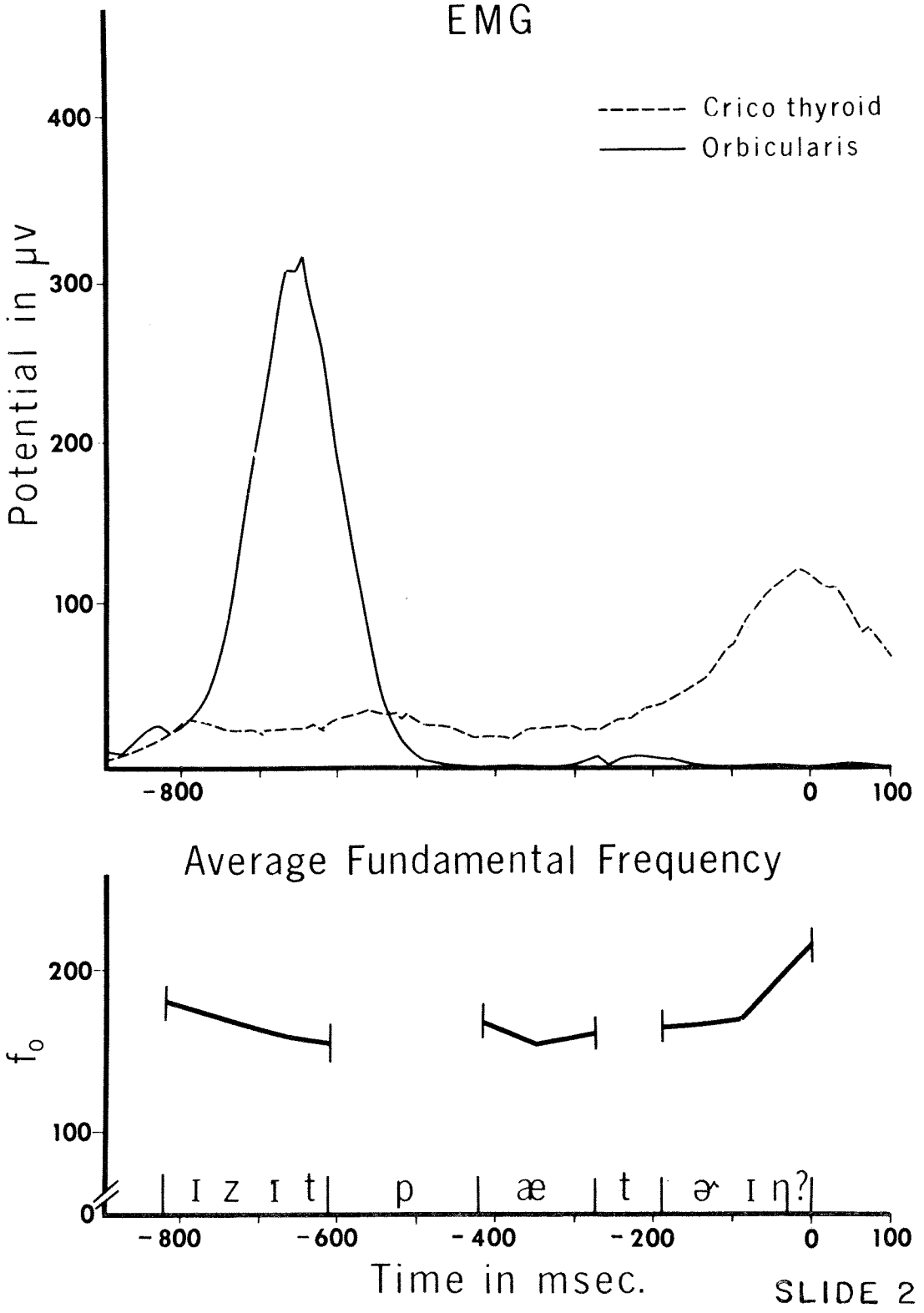
In addition to these utterances, some other examples in which the terminal word had different lexical stress were also used.

In Slide 1 we have presented the averaged rectified and smoothed electromyographic data for one subject for the sentence "It is pattering". In this case 20 tokens of the sentence were averaged together. The activity of the orbicularis muscle is plotted by means of a solid line while the activity of the cricothyroid muscle is plotted by means of dashes. The vertical scale on the graph is the electrical activity of the muscles in microvolts. Time is plotted on the horizontal axis in milliseconds. The negative and positive values of time refer to the computer 'line up' point which here occurs at the termination of voicing in the word "pattering".

At the bottom of Slide 1 the fundamental frequency of phonation for six of the above utterances is plotted on the same time scale. The fundamental frequency was measured on narrow band spectrograms by tracking the fifth harmonic of the fundamental.


EMG
Crico thyroid
Orbicularis
Potential in μv
400
300
200
100
-800
0
100
Average Fundamental Frequency
f_o
200
100
0
I t I z I p I æ I t I ɚ I ŋ I
-800
-600
-400
-200
0
100
Time in msec.

SLIDE I


EMG
Crico thyroid
Orbicularis
Potential in μv
400
300
200
100
-800
0
100
Average Fundamental Frequency
f_0
200
100
0
| I z I t | p | æ | t | ə˞ I ŋ? |
-800
-600
-400
-200
0
100
Time in msec.

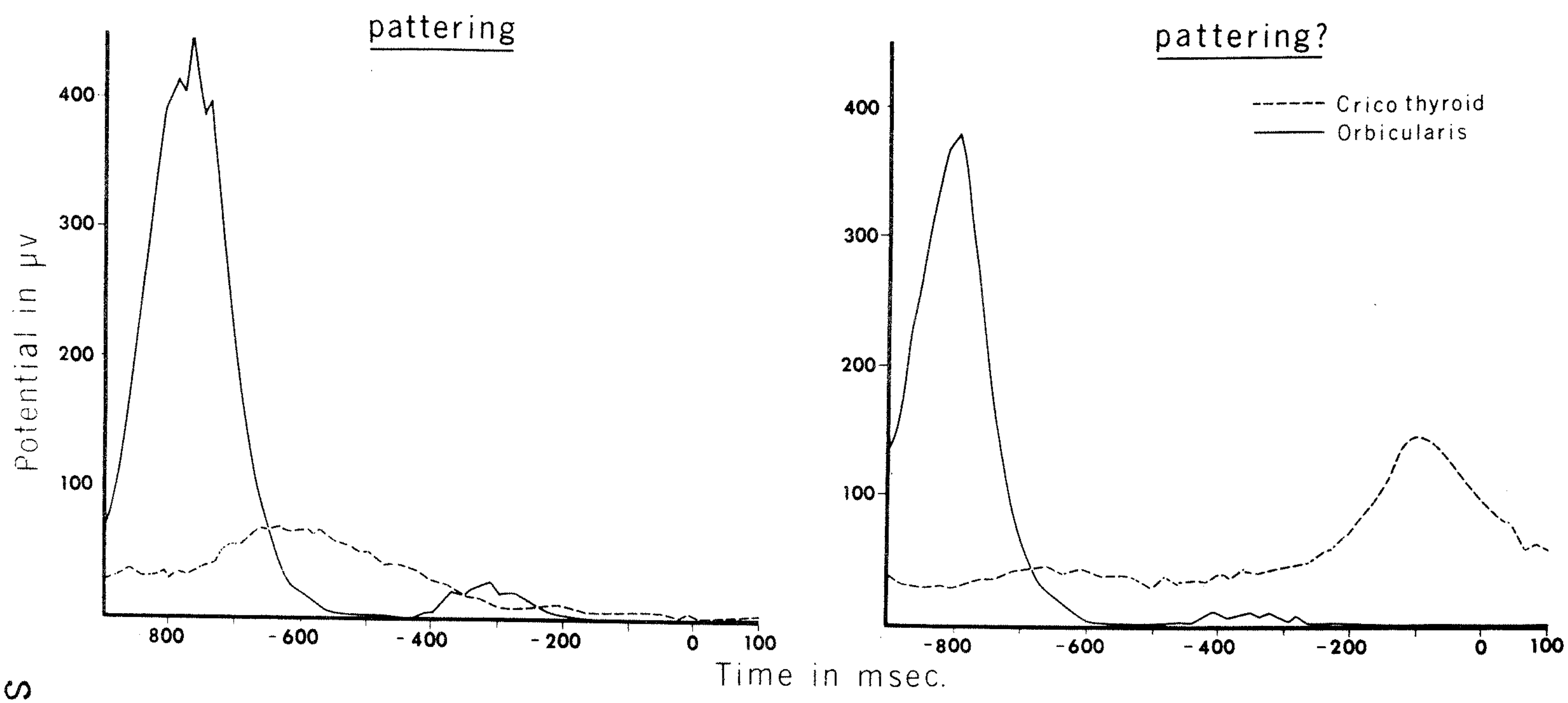
SLIDE 2

Note that the electrical activity of the orbicularis muscle is limited to a single peak centered on t = -650 msec. This peak corresponds to the closure of the lips for /p/, as we can see by referring to the fundamental frequency contour. Note also that no electrical activity occurs in the crico-thyroid muscle at the end of the sentence (t = 0 msec.). A small (50 microvolt) peak in crico-thyroid activity does occur at t = -550 msec. This peak corresponds with the primary lexical stress of the word 'pattering'.

In Slide 2 similar data are plotted for the sentence "Is it pattering?" Note that a peak in the orbicularis channel still occurs. Note also that, in contrast to Slide 1, electrical activity occurs in the crico-thyroid muscle only at the end of the sentence. For this subject at least the activity of the crico-thyroid muscle causes the increase in the fundamental frequency of phonation.

At the bottom of Slide 2, the fundamental frequency of phonation has been averaged for six of the above utterances and again plotted on the same time scale. Note that the fundamental frequency also rises at the end of the breath-group. Examination of the data for all of the sentences showed that the increase in the electrical activity of the crico-thyroid muscle and the increase in the fundamental frequency occurred at the end of the questions, irrespective of the number of syllables in the final word of the sentence or their lexical stress.

In the left side of Slide 3, electromyographic data are presented for the sentence "It is <u>pattering</u>" -- that is, the word <u>pattering</u> is especially stressed, or prominent. When this happens, we observe that there is increased activity of the crico-thyroid muscle for the stressed syllable in <u>pattering</u>. However, when we contrast with the right hand side of the figure,


pattering
pattering?
Crico thyroid
Orbicularis
Potential in µv
400
300
200
100
800
-600
-400
-200
0
100
-800
Time in msec.

SLIDE 3

we observe that if the word is prominent and in a question, activity is reduced for the prominent syllable, and increased only at the termination of voicing, to raise pitch for the question.

So far, we have shown information only for the crico-thyroid muscle. Similar data could be shown for a subject for whom we have only information from the vocalis muscle. It behaves quite similarly. However, let us go on to examine the productions of two subjects for whom we have information on both the crico-thyroid and the vocalis.

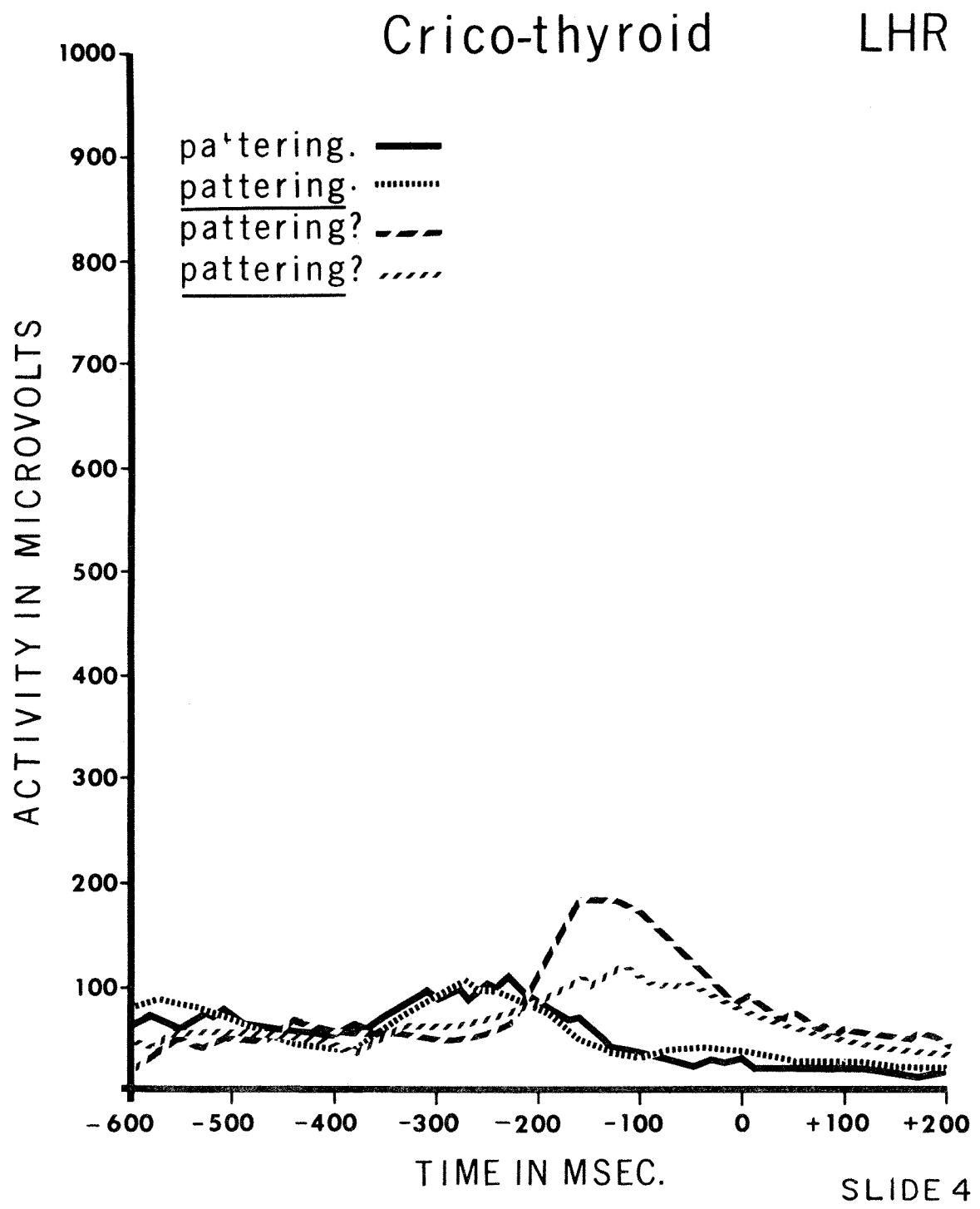
In Slide 4 we see, plotted on the same slide, information on the behavior of the crico-thyroid for all four sentence types for one subject, LHR.

For the two statements, the stressed syllable has a peak, which vanishes when the statements become questions. There is no difference in the level of the statement peaks, but there is a difference in that the question peak is higher, when it falls on a word which is prominent.

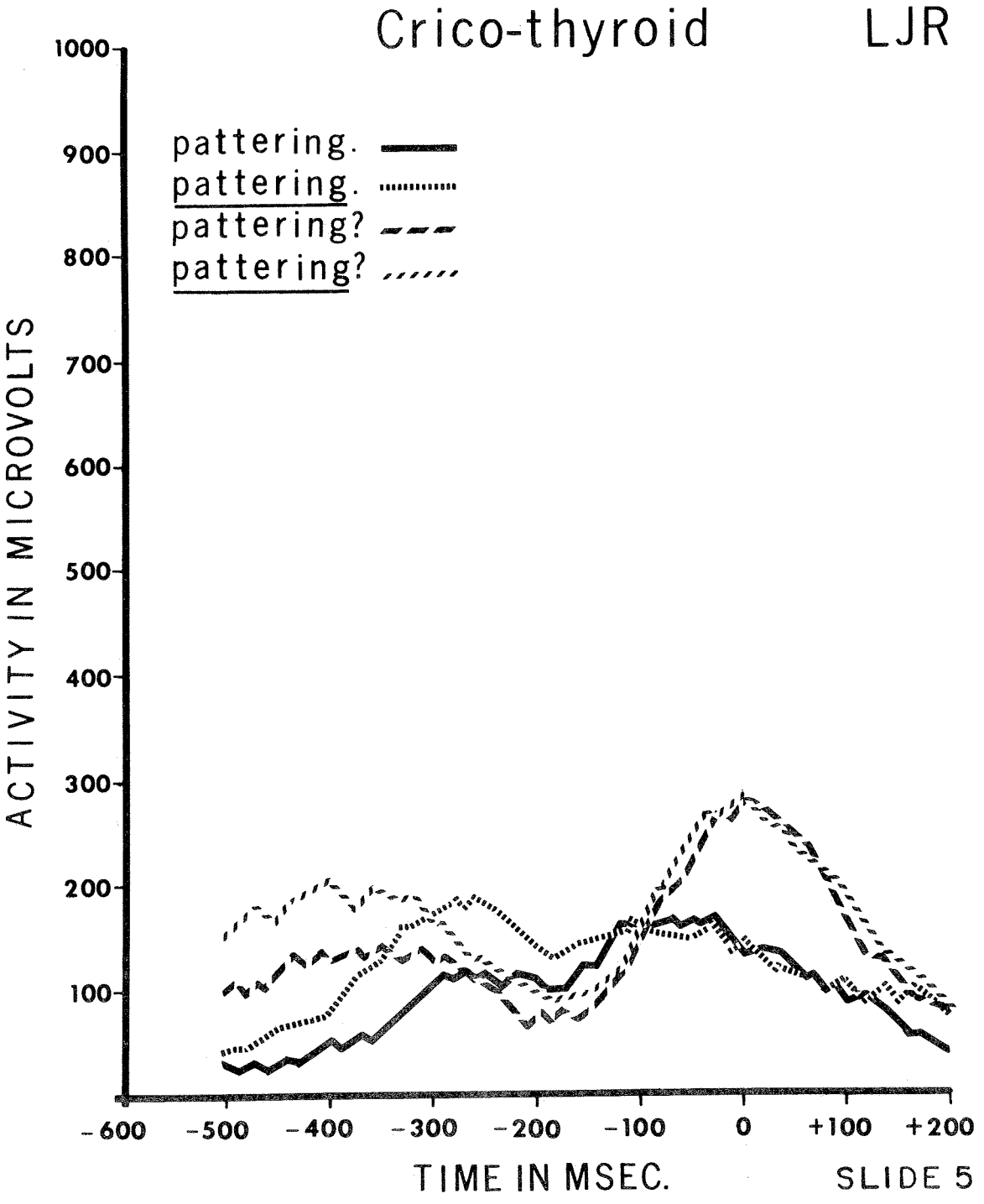
The behavior of the crico-thyroid muscle is shown for a second subject, LJR, in Slide 5. Here there is a difference in the amount of activity for the stressed syllable in statements if the word is made prominent. However, we do not see the characteristic reduction of activity on the prominent word when the statement becomes a question.

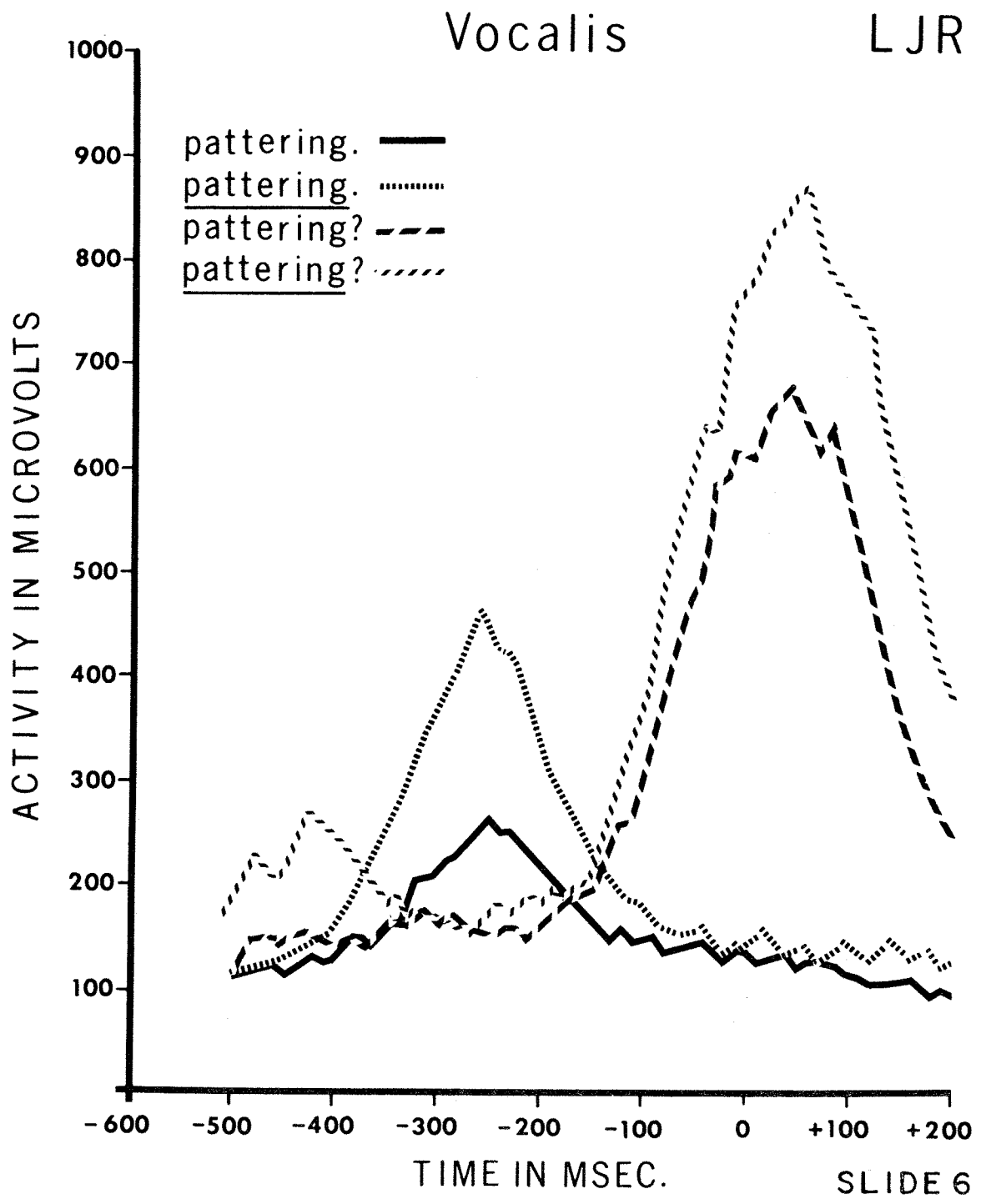
Slide 6 shows the data on the vocalis muscle for the same subject, LJR. Again, the two statements differ in the amount of activity on the stressed syllable, depending on whether it is or is not prominent. As before, a question with a prominent syllable shows decreased activity in the lexically stressed syllable and increased activity at the termination of phonation.

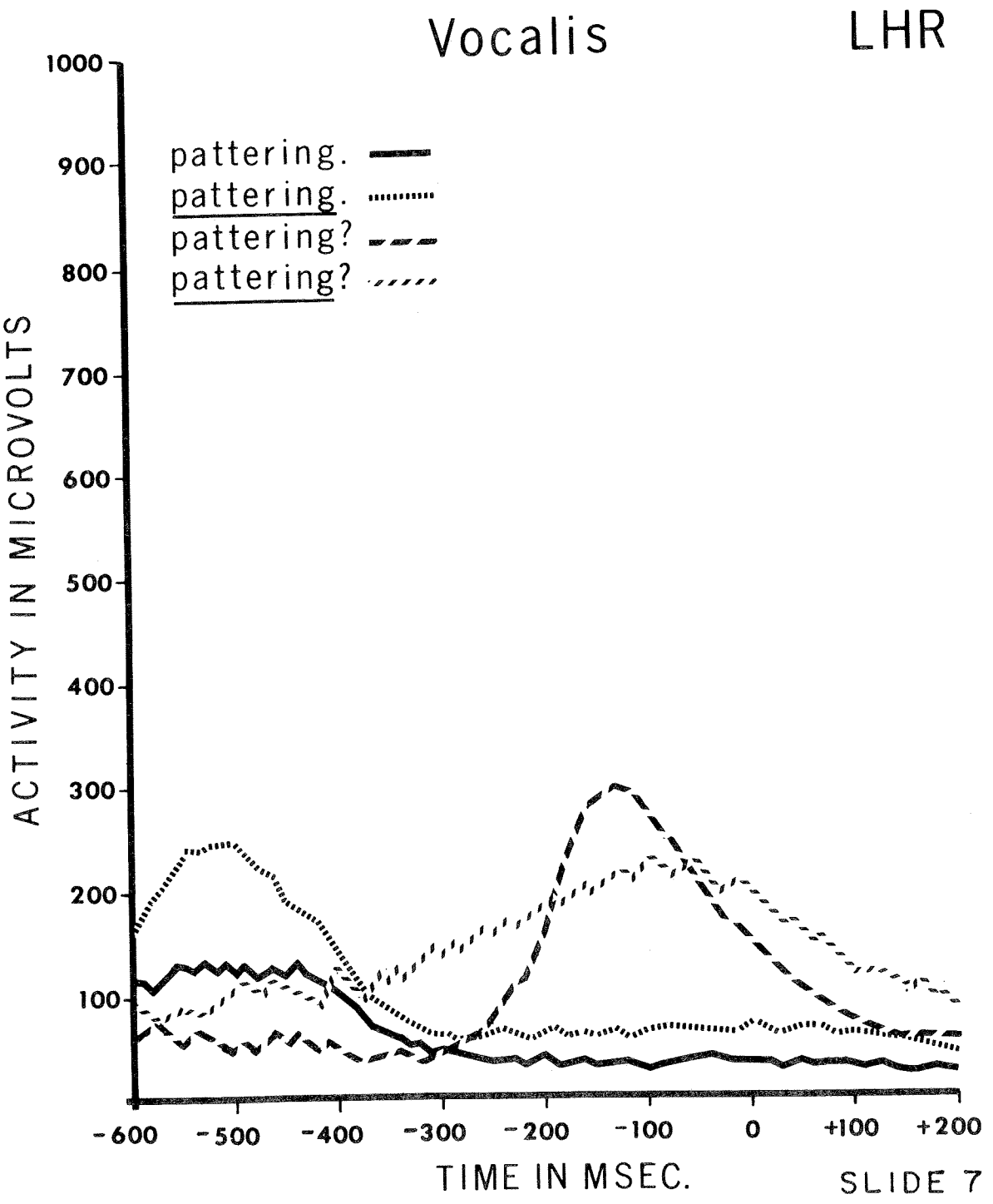
Slide 7 shows the four sentence types on the previous subject for the vocalis. Here we see some of the same general trends


Crico-thyroid
LHR
pa'tering.
pattering.
pattering?
pattering?
ACTIVITY IN MICROVOLTS
1000
900
800
700
600
500
400
300
200
100
-600
-500
-400
-300
-200
-100
0
+100
+200
TIME IN MSEC.

SLIDE 4


Crico-thyroid
LJR
pattering.
pattering.
pattering?
pattering?
ACTIVITY IN MICROVOLTS
1000
900
800
700
600
500
400
300
200
100
-600
-500
-400
-300
-200
-100
0
+100
+200
TIME IN MSEC.
SLIDE 5


Vocalis
LJR
pattering.
pattering.
pattering?
pattering?
ACTIVITY IN MICROVOLTS
1000
900
800
700
600
500
400
300
200
100
-600
-500
-400
-300
-200
-100
0
+100
+200
TIME IN MSEC.
SLIDE 6


Vocalis
LHR
pattering.
pattering.
pattering?
pattering?
ACTIVITY IN MICROVOLTS
1000
900
800
700
600
500
400
300
200
100
-600
-500
-400
-300
-200
-100
0
+100
+200
TIME IN MSEC.
SLIDE 7

as before, although the handling of the question peak is somewhat different on the prominent example -- there is probably increased overall activity but it appears more stretched out.

Let us try to summarize this rather complicated series of observations.

1). In general, statements terminate with a falling frequency contour, and there is no crico-thyroid or vocalis activity at the termination.

2). Questions terminate with a rising contour, and are accompanied by crico-thyroid and vocalis activity.

3). The effects of marking a word with special prominence differ depending on whether this occurs for a statement or a question. That is, laryngeal tension seems more likely to increase for a prominent word if the laryngeal muscles are not to be used to mark a question.

4). We have not produced any data to support the following additional conclusions, but let me just mention them. There does not seem to be a systematic difference in the action of crico-thyroid and vocalis muscles with respect to intonational manipulation. The differences we see between patterns are not consistent for the two subjects for whom we have data on both muscles.

Where does all this leave us with respect to a general theory about the physiology of intonation? In the limited number of examples we have studied, we see that the fundamental frequency rise which accompanies the asking of questions appears to be invariably accompanied by increased activity of the vocalis and crico-thyroid muscles. On the other hand, changes in laryngeal tension do not invariably accompany the placing of special prominence on a word -- indeed, it is as if the laryngeal muscles were reserved for the terminal question rise, and may accompany other intonational maneuvers only if they are free to do so.