Coordinated Tongue Muscle Activity During /əpVp/ Utterances

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1. Introduction

There are many studies in the phonetic literature that describe the EMG activity of various tongue muscles during the production of vowels. However, there are relatively few studies that have simultaneously recorded muscle activity with hooked-wire electrodes from the complete set of tongue muscles. Thus, phoneticians have been forced to rely on different experiments, which use different speakers, with different dialects, often producing different speech utterances, to make assumptions about tongue control during speech.

2. Method

The purpose of the present experiment was to study control during vowel production by simultaneously recording EMG potentials from the complete set of muscles responsible for tongue movements. We recorded from the extrinsic tongue muscles: anterior and posterior genioglossus, (GGA and GGP), hypoglossus (HG), and styloglossus (SG). To our knowledge, EMG potentials from the HG muscle have never been recorded with hooked-wire electrodes before. In addition, we recorded from the accessory tongue muscles, the geniohyoid (GH) and mylohyoid (MG), and from orbicularis oris superior (OOS). We also monitored jaw position using measurement techniques similar to those described by Sonoda and Wanishi (1982) and we extracted formant frequency trajectories from the acoustic signal with the aid of an LPC-based, interactive computer system. The data were obtained while a single speaker of a New York dialect of American English produced ten repetitions of a randomized list containing eleven vowels in a /əpVp/ environment. Ensemble averages of the ten tokens were created for the EMG, acoustic, and jaw movement channels.

3. Results and Discussion

Figure 1 shows the acoustic vowel space plotted in average F_1-F_2 values for the eleven vowels produced in this experiment. Formant values were obtained by averaging across the ten repetitions per utterance type and then pooling

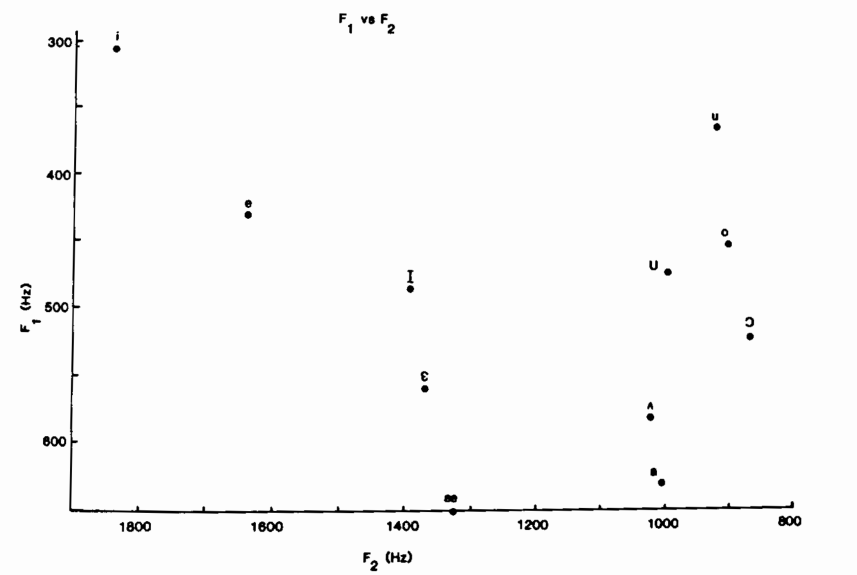

Fig. 1. Average F_1 - F_2 values for the eleven vowels produced in this experiment. Each data point represents the F_1 and F_2 values obtained by averaging both over time, during the vocalic segment, and over the ensemble of ten repetitions.

the data points within an average formant trajectory. The acoustic data suggest that this subject produced the vowels /i/ and /e/ with a high and front tongue position, when compared to the remaining vowels. The vowels /I/ and /ɛ/ are lower and more centralized. The back group appears more tightly clustered.

With the acoustic data in mind, we turn to the results of the EMG analysis. Figure 2 shows the ensemble averages for the EMG, acoustic, and jaw movement channels. The various channels are labelled across the vertical axis. Vowel type is shown across the top. For convenience, we have grouped front and back vowels, and show /ʌ/ separately. The units along the abscissa represent 100 ms intervals. The heavy vertical lines represent the acoustic onset of the vowel, which served as the line-up point for each of the tokens. The EMG signals were smoothed with a 70 ms window. Audio amplitude is shown on the top row.

The extrinsic tongue muscles are shown on rows two through five. Considering these muscles as a group, note that vowel-related EMG potentials for GGA, HG and SG are more clearly differentiated in front versus back vowel height in both the front and back group. GGP activity appears to be inconstant, that is, EMG potentials for this muscle vary with vowel height in both the front and back group. These muscles are differentially organized to horizontally and vertically position the tonguė. Jaw movement contributes primarily to vertical tongue position. With these comments in mind, we next consider the function of each of the extrinsic and accessory muscles on

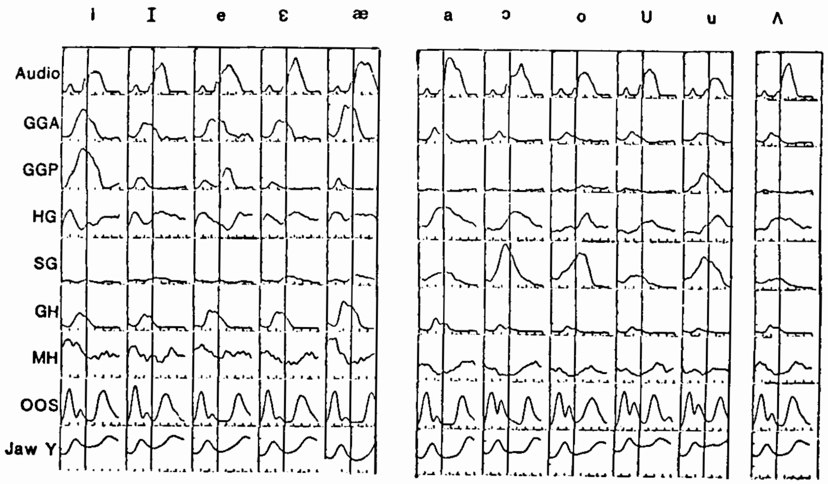

Fig. 2. Ensemble averages of the audio envelopes, electromyographic signals, and jaw vertical position signals for each of the eleven vowels. Electromyographic signals are shown for the anterior genioglossus (GGA), posterior genioglossus (GGP), hyoglossus (HG), styloglossus (SG), geniohyoid (GH), mylohyoid (MH), and orbicularis oris superior (OOS) muscles. Tick marks arbitrary. EMG data were smoothed using a 70 ms trianglar window and were averaged over ten repetitions. The vertical line through each set of plots indicates voice onset for the vowel, the temporal line-up point for ensemble averaging.

tongue positioning without taking into account the contribution of the jaw to tongue elevation.

Although the anterior and posterior fibers of the genioglossus are part of the same muscle anatomically, they can and do function independently in different vowel environments. GGA, shown on the second row, is much more active for front vowel than for back vowel production. GGP activity, shown on the third row, is most active during the production of the high vowels /i/, /e/, and /u/ than for the low vowels. Note that during the production of the high front vowel /i/, both GGA and GGP are active. Given the anatomical configuration of GGA fibers, this muscle should pull the tongue dorsum downward and forward. However, in the vowel /i/, the lowering component of GGA is reduced by activity of GGP, resulting in forward and upward movement of the tongue. During the production of the low front vowel /æ/, GGA, but not GGP, is active and during the production of the high back vowel /u/, GGP, but not GGA, is active. Thus, GGA contributes to tongue fronting and lowering, whereas GGP contributes primarily to tongue raising.

Next we consider the HG and SG muscles, shown on the fourth and fifth rows respectively. Note that these muscles show greater vowel-related activity for back vowels than for front vowels. During front vowel production, a peak in HG activity occurs at about the time of lip closure for the initial stop. This pre-vocalic activity possibly serves to lower the tongue during bilabial

closure. Peak activation is followed by vowel-related suppression of the HG. The magnitude of HG suppression is directly related to the magnitude of GGP activity. SG activity is negligible in all front vowel environments. The activity of the HG and SG for back vowels is clearly different from that observed for front vowels. First, note the absence of the pre-vocalic HG activity. The HG is active during the production of all back vowels, maximum activity occurring during the production of /a/. The SG is also active for all back vowels, the greatest activity occurring for the high back vowels /u/, /o/ and /ɔ/. Thus, while HG acting alone pulls downward and backward on the tongue body , and SG acting alone pulls upward and backward on the tongue body, these two muscles in fact act synergistically to vertically and horizontally position the tongue during the production of all back vowels by varying the timing and magnitude of their contraction.

Finally we consider the GH and MH muscles, shown on the sixth and seventh rows respectively. These muscles exert a mechanical influence on the hyoid-larynx complex: However, we still discuss here the contribution of GH and MH to tongue positioning. Note first that GH and MH EMG activity is greater for front vowels than for back vowels. For front vowels, these muscles serve to raise the tongue base by stiffening the oral floor. For back vowels, activity of these muscles is suppressed. Thus, GH and MH assist in lowering and backing tongue gestures by relaxing and lowering the oral floor. The patterns of activity for these two muscles are clearly different. The GH muscle has greater effect on horizontal tongue movement than does the MH. Notice that the peak in GH occurs at the same time as the peak in GGA activity, indicating that GH and GGA assist in tongue fronting. The MH has a greater effect on vertical tongue displacement, especially for the posterior part of the tongue, than does the GH. Although we recognize that MH function is complex, we note that during EMG activity temporally associated with the vowel, MH suppression is related to the HG activity. Greater MH suppression occurs when HG activity is high, as in the back vowel group. On the other hand, overall MH activity is high when HG activity is lower, as in the front vowel group.

In summary, we have presented the preliminary analysis of simultaneously recorded tongue EMG data collected from a single speaker of American English. The purpose of the study was to investigate the muscular control of the tongue during vowel production. We note that there is EMG activity associated with tongue movements prior to and following the period associated with the vowel. This activity shows some systematic variation with vowel identity, and thus bears further consideration. Tongue movements are dependent upon the complex interdependencies among extrinsic and intrinsic tongue muscles, the accessory tongue muscles, the hyoid-larynx complex, and jaw position. Before we can ultimately understand the complex control of the tongue, we must be able to specify the individual function of these various parameters, The study reported here is an attempt to do that by examining the relationship of some of these muscles in the same speaker.

Acknowledgement

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Reference

Sonoda, Y. and Wanishi, S. (1982). New optical method for recording lip and jaw movements. *J. Acoust. Soc. Am.* **72**, 700-704.