A Combined Cinefluorographic-Electromyographic Study of the Tongue During the Production of /s/: Preliminary Observations*

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The production of the voiceless fricative /s/, especially as it occurs in two and three consonant clusters, is perhaps the most demanding tongue gesture in spoken English. It is late in normal phonological development and it is quick to deteriorate under adverse circumstances whether pathological, such as with even a mild dysarthria, or experimental, as in a temporarily induced nerve block. The production of /s/ has been examined by X-ray films, by air pressure studies, and by acoustic analysis. The study, of which this paper is the first report, is designed to investigate the organization of motor commands to the tongue muscles in the normal production of /s/ both as a single consonantal phone and as it appears in combination with other consonants. To this end, we seek to explore the interrelationships of muscle activity, tongue movement, and the resultant acoustic signal.

Our preliminary observations are based on an analysis of X-ray movies and electromyographic (EMG) recordings of our first subject. For the cinefluorography, a 16-mm cine camera recorded X-ray films at 60 frames per second. The generator delivered X-ray pulses to a 6-in image intensifier tube. Barium sulfate cream was used as a contrast medium, and several #6 BB shots were glued to the tongue tip and dorsum of which only 2 remained in place for the experiment. Details of the instrumentation may be found in Gay, Ushijima, Hirose, and Cooper (1974).

The subject read a list of utterances in which /s/ occurred in initial and final positions of a syllable and in two and three consonant clusters with plosives /sp/, /spr/, /st/, /str/, /sk/, and /skr/. The stressed syllabic nucleus was /i/, /a/, or /u/, and each utterance contained a /p/ for easy identification of both X-ray movies and EMG graphs.

For the EMG recordings, hooked-wire electrodes were inserted into the following tongue muscles: the genioglossus, the superior longitudinal, the inferior

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longitudinal, and the middle intrinsics, and, for reference, the orbicularis oris (see Hirose, 1971). After the short combined X-ray and EMG run, a longer run of EMG alone was recorded with the list of 48 utterances repeated 10 times. These two runs were analyzed separately.

The analysis of the movement data required frame-by-frame tracing of the image as projected by a Perceptoscope. The two pellets, one on the tongue tip and one approximately halfway back to the terminal sulcus on the dorsal midline, were marked on each frame and later measured as X-Y coordinates in order to graph their relative fronting and elevation. The EMG recordings were analyzed according to the Haskins Laboratories computer averaging system. For details of this system, see Kewley-Port (1973).

At first glance, there were three observations that seemed noteworthy.

1) First of all, this subject produces /s/ with the tip of the tongue behind the lower gum ridge and the dorsum of the tongue elevated to form the constriction. Figure 1 shows the tongue tip resting behind the lower gum ridge and the dorsum bunched up. This configuration of the tongue for /s/ is consistent for this subject. The tongue tip remains fixed during /s/ but the dorsum reflects the phonetic environment of the sibilant. Although it was well-known that this alternate /s/ production occurs for many speakers, it remained to be seen what pattern of muscle activity accompanies this alternate production.

![Figure 1: Alternate configuration of the tongue for sustained /s/ production. Pellets on the tip and mid-dorsum of the tongue are indicated.](image)

For that information, we look to the EMG recordings (Figure 2) and we observe at least two muscles whose activity can be associated with the production of /s/, the inferior longitudinal and the middle intrinsics. Here the utterance is "asape." The horizontal boxes below the graphs indicate the actual duration of each segment of the utterance as measured from sound spectrograms. The top
Figure 2: EMG from the inferior longitudinal muscle and in the middle intrinsic muscles of the tongue during alternate /s/ production.
Figure 3: EMG from the inferior longitudinal muscle, which is active for /s/, and from the genioglossus muscle, which peaks for /l/.
graph shows the buildup of electrical potential from the contraction of the inferior longitudinal muscle, starting in this case about 100 msec before the acoustic event of the fricative during which it peaks. The inferior longitudinal muscle courses along the inferior aspect of the tongue and its contraction curves the tongue tip downward. It is apparent, then, that this low tongue tip /s/ is not passive, the result of being left behind when the dorsum elevates, but is the result of an active gesture of apical depression to facilitate the bunching of the tongue. The second graph is also indicative of a pattern that is consistent with the occurrence of /s/, a pattern of activity of the middle intrinsic muscles of the tongue. For this subject, then, the middle intrinsic muscles and the inferior longitudinal muscles were consistent in their contraction for the production of the alternate /s/.

Again, in Figure 3 the active apical depression by the activity of the inferior longitudinal can be seen in the top two graphs for the /s/ in syllable-final position, in /pis/ and /pos/. The lower pair of graphs represents the level of activity as recorded from the genioglossus muscle. It is apparent in these utterances that the genioglossus muscle is active for /i/ but not for /a/, a finding that is common and that relates to our second observation concerning /s/ clusters.

(2) As we see in Figure 4, the target shape for /i/ produced by this subject is remarkably stable whether it is preceded by /sp/, /st/, or /sk/.

![Diagram](image)

Figure 4: Tongue configuration for /i/ after /sp/, /st/, and /sk/.

The EMG signals (Figure 5), in contrast to the movement data, show that the contraction of the genioglossus for /i/ varies in its relative level of activity depending on whether the /i/ follows /sp/, /st/, or /sk/. The column of graphs on the left-hand side are of /spipə/, /stipə/, and /skipə/, on the right-hand side, /spipə/, /stripə/, and /skripə/. Notice how the activity of the
Genioglossus Activity for /i/ 

Figure 5: EMG from the genioglossus muscle for /i/ in several phonetic contexts.
genioglossus muscle is diminished after /sk/ and /skr/. It may be that the

            genioglossus effectively lifts the tongue for /i/ after /sp/ and /st/ but is
            aided by the mylohyoid or styloglossus muscles for tongue lifting for /k/;
            therefore, fewer demands are put on the genioglossus in this context.

            So we observe that although the movement data indicate that the target
            shape is the same for /i/ whether after /sp/, /st/, or /sk/, the muscles used to
            obtain this target vary according to the preceding consonants. This is an ex-
            ample of how there are not always invariant motor commands for each phoneme, but
            rather each command may be interlaced with other muscle commands for segments as
            large as /skri/ in this case, a four-phone syllable.

            (3) The last observation to report from these data concerns duration. An-
            other way to approach the question of how the motor commands are organized for
            speech is by looking at durational differences. Schwartz (1970), Klatt (1974),
            and others have reported that acoustically an /s/ is shorter before /p/ than it
            is before /t/ or /k/ in a consonant cluster, so in /sp/, the /s/ is shorter than
            in /st/ or /sk/. Lining up the acoustic signal with the movement and EMG data
            should tell us whether this durational difference is true on the movement level
            or on the motor command level. Is there an invisible inaudible /s/ in /sp/ hav-
            ing a duration similar to that in /st/ and /sk/ but simply occluded by the /p/?

            We've just started to look at these relationships but the durational differ-
            ences seem to hold up in the movement data. The tongue position for /s/ before
            /p/ is held only to the /p/ closure when it starts to move toward the vowel tar-
            get. Therefore, the target shape for /s/ is shorter in /sp/ than for /st/ and
            /sk/.

            Since the inferior longitudinal muscle was so consistent in its activity
            for /s/ in this subject, we looked there for the durational difference on the
            motor command level.

            In Figure 6 one can see that the inferior longitudinal is active for the
            final /s/ clusters in the left column of graphs. There is a tendency for the
            activity to fall off more sharply for the /s/ in /sp/ than in /st/ or /sk/
            where it is maintained longer. The arrows on the figure point to the slope dif-
            ferences. The durational difference, then, also operates on the EMG level. The
            same thing happens for initial clusters as seen in the right column of graphs.
            The falloff of activity is steeper for /sp/ than for the other clusters.

            With labial closure, the tongue is free to move on to the vowel target, but
            for /st/ or /sk/, the tongue is involved throughout the cluster. In other
            words, the tongue is free to coarticulate with the lips for /sp/ in anticipation
            of the vowel but not for /st/ or /sk/, since the tongue is delayed with its in-
            volvement in the /t/ and /k/ gestures.

            In conclusion, we find that by simultaneously viewing movement data and
            muscle activity data, we can observe evidence of different muscles contracting
            for the same target shape and phone depending upon which phones precede it. We
            can observe evidence of the freedom to coarticulate within a syllable as the
            tongue is free to move toward /a/ during the labial closure in /sp/. Finally,
            we have EMG evidence as well as movement evidence that there is more than one
            way to produce a sound that is acoustically acceptable and well within the
            phoneme boundaries of /s/, an alternate /s/.

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Duration of Inf. Long for /s/ Clusters

Figure 6: EMG from the inferior longitudinal muscle during /s/ clusters. Arrows pointing to the slopes indicate a tendency for activity to decrease more rapidly for /sp/ than for /st/ or /sk/.
We have filmed two more subjects who have tongue-tip high /s/ and are planning another experiment involving simultaneous EMG and cine X-rays of a fourth subject, also with a high apical /s/. It will be interesting to compare those data when they are processed with this subject to get an idea of subject variation in the motor organization of /s/ and /s/ clusters.

REFERENCES


