AN ELECTROMYOGRAPHIC STUDY OF CONSONANT ARTICULATION IN HEARING-IMPAIRED AND NORMAL SPEAKERS

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The purpose of this study was to obtain comparative information on the articulation of some common consonants by a very small sample of normal and deaf talkers. Information on the organization of articulation was collected by electromyography. Electrodes were placed on some diagnostic locations on the facial and tongue musculature, and the patterns of contractions were measured for 11 common consonants spoken in a disyllabic frame. The results show that patterns of facial muscle contractions in the deaf speakers are in general correct, by comparison with normals, although they are generally exaggerated. On the other hand, tongue muscle patterns of the deaf speakers are stereotyped but frequently wrong, though there is no consistent pattern to the direction of the errors.

PROBLEM

The purpose of the study to be reported here was to obtain comparative information on the articulation of some common consonants by normal and deaf talkers. Our immediate interest was to clarify, if possible, some of the factors which give deaf speech its perceived pathological quality; our more general goal was the better understanding of the organization of normal speech by considering the effects of various types of malfunction of the whole speech chain.

Most teachers of the deaf are convinced that they can recognize "deaf voice" by hearing it. A study by Calvert (1961) clarifies the role of several factors in the perception of "deaf voice." Experienced teachers of the deaf cannot consistently identify isolated vowels as deaf; they can discriminate deaf and

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normal productions of consonant-vowel syllables. "Deaf quality" is not strictly a matter of abnormal control of vocalization, on the one hand, or abnormal communication of the suprasegmental phonemes in running speech, on the other.

We can make a somewhat arbitrary division of the types of factors likely to be abnormal in productions of CV syllables. On the one hand, dynamic features may be distorted—that is, transitions from consonant articulatory configuration to vowel may be strange. On the other hand, purely topological features may be abnormal—that is, the "wrong" articulatory configurations may be commonly produced by deaf talkers. In this paper we will consider only the latter problem, studying the topology of consonant articulation using the technique of electromyography.

METHOD

The "normal" talkers were the two female authors of this paper. Both have normal audiograms and no history of speech pathology. One habitually speaks a version of General American dialect, the other modified Eastern.

The "deaf" talkers were two young women who had had regular, competent, and consistent therapy since early childhood. The hearing loss was noticed well prior to first grade; both were enrolled in special remedial schools for deaf children in New York City and continued in these programs through high school. Subject RB is currently enrolled at Gallaudet College; subject MH, a young housewife, is receiving speech correction privately. Although both these subjects are profoundly deaf, they differ somewhat in the severity of the speech problem, RB being somewhat more intelligible than MH. This difference is probably attributable to the presence of some useful hearing for RB, as shown in the audiograms displayed as Figure 1.* This subject feels she gains some benefit from a hearing aid; MH does not. RB used the aid during the collection of the data.

The patterns of articulation were studied by the technique of surface electromyography. Small surface suction electrodes were applied to locations on the oral articulators, while the subjects produced a series of utterances of the form [həˈ CVk]. The consonants [p], [b], [m], [w], [f], [t], [s], [ʃ], [r], [l], and [k] were combined with the vowels [i], [ɑ], and [aI]. The resulting lists of 33 items, in random order, were produced 10 times by the deaf talkers and 20 times by the normals.

Air microphone recordings were made during the experiment; they were later played to two experienced phoneticians for broad transcription. The results show a score of 90% correct for the normals, 54% correct for MH, and

*We have used an old audiogram for MH, because it forms part of a lengthy developmental series, taken by the Lexington School for the Deaf, which shows great internal consistency. A more recent audiogram, taken by us at Haskins, is in general agreement but shows some erratic responding around 1000 Hz which is difficult to interpret. We were not able to do a full workup because of the subject's time limitations.

72% correct for RB, for consonant articulation. This confirms our subjective impression that RB was a more intelligible speaker. The same consonants, however, tended to be missed by the two hearing-impaired girls. A rough comparison with the data of Hudgins and Numbers (1942) seems to indicate that the common articulation errors for our subjects were similar to those of their population although scoring techniques were different enough to make direct comparisons difficult.

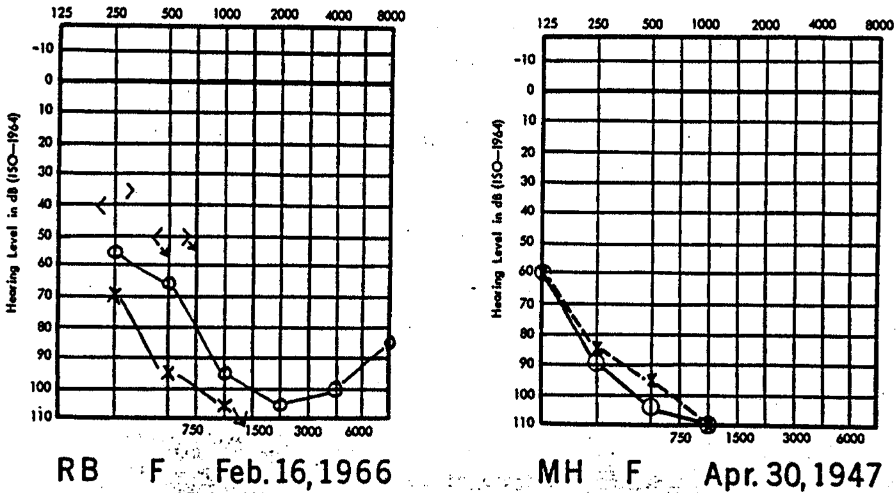

FIGURE 1. Audiograms of deaf talkers.

Figure 2 shows one of the subjects (MH) with the electrodes in place. In the discussion which follows, the following cabalistics are employed:

UL = upper lip
CL = corner lip
LL = lower lip
TT = tongue tip
MT = mid tongue
BT = back tongue—the most posterior tongue placement used in this study

FIGURE 2. Subject with electrodes in place. The one electrode which is unlabelled was not used in the experiment.

These positions were chosen to give a picture of a number of different aspects of the articulatory process although, obviously, not all. For example, these particular placements will not tell us anything about voicing activity, which is known to be a deaf problem. The electrodes themselves have been described in previous publications (Harris et al., 1964). All electrode output and various other information were recorded on 16-channel magnetic tape.

RESULTS

Figure 3 shows a typical sample of one of the utterances, as recorded on an inkwriter. The output from the six electrodes, after appropriate rectification and integration, is shown as lines 1-6. Line 8 shows the output of a vibration pickup positioned over the thyroid cartilage in such a way that the duration of phonation is recorded. Because individual tokens of a given utterance are variable, we average several tokens by techniques which have been described in detail elsewhere (Cooper, 1965). In brief, a point is chosen on the voice trace—in this case, the termination of phonation—designated as the "lineup point." Information is fed to a computer about the distance of this lineup point from the onset of an octal code (shown as line 7) which identifies the utterance. The computer can then average a specified set of tokens of the

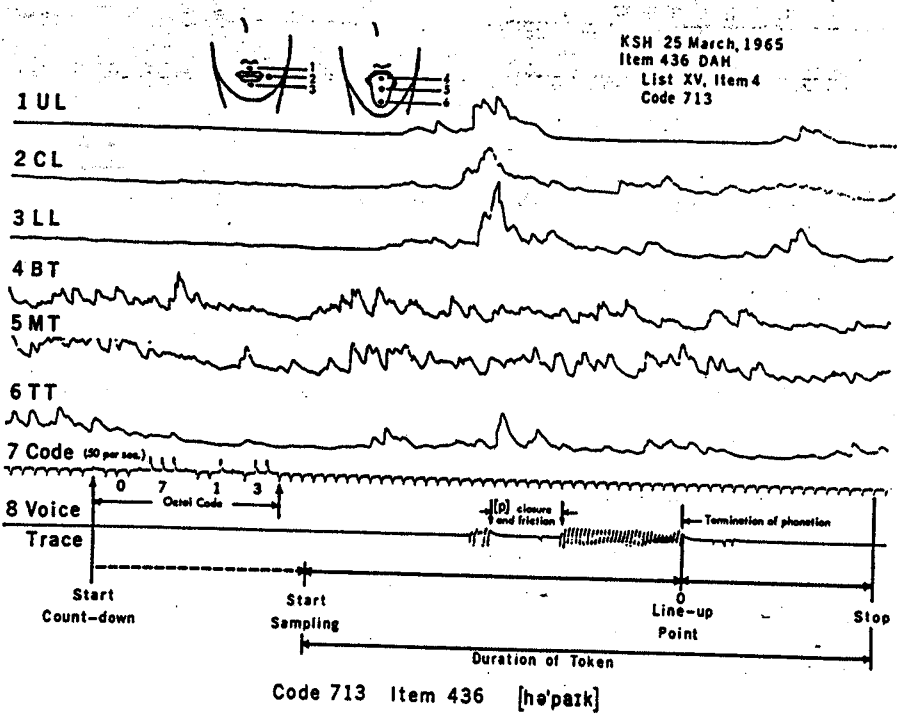

FIGURE 3. Sample ink writer record of a typical utterance, with coding information marked for computer averaging.

same type, superimposed at the lineup point, at a series of fixed times relative to the lineup point. The computer's output is an averaged trace for each of the six electrodes, for each utterance type, as a function of time.

Such averaged electrode traces are shown for the utterance [hə′ pαk] in Fig. 4. The outputs for the three circumoral electrodes are shown for a deaf (MH) and a normal (DAH) speaker.

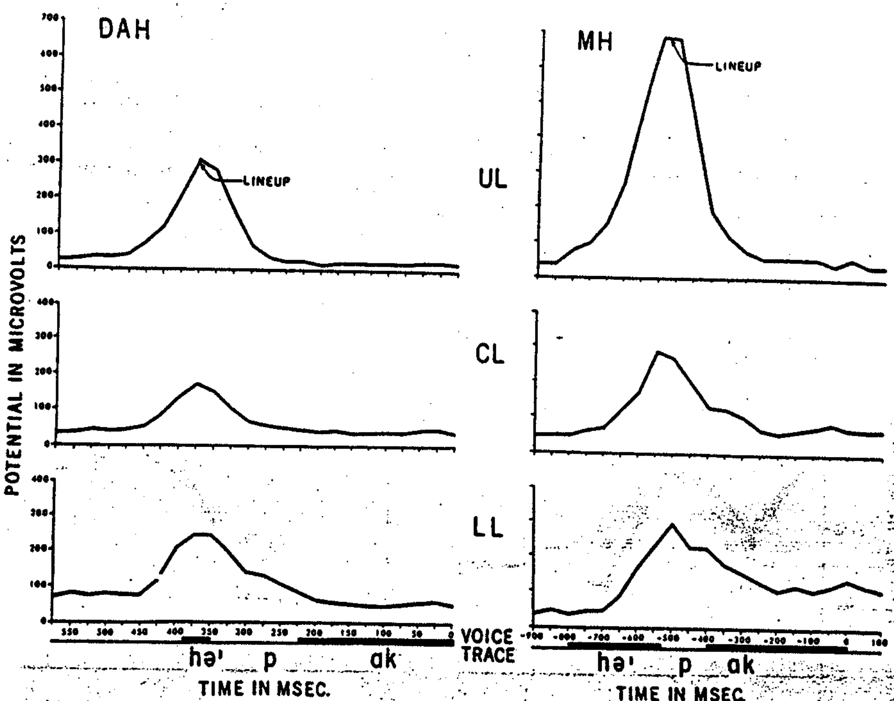

Figure 4. Averaged outputs for three electrodes for the utterance [hə′ pαk]. Every fifth sample plotted. A deaf and a normal subject compared.

For convenience, we have shown only three averaged electrode traces, and plotted only every fifth computer sample. Because MH's speaking rate was about half that of DAH, the sampling interval was set at 10 msec for her, as against 5 msec for DAH, and the plotting scale for DAH is twice that for MH. This characteristic slowness of deaf speech has been discussed by Calvert (1961) and Hood (1966).

Since the utterance is a bilabial, we would expect the lip electrodes to be active, as they are. Indeed, they are a great deal more active for the deaf speaker, especially the UL electrode. The obvious point about this figure is that there is a well-organized activity peak, apparently associated with [p] closure, somewhere near the point in time at which the voicing of the initial unstressed syllable ends. This peak is indicated by the arrow. A similar activity peak can be located for each of the 11 consonants in our sample. The output of all six electrodes, at the moment in time of peak activity on the most active electrode, provides a measure of the activity for the various consonants.

Figure 5 is a sample of this type of display. It is essentially a histogram of the activity of the six electrodes, at the time of peak activity of the most active electrode. For convenience, we will call this display a "peak activity profile." It compares the consonant activity for [p], a bilabial stop, with [s], an alveolar fricative for DAH. As we would expect, [p] shows an organized pattern of lip activity, while [s] shows an organized pattern of tongue activity. It is quite clear from the similarity of the tracings for [i], [ɑ], and [aI] that, at the point in the utterance we are examining, we are indeed observing very little influence of the vowel on the output voltage pattern. Of course, the similarity also gives us reassurance about the statistical stability of the data. Since consonant-vowel interactions appear small, we will characterize consonant activity by using data only from the vowel [ɑ]. We hope to discuss vowel effects in a later paper.

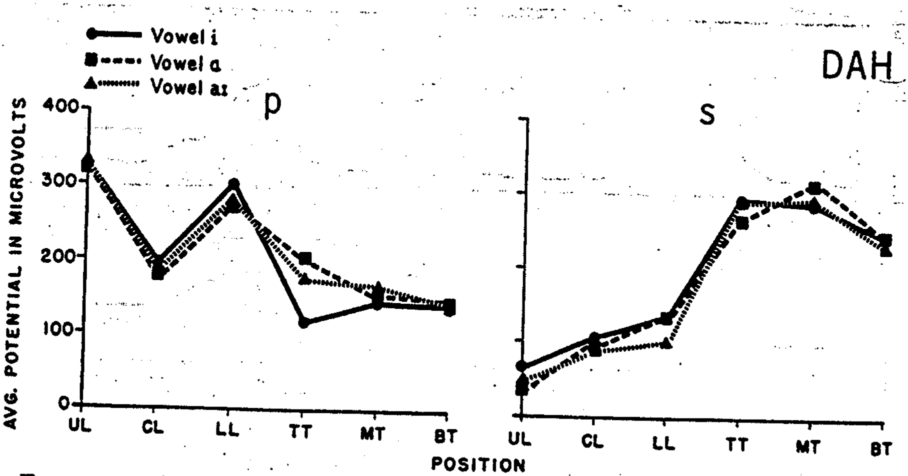

FIGURE 5. Peak activity profile for two consonants, three vowels compared for a single normal speaker.

Figure 6 shows the electrode patterns for the four labial consonants, with [f], a labiodental, for normal and deaf subjects. There is a gratifying consistency within consonant class, and between talkers, for the normal subjects. The deaf subjects are like the normals in showing lip activity for bilabial consonants, and showing the same general type of activity for the four members of the bilabial class. The details of pattern, however, are not identical for the two deaf talkers, and show greater activity for UL electrode than the normals. We found this overactivity repeated on other sounds which may involve lip rounding.

Figure 7 shows the three consonants [t], [s], and [ʃ] compared for the four speakers. Looking first at the normal talkers, we observe that for each of them the three consonants show great similarity, with [t] showing the greatest activity on the three tongue electrodes, [s] less, and [ʃ] least. This makes good sense if we assume that the tongue activity is concerned with raising the front of the tongue. The difference between the two speakers is chiefly in the gross amount of activity at the TT versus the MT electrode. On the basis of such a tiny speaker sample, this is hard to interpret. However, it may well reflect

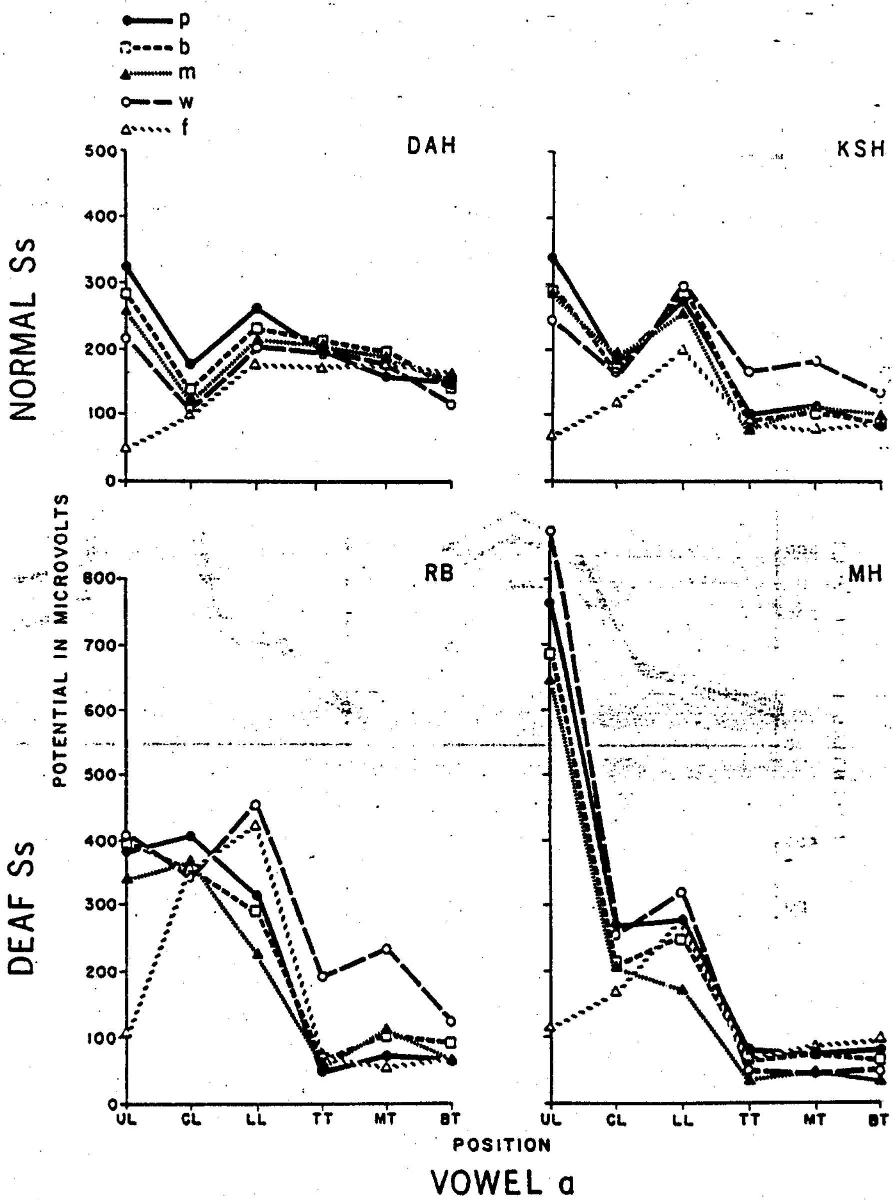

FIGURE 6. Peak activity profile for bilabials and labiodental, all subjects.

a dialect difference representing the difference between an Eastern dialect (KSH) and a General American dialect (DAH).

The deaf speakers are neither like the normals nor like each other. RB preserves the [t], [s], [ʃ] sequence in amount of activity for the three tongue electrodes but the electrode of greatest activity is the back position; MH does not discriminate the three except at the tip, where [s] and [ʃ] are contrasted with [t]. The lip electrode UL shows a great deal of activity for [ʃ] contrasted to [t] and [s].

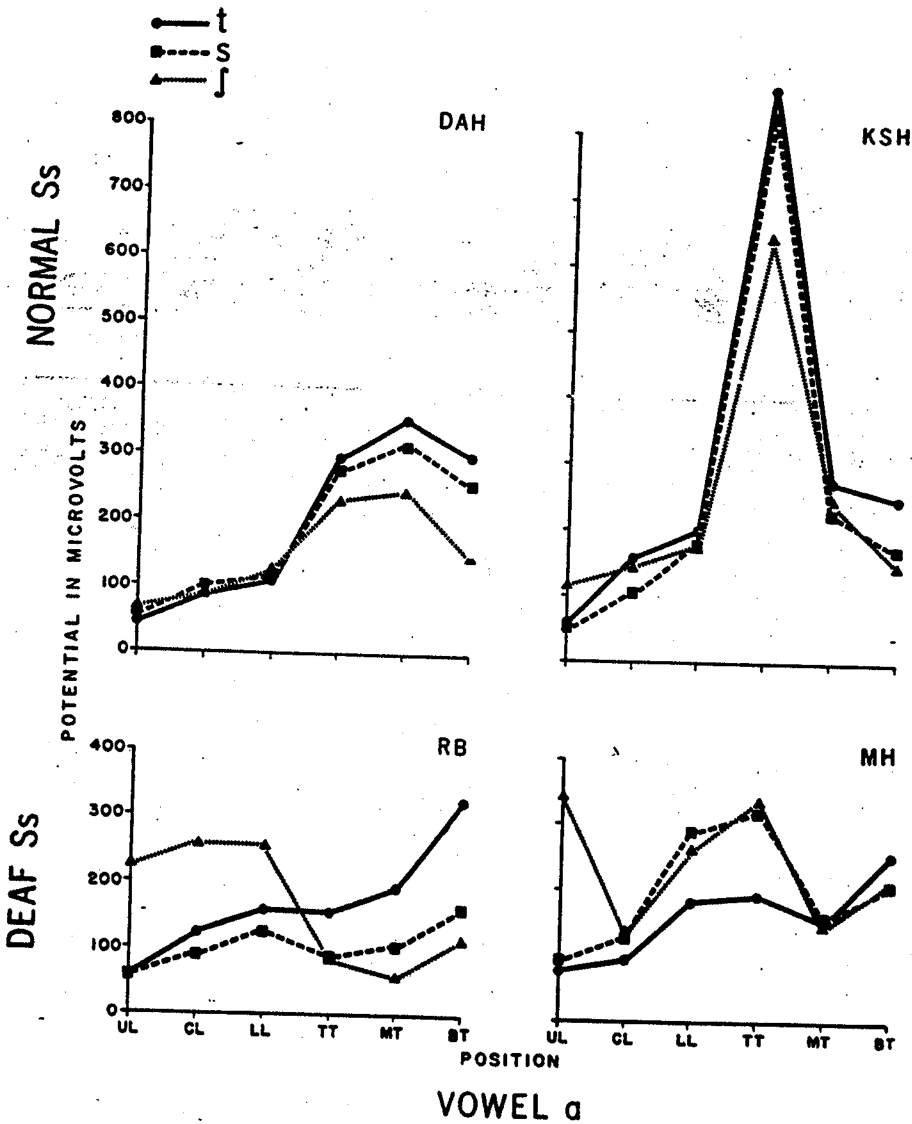

FIGURE 7. Peak activity profile for [t], [s], and [ʃ], all subjects compared.

Figure 8 shows [r] and [l] and [k]. Again, the normal subjects display reasonable internal consistency for sounds of the same class—[r] shows, as we would expect, greater lip activity. The absolute differences between KSH and

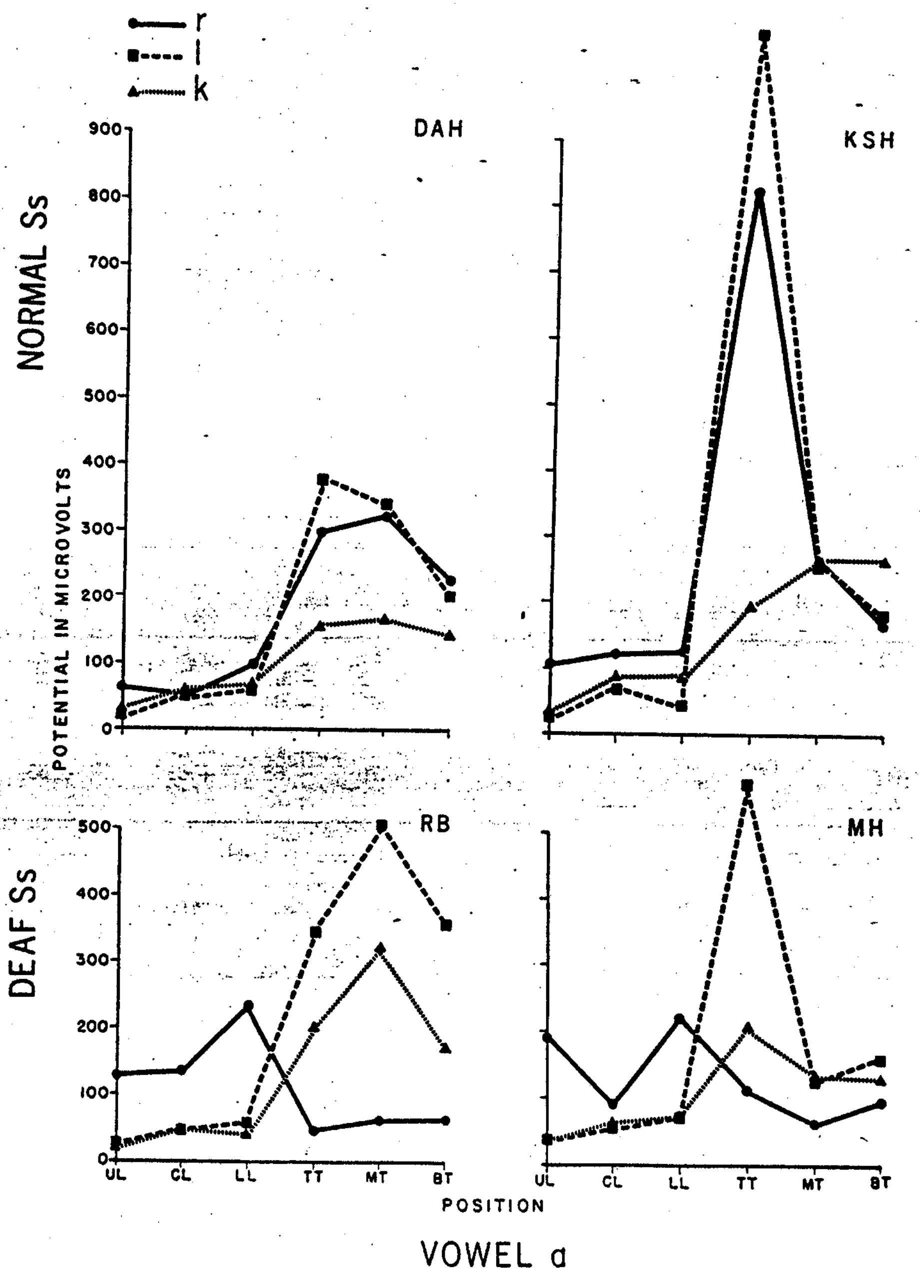

FIGURE 8. Peak activity profile for [r], [l], and [k], all subjects compared.

DAH, again may represent apical vs mesial articulation. The deaf subjects are different from each other and from the normals in that their [r] and [l] are not similar, though [l] is like the normal pattern for MH. [k] shows a great deal of activity for RB. As usual, both speakers show exaggerated lip activity on those consonants where it is appropriate for normals.

To summarize:

1. Deaf talkers have articulatory patterns which are distinctive one from another, but these patterns are not necessarily appropriate. Traditionally similar phonemes may display quite different patterns.

2. Generally speaking, our two deaf talkers have made use of visual observation of model talkers—that is, the consonants which show lip activity in normals show lip activity in deaf speakers, although it is exaggerated.

The analysis of the data just summarized has two deficiencies—it does not give us a quantitative measure of similarity and the visual displays are greatly affected by overall differences in output level for a given subject for a given electrode. These deficiencies can be overcome by summarizing the data in another fashion, by correlating the peak values for the various consonants for pairs of subjects, one electrode at a time. This was done, and the results are shown in Table 1.

Table 1. Correlations between peak potentials for consonant sets.

	Normal-Normal	*Normal-Deaf*				*Deaf-Deaf*
	DAH KSH	*DAH RB*	*DAH MH*	*KSH RB*	*KSH MH*	*RB MH*
UL	+.99	+.93	+.89	+.96	+.90	+.93
CL	+.82	+.81	+.82	+.81	+.73	+.82
LL	+.92	+.74	+.62	+.68	+.71	+.80
TT	+.91	+.45*	+.71	+.60	+.77	+.68
MT	+.70	+.26*	+.51*	+.46*	+.67	+.29*
BT	+.56	+.55	+.70	+.68	+.63	+.65
Average	+.82	+.62	+.71	+.70	+.74	+.70

*Not significant at the 0.05 level, one-tailed test.

The pattern of correlation within the table is quite interesting. First, and probably most important, all the correlations are positive, and all but 5 of the group of 36 are significantly so. This means that all speakers have a tendency to produce more or less potential for the same consonant, at all electrode locations. However, normal speakers are more like each other than they are like deaf speakers, or than the deaf speakers are like each other; in five out of six cases, the normal-normal correlation is the highest for that electrode, or as high as any. The deaf-deaf correlations are in the same range overall as the deaf-normal—that is, the deaf speakers are no more like each other than they are like normals.

The correlations are interesting also from the point of view of the individual electrodes. The UL and CL positions show the highest positive correlations;

furthermore, the deaf speakers correlate very well with normals—probably because they have good visual information on normal lip articulations. As we recall, the deaf *absolute* levels are very high on the UL electrode particularly; obviously, however, the relative levels for the various consonants are reasonable. On the visual aid hypothesis, we might expect LL to behave like UL and CL; it does not. We have no idea whether deaf performance is not more like normal because the muscles responsible for the potentials observed are less visible, or because teachers of the deaf explain LL action less well.

On the tongue, the BT position is not very interesting. An examination of peak heights shows that the range is not very large for any subject. However, for TT and MT, we have a clear pattern of greatest correlation for KSH and DAH, with lower correlations for deaf and normal speakers. To resummarize:

1. Deaf speakers are more likely to be like normal speakers where there is a possibility of getting visual feedback.
2. Deaf speakers are no more like each other than they are like normal speakers.
3. Overall, the whole matrix of speaker intercorrelations is positive and, in most cases, significantly so. This can be interpreted to mean that the topology of deaf articulation is not totally uncorrelated to normal pattern.

DISCUSSION

To return to our original question about the abnormalities present in deaf speech: it seems unlikely that the unintelligibility of the speech of the deaf talkers can be accounted for on a topological basis only. As we indicated earlier, listeners who judged tape recordings of the air microphone output that was taken simultaneously with the myographic recordings found a substantial difference in the intelligibility of the two talkers; this difference is not reflected in a higher correlation of RB's scores with the normals than those of MH. The data show that the speaker's problems are partly topological, but not entirely.

A question about deaf speech which is of great therapeutic importance is whether it is possible to form satisfactory topological speech habits on the basis of visual models. The performance of these deaf talkers was comparable to normal on "lip habits" where visual information would be available. Presumably, visual information about tongue position could be used by the deaf, if it were available in suitable form. The exaggeration in lip potential magnitude might also be reduced by electromyographic visual feedback, if it were esthetically desirable.

We are presently performing some experiments on dysarthric speakers by the techniques described in this article and a preliminary paper is being published (Shankweiler & Harris, in press) on their electromyographic patterns. We can only make qualitative comparisons thus far, but the dysarthric patterns are quite dissimilar to the deaf. Repeated utterances of a given syllable are extremely variable, while at the same time there is a tendency for all articulators to move together. In contrast, the deaf have well-organized habits, which may be "correct" or "incorrect" by comparison with normals, but are not dissimilar in kind.

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