FRICATIVE CONSONANTS AND THEIR ARTICULATORY TRAJECTORIES

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ABSTRACT

Articulatory paths relevant to the production of some fricatives are related to the changing acoustic patterns as seen on spectrograms. Two techniques are used: aerodynamically derived area (A) traces and electropalatography (EPG) contacts. [pVCV] sequences are analysed.

1. INTRODUCTION

Better descriptions are needed for the production of fricative consonants: Fricatives in speech-like sequences are characterised not only by their quasi-static spectra but also by rapidly changing acoustic patterns. The latter seem to be essential for the identification of /f/ versus /θ/ and /v/ versus /ð/ [2], [3]. Phonemically, fricative consonants and adjacent vowels are considered as separate entities but in the processes of speech production there is no clear boundary between them. Between segments clearly associated with either consonants or vowels there are regions of rapid change: in these, there are changing combinations of the acoustic sources - voice, aspiration noise (generated just above the glottis) and frication noise (generated downstream from a vocal tract constriction) - as well as rapidly changing formant frequencies. Inter-articular coordination and the form of transitions for individual articulators are both important in determining how sources and filters covary across this boundary region.

The study reported here is an exemplification of part of a larger study (Grenoble, Southampton, Leeds), based on multiple analyses for two speakers. A studio recording made by the speaker provides cueing, so as to match the speaking style and rate across data gathered on different occasions and in different laboratories. Articulatory paths in the natural speech are to be copied in models of speech production [4], [1], [6]. Analysis-by-synthesis will be used to obtain good aerodynamic and acoustic matches between the natural and the simulated speech. The aim is to characterise, as general rules, the production and acoustics of the speakers' fricatives.

2. APPROACH OF THE STUDY

This paper focusses on [s] produced in phonetically controlled [V-V] contexts by one of the speakers, a woman speaker of General American English. Sequences such as [pi'sipi'sipis i...] produced on a single expiratory breath allowed subglottal pressure (PSG) to be estimated.

Two techniques for the estimation of vocal tract articulation relevant to the production of alveolar fricatives are included here. First, aerodynamic parameters are used to give an Area (A) trace, indicating the cross-section area of the alveolar constriction of the vocal tract; secondly, electropalatography (EPG) is used to show the regions of contact between the tongue and the hard palate. Articulatory paths estimated by each method in turn are time matched to spectrograms from simultaneously made recordings. In this way, part of the detailed articulatory-to-acoustic mapping is studied. An additional aim is to demonstrate that the two methods are consistent and complementary.

3. AREA (A) TRACE

3.1. Method

This is a parameter for one of the two major constrictions of the respiratory tract, the other one being the glottal area. Volume flowrate of air through the mouth, U (in cm^3/s) and oral air pressure, P (in cmH_2O) are combined, using the orifice equation with an empirical constant k=0.00076 to give:

$$A = k.U/P^{0.5}$$

The methods have been described elsewhere [5], [7]. The A trace is not the true value of the minimum cross-section area for the alveolar ridge portion of the vocal tract, and may be expected to depend on the taper angle into and out of the constriction and its length. Total airflow through nose as well as mouth is recorded, but checks showed that all the airflow was through the mouth for the sequences analysed. Oral air pressure is taken as pressure drop across the constriction but actually includes any pressure drop across the teeth and lips also. The method has the advantage that it links articulation and aerodynamics in a way that is internally consistent and consistent with the descriptive framework of one of the composite models [7] in which it is to be used.

3.2. Results

Figure 1 shows an example of the aerodynamic traces, with some of the simultaneously obtained acoustic traces.

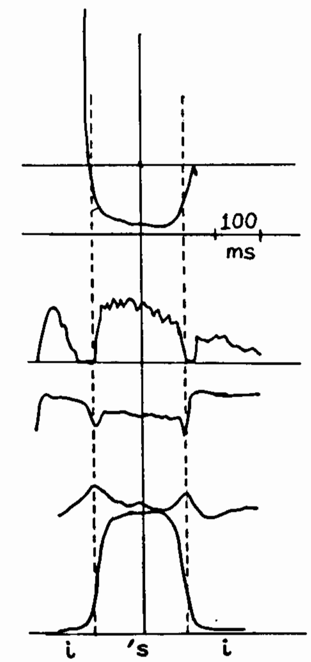

Figure 1. Articulatory, aerodynamic and acoustic traces as functions of time, for the third in a series of [(p)i'si(p)]. from top to bottom: Area A, with a line at 0.2 cm^2; I.L. H.P. filtered at 3.9 kHz, I.L. H.P. filtered at 500 Hz; Oral (total) volume flowrate of air U; oral air pressure P.

An auditory check confirmed that this

was an acceptable example of [i'si]. Figure 2 shows the relationship between the articulatory trace and the acoustics.

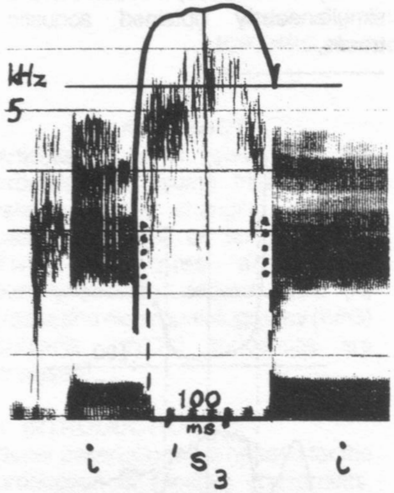

Figure 2. Area (A) trace from Figure 1, inverted, combined with spectrogram (frequency versus time) pattern features of the identical utterance. Time scales are matched with voice offset and onset aligned.

It may be seen that the 0.2 cm^2 threshold for the A trace goes beyond the domain of frication noise to include the boundary regions. The inverted form of the A trace may match the changing spectral pattern for the frication noise, but the evidence is not conclusive.

The peaks of airflow seen in Figure 1 and shown by the dotted lines in Figure 2 almost coincide with voice offset and voice onset shown by the dashed lines. The airflow peaks are located at the boundary region, between the frication noise segment and the vocoid, where the acoustic sources including voice and aspiration noise are changing rapidly.

4. EPG DATA

4.1. Method

EPG data for the fricatives in the same [...pV'-Vp...] context are analysed as follows: the number of contacts is determined for: the first, second and third lines of contact (*front*, shown by a solid line) and the fourth to the eighth line (*back*, shown by a dotted line). The results are plotted on a grid which shows time vs number of contacts. The two resulting traces represent changes in the amount of contact between tongue and palate for the front and the back of the mouth; transitions from and to vowels are investigated.

4.2 Results

Figure 3 shows the relationship between the articulatory traces and the acoustics for a representative example of [i'si].

A threshold (indicated by the arrow in Figure 3) was chosen to define the quasi-static segment observed for all of the fricatives analysed so far. It was found that this threshold corresponds rather closely with the frication noise segment. The match is excellent in this example.

The contact for the back portion of the tongue, however, decreases during the frication noise segment. This may perhaps indicate a lowering of the tongue dorsum similar to that observed by Wood [8] on X-ray traces. As Wood suggests, this may enhance the acoustic separation of front and back cavities. Referring back to the noticeable change in spectrum during this portion of a different production of the same fricative, seen in Figure 2, this explanation seems a plausible one. The speaker appears to be tuning the front cavity resonance.

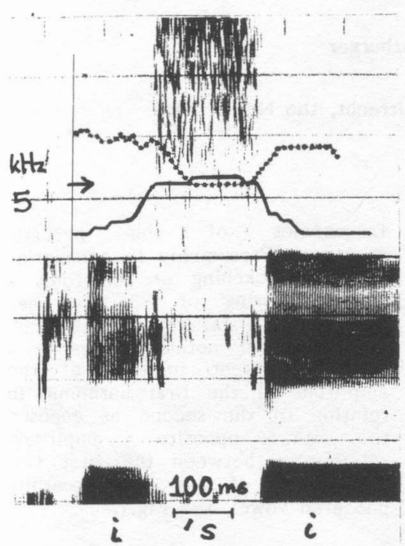

Figure 3. EPG contact traces combined with spectrogram pattern features (solid line for front contacts, dotted line for back contacts).

5.CONCLUSION

The area trace seems to define a wider domain than does the front contact shown by the EPG data. The area trace may reflect changes in the overall tongue configuration such as that discussed above, and possibly mouth outlet shape also. This interpretation of the two kinds of articulatory data will be tried out in the modelling.

6. ACKNOWLEDGEMENT

The work was funded in part by a collaborative EC SCIENCE award: CEC-SCI * O147C (EDB).

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