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ACOUSTIC THEORY OF LATERAL CONSONANTS: SWEEP-FREQUENCY (AND OTHER) EVIDENCE.

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The acoustic theory of the production of lateral sounds, as it stands, follows the acoustic theory of vowels in tending to seek, albeit rather cautiously and with some risk of oversimplification, physiological correlates likely to be affiliated with the various spectral properties (resonances and antiresonances) which laterals exhibit.

Fant's pioneering work <u>Acoustic Theory of Speech Production</u> (1960) on which that theory is very largely based, was derived from data on the two laterals in Russian, both postdental, one palatalized, the other often called velarized but which in Fant's X-ray tracings looks more pharyngealized. The objectives of the present work have been to extend this body of data to at least five different lateral articulations, and to investigate the implications of this fuller body of data (a) for the acoustic theory of the transfer function of laterals and (b) for a physiologically-based model of the lateral dimension of tongue displacement.

The five lateral sounds under consideration are shown in Figure 1 which summarizes some of their acoustic properties. All the laterals are voiced and non-fricative.

- [l̪] a <u>dental</u> with some <u>palatalization</u>, as occurring in Irish, or French adjacent to close front vowels;
- [l] an <u>alveolar</u> tending to "clear" as observed in RP, German;
- [ɫ] an <u>alveolar</u> with <u>tongue-root retraction</u> or <u>pharyngealization</u> as in American English, or Arabic;
- [ɭ] a <u>retroflex</u>, tongue-tip making <u>postalveolar</u> contact as in Tamil, Swedish;
- [ʎ] a <u>palatal</u>, tongue-tip lowered as in Castilian Spanish and Italian.

For the present discussion, frequency measurements have been averaged over each of three vowel contexts of approximately [li la lu] quality, and over all male speakers. The data in Figure 1, derived from sweep-frequency measurements, represent the central frequencies of formants (filled data points) and of antiformants (unfilled data points), and they match closely with similar data obtained by spectrographic measurements, which are not presented here.

The standard view that a palatalized [l̪] derives its F_2 from a half wavelength of the mid and back cavities (behind the closure), and is thus comparable to [i], is apparently valid and extendable to the clear alveolar and the palatal. As predicted, F_2 is highest when the cavity length is smallest, namely for [ʎ]; and the dental's F_2 is higher than the alveolar's, not because its total cavity length is shorter (it is not), but because the dental we have recorded is more palatalized.

The mid-and-back cavity volume behind [ɭ] is considerably greater, and this might correlate with the substantial drop in F_2. Dark [ɫ] always has a very low F_2, and this seems to be related to the uvular or pharyngeal constriction which it shares with back vowels.

These observations accord with existing descriptions.

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F_1 presents roughly a mirror-image to the F_2 frequency pattern, though with less variation (even allowing for the perceptual distortion of the frequency scale in Hz). We can confirm from all five laterals the general view that F_1 in laterals is uniformly low (Joos 1948, O'Connor et al. 1957, Fant 1960, Lehiste 1964, Dalston 1975).

The traditional affiliation of F_1 with the backmost cavity seems however to have poor general applicability. X-ray tracings of laterals of our kinds by Delattre (1965) and by ourselves show small pharynx cavity volumes for [ɫ], which does, as would be expected traditionally, have a high F_1; and the largest pharynx cavity volume occurs in the dental with its advanced tongue body. However, a plot of approximate midsagittal area of the pharynx against F_1 shows poor correlation over the five laterals ($r = -0.58$). This is shown as the unconnected data points in Figure 2. As an alternative explanation, since the F_1 of laterals is relatively invariable, its source might appropriately be sought (as Fant has proposed) in the cross-sectional area of the lateral constriction. This kind of data is difficult to obtain. So we have recently been making estimates of that constriction area by aerodynamic methods, calculating it from measurements of intra-oral pressure and flow-rate. These give the results shown in Figure 2 as connected data points, suggesting an extremely strong correlation in all five laterals between increased lateral constriction area and increased F_1 ($r = 0.99$).

F_4 is supposed, at least in some cases, to be a whole wavelength fundamental resonance of the whole cavity system behind the primary constriction. But that would predict a higher value for F_4 in the shorter cavity system, namely the alveolar one, which is not found.

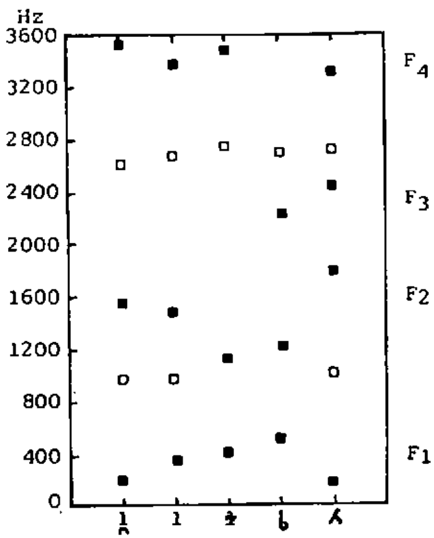

Fig 1

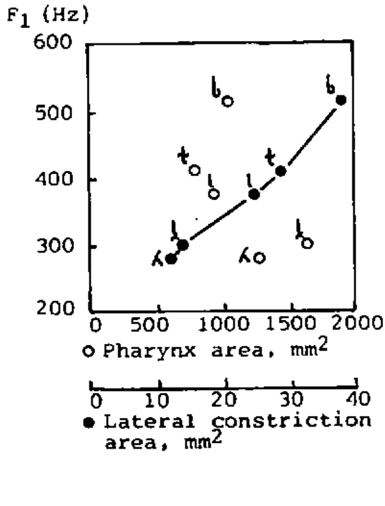

Fig 2

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The role of the formant we have called F4 is apparently much more complex than has been described. First, consider the effect of antiformants in these spectra.

An antiformant in the range 2 to 3 kHz is invariably present in these laterals, often effectively cancelling the F3 in that frequency range. Thus F4 may be regarded as assuming some of the role of F3. In particular, F_4 in a lateral may be affected by the dimensions of the anterior mouth cavity; this would cause an upward shift in the dental's F_4, with its small front cavity, as observed.

In any case F_4 may be associated in its own right with the frontmost cavity, as can be shown from independent evidence on lip-rounding in selected cardinal vowels - evidence which cannot be presented here. But there are then two reasons why F_4 in laterals, while perhaps tuned primarily by the back cavities, is seen to be appreciably shifted in response to front cavity modifications.

F_3 will be considered in conjunction with the antiresonances or zeros. Existing acoustic theory in respect of lateral zeros must be treated with caution, because in spectrograms at least two and often three spectral minima below 5 kHz can be detected. Of these minima, it is apparent from the sweep-frequency data that only one can be considered a true zero, namely that one falling in the range 2 to 3 kHz which typically eliminates a formant.

However, in the retroflex [ɭ] and palatal [ʎ] a strongish F3 is usually present, in the latter case along with an F4 also. Why is F3 maintained in these laterals, but rarely in the cases of the types surveyed by Fant? An explanation would seem to lie in the fact that the retroflex and the palatal have a larger and better defined anterior mouth cavity than do the other laterals.

If we turn to examine the antiformants, a variation in frequency is visible which is only modest, but about which we can be fairly confident, because measurement of a central frequency of the antiformant was strikingly easy from the sweep-frequency data, which consistently showed a dramatic drop in amplitude within a very narrow handwidth. However, it is difficult to explain this antiformant frequency as a function of lateral constriction length, as is traditionally done. Fant says (1960: 164) that the antiresonance frequency is a quarter wavelength of the shunting system, since that lateral cavity can be approximated by a tube closed at its far (oral constriction) end. Our calculations of lateral cavity lengths have been made from X-ray tracings of a wide variety of laterals. These show that there is consistently far greater variation in lateral cavity length (measured from the point of maximum articulatory constriction to the rear intersection of the tongue surface with the place of the underside of the upper molars)than in the observed antiformant frequency. The resulting correlation ($r = 0.55$) between measured and calculated LCL is rather unimpressive.

A spectral minimum of a different nature occurs between F_1 and F_2 at a centre frequency very close to 1000 Hz. It is of broad bandwidth; its amplitude dips less far than that of the true antiformant; and its amplitude is apparently a function of the distance $F_2 - F_1$, reducing as that distance increases. Since this minimum frequency is so uniform across all laterals, it has been suggested that it may not be a vocal-tract filter characteristic at all, but due to the voice source, specifically a subglottal shunt.

Two serious objections to this theory can be raised today: (1) other voiced sounds, such as nasals (which commonly have a formant in the middle of the debated range) and indeed vowels, would be expected to show the supposed subglottal minimum, but do not; and (2) our sweep-frequency data consistently show the presence of this spectral minimum in laterals, even though for the experimental purposes the sounds are produced with a closed glottis. This seems to argue strongly against the subglottal shunt theory. Quite possibly, this spectral minimum can be accounted for in terms of the conventional inter-formant spectral slope of the vocal-tract filter function.

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