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MODEL EXPERIMENTS ON LIP, TONGUE AND LARYNX POSITIONS FOR PALATAL VOWELS

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Abstract: Languages contrasting [y] and [i] prefer prepalatal constrictions. The larynx is low for [y] and high for [i], the lips are less rounded for [y] than for [u] and the tongue blade tends to be raised for [y]. The consequences of these manoeuvres were studied in a series of model experiments. Their advantages are twofold: they provide the best plain-flat [i]-[y] spectral contrast and they ensure stable resonance conditions in the vocal tract.

Introduction

X-ray tracings collected from the literature (Wood 1975) revealed language-specific preferences for either prepalatal or midpalatal tongue body positions for palatal vowels (Wood 1977). Languages contrasting [y] or [ʉ] qualities with [i] prefer the prepalatal position. There should be little difference of F_2 between the two positions since this formant is least sensitive to constriction location perturbations throughout the prepalatal and midpalatal region (Stevens 1972). Three-parameter model nomograms (Stevens and House 1955, Fant 1960) show that when the mouth-opening is narrowed, this zone is shifted anteriorly away from the glottis. Rounding the lips for [y], unaccompanied by other articulatory modifications would yield a vowel with F_2 more sensitive to coarticulatory displacements of the palatal constriction. There is a common belief that the tongue is retracted for

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[y], compared with [i]. This is probably a misinterpretation of the lower F_2. Retraction for [y] would take the constriction even further from the zone where F_2 is least sensitive to location perturbations, and make the vowel even more sensitive to coarticulation. Published X-ray tracings do not support retraction for [y] (Wood 1975). On the contrary, the vocal tract is often narrowed anteriorly to the prepalatal constriction (especially Danish, private communication from Eli Fischer-Jørgensen and Nina Thorsen). This is achieved by raising the tongue blade. This narrowing should occur in the zone (now advanced by lip-rounding for [y]) where F_2 is least sensitive to location perturbations. The effect of this should be to make the vowel less sensitive to lingual coarticulation. The effect of tongue body position on vowel spectra was studied in a series of model experiments by systematically altering a prepalatal configuration to a velar configuration in steps. The consequences of tongue blade raising will not be described here but will be deferred to a forthcoming report.

The larynx is lower for rounded vowels and higher for spread-lip vowels. X-ray tracings indicate an average overall range of about 15 mm for vertical larynx movement. Trained singers who have learned to control their larynxes may utilize a larger range (Sundberg and Nordström 1976). There are suggestions that larynx lowering compensates for labial undershooting (Riordan 1977), whereas X-ray films indicate that the larynx is lower the more the lips are rounded (Wood 1975, 1977), and that the lower lip alone very successfully compensates for disturbances to lip-rounding (Wood, forthcoming). I offer the following hypothesis: increased lip-rounding shifts further from the glottis the zone where F_2 is least sensitive to location perturbations; simultaneous larynx-lowering should restore that region to the vicinity of the hard palate so that the spectral consequences of tongue body manoeuvres and coarticulatory location perturbations will remain similar for all palatal vowels irrespective of rounding. To investigate this, the model experiments were repeated with both high and low larynx position.

Whenever differences of lip-rounding have been reported for [y] and [u], they have always indicated less close rounding for [y] (Lyttkens and Wulff 1885, Hadding et al. 1976, McAllister et al. 1974, Bannert et al. 1976 for Swedish; Benguerel and Cohen 1974, Riordan 1976 for French). The same can be seen on X-ray tracings of Danish vowels (private communication, as above). The closer the lips are rounded for [y] the greater is the shift away from the glottis of the zone where F_2 is least sensitive to location perturbations. I hypothesize that beyond a certain degree of rounding for [y] this zone is so far advanced that the palatal tongue gesture no longer produces its desired effect. The model experiments were repeated with four different lip conditions - spread, neutral, moderately rounded and closely rounded.

To test the generality of the results, key parts of the investigation were repeated with both longer and shorter vocal tracts. This will not be reviewed here. The check did confirm that the results would apply to all vocal tract sizes.

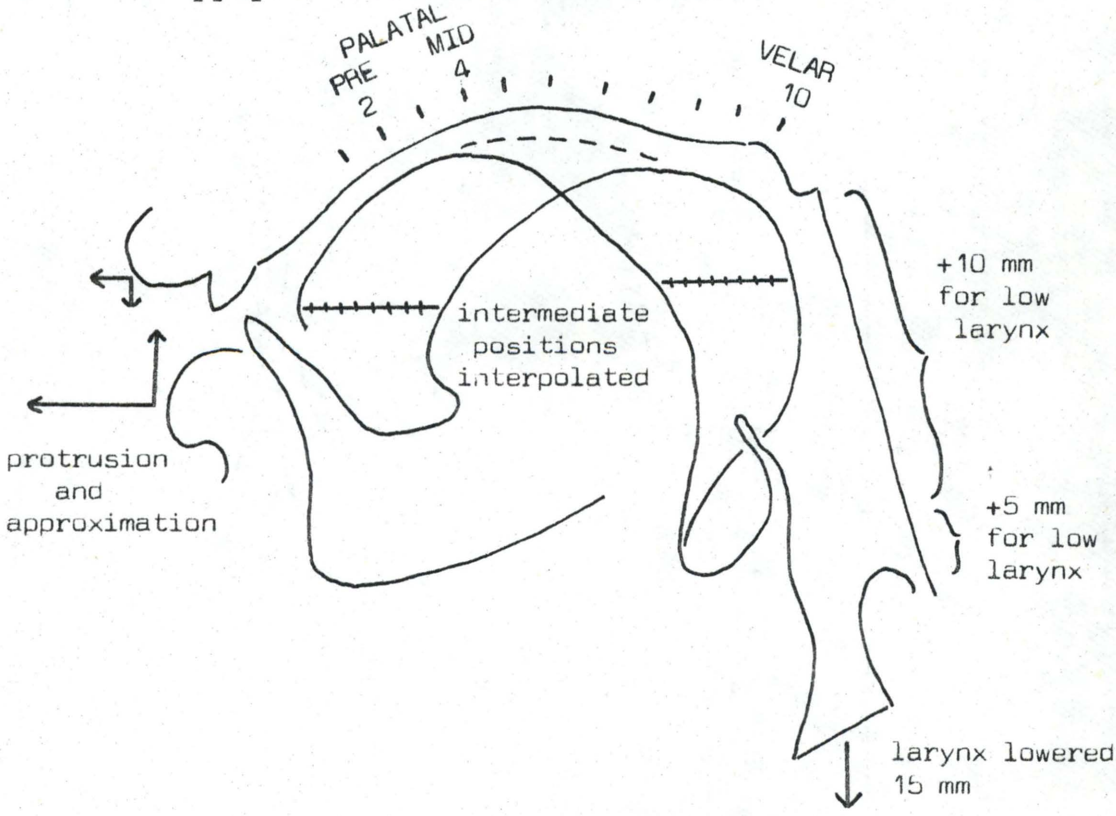

Figure 1

The modifications made to the model vocal tract: 10 tongue body positions from pre-palatal to velar, 4 lip positions from spread to closely rounded, high and low larynx positions.

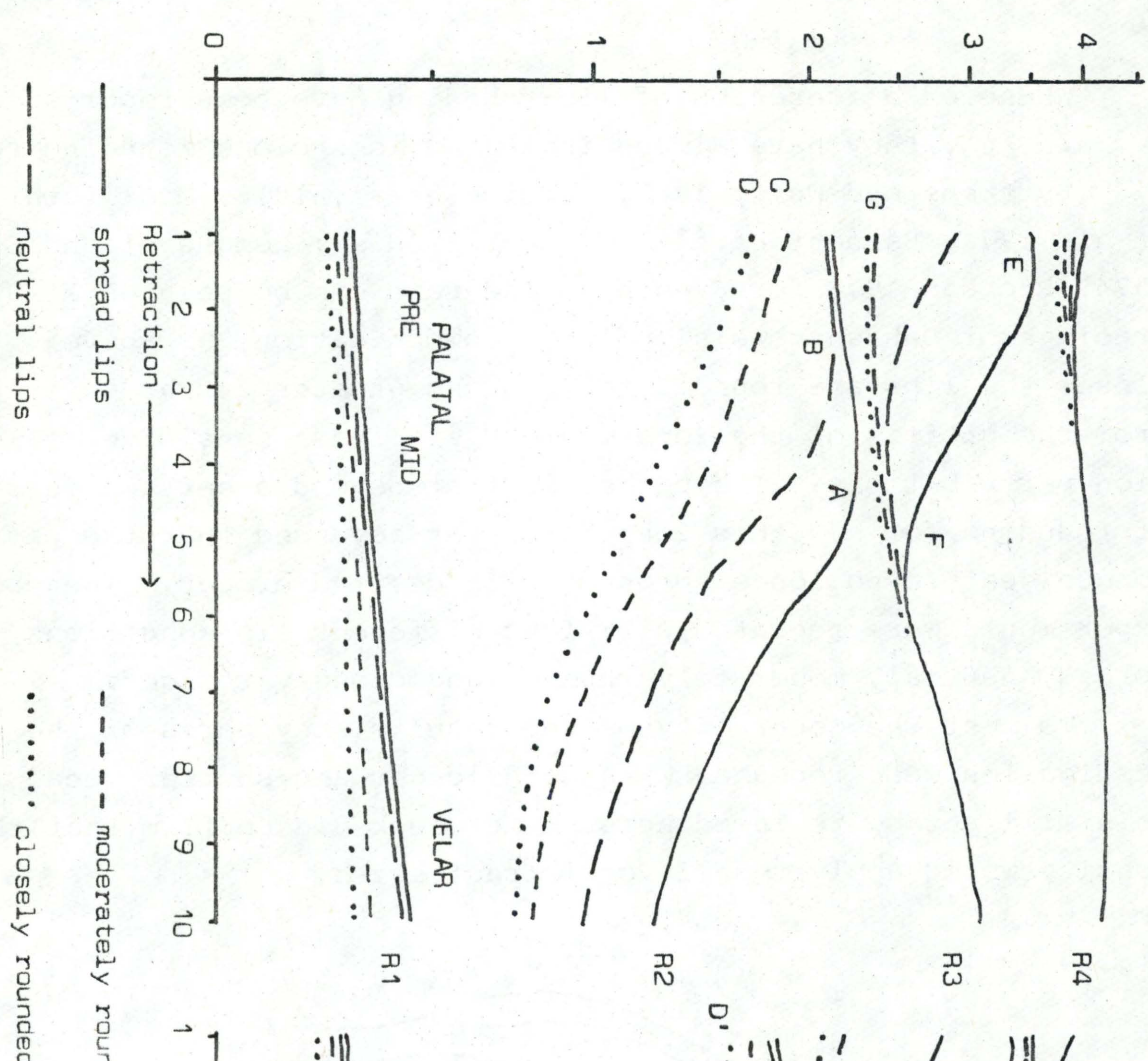

Figure 2

Consequences of four different lip positions at 10 tongue positions (high larynx).

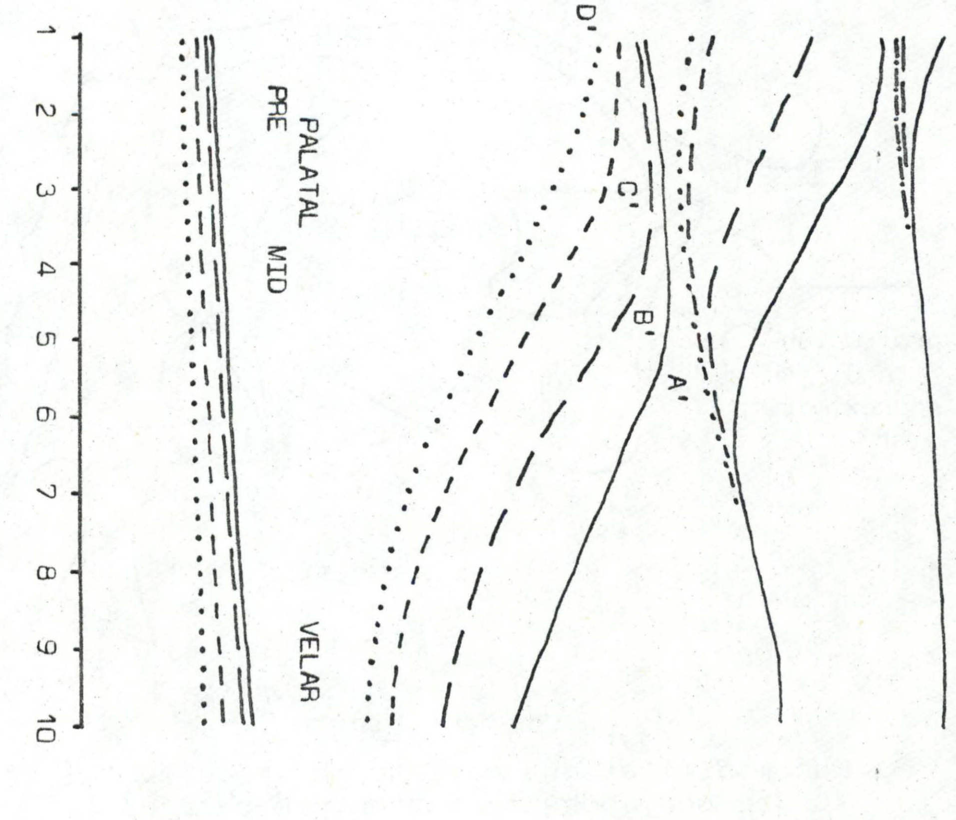

Figure 3

Consequences of four different lip positions at 10 tongue positions (low larynx).

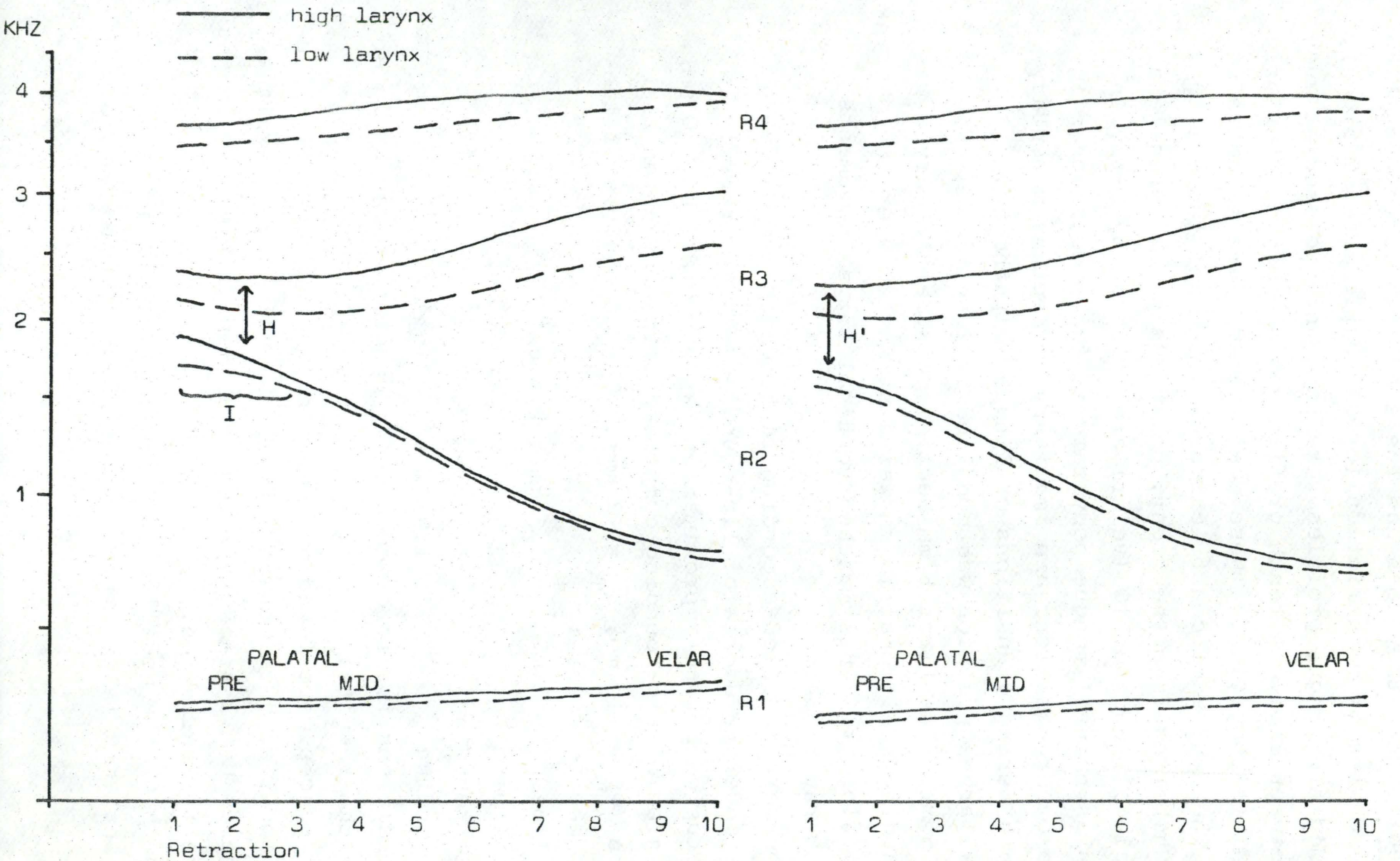

Figure 4

Consequences of larynx-lowering at 10 tongue positions (moderate rounding).

Figure 5

Consequences of larynx-lowering at 10 tongue positions (close rounding).

Procedure

Two X-rayed configurations (prepalatal [i] and velar [u]) were adjusted so that they both had the same high larynx position and the same degree of constriction (cross-section area 0.5 cm^2). Seven intermediate tongue profiles were then interpolated at even distances between them. A tenth profile was projected anteriorly to the prepalatal position. These modifications are illustrated in fig. 1. The degree of constriction was constant for all 10 profiles. Numbering from the front, positions no. 2 (prepalatal), no. 4 (midpalatal) and no. 10 (velar) are attested by X-ray investigations as natural tongue body targets for monophthongs in speech. The other positions are imaginary, except as momentary passing points during transitions or lingual diphthongs.

The low larynx position was modelled by lengthening the pharynx by 15 mm. The first 5 mm section outside the larynx was duplicated and an additional 10 mm was distributed over the pharynx above the epiglottis. This matched vertical larynx movements observed on X-ray films.

The lips were modelled according to Lindblom and Sundberg (1971). The moderate degree of lip-rounding was arbitrarily set at full protrusion but no approximation (w_m = -10 mm, h_m = 0 mm). The close degree of lip-rounding comprised both protrusion and approximation (w_m = -10 mm, h_m = -2 mm). The dimensions of the modelled lip sections were:

spread lips	0.5 cm x 2.5 cm^2
neutral lips	0.5 cm x 0.95 cm^2
moderate rounding	1.5 cm x 0.66 cm^2
close rounding	1.5 cm x 0.33 cm^2

Resonance conditions for intermediate lip conditions can be interpolated from the results.

The resonances were found by computing the pressure distribution in the modelled vocal tract for increasingly higher excitation frequencies until standing waves were found. The only losses included were for radiation.

The length of the modelled vocal tract from the glottis to the central incisors (high larynx) was 14.5 cm. Three X-rayed male subjects had this length for [i]. Two others had 15 cm. The corresponding measure for Fant's Russian subject was 16 cm.

Results

Fig. 2 shows how the frequencies of the first four resonances changed when the tongue body position was retracted in 10 steps from pre-palatal to velar, for four different lip positions and high larynx. Fig. 3 shows the same for the low larynx. Fig. 4 shows the consequences of larynx-lowering at the 10 tongue body positions with moderate lip-rounding. Fig. 5 shows the same for close lip-rounding.

Discussion

For spread lips and high larynx, F3 was high with the pre-palatal tongue position (E on fig. 2) and low with the midpalatal position (F on fig. 2). This is why the prepalatal [i] sounds sharper than the midpalatal [i]. It is well known that for the plain-flat spectral contrast all the formants are lowered for [y] relative to [i] and the spectrum is "flattened" by bringing F3 close to F2. Fig. 2 (or fig. 3) shows that lip-rounding lowered F1 and F2 generally, F3 only for anterior tongue body positions and F4 hardly at all. Fig. 4 (or fig. 5) shows that laryngeal depression lowered F4 and F3 generally, F2 mainly for anterior tongue body positions and F1 slightly. These consequences of lip-rounding and larynx-lowering are predictable from acoustic theory (Fant 1960, pp. 63 and 64). For lowering the individual formant frequencies of palatal vowels, lip-rounding and laryngeal depression are complementary rather than interchangeable, except with the prepalatal configuration where the two manoeuvres combine to lower F2 and F3 (although the 200-300 Hz laryngeal contribution to F3 was small compared with the labial contribution). With the prepalatal configuration, lip-rounding lowered F3 much more than F2 (about 1000 Hz and 300 Hz respectively). It is this very large lip contribution to F3 of the prepalatal [y] that brings F3 close to F2 to flatten the spectrum. With the midpalatal configuration the situation was reversed: lip-rounding lowered F2 more than F3 and consequently the difference between F3 and F2 actually increased. Lip-rounding does not flatten the spectrum with a midpalatal configuration. Only the prepalatal position is favourable for spectral flattening.

The effect of degree of lip-rounding, tongue body position and larynx-lowering on the plain-flat spectral contrast can be studied in figs. 4 and 5. With moderate lip-rounding (fig. 4) and high larynx, retraction from the prepalatal position caused F2 and F3 to diverge (H) with consequent loss of spectral flattening. With the larynx lowered, the F2 and F3 curves were virtually parallel in the prepalatal region (I) so that coarticulatory location pertubations would have no appreciable effect on spectral flattening there. With close lip-rounding (fig. 5) retraction caused F2 and F3 to diverge (H') whether the larynx was high or low. Thus, moderate lip-rounding, with the prepalatal configuration and low larynx, is the more favourable combination for preserving the flattened spectrum of [y] (and hence the plain-flat contrast) against coarticulatory location perturbations.

The results illustrate Stevens's finding that F2 of [i] is hardly sensitive to location perturbations. For spread lips and high larynx, F2 varied about 5 Hz per mm of constriction displacement within the prepalatal and midpalatal region (A on fig. 2). At tongue body positions further back than mid-palatal, F2 was very sensitive to location perturbations and fell about 50 Hz per mm of retraction. F_2 of [i]-like vowels is very similar at both the prepalatal and midpalatal positions. With neutral lips and high larynx the least sensitive zone of F2 is more anterior (B on fig. 2) as anticipated. For the two rounded conditions the least sensitive zone is considerably advanced (C and D on fig. 2).

With the larynx lowered 15 mm the least sensitive zone of F2 was less advanced and was located in the palatal region (A', B', C' on fig. 3), as hypothesized. For moderate lip-rounding, the least sensitive region of F2 coincided with the prepalatal constriction (C' on fig. 3), while F2 was still very sensitive to location perturbations at the midpalatal position. In this respect, the prepalatal tongue body position, with moderate lip-rounding and lowered larynx, is more favourable for [y]. The midpalatal position is less favourable, even with the lowered larynx.

With close lip-rounding, the least sensitive zone for F2 is very much advanced even with the larynx lowered (D' on fig. 3). In this respect, close lip-rounding is less favourable for [y] at either tongue body position and with any larynx height. Other experiments (report forthcoming) show that raising the tongue blade will in this case make F2 less sensitive to location perturbations.

Conclusions

The prepalatal position is more favourable for the plain-flat contrast. F3 is high in [i] and low in [y], providing the greatest contrast. F_3 is lowered more than F_2 by lip-rounding so that both formants come closer together in [y], ensuring spectral flattening. The midpalatal position is less favourable since F3 is already low for [i], providing a smaller [i]-[y] contrast. Further, lip-rounding lowers F_3 less than F_2 so that the [y] spectrum would not be flattened.

With more than moderate lip-rounding, the spectral flattening of [y] becomes increasingly sensitive to lingual coarticulation, F2 and F3 responding differently to location perturbations. With moderate lip-rounding and the larynx lowered, F2 and F3 respond similarly to location perturbations throughout the prepalatal region so that the spectral flattening of [y] is safeguarded against coarticulatory location perturbations.

The laryngeal contribution to formant frequency lowering for prepalatal [y] is small compared with the labial contribution. I conclude therefore that the main function of larynx-lowering for [y] is to stabilize resonance conditions with the consequence that lingual gestures have a similar effect on the formants of both spread-lip and rounded palatal vowels. This requires the larynx to be lower as lip-rounding increases, a correlation that can be observed on X-ray films. This stabilizing effect can be backed up by raising the tongue blade.

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