First formant difference for /i/ and /u/: A cross-linguistic study and an explanation

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When the acoustic space that can be reached by a realistic articulatory model (Mermelstein, 1973) is explored systematically, an interesting asymmetry between front and back vowels is found (de Boer, 2009). The first formant of the highest possible back vowel [u] is lower than the first formant of the highest possible front vowel [i]. In order to test this observation in real languages, the value of the first formant of the highest back and highest front vowels has been determined for near minimal pairs in a sample of 30 languages: !Xõõ, Banawa, Basque, Berber, Bukiyip, Burmese, Finnish, Fulfulde (Maasina), Greek, Guarani, Hawaiian, Hebrew, Hindi, Italian, Japanese, Kannada, Korean (Cheju), Luo, Malay (Pattani), Norwegian (Bokmål), Pitjantjatjara, Q'eq'chi, Quechua, Serbian, Swahili, Thai, Turkish, Welsh, Yoruba, Zapotec (based on Greenberg's (1963) sample). Publicly available data from the UCLA Phonetics lab archive were used except for Italian and Japanese (http://archive.phonetics.ucla.edu/ retrieved October 2009).

It was found that for 29 out of 30 languages the average of the first formant is higher for the highest back vowel than for highest front vowel ($p = 5.8\times10^{-8}$ using the sign test) . In addition, for 26 out of 28 languages (for two languages only averages were available) the majority of minimal pairs have a higher first formant in the highest back vowel than in the highest front vowel ($p = 4.2\times10^{-7}$ using the sign test). A trend towards smaller differences was found in women, but this is not significant in the present data set (median 27 Hz in women, and 50 Hz in men, $p = 0.16$, using the Wilcoxon rank sum test).

This phenomenon could be explained by anatomical constraints. Acoustical analysis shows that abrupt transitions are needed for producing minimal formant frequencies, while gradual transitions are necessary for maximal formant frequencies (de Boer, 2008). In fact, for producing an ideal [u], three abrupt transitions in the area function are necessary. As the human vocal tract consists of soft, flexible tissue, it is much easier to make controlled gradual transitions in the area function than to make controlled abrupt transitions. This allows for a better approximation of the ideal [i] than of the ideal [u]. The most noticeable effect is on the first formant, and this would explain why the highest front vowels of languages tend to have lower first formants than the highest back vowels.

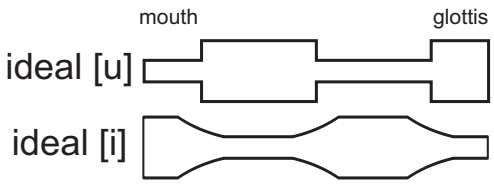

Fig. 1: Tracts for ideal [u] and [i].

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