

**Pronunciation Teaching Methods of English Tense/Lax Vowels, /u:/ and /ʊ/
Based on Vowel Tenseness, θ_1 and $F_{tense}(t)$:
A Quantitative Study of Japanese Tense and Lax Vowels, /uR/(HL) and /uR/(LH)**

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To date, vowel tenseness has been discussed discretely in two ways: tense and lax. A definition based on a quantitative scale in any language has never been developed. Regarding vowel tenseness, Jakobson, Fant and Halle (1951) and Chomsky and Halle (1968) pointed out the relationship between tenseness and vocal tract. Ishizaki (2019, 2022) followed their idea and used the formant angles, θ_1 and θ_{F1} , and the first derivative $dZ1(t)/dt = \lim \tan\theta_1(t)$ to consider vowel tenseness. He made an indirect quantification of vowel tenseness within the duration of vowels.

In this study, we investigated θ_1 , the second derivative $a_{tense(t)} = d^2Z1(t)/dt^2$, and the Force of Tenseness $F_{tense}(t) = mkd^2Z1(t)/dt^2$ for English tense/lax vowels, /u:/ and /ʊ/, and Japanese vowels, /uR/(HL) and /uR/(LH). Based on these data, we considered the pronunciation methods of /u:/ and /ʊ/ in consideration of the time dependence of vowel sound quality.

The formant angle θ_1 for the Japanese vowel /uR/(HL) was significantly different from the one for the Japanese vowel /uR/(LH) ($p < .001$). Regarding Japanese vowels, /uR/(HL) and /uR/(LH), which are classified as close vowels in articulatory phonetics, there was a correlation between vowel tenseness and pitch accents ($r = 0.505$).

We identified a statistically significant difference in the formant angle θ_1 between English tense/lax vowels, /u:/ and /ʊ/ ($p < .001$). Based on the data, we devised pronunciation teaching methods of /u:/ and /ʊ/ for Japanese speakers, taking into account the time dependence of vowel tenseness and formant frequencies.

We also calculated the Force of Tenseness $F_{tense}(t)$ and showed that it is theoretically possible to compare the estimated force applied to the oral cavity in the vertical direction during vowel pronunciation between any languages, such as Japanese and English.

A comprehensive study on pronunciation teaching methods of English vowels /i:/, /ɪ/, /u:/, and /ʊ/ was conducted for Japanese speakers. There is a possibility that vowel tenseness in English can be realized by using the pitch accents of Japanese vowels.

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