

Coordination of tongue and lips in Taiwan Mandarin high rounded vowels

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A traditional view holds that the two high rounded vowels in Taiwan Mandarin, /y/ and /u/, contrast mainly in their tongue positions and share the feature of lip roundedness. However, the association of rounded lips does not guarantee uniformity in lip postures—such as protrusion, compression, or aperture area—as observed in other languages (cf. endolabial vs. exolabial in [1, 2]). A more recent study reported that /y/ requires more lateral pull, indicating greater distances between the mouth corners, than does /u/ [3]. The latter is associated with a more circular round posture, while the former is linked to a more laterally compressed posture. It is also noted that some speakers tend to merge lip postures for /u/ and /y/ (i.e., the merged speakers) more than others (a.k.a., the contrastive speakers) and the merging can be contingent on speech registers. Crucially, lip contrasts between /u/ and /y/ can be enhanced when the tongue positions are constrained [4], which suggest reweighing between the lips and tongue. This study aims to investigate how lip postures affect tongue position contrasts between merged speakers and contrastive speakers? Specifically, this study aims to examine the interplay between the tongue and lip movements that contrast with /u/ from /y/.

Thirteen native speakers of Taiwan Mandarin (5 female, mean age = 22.2) participated in a vowel production experiment. A portable ultrasound machine (CGM OPUS 5100) was employed to capture tongue images in real time using a transvaginal curved array probe fixed by a 3D printable ultrasound transducer stabilizer [5]. A camera was set up in front of participants (at a distance of approximately 0.5m) to capture their lip movements with four melting beads attached to the nose, the center of the upper vermillion boundary, the center of the lower vermillion boundary, and the right corner of the mouth. A mirror was positioned at a 45-degree angle to the participants' midline to enable the camera to capture a side view of the melting beads. These beads were positioned in order to calculate the lip protrusion and lip aperture. Audio information was simultaneously recorded at a sampling rate of 44100 Hz. Participants were instructed to produce disyllabic nonsense words with the first syllable being /pa/ in a high-level tone, followed by a target vowel (one of /i/, /u/, /y/) matched with four lexical tones. Twenty tokens for each target syllable were collected in a random order. The interplay between the tongue and lip was quantified by comparing the dynamic change the tongue backness (measured from the highest point of the tongue), lip protrusion and the lateral pull of the lips over time. These measurements were submitted to generalized additive mixed models (GAMMs, [6]), where they were treated as predicted values. The syllables (/pa/, /i/, /u/, and /y/) were treated as fixed-effect predictors, with participants and tones included as random effects. Measurements were also submitted to functional principal component analyses (FPCA, [7]). Only the first two PCs were reported.

Results showed that Mergers demonstrated more UL protrusion for /y/ whereas non-mergers had more protrusions for /u/ in both UL and LL (Figure 1). Our results also revealed larger contrasts in tongue backness between /u/ and /y/ were observed for merged speakers than for contrastive speakers (Figure 2). FPCA results for tongue backness are associated with the largest ratios explained when combined FPC1 and FPC2 (merged: 84.6%; contrastive: 85.7%). FPCA for lateral pull also revealed substantial data explained (merged: 74.3%; contrastive: 77.2%). More protrusion data were explained for lower lip (merged: 73.1%; contrastive: 77.2%) than for upper lip (merged: 47.6%; contrastive: 68.2%).

Our results first confirm that differentiated lip postures between /u/ and /y/ may not be fully manifested in all individuals. Second, the contrast of tongue backness between /u/ and /y/ was more robust for non-mergers than that for mergers (Figure 2). For non-mergers who demonstrated more distinct lip contrasts, the degree of contrast in tongue backness was less pronounced. In contrast, for mergers (i.e., those showing less lip contrast), a greater contrast in tongue backness was observed. Crucially, no difference in acoustics for both speaking groups suggests that variations can happen only

at the level of articulatory postures while acoustic targets remain unaffected. Taken together, these findings suggest that the differentiation between /u/ and /y/ is coordinately contributed to by both lip and tongue positioning, which act together as a functional unit. Within a functional unit, when one posture is more variable, the other would be more contrastive in order to achieve the intended target. This interpretation aligns with the concept of motor equivalence, which will be discussed further.

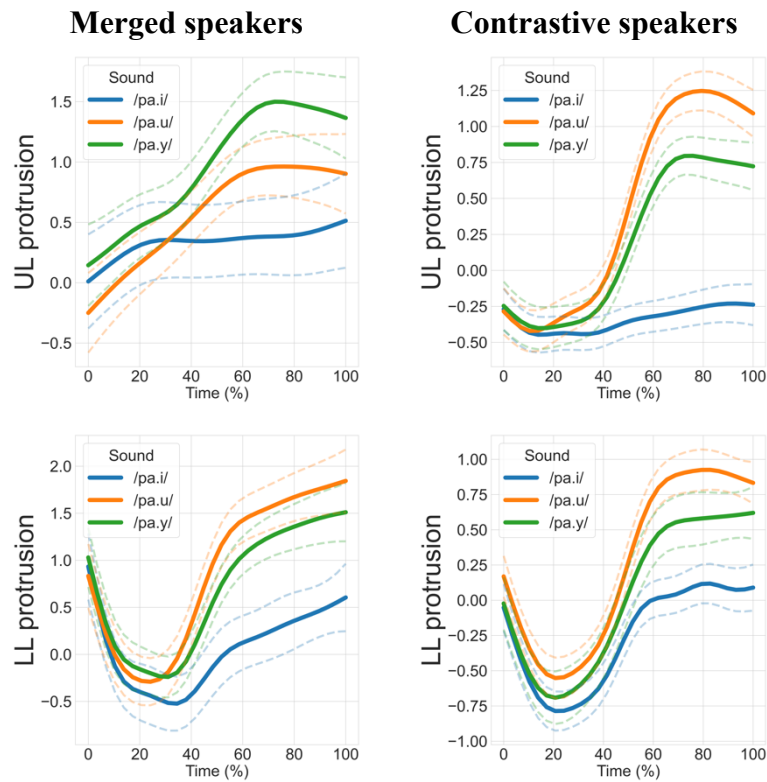


Figure 1. GAMM smooths results of lip protrusion for merged (left) and contrastive speakers (right).

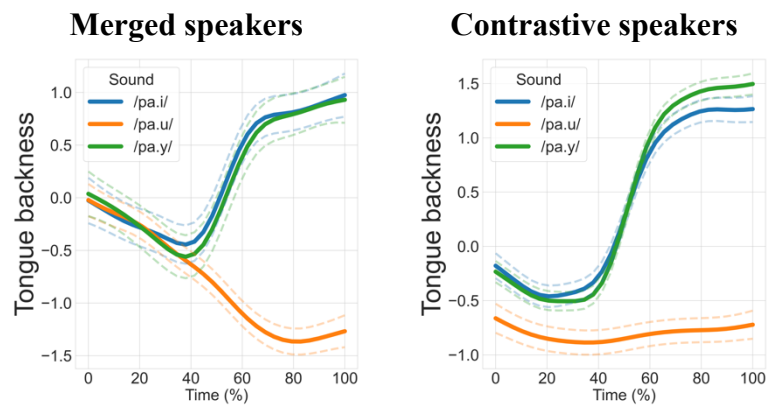


Figure 2. GAMM smooths of tongue backness for merged (left) and contrastive speakers (right).

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