The effects of ultrasound biofeedback on vowel acoustics

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Ultrasound biofeedback has been applied in second language (L2) pronunciation teaching for decades, with many studies showed positive impacts on L2 pronunciation [1, 2, 3]. However, several studies provided mixed results from different training consonants [3, 4] and vowels [5, 6]. Insofar, the effects of ultrasound biofeedback on vowel acoustics remains unexplored. The current study aims to tackle this issue and to investigate how vowel dimensions influence the training effects.

Twenty-eight native speakers of Taiwan Mandarin (12 males, mean: 23.3 year old) who have not learnt the training vowels prior to the experiment were recruited. The training vowels were Cantonese /ɐ/ and Japanese /ɯ/, designated for vowel height and vowel frontness trainings, respectively. Participants received a 20-minute ultrasound biofeedback training session for each training vowel. During the session, participants would see real-time ultrasound tongue images with a superposed target contour. When hearing a syllable, they were asked to mimic the sound and, in the meantime, move their tongue toward the target. There were 20 blocks with 15 syllables each, yield 300 trials for one training session. Pre-training and post-training tests were administered to assess the training effects. The ultrasound tongue images and acoustic signals were recorded simultaneously, and a 3D-printed transducer stabilizer [7] was applied throughout the experiment.

To quantify the training effect on the acoustics performances. Mahalanobis distances (MD) between the target sound and individual tokens in F1 × F2 vowel space were calculated, serving as an index of accuracy. Larger MD differences between pre- and post-training suggest stronger improvement in *accuracy* after training. Meanwhile, the area of ellipse (AE) enclosing a 95% CI from the tokens in F1 × F2 vowel space delineates production variability. Larger AE differences between pre- and post-training indicate stronger improvement in *precision* after training. One-tail *t* test was applied to see if there is a positive training effect and paired-*t* test was employed to see if the training effects from different vowel dimensions are significantly different. Besides, to get the number of participants who improved, if the difference reached 10% of the pre-training test, it would be seen as an individual improvement.

Several findings were obtained from the results. While our articulatory results suggest that learning the difference in the vowel height dimension is easier than that in the vowel frontness dimension, the acoustic results showed the absence of accuracy improvements between pre- and post-training (vowel height: 5.28, $p = .481$; vowel frontness: -5.08, $p = .115$) despite a significant difference between the two ($p < .05$). Second, the trends of individual improvements from the vowel height training (Table 1) were similar between articulatory and acoustic data, where most people improved only in accuracy not in precision. On the other hand, the trends of individual improvements from the vowel frontness training (Table 2) revealed that participants improved either both accuracy and precision or none in terms of articulation while they mostly improved only in precision in terms of acoustics. Collectively, our results provide supportive evidence that different vowel dimensions may induce different biofeedback training outcomes. These results could further offer suggestions for customized training in both L2 pronunciation pedagogy and language therapy.

Table 1. The numbers of participants and ratios (in parentheses) showing accuracy and precision improvements during the vowel height training

Acoustics	Improved *accuracy*	No improved *accuracy*	Total
Improved *precision*	4 (14.3%)	6 (21.4%)	10 (35.7%)
No improved *precision*	14 (50.0%)	4 (14.3%)	18 (64.3%)
Total	18 (64.3%)	10 (35.7%)	28 (100.0%)

Table 2. The numbers of participants and ratios (in parentheses) showing accuracy and precision improvements during the vowel frontness training

Acoustics	Improved *accuracy*	No improved *accuracy*	Total
Improved *precision*	2 (7.1%)	15 (53.6%)	17 (60.7%)
No improved *precision*	4 (14.3%)	7 (25.0%)	11 (39.3%)
Total	6 (21.4%)	22 (78.6%)	28 (100.0%)

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