



Effects of Language Contact on Vowel Nasalization in Wenzhou and Rugao Dialects

Yan Li, Ying Chen*, Xinya Zhang, Yanyang Chen, Jiazheng Wang

MIIT Key Lab for Language Information Processing and Applications
School of Foreign Studies, Nanjing University of Science and Technology
yan.li@njjust.edu.cn, ychen@njjust.edu.cn*, zhang_xinya@njjust.edu.cn,
ChenYanyang@njjust.edu.cn, jiazheng.wang.21@ucl.ac.uk

Abstract

This study examined the nasality of pre-nasal vowels /a, o, e/ in Wenzhou—a dialect of Wu contacting with Mandarin and Min, and pre-nasal vowels /ɔ, ə/ and nasal vowels /a, e, u, i/ in Rugao—a dialect of Mandarin contacting with Wu. Three age groups of native speakers were recruited as the talkers for each dialect. The acoustic parameter A1-P0, i.e., the differential between A1 (the amplitude of the first formant) and P0 (the extra peak below the first formant) was measured to evaluate the nasality for non-high vowels, and A1-P1, i.e., the differential between A1 and P1 (the extra peak between the first two formants) for high vowels. The statistical results reveal that the degree of nasalization varied across age group, vowel type, and point of vowel duration. Younger speakers produced overall more nasalization than the middle-aged and older speakers in Wenzhou /o/ and Rugao /ə, e, u, i/. The midpoint of vowel showed less nasalization than the start and end points in non-high vowels in both Wenzhou and Rugao dialects. These results suggest different effects of language contact on sound change in Chinese dialects.

Index Terms: vowel nasalization, coarticulation, Chinese dialects, language contact

1. Introduction

To produce nasal consonants, such as /m, n, ŋ/, speakers have to lower the velum before the articulation, which inevitably involves some overlap with the articulation of the preceding vowel [1]. This coarticulation affects the acoustic structure of the vowel and results in the nasalization of the pre-nasal vowel, which may vary across speaker, vowel, and phonetic context [1]. It was also reported that the degree of nasalization of pre-nasal vowels differed among the speakers of different languages [2]. Besides, vowel height seemed to correlate with the degree of nasalization. It was observed that low vowels were more nasalized in both VN and NV syllables due to the earlier lowering of the velum and greater amplitude of velic opening than high vowels [2].

Nasalization of vowels can be quantified via the analysis in the frequency domain to infer the size of velic opening because vowel nasalization results in spectral prominence and reduction of the first formant amplitude [3, 4]. The acoustic correlates of the nasalization are calculated on the amplitudes in dB of the first formant (A1), the nasal peak above the first formant (P1), and the nasal peak at low frequencies (P0) [3]. Specifically, the value of the parameter A1-P1 is adopted to quantify the nasalization of high vowels, whereas A1-P0 is used to measure the nasalization of non-high vowels, with the value of both A1-

P1 and A1-P0 reversely related to the degree of nasalization [3]. Based on the above-mentioned research methods and findings, this study selected Wenzhou and Rugao dialects as target languages to quantify vowel nasalization and examined it from a sociophonetic point of view.

Wenzhou City is located in the southeast of Zhejiang Province and abuts on the north border of Fujian Province. Wenzhou dialect is the southernmost dialect of Wu, a Chinese language spoken in the area from the south bank of Yangtze River to Zhejiang Province, and it is mostly in contact with Min, another Chinese language mainly spoken in Fujian. There is a velar nasal coda /ŋ/ in Wenzhou dialect, and three vowels /a, o, e/ legally precede it [5]. Rugao City is located in the southeast of Jiangsu Province. Rugao dialect belongs to Jianghuai Mandarin, a Mandarin dialect spoken in the area between Huaihe River and Yangtze River. It is greatly influenced by Wu and displays transitional characteristics between Jianghuai Mandarin and Wu [6]. Rugao dialect has both nasal vowels and velar nasal coda /ŋ/. The VN syllable and nasal vowels in Rugao dialect are /ɔŋ, əŋ, ê, ô, î/ plus a low vowel with nasal transcribed as either /aŋ/ [6] or /ã/ [7]. All Wenzhou and Rugao speakers are societal bilinguals/bidialectals. Wenzhou bilinguals acquire Wu firstly and then Standard Mandarin, and Rugao speakers acquire Jianghuai Mandarin and Standard Mandarin sequentially. Moreover, as a result of the countrywide popularization of Standard Mandarin (*Putonghua*) as the official language and the rapid development of Mandarin media in China since the late 1970s [8], the young generation in both dialects possesses earlier age of learning (AOL) Standard Mandarin, extensive amount of Standard Mandarin use, and exposure to higher quality and quantity of Standard Mandarin compared to the middle-aged and old generations.

In terms of the social bilingualism in the two cities, the present study aims to investigate the following research questions: (1) Since both Wenzhou and Rugao dialects have the only coda nasal /ŋ/ and similar nasalized vowels but contact with Standard Mandarin and Min or Wu, do native speakers of these dialects produce nasalization of the nasal rimes similarly or differently in these two dialects? (2) Since younger and older generations have different language experience of Standard Mandarin, do native speakers in distinct generations produce nasalization of the nasal rimes distinctly in Wenzhou/Rugao dialect? (3) Are there any other factors that affect nasalization of the nasal rimes in Wenzhou/Rugao dialect, e.g., vowel type and time course of the vowel?

2. Experiment 1: Wenzhou Dialect

This experiment investigates vowel nasalization in Wenzhou dialect produced by native Wenzhou speakers.

2.1. Methods

2.1.1. Participants

Eighteen native speakers of Wenzhou dialect were recruited for three age groups: younger (mean age 21.3 yrs. with SD 4.46; three females and three males), mid-age (mean age 42.3 yrs. with SD 4.31; four females and two males), and older (mean age 63.0 yrs. with SD 7.53; two females and four males). All participants are bilingual speakers of L1 Wenzhou dialect and L2 Standard Mandarin. To avoid diversity within the dialect to the largest extent, all Wenzhou participants in the current experiment were recruited from Longwan District, Wenzhou City, Zhejiang Province.

2.1.2. Stimuli

The stimuli were high-frequency words selected from [5]. The 18 real monosyllabic words consist of two initial consonants /t, ts/, three vowels /a, o, e/ with velar nasal coda /ŋ/ and three tones (mid-level, high-rising and high-falling, respectively marked as “33” “45” and “42” in the five-scale system of tone values). For tone 33, there were /taŋ/ (灯, ‘lamp’), /tsaŋ/ (针, ‘needle’), /toŋ/ (东, ‘east’), /tsoŋ/ (棕, ‘brown’), /teŋ/ (钉, ‘nail’), /tseŋ/ (蒸, ‘stem’); for tone 45, there were /taŋ/ (等, ‘wait’), /tsaŋ/ (枕, ‘pillow’), /toŋ/ (懂, ‘understand’), /tsoŋ/ (总, ‘total’), /teŋ/ (顶, ‘top’), /tseŋ/ (井, ‘well’); and for tone 42, there were /taŋ/ (炖, ‘stew’), /tsaŋ/ (震, ‘shock’), /toŋ/ (冻, ‘freeze’), /tsoŋ/ (粽, ‘dumpling’), /teŋ/ (订, ‘order’), /tseŋ/ (证, ‘proof’). The target words above were embedded in a carrier sentence in Wenzhou dialect /X, kei kai zɿ X zɿ/ (“X, this is X character”) for recording.

2.1.3. Procedure

All participants were requested to read the 18 stimulus sentences in Wenzhou dialect that were presented in a pseudo-randomized order with five repetitions. The second, third, and fourth repetitions of the first presentation of target words, i.e., the first X, in the carrier sentence in each Wenzhou talker’s production were extracted for acoustic analysis in the current study, which yielded 972 tokens (18 words × 3 times × 18 participants) in Wenzhou dialect. Note that the first and the fifth repetitions were abandoned respectively due to the potential uncertainty of the production and fatigue effect.

All recordings were conducted in the quiet rooms, using a Marantz PMD661 professional recorder and a Shure SM10ACN head-worn dynamic microphone in mono channel with a 44,100 Hz sampling rate. The sound files were digitized into an SD card to save on a personal computer.

2.1.4. Data analysis

The acoustic correlates of vowel nasalization were calculated on the value of the amplitudes (dB) of the first formant (A1), subtracted by that of the extra peak below the first formant (P0), or by that of the extra peak between the first two formants (P1), in the spectrum of the vowel [3, 4]. For non-high vowels, A1-P0 is regarded as a better measure than A1-P1 since the P1 peak is presumably not distinctly observable due to the relatively high F1 of non-high vowels; for high vowels, nevertheless, A1-P1 is a better measure than A1-P0 since F1 at a low frequency affects and is affected by the P0 peak [3, 4]. A1-P0 was measured for Experiment 1 since /a, o, e/ are all non-high

vowels. It was examined at the start, mid, and end points of the vowels preceding the nasal coda /ŋ/ in Wenzhou dialect.

All the values of A1-P0 or A1-P1 (in both Experiment 1 and Experiment 2) were automatically generated by Nasality AutoMeasurement Script (version 5.9) [9]. R (version 4.1.3) [10] was used for statistical analysis. The *lme4* and *lmerTest* packages [11] were employed to perform a linear mixed-effects model. Subject (18 subjects), repetition (3 repetitions), initial consonant (2 consonants: /t, ts/), and lexical tone (3 tones: “33, 45, 42”) were set as random factors and age group (3 levels: younger, mid-age, older), vowel type (3 levels: /a, o, e/), point of vowel duration (3 levels: start, mid, end) as fixed factors. The *emmeans* package was used for post hoc comparisons [12] and *ggplot2* package for graphics [13]. All statistical results are reported at a significance level of 0.05.

2.2. Results

2.2.1. A1-P0 for vowels /a, o, e/ in Wenzhou dialect

The mixed model ANOVA results reveal that vowel type and point of vowel duration had significant main effects on nasalization of the three vowels in Wenzhou dialect. Two-way and three-way interactions among age group, vowel type, and point of vowel duration all showed statistical significance (see Table 1).

Table 1: Mixed model ANOVA results of A1-P0 (dB) in vowels /a, o, e/ by Wenzhou speakers

| | dfNum | dfDen | F | p |
|-----------------|-------|-------|---------|--------|
| Vowel | 2 | 2871 | 164.284 | <0.001 |
| Point | 2 | 2871 | 462.555 | <0.001 |
| Age×Vowel | 4 | 2871 | 4.138 | 0.002 |
| Age×Point | 4 | 2871 | 4.732 | <0.001 |
| Vowel×Point | 4 | 2871 | 26.889 | <0.001 |
| Age×Vowel×Point | 8 | 2871 | 3.416 | <0.001 |

Tukey-HSD post hoc comparisons based on the three-way interaction demonstrate (detailed results are not reported due to the space limitation) that all age groups produced significantly more nasalization of /e/ than that of /a/ at all points of vowel duration, except for endpoint by the older group. For both /a, e/, all speakers generated significantly more nasalization at endpoint of vowel duration than the start point, followed by the midpoint, which is also graphically displayed in Figure 1.

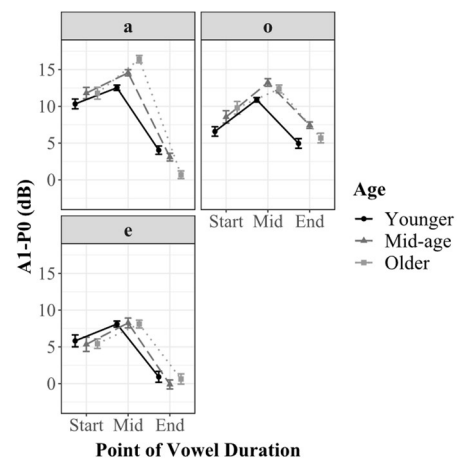


Figure 1: A1-P0 in Wenzhou speakers’ vowels /a, o, e/ by vowel type, age group, and point of vowel duration.

3. Experiment 2: Rugao Dialect

This experiment examines vowel nasalization in Rugao dialect produced by native Rugao speakers.

3.1. Methods

3.1.1. Participants

Eighteen native speakers of Rugao dialect were recruited for three age groups: younger (mean age 19.8 yrs. with SD 0.90), mid-age (mean age 42.3 yrs. with SD 5.28), and older (mean age 61.5 yrs. with SD 5.54). Each group had three males and three females. All subjects are bidialectal speakers of Rugao dialect and Standard Mandarin. To avoid diversity within the dialect as much as possible, all Rugao participants in the present experiment were recruited from Xiayuan Town, Rugao City, Jiangsu Province.

3.1.2. Stimuli

The stimuli were high-frequency words selected from [7]. The 24 real monosyllabic words consist of two initial consonants /t, s/, six nasal rimes (nasal vowels /ā, ē, ǒ, ī/ and vowel with velar nasal /əŋ, əŋ/), and two lexical tones (low-falling and mid-level, marked as “21” and “33” in the five-scale system of tone values). For tone 21, there were /tā/ (当, ‘should’), /sā/ (商, ‘business’), /tē/ (单, ‘alone’), /sē/ (三, ‘three’), /tō/ (端, ‘take up’), /sō/ (酸, ‘acid’), /tī/ (掂, ‘weigh in hand’), /sī/ (善, ‘goodness’), /təŋ/ (冬, ‘winter’), /səŋ/ (松, ‘loose’), /təŋ/ (灯, ‘lamp’), /səŋ/ (生, ‘student’). For tone 33, there were /tā/ (档, ‘level’), /sā/ (上, ‘up’), /tē/ (旦, ‘dawn’), /sē/ (散, ‘disperse’), /tō/ (断, ‘break’), /sō/ (蒜, ‘garlic’), /tī/ (电, ‘electricity’), /sī/ (扇, ‘fan’), /təŋ/ (冻, ‘frozen’), /səŋ/ (送, ‘send’), /təŋ/ (顿, ‘put’), /səŋ/ (肾, ‘kidney’). The target words were embedded in a carrier sentence /X, tsəʔ kʊ sɿ X tsʰɿ/ (“X, this is X character”) for recording.

3.1.3. Procedure

The recordings were conducted in the same procedure as in Experiment 1, which yielded 1,296 tokens (24 words × 3 times × 18 participants) in Rugao dialect. Note that five repetitions of /səŋ33/ by one male speaker in the older group were missed, leading to only 1,293 tokens for further analysis.

3.1.4. Data analysis

The present experiment analyzed A1-P0 for non-high vowels /ā, əŋ/, ē, əŋ/ and A1-P1 for high vowels /ǒ, ī/. They were examined at the start, mid, and end points of all nasal and pre-nasal vowels. Two sets of linear mixed-effects model were separately conducted for the two dependent variables A1-P0 and A1-P1. Subject (18 subjects), repetition (3 repetitions), initial consonant (2 consonants: /t, s/), and lexical tone (2 tones: “21, 33”) were set as random factors, and age group (3 levels: younger, mid-age, older), vowel type (4 levels for A1-P0: /ā, əŋ/, ē, əŋ/; 2 levels for A1-P1: /ǒ, ī/), point of vowel duration (3 levels: start, mid, end) as fixed factors.

3.2. Results

3.2.1. A1-P0 for vowels /a, ə, e, ə/ in Rugao dialect

The results of statistical analysis in Table 2 display significant main effects of vowel type and point of vowel duration on

vowel nasalization as attested by the prediction of the acoustic measure A1-P0 (dB) in Rugao dialect. Significant interactions were observed between age group and vowel type, age group and point of vowel duration, vowel type and point of vowel duration, as well as among age group, vowel type, and point of vowel duration.

Table 2: Mixed model ANOVA results of A1-P0 (dB) in vowels /a, ə, e, ə/ by Rugao speakers.

| | dfNum | dfDen | F | p |
|-----------------|-------|-------|---------|--------|
| Vowel | 3 | 2582 | 81.915 | <0.001 |
| Point | 2 | 2582 | 183.384 | <0.001 |
| Age×Vowel | 6 | 2582 | 8.258 | <0.001 |
| Age×Point | 4 | 2582 | 3.793 | 0.004 |
| Vowel×Point | 6 | 2582 | 6.970 | <0.001 |
| Age×Vowel×Point | 12 | 2582 | 2.316 | 0.006 |

Based on the three-way interaction, Tukey-HSD post hoc comparisons were conducted. The detailed data of A1-P0 were plotted in Figure 2 by vowel type firstly, then age group and vowel duration, illustrating that start and end points of vowel duration exhibited lower A1-P0 than midpoint for all vowel types by all age groups, suggesting greater degree of nasalization, except for vowel /e/ produced by mid-age Rugao speakers. Note that all the error bars in the present paper indicate SE.

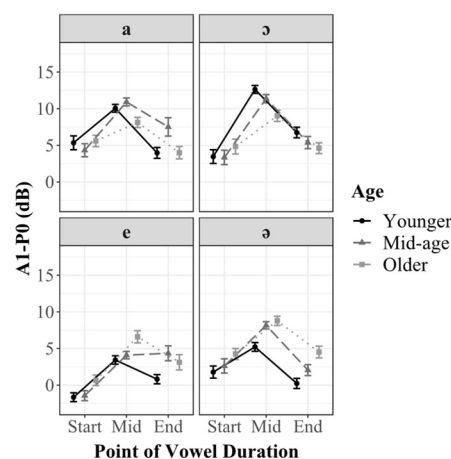


Figure 2: A1-P0 in Rugao speakers' vowels /a, ə, e, ə/ by vowel type, age group, and point of vowel duration.

3.2.2. A1-P1 for vowels /o, i/ in Rugao dialect

Another set of linear mixed-effects model was performed for A1-P1 (dB) of vowels /o, i/ in Rugao dialect. The statistical results of mixed model ANOVA demonstrate significant main effects of age group and vowel type upon vowel nasalization in Rugao dialect. Two-way interactions were found significant between age group and vowel type, and between vowel type and point of vowel duration (see Table 3).

Table 3: Mixed model ANOVA results of A1-P1 (dB) in vowels /o, i/ by Rugao speakers.

| | dfNum | dfDen | F | p |
|-------------|-------|-------|---------|--------|
| Age | 2 | 15 | 4.220 | 0.035 |
| Vowel | 1 | 1261 | 207.421 | <0.001 |
| Age×Vowel | 2 | 1261 | 6.806 | 0.001 |
| Vowel×Point | 2 | 1261 | 4.822 | 0.008 |

Post hoc comparisons were performed accordingly. The detailed data of A1-P1 were plotted by vowel type, age group, and point of vowel duration (see Figure 3). Visual inspection suggests that younger speakers produced lower A1-P1 than mid-age and older groups for both vowels, indicating greater degree of nasalization. Furthermore, /*ʊ*/ had generally lower A1-P1, thus higher degree of nasalization, than /*i*/ at all the points of vowel duration for all the age groups.

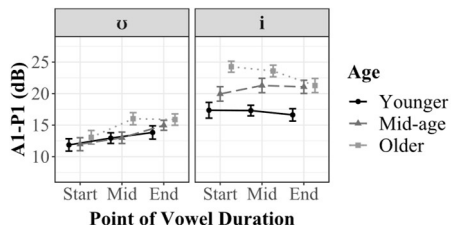


Figure 3: A1-P1 in Rugao speakers' vowels /*o*, *i*/ by vowel type, age group, and point of vowel duration.

4. Discussion

The reported results answered the first research question that the nasalization of vowels in Wenzhou and Rugao dialect produced by the native speakers were somewhat different. Two vowel types, i.e., /*a*/ and /*e*/ with nasal exist in both phonological systems of the two dialects according to the documentation [5, 7]. Comparing the A1-P0 (dB) trajectories in Fig. 1 and Fig. 2, we find that Wenzhou speakers demonstrated a drastic increase in nasalization from the midpoint to endpoint (note that the value of both A1-P0 and A1-P1 are negatively related to the degree of nasalization), while the nasalization did not rise so sharply in Rugao dialect. Statistically, A1-P0 values of /*e*, *a*/ in the endpoint were significantly lower than those in the midpoint by all age groups in Wenzhou dialect according to the post hoc comparisons (not reported in detail due to the space limitation). This phenomenon might be attributed to the fact that /*e*(ŋ)/ and /*a*(ŋ)/ in Wenzhou dialect are nasalized vowels followed by a nasal coda, which led to more nasalization when approaching the nasal murmur, while /*ẽ*/ and /*ã*/ in Rugao dialect are nasal vowels with nasalization throughout the time course of the vowel, which led to relatively high degree of nasalization from the start point. Therefore, the documented transcriptions for the two dialects [6, 7] are reasonably accurate from the perspective of acoustic analysis; /*ã*/ [7] might be a more proper transcription than /*ay*/ [6] for the nasalized /*a*/ in Rugao dialect.

Regarding the second research question, the statistical results indicate that vowel nasality varied across age groups in both Wenzhou and Rugao dialects. Age group demonstrated significant three-way interactions with point of vowel duration and vowel type for non-high vowels in Wenzhou and Rugao dialects. Albeit no three-way interaction being observed, age group significantly interacted with vowel type and also had main effect on the nasalization of high vowels /*ʊ*, *i*/ in Rugao dialect. In Wenzhou dialect, however, the younger generation produced more nasality than the other two groups at the midpoint of /*a*/ (see Fig. 1), particularly with a statistically significant difference from the older group. This phenomenon, to some extent, can be explained by younger speakers' Wenzhou production closely contacting with Standard Mandarin. Younger Wenzhou speakers possibly produced low back vowel /*a*/, which serves as pre-velar-nasal vowels in Standard Mandarin, instead of low front vowel /*a*/ in the current

experiment due to more experience in using Standard Mandarin. The low back vowel /*a*/, therefore, led to greater amplitude of velic opening and thus more nasality. Interestingly, the endpoint of /*i*/ in Rugao dialect produced by the younger group showed more nasalization than by mid-age and older groups with a statistically significant difference from the older group. This can be attributed to the fact that younger speakers' production of Rugao dialect has also been greatly influenced by Standard Mandarin, in which there are /*in*, *iy*/ and presumably the end point of prenasal vowel has more nasalization than the start and mid points. This explanation was further attested in the Mandarin production of /*in*, *iy*/ by the same talkers. The younger Rugao speakers produced more nasalization for /*i*/ in Standard Mandarin than mid-age Rugao speakers, especially at the endpoint [14]. From the perspective of sociolinguistics, such age effect in vowel nasalization may be attributed to the National Popularization of Standard Mandarin and school education, as well as the development of social media, which provide younger speakers more opportunities to use Standard Mandarin in daily life than older generations [8, 15].

As for the third research question, results show significant interaction among age group, vowel type, and point of vowel duration on nasalization of non-high vowels in both Wenzhou and Rugao dialects. Nonetheless, all age groups of Wenzhou speakers produced generally more nasalization of /*e*/ than that of /*a*/ at all the three points of vowel duration. This result somewhat mirrors Clumec's postulation that lower vowels generating higher degree of nasalization is more likely to occur in cases of high vs. non-high vowels rather than low vs. non-low vowels. In Rugao dialect, vowel type and point of vowel duration also demonstrated two-way interactions on nasalization of high vowels /*ʊ*, *i*/. Pertaining to the effect of vowel type, /*õ*/ had significantly higher degree of nasalization than /*i*/ in Rugao dialect. This can be explained by the tendency that low vowels result in more nasalization than high vowels, and back vowels more than front vowels, because velum position tends to be relatively lower when tongue position is low and back [2]. As for the role of point of vowel duration, midpoint of vowel showed less nasalization than the start and end points in non-high vowels in both dialects. It might be related to the coarticulation with initial consonants /*t*, *s*, *ts*/, for which the tip of the tongue was raised to the upper teeth ridge and thus the back of the tongue is even lower than its status for the pure vowels. It was also plausibly affected by other confounded factors during the articulation related to sound change caused by language contact.

5. Conclusions

This study investigates the nasality of vowels /*a*(ŋ), *o*(ŋ), *e*(ŋ)/ in Wenzhou dialect and /*ã*, *ɔ*(ŋ), *ə*(ŋ), *ẽ*, *õ*, *ĩ*/ in Rugao dialect. The acoustic results indicate that degree of vowel nasalization varied across age group, vowel type, and time course of the vowel. The nasalized /*a*/ in Rugao dialect was acoustically more likely to be /*ã*/ than /*a*(ŋ)/. Younger speakers produced different patterns of nasal rimes in both Wenzhou and Rugao dialects in comparison to the production of the middle-aged and the older generations, suggesting sound change as a result of contact with Standard Mandarin.

6. Acknowledgements

This work was supported by Humanity and Social Science Foundation of Ministry of Education of China, approval number 18YJA74007.

7. References

- [1] C. E. Goodin-Mayeda, *Nasals and nasalization in Spanish and Portuguese: Perception, phonetics and phonology*. John Benjamins Publishing Company, 2016.
- [2] H. Clumeck, "Patterns of soft palate movements in six languages," *Journal of phonetics*, vol. 4, no. 1, pp. 337-351, 1976.
- [3] M. Y. Chen, "Acoustic analysis of simple vowels preceding a nasal in Standard Chinese," *Journal of Phonetics*, vol. 28, no. 1, pp. 43-67, 2000.
- [4] M. Y. Chen, "Acoustic correlates of English and French nasalized vowels," *The Journal of the Acoustical Society of America*, vol. 102, no. 4, pp. 2360-2370, 1997.
- [5] S. F. Zheng zhang, *Dialect record of Wenzhou city (Wenzhou fangyanzhi)*. Beijing: Zhonghua Book Company, 2008.
- [6] L. Y. Li, *The study of Rugao dialect's phonetic system*, M. A. Thesis, Nanjing University, 2015.
- [7] F. S. Wu, *Studies of Rugao dialect (Rugao fangyan yanjiu)*, Beijing: China Federation of Literary and Art Circles Publishing House, 2006.
- [8] B. Spolsky, "Language management in the People's Republic of China," *Language*, vol. 90, no. 4, pp. 165-179, 2014.
- [9] W. Styler, "Nasality AutoMeasurement. Praat. Version 5.9," https://github.com/stylerw/styler_praat_scripts/, 2017.
- [10] R Core Team. "R: A language and environment for statistical computing. Version 4.1.3," <https://www.R-project.org/>, 2022.
- [11] D. Bates, M. Mächler, B. Bolker and S. Walker, "Fitting Linear Mixed-Effects Models Using lme4," *Journal of Statistical Software*, vol. 67, no. 1, pp. 1-48, 2015.
- [12] R. V. Lenth, "Emmeans: Estimated Marginal Means, aka Least-Squares Means," *R package version 1.7.2.*, 2022.
- [13] H. Wickham. *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York, 2016.
- [14] X. Zhang, Y. Y. Chen, J. Wang and Y. Chen, "Acoustic Analysis of Nasalization in Mandarin Prenasal Vowels Produced by Wenzhou and Rugao Speakers," *2020 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)*, pp. 584-588, 2020.
- [15] Y. Chen, Y. Xu and S. Guion-Anderson, "Prosodic realization of focus in bilingual production of Southern Min and Mandarin," *Phonetica*, vol. 71, no. 4, pp. 249-270, 2015.