The Acoustic Correlates and Time Span of the Non-modal Phonation in Kunshan Wu Chinese

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Abstract

This study investigates the acoustic correlates and time span of the non-modal phonation in Kunshan Wu, a Northern Wu dialect spoken in a city neighboring Shanghai and Suzhou.

While previous studies mostly believe that the non-modal phonation in the lower register in Wu dialects is breathier, the phonetic correlates and methods of measurement vary among researchers, and measurement biases render some results to be unreliable. In this study, twelve native speakers of different ages and genders were recorded for examination of the acoustics in isolated monosyllabic words.

Results show that the lower register generally exhibit higher spectral tilts and more noise, which confirms that the non-modal phonation is breathier. Based on the time course of two measures that are consistently useful across age and gender, the time span of the non-modal phonation is on average eight-ninths of unchecked vowels or entire checked vowels from the onset. Moreover, in one of the lower register unchecked tones, the non-modal phonation is found to last no shorter than the modal phonation in the upper register.

Index Terms: Kunshan Wu Chinese, phonation, acoustics

1. Introduction

Wu Chinese is well-known for its preservation of a voicing distinction inherited from Middle Chinese, which has been found to surface as phonation contrasts rather than phonetic voicing contrasts (shown by VOT) in the word-initial position, especially in the Northern varieties [1, 2, 3, 4, 5]. Moreover, tonal systems in Chinese dialects were proposed to consist of two registers that correlate with pitch and/or voice quality, and Wu tones were thus categorized into the upper and lower registers primarily based on contrasts in phonation [6, 7, 8]. In general, syllables with a phonologically voiceless onset carry upper register tones and are produced with modal phonation, while those with a phonologically voiced onset carry lower register tones and are produced with non-modal (usually breathier) phonation [2, 3, 6, 7]. In other words, voicing, tone and phonation are interdependent in Wu dialects.

Despite of the consensus on the phonology side, at least two complications have arisen on the phonetic realization of the non-modal phonation in the lower register.

On the one hand, while the non-modal phonation has been mostly believed to be breathier than modal voice, diverse terms, including ‘breathy voice’ [3, 9], ‘slack voice’ [10] and ‘whispery voice’ [11, 12], were preferred by different researchers. Nevertheless, it is worth pointing out that the terminology, criteria and measures adopted were not consistent across studies, which renders it somewhat a methodological issue to reach more faithful conclusions. Apart from controversies over the cross-linguistic typology of breathier phonation among scholars that have been extensively reviewed in [3, 12, 13], choices of phonetic correlates and methods for measurement were also variegated.

In Shanghainese, for example, Gao and Hallé [14, 15] found the spectral tilt H1-H2 to correlate with the phonation contrasts, whereas Tian and Kuang [12] concluded that it was not a reliable measure. Such disagreement is likely to be a result of measurement bias instead of sampling bias. In [14, 15], there was a fallacy that /ɛ/ (the only vowel used) was low enough for harmonics to be free from influence of formants, for which the measure was not corrected as in [12]. In fact, F1 of /ɛ/ (around 500Hz in Shanghainese [14, 16]) can be very close to 2F0 (e.g. when F0 = 250Hz) in upper register words, especially during the onset part of the vowel. In this case, the second harmonic could have been significantly excited by F1, thus producing lower H1-H2 in the upper register that in turn seemingly indicated breathiness in the lower register.

On the other hand, the time span of the non-modal phonation in Wu dialects is still undefined. Putting aside phonological proposals that assume phonation contrasts to be a feature of onsets or syllables [2, 7, 9], the duration of breathiness within the rime remains uncertain. Regarding Shanghainese, earlier studies found that only the onset part of the vowels showed breathiness [3, 13], while in later studies breathiness was able to last until the midpoint of unchecked vowels or over entire checked vowels [14, 15]. These results are not comparable nor reliable though because uncorrected spectral measures were used in different vowel contexts, which could have been biased due to reasons mentioned above.

To study the time course of the phonetic correlates that quantify the phonation contrasts, measurement is usually averaged on small portion of the vowel, which can be real-time intervals (25ms [17]) or normalized-time intervals (e.g. thirds or ninths of the vowel [18, 19]). Although time normalization has become a mainstream technique, as was used in [12, 14, 20] for Shanghainese, it is too early to obsolete the use of real-time measurement. According to [17], there is no global articulatory requirement for non-modal phonation to be short, whereas extra articulatory effort might be needed to maintain non-modal glottal states. In addition, conflicting perceptual demands from both phonation and tone may favor a modal portion to facilitate perceptual salience of pitch, given that breathiness usually spoils periodicity [21]. Therefore, the actual pattern is probably twofold: the default duration is imposed by the phonology as certain portion of the vowel, while modulation in real time can be driven by physiological and perceptual factors as well as idiosyncratic factors such as word frequency, contexts, and speaking rates.

These complications have inspired investigation of the phonation contrasts in Kunshan Wu, a Northern Wu variety neighboring Shanghai and Suzhou. Although this dialect is understudied, it features phonological inventories that are more conservative than those in Shanghainese [22, 23]. Since electroglottographic data was not collected, usefulness of relevant acoustic correlates in distinguishing phonation contrasts will be assessed, and the relationship between register/tone, pitch, and phonation will be further examined. Based on the time course of useful acoustic correlates in both real time and normalized time, the time span of the non-modal phonation will be determined.

2. Method

2.1. Speakers

Twelve native speakers of the downtown Yushan dialect were recorded in this study, with half elderly speakers (70 years old or above) and half middle-aged speakers (35–50 years old). Each age group contained three males and three females. All the speakers were born and raised in Kunshan. All of them could also speak Mandarin, and the elderly speakers learned Mandarin no earlier than primary school.

2.2. Materials

The recording material was a list of 82 isolated monosyllabic words covering all citation tones and three onset types: stops, fricatives and zero onsets. Voiceless aspirated stops and sonorants were not included as they are beyond the scope of this study. Affricates were not included because there were too few words containing the chosen vowels. The voiceless glottal fricative /h/ was included for comparison with zero onsets.

Only lower vowels /a ɛ/ were used in unchecked syllables and /aʔ əʔ/ in checked ones. High vowels such as /i y/ were excluded because they are usually fricated in Kunshan, as is in Suzhou [24], which are expected to introduce more noise.

2.3. Procedure

All the speakers were recorded with three repetitions of the whole wordlist. To accurately obtain amplitude measurement of lower harmonics, a condenser microphone Audio Technica AT2020USB+ was used for its flat frequency response.

The acoustic correlates measured were F0, spectral tilts and noise measures. Spectral tilts included H1-H2 (amplitude difference between the first and second harmonics), measures between F0 and harmonics closest to the formants (H1-A1, H1-A2, H1-A3), and other relevant ones (H2-H4, H4-H2K, H2K-H5K, H1-H4, H1-H2K, H1-H5K). Noise measures are the harmonics-to-noise ratios (HNR) and Cepstral peak prominence (CPP). Measurement was obtained in VoiceSauce [25] and corrected for formant frequencies and bandwidths based on [26, 27], which are marked by asterisks (*).

A total of 2,868 tokens were measured, and the results were averaged on ninths of the vowel (normalized-time intervals) and 25ms real-time intervals. Measurement was standardized into z-score within each speaker for each measure, and outliers exceeding three standard deviations were discarded. Linear mixed effects models (LME) were fitted on normalized-time intervals for each measure with automatic backward elimination performed. Soothing-Spline ANOVA (SSANOVA) was performed to analyze the time course of useful acoustic correlates. Results involving H2* for /ɛ/ and H4* for /a/ were excluded due to reasons to be explained in Section 4.3.

3. Results

3.1. Relationship between register and the measures

The F0 contours of the citation tones are illustrated in Figure 1, and mean duration of each tone pooled across speakers is given in Table 1. The upper register tones are marked with ‘a’ and the lower ones ‘b’ (T2b has merged into T3b). Z-score of F0 showed that the upper register tones generally had a higher pitch onset, and F0 of both registers did not cross z-score = 0 and cluster together until the 4th or 5th normalized-time interval within speakers. This means that the F0 range is well separated by register during approximately the first half of the vowel, which coincides with the patterns in Figure 1.

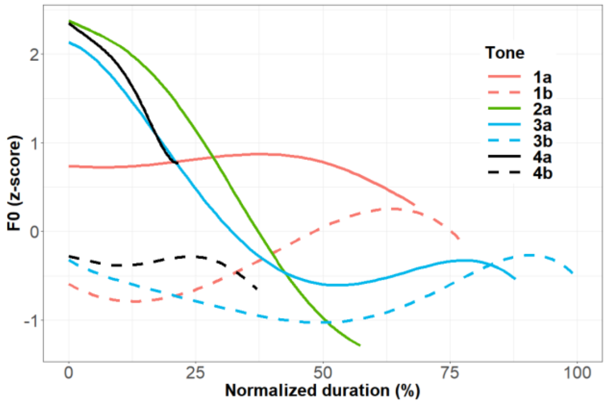

Figure 1: *F0 contours of Kunshan citation tones*

Table 1: *Mean duration of Kunshan citation tones.*

Tone	(ms)	Tone	(ms)
Upper:	**245**		
T1a	241		
T2a	203	T4a	76
T3a	311		
Lower:	**328**		
T1b	273	T4b	131
T3b	354		
Unchecked	**283**	**Checked**	**101**

Table 2: *Correlations between F0 and other acoustic correlates over the entire vowels by gender and register (***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$).*

Measures	Female		Male	
	Upper	Lower	Upper	Lower
H1*-H2*	0.44***	0.21***	0.26**	·
H1*-H4*	0.17***	0.17**	·	·
H1*-H2K*	-0.10**	·	·	-0.16***
H1*-H5K	-0.15***	·	-0.49***	-0.14***
H4*-H2K*	-0.49***	-0.37***	-0.62***	-0.40**
H2K*-H5K	0.11**	0.18***	·	·
H1*-A1*	·	-0.20***	-0.26***	-0.36***
H1*-A2*	·	-0.29***	-0.29***	-0.37***
H1*-A3*	-0.18***	-0.35***	-0.37***	-0.28***
CPP	-0.38***	0.20***	-0.20***	0.14***
HNR05	0.11**	·	0.11**	-0.31***
HNR15	-0.12***	-0.10*	-0.08*	-0.13**
HNR25	-0.10**	·	-0.08*	-0.28***
HNR35	·	·	·	-0.38***

Correlations were calculated between mean values of F0 and the other acoustic correlates over the entire vowel within each register, in order to eliminate potential multicollinearity introduced by register and phonation. The results are given for each gender in Table 2. Overall, most of the measures showed different patterns between genders, which implies that female and male speakers may alter their glottal configuration differently for different registers.

LME models were fitted between each measure and the fixed effects (*Age*, *Gender*, *Manner*, *Register*) with random effects (*Speaker* and *Word*). For formant-related measures, *Vowel* was added as a fixed effect because they are dependent on vowel quality [27], which did improve the model fit. Random slopes were not included as the focus was the overall usefulness of each acoustic correlate. Measures were averaged on ninths of unchecked vowels and thirds of checked vowels according to their mean duration (see Table 1). The results are summarized in Table 3. Aside with significance of the main effect *Register*, a sign is given for the upper register if the coefficients were significant and showed consistent patterns across age and gender.

In unchecked vowels, all the spectral tilts were somewhat useful in distinguishing the register contrast during some portion of the vowel. Across age and gender, the lower register showed higher H1*-H4*, H1*-H5K, H2K*-H5K, H1*-A1*, H1*-A3* for at least one-third of the vowel. The other spectral tilts were also useful in the first half of the vowel, but the patterns were divergent among different groups of speakers. For example, in the lower register, H1*-H2* was significantly lower in male speech, but higher in middle-aged female speech, and did not show significant difference in elderly female speech. As for the noise measures, the lower register showed lower CPP and HNRs, thus more noise, during the first third of the vowel.

In checked vowels, useful measures were H1*-H4*, H1*-H5K, H4*-H2K*, all formant-related measures (H1*-A1*, H1*-A2*, H1*-A3*) and all noise measures (CPP, HNRs). The lower register generally showed higher spectral tilts and more noise.

3.2. Time course of the acoustic correlates

As is shown in Table 3, most of the acoustic correlates were useful for at least one-third of the unchecked vowels, while H1*-H5K accounted for the longest portion, i.e. eight-ninths of the vowel. Besides, H1*-H4* and H2K*-H5K maintained significant differences until the last ninth of the vowel. In checked vowels, H1*-H5K and H1*-A3* were consistently different for the entire vowel. These results indicate that the non-modal phonation was able to last over the entire vowel.

Meanwhile, the time course of the acoustic correlates was also analyzed in real time, given that a measure showed generally consistent patterns across the speakers. Therefore, H1*-H5K and CPP in unchecked vowels were selected as two representatives that account for different aspects of the phonation contrasts. Furthermore, as both measures had some correlations with F0, there could be concurrent changes along with F0 perturbation, so tones rather than registers should be preferred as the grouping factor in SSANOVA. The results are plotted in Figure 2 for 10 real-time intervals (250ms), which approximately equals the mean duration of the upper register unchecked tones.

Table 3: *Significance of the main effect Register on normalized-time intervals (***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$)*

Measures	Unchecked vowels									Checked vowels		
	1	2	3	4	5	6	7	8	9	1	2	3
H1*-H2*	***	***	***	***	*							**
H1*-H4*	***	***	***	– ***	– ***	– ***	***	– ***	– **	– ***		
H1*-H2K*	***	***	***	– ***	***	*			*	**	**	
H1*-H5K	– ***	– ***	– ***	– ***	– ***	– ***	– ***	– ***		– ***	– ***	– ***
H4*-H2K*			*	– ***	**		*	***	**		– ***	– ***
H2K*-H5K		***	***	***	– ***	– ***	– ***	– ***	– **			
H1*-A1*	***	– ***	– ***	– ***	– ***	***	***	***		– ***	– ***	***
H1*-A2*	***	– ***	– ***	***	***	***	***		*	***	– ***	– ***
H1*-A3*	– ***	– ***	– ***	– ***	***	***	***			– ***	– ***	– ***
CPP	+ ***	+ ***	+ ***	+ ***	***	+ ***	*		***	***	*	– ***
HNR05	+ ***	+ ***	+ ***	*					– **	+ ***	+ ***	
HNR15	+ ***	+ ***	**							+ ***	+ ***	
HNR25	+ ***	+ ***	**			*	*			+ ***	***	
HNR35	+ ***	+ ***	***			*	*			+ ***	***	

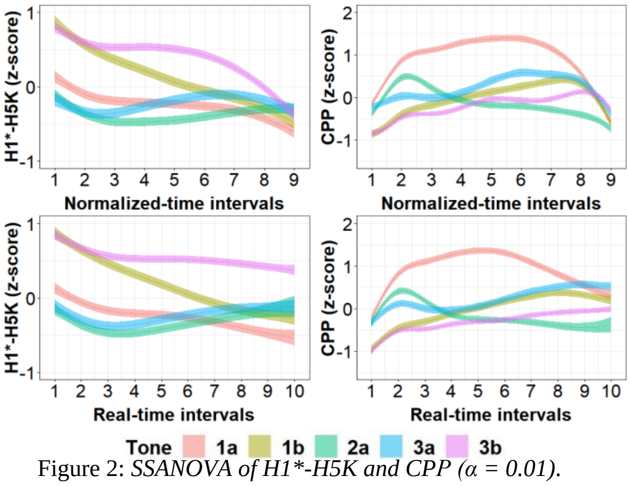

Figure 2: *SSANOVA of H1*-H5K and CPP (α = 0.01).*

In normalized time, T1b (gold) does not cluster with the upper register tones until Interval 6 regarding H1*-H5K, and Interval 4 regarding CPP, while T3b (pink) remains distinct from the upper register tones until Interval 8 regarding both measures. Although CPP of T2a (green) drops severely at Interval 4, it is believed to be a result of laryngealization in this high-falling tone. In real time, as the curves also embed the durational information of each tone, changes of longer tones are slower, and later part of them are not shown. The patterns of T1b are similar, but T3b remain distinct from the upper register tones regarding both measures (except T2a for CPP) until the last interval, which is no shorter than the mean duration of the upper register tones.

4. Discussion

This study is aimed to find out the acoustic correlates that are useful in distinguishing the phonation contrasts in Kunshan Wu, and based on their time course, the time span of the non-modal phonation. The results were different from previous findings in Shanghainese.

4.1. Acoustic correlates of the non-modal phonation

In general, significant differences tested for all the measures used indicate that contrastive phonation types were used in different registers. The lower register overall showed higher spectral tilts and more noise for at least one-third of the vowel across different age and gender groups.

Usefulness of the formant-related measures (H1*-A1*, H1*-A2*, H1*-A3*) and noise measures (CPP, HNRs) is consistent with the results in Shanghainese [12], implying that the non-modal phonation was probably realized with some posterior glottal opening [28]. However, H2K*-H5K was also useful in Kunshan, and H1*-H2* was found to be useful in male speech, while both were generally not useful in [12].

In addition to measures proposed in [29], measures between the first harmonic and higher harmonics were also examined, and most of them were found to be useful, especially H1*-H5K. These measures were believed by Zhang [30] to correlate with vocal fold thickness, which could be more important than glottal width in altering voice quality [31].

4.2. Time span of the non-modal phonation

In our data, H1*-H5K remained contrastive between registers for eight-ninths of the unchecked vowels and for the entire checked vowels in normalized time. Alternatively, differences in H1*-H5K and CPP were analyzed in real time between tones. The result implies that T3b could on average maintain distinctively higher H1*-H5K and lower CPP throughout the mean duration of the upper register tones. If these measures did faithfully reflect the breathier nature of the phonation type, we can conclude that the non-modal phonation was able to last no shorter than the modal phonation in the upper register. This confirms that there is no articulatory obstacles for maintaining the non-modal phonation.

As mentioned above, Silverman [21] and Blankenship [17] believed that a modal portion in non-modal vowels may be favored for perceptual salience of pitch. This was later backed by Gordon and Ladefoged [32], who added that breathy vowels could be substantially longer to accommodate both modal and non-modal portions. However, based on the results in Kunshan Wu, it is possible that compensation for pitch perception can be realized mostly by lengthening the tones instead of requiring a larger modal portion. In fact, when we talk about the time span of the phonation, there is obviously definitional issue regarding the time scale, which could be overlooked by researchers. Historically, modern Wu tones are descendants of Middle Chinese tones via a two-register split [33], but contemporarily, tones in the lower register were found to be generally longer in Kunshan. While it is natural to do time-normalization from the perspective of Chinese phonology, the temporal information of the lower register tones would have been contracted in this case. And it is not uncommon that duration is a distinctive feature or perceptual cue for tones in Chinese [34, 35]. Further research need be done on the interaction between phonation and duration in Wu dialects to find out if such interdependence is ubiquitous, and if so, whether the duration differences are closely related to or even inspired by the phonation contrasts.

4.3. Measurement issues

It was noticed that H1*-H2* and H2*-H4* showed reverse patterns for /a/ and /ɛ/ between registers, especially during the onset of T2 and T3. The reason was believed to be over-correction of H2 and H4 due to underestimation of formant bandwidth by formulas from [36] in VoiceSauce, which is conspicuous when a harmonic is very close to the formants. This problem was only mentioned for H4 and H2K in [25], and there was no alternative but to exclude the results that could be biased because bandwidth measurement from software has been shown to be even more unreliable [37].

5. Conclusion

In summary, phonation contrasts were confirmed to be present in Kunshan Wu between tone registers. The lower register tones generally showed higher spectral tilts and more noise, suggesting that the phonation type is breathier. Moreover, the time course of two generally useful acoustic correlates, H1*-H5K and CPP, showed that the time span of the non-modal phonation was on average eight-ninths of unchecked vowels or entire checked vowels, and that the non-modal phonation in T3b lasted no shorter than the modal phonation in the upper register. The results also call for future research with help of electroglottographic data, perception experiments and within-speaker analysis, so as to reveal relative importance of different aspects of the phonation contrasts, and hence the type of the non-modal phonation in Kunshan Wu.

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6. References

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