Distinct Acoustic Features and Glottal Changes Define Two Modes of Singing in Peking Opera

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Summary: Objective. We aimed to delineate the acoustic characteristics of the Laodan and Qingyi role in Peking Opera and define glottis closure states and mucosal wave changes during singing in the two roles.
Methods. The range of singing in A4 (440 Hz) pitch in seven female Peking Opera singers was determined using two classic pieces of Peking Opera. Glottal changes during singing were examined by stroboscopic laryngoscope. The fundamental frequency of /i/ in the first 15 seconds of the two pieces and the /i/ pitch range were determined. The relative length of the glottis fissure and the relative maximum mucosal amplitude were calculated.
Results. Qingyi had significantly higher mean fundamental frequency than Laodan. The long-term average spectrum showed an obvious formant cluster near 3000 Hz in Laodan versus Qingyi. No formant cluster was observed in singing in the regular mode. Strobe laryngoscopy showed complete glottal closure in Laodan and incomplete glottal closure in Qingyi in the maximal glottis closure phase. The relative length of the glottis fissure of Laodan was significantly lower than that of Qingyi in the singing mode. The relative maximum mucosal amplitude of Qingyi was significantly lower than that of Laodan.
Conclusion. The Laodan role and the Qingyi role in Peking Opera sing in a fundamental frequency range compatible with the respective use of da sang (big voice) and xiao sang (small voice). The morphological patterns of glottal changes also indicate that the Laodan role and the Qingyi role sing with da sang and xiao sang, respectively.
Key Words: Acoustic features−Glottal changes−Peking opera−Da sang−Xiao sang.

INTRODUCTION

Traditional Peking Opera epitomizes Chinese culture and art and includes four standard categories of player roles: Sheng, Jing, Chou, and Dan. Sheng is a male role in Peking Opera and includes Laosheng, Xiaosheng, and Wusheng. Laosheng plays the role of mostly upright and resolute characters such as dignified generals or high-ranking military officers. Laosheng sings in a natural voice. Xiaosheng, on the other hand, plays a young male role singing in a high-pitched and shrill voice. Wusheng appears in battle scenes and is well versed in martial arts. Jing is a male role with a painted face; some of the Jing roles focus on singing, whereas others focus on actions. Chou plays a male clown role and usually plays a secondary role in a troupe.

The Dan role is further divided into subcategories of Laodan, Qingyi, Huadan, and others according to age, gender, and voice characteristics of the role to be performed. The Laodan role has its own set of movements and gestures and singing styles and the performer sings in a lower pitched voice. The Qingyi role has little movement and focuses on singing in a very high pitched and piercing voice.

Bartholomew first observed that a good operatic voice concentrates a clustering of energy in the frequency range of around 3000 Hz in Western operatic singing.[1] Sundberg further demonstrated the presence of a secondary peak of acoustic energy in the 2000−3000 Hz region for operatic singing, known as the singer's formant cluster, and a prominent spectrum enveloping the peak in the vicinity of 3000 Hz in all vowel spectra.[2] In an acoustic study of Peking Opera singers, Sundberg et al observed a scale tone structure for songs, but found no trace of a singer's formant cluster on long-term average spectrum (LTAS) curves.[3] The same study observed a marked peak near 3300 Hz on LTAS curves of the Colorful Face (Hualian) role.

Similar to Western operatic singing, Peking Opera singing uses an anhemitonic pentatonic scale as the main melody structure, and a hexachord scale as the secondary melody structure. The notation used in Peking Opera is called "numbered music notation" (see Appendix S1). The key notation is not fixed and singers may change it to the most fitting during performance.

Vocal productions in Peking Opera include song with music, verse recitation, prose dialogue, and nonverbal vocalizations[4] that are based on breath, pronunciation, and unique Peking Opera pronunciation. Breath is based in the pubic region assisted by the abdominal muscles, which allow strong centralized breathing. The singer masters the techniques to exhaling and inhaling the precise amount of air required for the intended vocalization. Tone production is engendered by shaping the throat and mouth, including opened or closed mouth, level-teeth, and scooped lips, to utter the desired vowels and consonants.

Evidence indicates that the singing vibratos of different roles in Peking Opera exhibit distinct acoustic features.[5] However, currently, data are scarce on the fundamental frequency ranges where vocal registration events occur in Peking Opera singers. Laryngeal evidence is also lacking on Peking Opera singing. A search of PubMed for literature on Peking Opera returned three papers,[3,5,6] but none of these

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addressed the issue of vocal registration or performed laryngoscopic evaluation of Peking Opera singers.

There are mainly two types of singing in Peking Opera: the da sang (big voice) and the xiao sang (xiao sang).[1] It has been speculated but not yet proven that the Laodan role sings mainly with the da sang and the Qingyi role principally sings with the xiao sang. When singing in the da sang, the Laodan performer's breath is based in the pubic region assisted by the abdominal muscles; this centralized breathing moves upward and produces a lower pitched voice by creating resonance in the larynx. Although there is no consensus definition in Peking Opera for big and xiao sang, voice engendered through this mode of vocal production is generally considered da sang. Compared to da sang, when a performer sings in the xiao sang, the opening between the vocal folds becomes narrowed and elevated; the air stream becomes thinner, producing a very high pitched and piercing voice.

In the current study, to examine the hypothesis that the Laodan role sings mainly with the da sang and the Qingyi role principally sings with the xiao sang, we sought to delineate the acoustic characteristics of the Laodan role and Qingyi role of Peking Opera singers and investigate glottis closure states and mucosal wave changes during singing in the two roles.

SUBJECTS AND METHODS

Subjects

Seven female professional solo Peking Opera singers participated as subjects in the current study. They received their professional solo singer education for Peking Opera at Beijing Opera and Art College, Beijing, China. A subject was included if (1) she was trained to play the roles of Laodan or Qingyi in Peking Opera, (2) she had no hoarseness or respiratory tract infection within the preceding month, (3) she was not menstruating during the study period, and (4) she had no vocal fold nodules, polyps, and other vocal cord proliferative lesions, and glottal compression. All subjects received 1 week of training in singing in the role of Laodan and Qingyi by professional trainers prior to the study. The trainers assessed the perceived singing voice, and those who met the singing criteria for the da sang and the xiao sang were finally selected, including 4 students from the Class of 2013 and 3 students from the Class of 2017. Their mean age was 16 years (range 14−17 years). They had received training for 3−5 years, including three Laodan students who had also learned to perform the role of Qingyi for 6 months and three Qingyi students who had also learned to perform the role of Laodan for 1−6 months.

The study protocol was approved by the institutional review board at the authors' affiliated institution and all subjects provided informed consent to the study.

Data acquisition

The range of singing was determined using the classic piece "I saw my dear son Zhang Yi again while I was half asleep" from the Peking Opera *Weep before the Bier* and the classic piece of "All of my early love suddenly vanished without a trace " from the Peking Opera *The Unicorn Purse*. All seven subjects were asked to sing the pieces in the regular mode and in the roles of Laodan and Qingyi at the pitch of A4 (440 Hz). The phonation quality of the singing subjects was monitored by the trainers. The singing was recorded using the 4150 Voice Analysis System (KAY Co., Beijing, China) with a sampling frequency of 44 kHz and the vowel /i/ was extracted using the *Multidimensional Voice Program* (*MDVP*, Beijing, China) to generate LTAS curves under each phonation mode. Using the *Praat* (Beijing, China) sound analysis software, the minimum, maximum, and the mean fundamental frequency of sound in the first 15 seconds of the two classic pieces were extracted, and the /i/ pitch range was determined according to the extracted data using the stroboscopic laryngoscope.

Laryngoscopic evaluation

Lidocaine (1%) was used for topical anesthesia of the intranasal cavity and the pharynx. A flexible fiber optic digital strobolaryngoscope (KARL STORZ-ENDOSCOPE) or XION electronic strobe laryngoscope (Beijing, China) was advanced from the nasal cavity to the superior border of the epiglottis. The subjects uttered the /i/ sound in the regular comfortable mode, and the da sang, and xiao sang mode. Intonation followed the ascending tones as in regular singing mode, and the glottis in three intonation modes (regular singing mode, da sang, and xiao sang) was examined and video-recorded, which was played using the *Storm video playback software* (Beijing, China). Two complete glottal vibration cycles were captured and played frame by frame. The image with the smallest closed glottis and the image with the maximum amplitude of vocal cord mucosal wave during the vibration period were selected. The length of the glottis fissure and the vocal folds was measured using the *Adobe Photoshop CS4 software* (Beijing, China) and the relative length of the glottis fissure (RLGF) was calculated by dividing the length of the glottis fissure by that of the vocal fold (Figure 1A). The relative maximum mucosal amplitude (RMMA) was calculated by dividing the vertical distance from the midpoint of the mucosal curvature wave of the vocal cords to the medial margin of the vocal cords by that of the outer margin of the membranous vocal fold (Figure 1B). The /i/ vowel was analyzed instead of the /a/ vowel because of better glottis exposure under the strobolaryngoscope.

Statistical analysis

Data were expressed as mean ± SD and analyzed using the *SPSS 11.5 software* (SPSS Inc., Chicago, IL). Student *t* test was used for analysis of data from the singers performing in the role of Laodan and Qingyi. A *P* value less than 0.5 was considered statistically significant.

RESULTS

Spectral characteristics of Laodan and Qingyi

Spectral analysis revealed that the mean fundamental frequency of Qingyi was 570.14 ± 24.57 Hz, which was

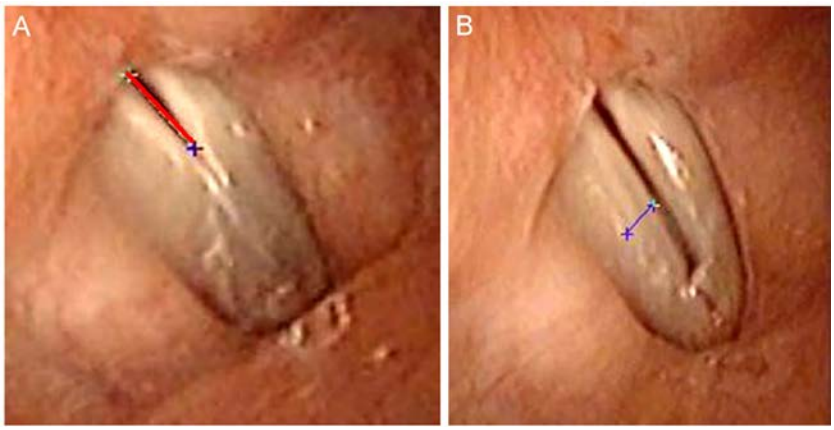

FIGURE 1. **A.** Representative photograph of the glottis of a singer in the Qingyi role of Peking Opera. The smallest closed glottis is shown when the /i/ sound is uttered. Red line indicates the length of the posterior glottis fissure. **B.** The maximal mucosal wave is shown when the /i/ sound is uttered in the regular mode. Blue line indicates the distance of the free edge of the vocal fold to the border of the membranous vocal fold. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

significantly higher than that of Laodan (429.29 ± 6.56 Hz; $P = 0.001$) (Figure 2). The minimum fundamental frequency of Qingyi (380.43 ± 21.88 Hz) was significantly higher than that of Laodan (290.14 ± 15.60 Hz; $P = 0.03$), and the maximum fundamental frequency of Qingyi (719.86 ± 38.17 Hz) was also significantly higher than that of Laodan (543.14 ± 14.76 Hz; $P = 0.006$). Representative spectrograms in three phonation modes are shown in Figure 3. The LTAS showed an obvious formant cluster near 3000 Hz in singing in the roles of Laodan. A cluster was also observed in singing in the roles of Qingyi, but the peaks and widths were apparently smaller than those in singing in the roles of Laodan. On the other hand, in the regular mode, no apparent clustering of energy was observed near 3000 Hz.

Stroboscopic characteristics of Laodan and Qingyi

Strobe laryngoscopy showed that in the glottal vibration cycle, when Laodan uttered the /i/ sound, vocal fold vibration exhibited complete glottal closure in the maximal glottis closure phase (Figure 4). In the singing mode in Qingyi, an apparent gap was present in the posterior glottis in the maximal glottis closure phase. Mild insufficient closure was present when Qingyi uttered the /i/ sound in the regular mode (Figure 5). The RLGF of subjects in the singing mode of Qingyi was not significantly different from that in the

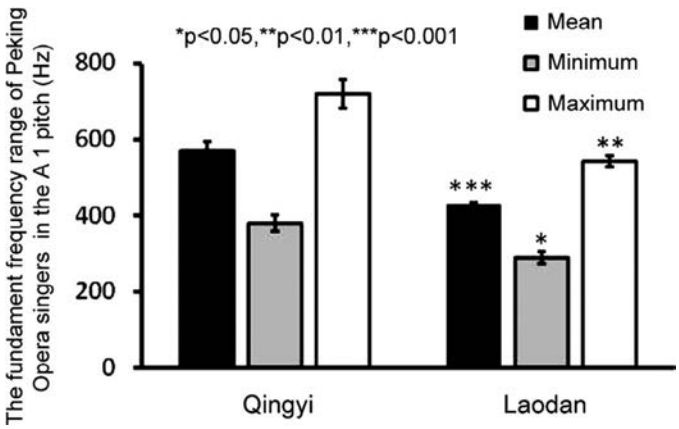

FIGURE 2. The fundament frequency range of Peking Opera singers in the Laodan role and Qingyi role in the A 1 pitch.

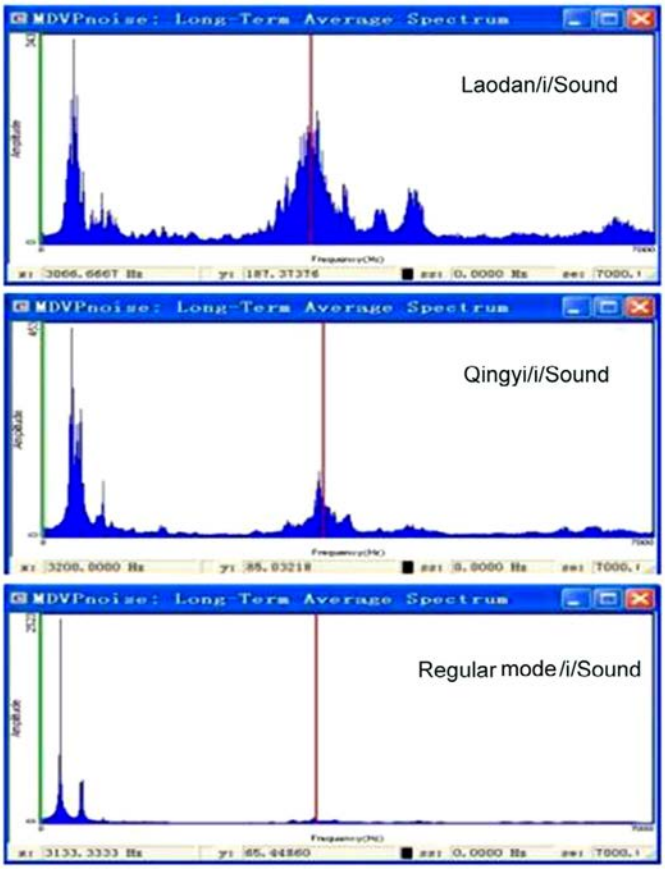

FIGURE 3. The long-term average spectrum of Peking Opera singers when the /i/ sound is uttered in the Laodan (da sang) and Qingyi (xiao sang) mode and the regular mode.

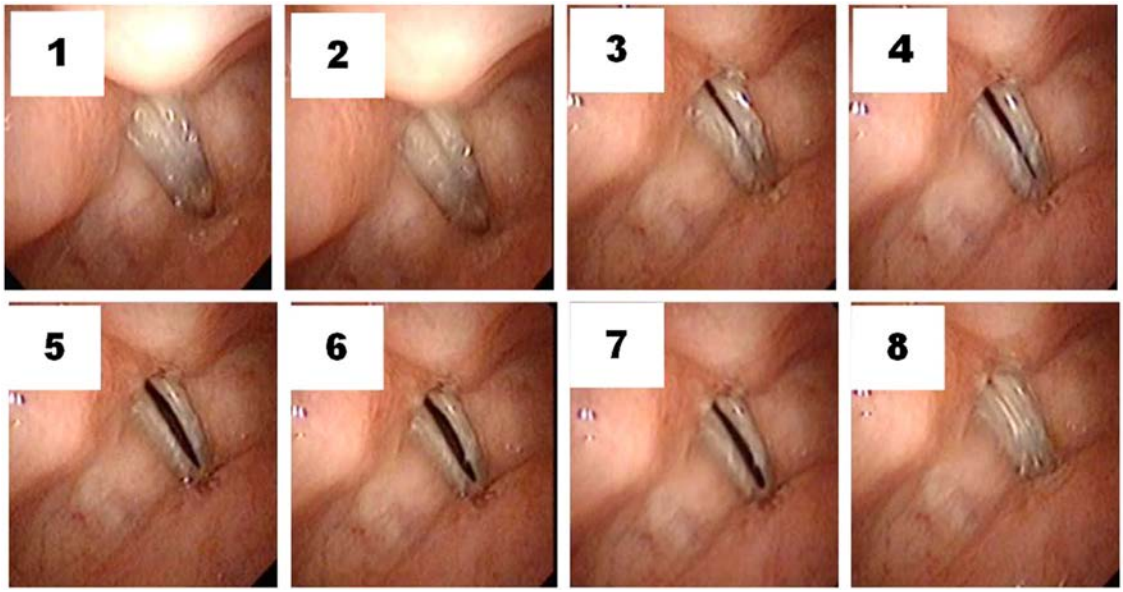

FIGURE 4. The glottal vibration cycle when the /i/ sound is uttered in the Laodan (da sang) mode by strobe laryngoscopy. Numbers indicate chronological sequence. (1) Shows full glottal closure.

regular mode ($P = 0.171$) (Figure 6). The RLGF of subjects in the singing mode of Laodan was significantly lower than that of subjects in the singing mode of Qingyi ($P = 0.001$) and the regular mode ($P = 0.008$).

The mucosal wave was present in all three modes for the /i/ sound. The RMMA in the singing mode of Qingyi [$(52.70 \pm 4.89)\%$] and Laodan [$(68.39 \pm 7.94)\%$] was comparable to that in the regular mode [$(56.22 \pm 4.84)\%$; $P > 0.05$] (Figure 7). The RMMA in the singing mode of Qingyi was significantly lower than that of Laodan [$(68.39 \pm 7.94)\%$; $P = 0.041$].

DISCUSSION

In this study, we investigated the acoustic characteristics of singing in the Laodan role and the Qingyi role of Peking Opera singers who sing in the da sang and xiao sang, respectively. The vowel /i/ was extracted and analyzed because the vocal cords are adequately exposed under the laryngoscope when /i/ is uttered. We found that, consistent with their singing styles in Peking Opera, the Qingyi role had significantly higher mean fundamental frequency than the Laodan role. Our findings are consistent with those by Qu and Liu who reported a higher mean fundamental frequency for the

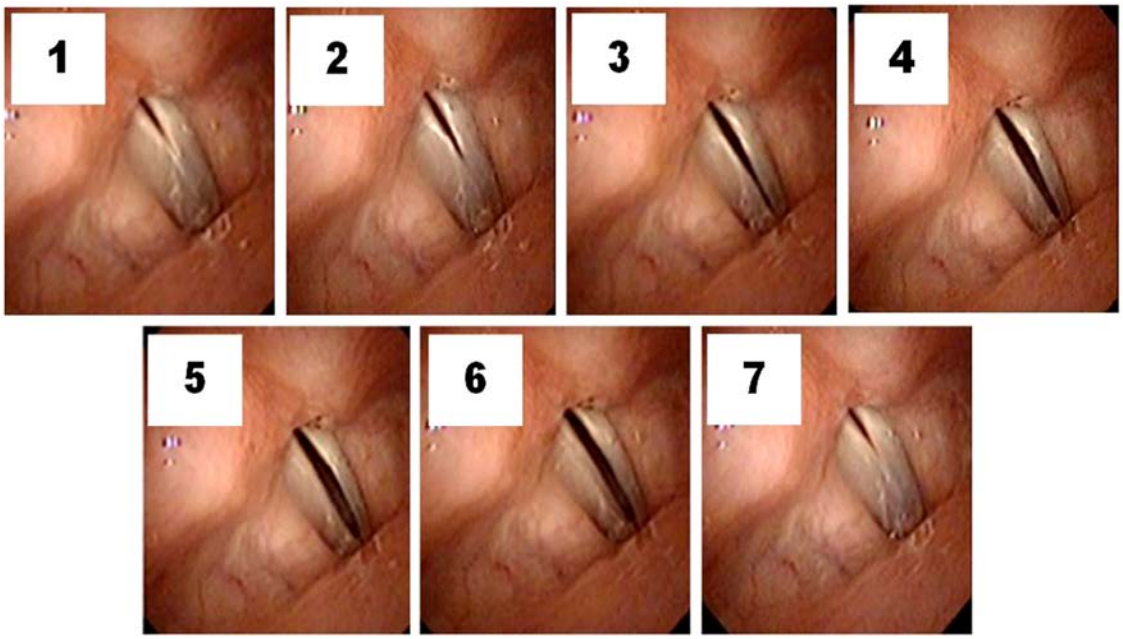

FIGURE 5. The glottal vibration cycle when the /i/ sound is uttered in the Qingyi (xiao sang) mode by strobe laryngoscopy. Numbers indicate chronological sequence. (1) Shows incomplete closure of the posterior glottis.

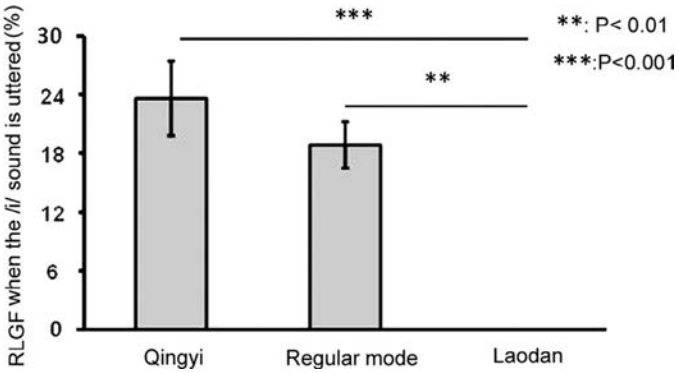

FIGURE 6. The relative length of the glottis fissure (RLGF) of Peking Opera singers in the Laodan (da sang), Qingyi (xiao sang), and regular mode when the /i/ sound is uttered. Bar indicates mean ± SE of three independent measurements.

Qingyi role (548.0 ± 69.5 Hz) than the Laodan role (427.6 ± 47.2 Hz).[6] Furthermore, we also found that the Qingyi role had a greater range of fundamental frequency than the Laodan role.

Voice quality or timbre is commonly perceived as a characteristic color of an individual voice and in Peking Opera, and the singer's formant cluster is a prominent timbre component of voices. Plomp considered that the timbre of steady-state sounds was determined by the frequency spectrum.[7] Our spectral analysis showed a more prominent formant cluster near 3000 Hz in the Laodan role versus the Qingyi role, suggesting that the two roles in Peking Opera sing with distinct acoustic features.

The Qingyi role in Peking Opera typically represents a mature and sometimes married woman and sings in xiao sang. Sataloff and Jiang showed that timbre falls into the modal register, loft register and pulse register in the vocal register.[8,9] Apart from the vocal tract resonance effect, the fundamental frequency of female xiao sang falls into the range of 490−1130 Hz.[9,10] Our spectral analysis showed that the fundamental frequency of the Qingyi role that sings in the xiao sang mode ranged from 380.43 ± 21.88 Hz

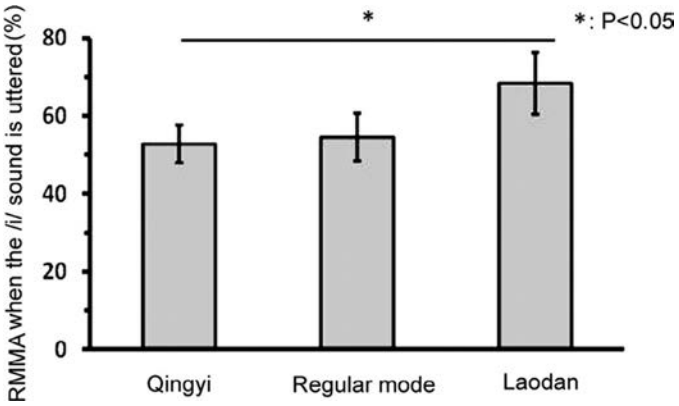

FIGURE 7. The relative maximum mucosal amplitude (RMMA) of Peking Opera singers in the Laodan (da sang), Qingyi (xiao sang), and regular mode when the /i/ sound is uttered. Bar indicates mean ± SE of three independent measurements.

to 719.86 ± 38.17 Hz with a mean of 570.14 ± 24.57 Hz, lending support to the hypothesis that the Qingyi role sings with xiao sang. The fundamental frequency of female da sang falls into the range of 130−520 Hz. We found that the Laodan role sang with a mean fundamental frequency of 429.29 ± 6.56 Hz, indicating that the Laodan role sings with da sang. This is consistent with the singing style of the Laodan role in Peking Opera who sings in a lower pitched voice. These findings demonstrate that the Laodan role and the Qingyi role sing with a fundamental frequency compatible with their singing styles in Peking Opera and lend support to the big/xiao sang hypothesis for the two roles.

No study has been conducted on the physiological basis of phonation in Peking Opera. We evaluated glottal changes in Peking Opera singers by strobe laryngoscopy and showed that the Laodan role had significantly lower RLGF than the Qingyi role, whereas the Qingyi role had significantly lower RMMA than the Laodan role. We also noticed an apparent fissure in the maximal glottis closure phase in the posterior glottis in the Qingyi role in the singing mode, suggesting insufficient closure. In the Qingyi role, the glottis closure phase is shorter or absent and the vocal folds become thinned.[10] When the vocal folds reached the maximum contraction length, further elevation of pitch would increase the opening of the glottis in the glottis closure phase, leading to increased vibration frequency and reduced amplitude. This is further corroborated by the current study, suggesting that incomplete glottis closure is not erroneous, but a distinct singing method compatible with the singing style of the Qingyi role in Peking Opera by raising the pitch of the singing piece. Woo reported that a small fissure in the posterior glottis was present in many female singers and only when the fissure length exceeded one-fourth of the length of the vocal cord, the fissure became abnormal.[11] The RLGF of the Qingyi role was 22.1% of the length of the vocal cord in this study.

The current study showed that the Laodan role exhibited full glottis closure and a prominent formant cluster near 3000 Hz. This is consistent with da sang singing in which the secondary peak of acoustic energy is conspicuously concentrated in the 2000−3000 Hz region.[12] Heuer et al demonstrated that complete glottal closure facilitated maintenance of subglottic pressure with resultant increased amplitude.[13] Consistently, the current study showed grand mucosal wave in the Laodan role and modest mucosal wave in the Qingyi role, lending further support that the Laodan role sings with da sang, whereas the Qingyi role sings with xiao sang.

In conclusion, the current study shows that the Laodan role and the Qingyi role in Peking opera sing in a fundamental frequency range compatible with the respective use of da sang and xiao sang. The morphological patterns of glottal changes also indicate that the Laodan role and the Qingyi role sing with big and xiao sang, respectively. Our findings provide acoustic and physiological evidence for the big/xiao sang hypothesis of the two modes of singing in Peking Opera.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at doi:10.1016/j.jvoice.2018.01.009.

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