Proceedings of the 12th International Conference on Music Perception and Cognition and the 8th Triennial Conference of the European Society for the Cognitive Sciences of Music, July 23-28, 2012, Thessaloniki, Greece
Cambouropoulos E., Tsougras C., Mavromatis P., Pastiadis K. (Editors)

Vocal Fold Vibratory Differences in Different Registers of Professional Male Singers with Different Singing Voice Types

Nan Yan,[*1] Manwa L. Ng [*2], Edith K. Chan [*3], Dongning Wang [*4], Chengxia Liao[#5]

[*]*Speech Science Laboratory, Division of Speech and Hearing Sciences, the University of Hong Kong, China*

[#]*Vocality Department, Xinghai Conservatory of Music, China*

[1]nyan@hku.hk, [2]manwa@hku.hk, [3]kau624@hku.hk, [4]wangdn03@gmail.com, [5]bangii56@yahoo.com.cn

ABSTRACT

Vocal register is an important concept of singing voices and have been related to vocal fold vibratory characteristics. This study examined the relationship between different singing voice types and the associated vocal fold vibratory characteristics. A total of 19 tenors, 10 baritones professional singers participated in the study. A total of 84 vowel sounds sung in chest, head and falsetto registers at a constant loudness and most comfortable pitch level were analyzed by using electroglottography (EGG). The open quotient (Oq) and fundamental frequency (F0) parameters were extracted and the gradient Oq/log(F0) were determined. Results showed that tenors had significantly higher Oq/log(F0) gradient than baritones in chest and head registers, while no significant difference was found in falsetto register between the baritones and tenors. Moreover, gradient Oq/log(F0) was significantly greater in falsetto register when compared with chest and head registers produced by baritone singers. The present results provide insights to the application of vocal fold vibratory characteristics in voice classification for male singers.

I. INTRODUCTION

Vocal register is an important aspect of singing. It has been used for perceptually distinct regions of vocal quality that can be maintained over some ranges of pitch and loudness (Titze et al., 1994). It has also been described as "a totally laryngeal event; it consists of a series or a range of consecutive voice frequencies which can be produced with nearly identical phonatory quality" (Hollien, 1974).

It is commonly believed that registers are related to vocal fold vibratory characteristics. According to Henrich, d'Alessandro, Doval, and Castellengo (2005), the thick vocal folds seen in male singers singing at chest and head registers exhibited a longer closing and opening phase, and was known as laryngeal mechanism 1. The thin vocal folds that vibrate without any vertical phase difference in the falsetto register was known as laryngeal mechanism 2. The open quotient which is defined as the ratio of the glottal open time over the fundamental period seems to be strongly dependent of laryngeal mechanism used by the singer. In past years, research studies have investigated the correlation between register and laryngeal mechanism by using open quotient (Oq). In general, three scientifically-defined laryngeal mechanisms were identified (labeled as M0, M1, M2) (Sundberg and Högset, 2001; Henrich et al., 2004; 2005; Salomao & Sundberg, 2009). The three laryngeal mechanisms musically correlate well with singing registers. M0 correlates with vocal fry, M1 correlates with chest, modal, and male head register, and M2 correlates with falsetto for male and head register for female (Roubeau, Henrich & Castellengo, 2009). Vocal fold Oq was also found to correlate with vocal intensity and F0 in different laryngeal mechanisms (Henrich et al., 2005). Salomao and his colleagues also found that there were systematic differences between modal register and falsetto register in singers, regardless of experience of singing and the thicker vocal folds were found in modal register.

Moreover, the relationship between vocal source characteristics and different performance genres has also been examined. Barlow and LoVetri (2010) investigated the voice source characteristics of 20 adolescent singers using "classical" and "musical theatre" singing styles. They found a significantly higher average closed quotient value for the "musical theatre" style than the "classical" style, suggesting a systematic difference in vocal fold vibratory characteristics indifferent singing types.

Despite the many studies in this aspect, few focused on the relationship between singing voice type and vocal source characteristics. There was only one study on the singing voice type and vocal fold contact time using electroglottography (EGG) (Sundberg & Högset, 2001). In the study, 13 professional singers consisted of baritones, tenors, and counter tenors sang notes at the same pitches and intensities using both modal and falsetto registers. They found that he closed quotient differences between modal and falsetto registers sung by baritones were larger than the closed quotient differences of tenors and countertenors (Sundberg & Högset, 2001). However, generalization of results should be made with caution as only 13 singers participated in the study, representing only a small pool of the singer population (Sundberg & Högset, 2001). Traditionally, professional singing voices are categorized by experienced vocal pedagogues into at least three main singing types in each gender: bass, baritone, and tenor for male singers, and alto, mezzo-soprano, and soprano for female singers (Titze, 1994). Each singing voice possesses a unique set of attributes, and based on which different professional singing voices are distinguished from each other, at least perceptually. So the vocal registers in different singing type would be described the unique characteristics in vocal source vibration. Yet, the study on voice source characteristics of registers in different singing types is still rare.

The present study attempted to extend these studies and examine the contribution of vocal fold vibratory characteristics to different singing types in male classic singers, taking into account vocal registers, loudness and pitch used, based on a larger sample of professional singers. We hope that our results will help to make clearly the relationship between the vocal fold vibration and register in different singing types, and be useful to operatic singer classification. The electroglottography (EGG) was chosen as a noninvasive technique to measure vocal fold vibration characteristics and the differentiated EGG signal (dEGG) was used for Oq measurements. The EGG is non-invasive, easy-to-handle, and not being affected by ambient noise, providing a direct way of monitoring vocal fold vibrations during phonation (Kitzing, 1990). It has been found useful in documenting voice quality, investigation of vocal registers, intonation contour, voice roughness and voice pitch, diagnosis and treatment of dysphonia clinically (Kitzing, 1990; Henrich et al., 2005).

II. METHODS

A. Participants

A total of 29 professional singers were recruited from the Xinghai Conservatory of Music in China as participants of the research, including 19 tenors, 10 baritones. All singers were classified into different singing voice types using the same criteria. Their singing quality was consistently confirmed by experienced pedagogues. Their ages ranged from 19 to 27 years, with duration of singing training ranged from 2 to 9 years. All singers could voluntarily sing with different registers. They had no reported history of any craniofacial abnormalities, and no upper respiratory tract diseases at the time of data collection.

B. Singing Materials and Procedures

Each participant was asked to produce a loud tone, a comfortable tone, and the recording gain was adjusted such that the signal was not clipped. The participants were asked to sing asked to sing the first sentence of the song "happy birthday" using the same loudness level of mezzo-forte at the pitch that they found most comfortable in different registers. The participants were asked to maintain a consistent loudness and voice quality throughout their production. The subjects were required to repeat the above singing task using different vocal registers (chest register, head register, and falsetto). Each sound lasted for 4 to 8 s, and in cases when the laryngeal mechanism could not be straightforwardly identified, the subject indicated which laryngeal mechanism he or she was using. The subjects were asked to reduce the amount of vibrato if possible.

The EGG signal was recorded by a using the laryngograph (Electroglottograph EG2, Glottal Enterprises, NY). The EGG signal was extracted from two surface electrodes of a laryngograph were attached to each side of the thyroid cartilage. Both audio and EGG signals were recorded on separate channels of a DAT recorder at the same time. The whole procedure lasted for about 20 minutes.

C. Data analysis

To quantify vocal fold vibratory characteristics, the open quotient (Oq), which refers to the percentage of time within each cycle during which the vocal folds are open, and fundamental frequency (F0) values were obtained. The sung vowel /a/ was extracted and used for later analysis. The DECOM (dEGG Correlation-based Open Quotient Measurement) method as described by Henrich et al. (2004) was used to derive the Oq and F0 from the differentiated electroglottographic (dEGG) signals. The DECOM method was applied to a four-period windowed to separated dEGG signal into two parts: positive part, which shows strong peaks related to glottal closing instants, and its negative part, which shows weaker peaks related to glottal opening instants. The open time is derived from the inter-correlation function calculated between the positive part and the negative part. These measures are accurate in the case where the glottal opening and/or closing peaks are single and precise. So, in this study, the Oq was only measured on that the glottal cycles for which the opening and closing peaks are unique. Figure 1&2 shows the example of the EGG and dEEG signals and the calculated Oq and F0 from these signals of one vowel which produced by one tenor participant using chest register.

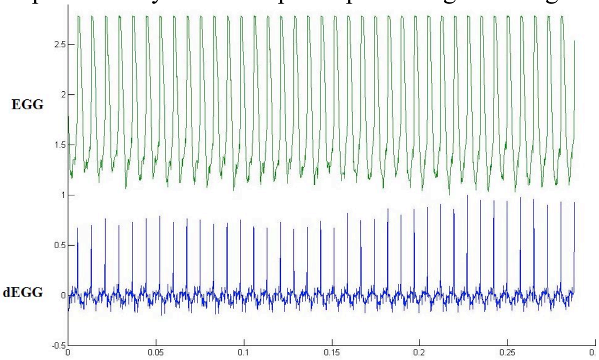

Figure 1. The EGG signal and dEGG signal of one example vowel produced by one tenors using chest register.

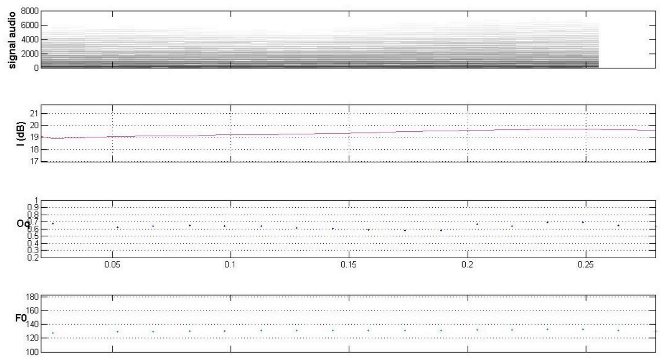

Figure 2. The Open quotient and Fundamental frequency calculated from one example vowel.

Since previous research studies suggested that the Oq could be affected by vocal intensity and F0 (Henrich et al., 2005), the absolute Oq differences between different voice types might not directly indicate the difference between voice types. As such, the gradient [Oq/ log(F0)] was also used for analysis to eliminate the effect of F0 on Oq (Howard, 1995).

III. RESULTS

Descriptive data of vocal fold vibratory characteristics in chest, head and falsetto registers obtained from tenors and baritones are illustrated in Table 1.

To assess the effect of voice type and register, two-factor mixed-design analysis of variances (ANOVAs) (voice type x register) were performed on Oq/log(F0) gradient. As there was a significant interaction effect between voice type and register with respect to Oq/log(F0) gradient [$F(2, 54) = 17.142$, $p < .001$], each independent variable (voice type and register) was tested individually.

Table 1. Mean and standard deviation values of Oq/log(F0) gradient of male singers with different singing voice types

	Oq/log(F0) gradient (SD)		
Voice types	Chest register	Head register	Falsetto register
Baritones	0.22 (0.03)	0.20 (0.03)	0.28 (0.04)
Tenors	0.25 (0.03)	0.25 (0.02)	0.26 (0.02)

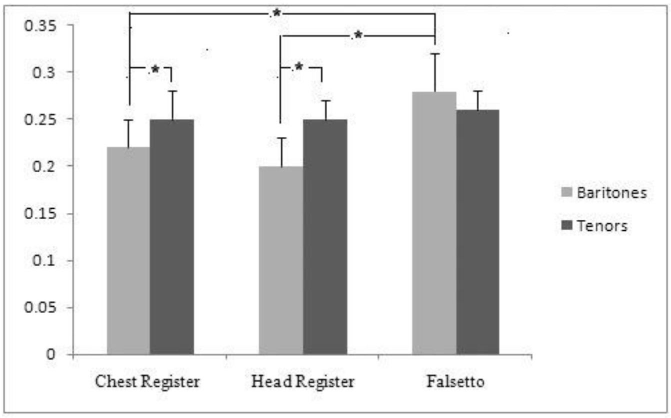

Figure 3. Oq/log(F0) gradient of different male singing voice types in different registers

A. Effects of singing voice types

Independent-samples t-tests were carried out to determine the effect of voice types on Oq/log(F0) gradient in different registers (chest, head, and falsetto). Results indicated that baritones had significantly greater Oq/log(F0) gradient than tenors in chest register [t (27) = -3.061, p < .01] and in head register [t (26.66) = -4.956, p< .001]. No significant difference on Oq/log(F0) gradient was observed in falsetto register between baritones and tenors [t(27) = 1.680, p = .104].

B. Effects of registers

Two one-way ANOVA were then carried out to study the effect of register on Oq/log(F0) gradient in different voice types (baritones and tenors). Mauchly's test indicated that the assumption of sphericity had been violated; therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. The results showed that there was a significant main effect for register [F (1.21, 10.86) = 58.498, p< .001] on Oq/log(F0) gradient in baritones. Pair-wise comparisons with Bonferroni adjustment showed that the Oq/log(F0) gradient in baritones was significantly higher in falsetto register than in chest register (p< .001)as well as in head register (p< .001), while that Oq/log(F0) gradient in chest and head register were not significantly different from each other (p = .309). For tenors, no significant effect of register was found [F(1.49, 26.86) = 1.596, p = .222].

C. Effects of singing voice types on differences between registers

Finally, the independent samples t-tests were carried out to compare the Oq/log(F0) gradient differences between registers (chest-head, head-falsetto, chest-falsetto) of the two voice classes (baritones and tenors). Results showed that baritones had significantly larger Oq/log(F0) gradient differences between chest and falsetto registers [t(30) = 3.664, p < .01] as well as between head and falsetto registers [t(30) = 5.810, p < .0001] than those of tenors. There was no significant difference in chest-head Oq/log(F0) gradient differences between baritones and tenors [t (30) = -.208, p = .837].

IV. DISCUSSION

The present results suggested quite different Oq values for different male singing voice types when register was taken into account, with F0 and vocal intensity being controlled. It was found that tenors had significantly higher Oq/log(F0) gradient than baritones when using chest and head registers, corresponding to a higher Oq in tenors than baritones in chest and head registers when the effect of F0 and intensity was eliminated. No significant difference was found between the two voice types in falsetto register. Oq describes the percentage of time when the vocal folds are open within a vibratory cycle. When F0 and vocal intensity were kept constant, tenors had shorter vocal fold contact time than baritones in chest and head registers, but had similar contact time in falsetto register.

The difference in the Oq/log(F0) gradient between baritones and tenors in chest and head registers might be due to the possible anatomical differences in their vocal structures. Singers of different singing voice types are associated with different vocal configurations. For example, Roers et al. (2009) found that different singing voice types consistently exhibited different mean vocal fold lengths; basses tended to have longer antero-posterior vocal fold dimension than tenors, and baritones also longer than tenors. The shorter vocal fold length in tenors might contribute to a shorter anterior-posterior time lag, a shorter vocal fold contact time, and thus a higher Oq/log(F0) gradient in tenors compared with baritones in chest and head registers.

However, no significant difference in the Oq/log(F0) gradient was founded between baritones and tenors in falsetto register. This result seems due to the different vibratory modes between the chest, head and falsetto registers. In male singer, the chest and head registers are produced using the scientifically M1 mechanism, while falsetto register was produced using M2 mechanism (Roubeau et al., 2009). Titze et al. mentioned that when vocal fold vibrated in M1 mechanism, the entire cover including the ligament layer is relatively more lax for vibration. On the contrary, only the border of the mucosa layer can be relatively relaxed for vibration in M2 mechanism, while the ligament layer remains firm and was not involved in vibration (Titze, 1994; Miller, 1996). It followed that the vocal folds involved in M1 mechanism are generally more massive and thicker. Moreover, in M1 mechanism, the thyroarytenoid muscles tend to be more active and increase the vocal fold mediation, resulting in a greater contact surface area during vibration (Titze, 1994). On the other hand, in M2 mechanism, the edge of vocal fold is extremely thin and the posterior portion of vocal folds is damped, making reduce the length of vibrating surface and brief contact (Seikel et al., 2005). These resulted in a short, thin and superficial contact is involved in falsetto register, and reduce the effect of the vocal fold length and mass differences between the two voice types. So it might lead to the similar vocal fold vibration model in falsetto register for both baritones and tenors.

We also found that trend that the Oq/log(F0) gradient was higher in falsetto register (M2) than chest and head register (M1). The Oq/log(F0) gradient was significant higher in falsetto register than chest and head register in baritones and falsetto register yielded a higher Oq/log(F0) value than chest and head registers in tenors although without significant. This trend was followed with the previous studies which showed a higher open quotient in M2 than M1, suggesting thinner vocal folds in M2 than in M1 that lead to a smaller phase lag between the upper and lower layer of vocal fold (Sundberg & Högset, 2001; Henrich et al., 2005; Salomao & Sundberg, 2009). However, no statistical analysis was carried out to testify the difference between mechanisms as well as their interaction with voice types due to limited number of participants in these studies (Sundberg & Högset, 2001; Henrich et al., 2005; Salomao & Sundberg, 2009). The results in this study seem to suggest that the singing types are also influence the effect of mechanism (or register) on vocal folds vibration. The lower singing type (baritones) seems to have large difference between mechanisms than the higher singing voice type (tenors). Results in comparison of inter-register Oq/log(F0) differences between different singing types were also supported this finding. The results showed that the Oq/log(F0) gradient differences between head and falsetto register, and between chest and falsetto register were significantly larger in baritones than in tenors. Similar trend was also showed by Sundberg and Högset (2001) that baritones had larger Oq differences between mechanisms as compared with tenor and counter tenor, though without statistical analysis to support. The possible reason for this finding is the shorter vocal fold length in tenors. As discussed in previous, the tenors might have shorter vocal fold length, so the influence of tensing vocal fold in M2 mechanism might not larger effect compare to baritones. Also, as tenors often need to sing at high pitches than do baritones, they might have more frequent use of combinations of chest, head and falsetto registers. As noticeable register transitions are generally unacceptable in classical operatic singing (Titze, 1994), tenors might try to bridge the differences in voice quality by using higher value of open quotients in chest and head registers and lower value in falsetto register so as to smoothen the difference in open quotient at the transition.

V. CONCLUSION

With regard to vocal fold vibratory characteristics, the present data showed a significant interaction between singing voice type and vocal register, as indicated by the Oq/log(F0) gradient measures in male singers. The study suggested that Oq/log(F0) gradient value which measures the vocal fold vibratory characteristics could be one possible objective parameter for voice classification. The knowledge of correlation of Oq/log(F0) with singing voice types and laryngeal mechanisms could be applied in real-time visual display to complement traditional singing training for different voice types and laryngeal mechanisms.

ACKNOWLEDGMENT

The authors would like to thank all the singers for their enthusiastic participation in this project. The authors would also like to thank the Vocality Department of Xinghai Conservatory of Music for providing supports during data collection.

REFERENCES

Barlow, C., & LoVetri, J. (2010). Closed Quotient and spectral measures of female adolescent singers in different singing styles. *Journal of Voice, 24,* 314-318.

Henrich, N., d'Allessandro, C., Doval, B., & Castellengo, M. (2004). On the use of the derivative of electroglottographic signals for characterization of nonpathological phonation. *Journal of the Acoustical Society of America*, *115*(3), 1321-1332.

Henrich, N., d'Alessandro, C., Doval, B., & Castellengo, M. (2005). Glottal open quotient in singing: Measurements and correlation with laryngeal mechanisms, vocal intensity, and fundamental frequency. *Journal of the Acoustical Society of America*, *117*(3), 1417-1430.

Hollien H. (1974). On vocal registers. *Journal of Phonetics,* 2, 125-143.

Howard, D. M. (1995). Variation of electrolaryngographically derived closed quotient for trained and untrained adult female singers. *Journal of Voice*, 9(2), 163-172.

Kitzing, P. (1990). Clinical applications of electroglottography. *Journal of Voice, 4*(3), 238-249.

Miller, R. (1996). *The structure of singing: system and art in vocal technique*. New York, NY: Schirmer Books.

Roers, F.,Murbe, D., & Sundberg, J. (2009). Predicted singers' vocal fold lengths and voce classification - A study of x-ray morphological measures. *Journal of Voice*, 23, 408-413.

Roubeau, B., Henrich, N., & Castellengo, M. (2009). Laryngeal vibratory mechanism: the notion of vocal register revisited. *Journal of Voice*, 23, 424-438.

Salomao, G. L., & Sundberg, J. (2009). What do male singers mean by modal and falsetto register? An investigation of the glottal voice source. *LogopedicsPhoniatricsVocology*, *34*, 73-83.

Seikel, J. A., King, D. W., & Drumright, D. G. (2005). *Anatomy and Physiology for Speech, Language, and Hearing.* Australia: Thomson Delmar Learning.

Sundberg, J., & Högset, C. (2001). Voice source differences between falsetto and modal registers in counter tenors, tenors and baritones. *Logopedics PhoniatricsVocology*, 26, 26-36.

Titze, I. R. (1994). *Principles of voice production.* Englewood Cliffs, NJ: Prentice-Hall.