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Investigating the physiological and acoustic contrasts between choral and operatic singing

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Abstract

In this study, the difference in glottal vibration and timbre of singing voice in choral and operatic singing was investigated. Eight professional singers with active careers in operatic and choral performances participated in the experiment and sang excerpts from three operatic songs and two choral songs. Audio and electroglottograph signals were simultaneously recorded. The open quotient (O_q) and singing power ratio (SPR) of the voices were analyzed, and it was found that the O_q of choral singing tends to be higher and the SPR of choral singing tends to be lower than those of operatic singing. This suggests that choral singing is conducted with laxer vocal fold coordination, and it has less ringing timbre than operatic singing. However, the O_q and SPR were not directly correlated: the degree of adjustment of SPR differed across singers, suggesting that the strategy to achieve a desired voice quality is individualistic in nature.

Index Terms: singing voice, EGG, open quotient, singing power ratio, choral singing, operatic singing

1. Introduction

1.1. Aim

In the choral culture of Western classical music, singers acquire a distinctive singing style, which is called hereinafter "choral singing." Choral singing often represents soft and blending timbre with little vibrato. In this study, the contrast between choral and operatic singing was investigated from acoustic and physiological perspectives using simultaneously recorded audio and electroglottograph (EGG) signals. That makes it possible to understand the less-explored choral singing in relation to the well-investigated operatic singing.

Measuring choral singing is difficult, especially in Japan. Most Japanese choirs are based on short-term club activities at schools, and the choir singers are usually untrained, having only a few years of singing experience, resulting in unstable measurements. Therefore, in this study, professional singers were recruited who have active careers in operatic and choral performances.

The singers were also asked to sing classical and well-known songs with actual lyrics from both the operatic and the choral repertoire, instead of requesting them to sing sustained vowels. It was expected that such stylistic repertoires would help singers exhibit an appropriate singing style.

1.2. Background

1.2.1. EGG and open quotient

An EGG is a noninvasive technique to measure the vocal fold vibration [1]. The relationship between the EGG signal, the vocal fold movements, and the voice quality are well investigated [2, 3]. Using two electrodes attached to the neck, it measures the electrical impedance change by applying a small amount of electric current. When the vocal fold is closed, the impedance across the vocal fold becomes lower; when opening, the impedance becomes higher because of the airy gap between the vocal cords. An EGG records the opening and closing of the vocal fold by measuring the electric impedance at the neck.

The open quotient, O_q, represents the ratio of the period of the vocal fold opening to the period of the vocal fold vibration, as described in Section 3.2 in detail. In principle, the higher value O_q takes, the opener and laxer the vocal fold is. Yokonishi et al. investigated the O_q at four different modal phonations (i.e., falsetto, breathy, pressed, and normal speaking) with sustained vowels [4]. O_q exhibited a higher value when the voice quality was laxer, in the continuum of tense–lax voice quality. In addition, O_q negatively correlated with the intensity of the voice, while O_q did not correlate with the fundamental frequency of the voice. In this study, O_q was considered to be a representative feature for the physiological changing along with tense–lax coordination of vocal fold vibration.

1.2.2. Singer's formant and singing power ratio

Studies about operatic singing often refers to a "singer's formant," which was initially reported by Sundberg [5, 6]. Professional male opera singers showed a peak of approximately 3 kHz in the spectral envelope of the singing voice. This peak is typically found in the voiced sounds sung by opera singers of Western classical music. It is widely accepted that voices with the singer's formant ring well against orchestra sounds.

The singing power ratio (SPR) is the measure of this "ringing" quality of the singing voice [7]. Rather than considering the presence/nonpresence of the singer's formant, the SPR represents the degree of power increase at the 2–4-kHz frequency band. Here, the SPR is considered to be the acoustic measure of vocal quality that characterizes operatic singing.

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Table 1: *List of songs*

Acronym	Title	Composer	Year	Mode	Accompaniment
LM	*Libera me* from *Requiem* in F minor, Op. 48	Gabriel Fauré	1900	Operatic	Accompanied
CMB	*Caro mio ben*	Tomasso Giordani	1783	Operatic	Accompanied
YMO	*Yumimita mono wa*	Makiko Kinoshita	1989	Operatic	Unaccompanied
YMC	*Yumimita mono wa*	Makiko Kinoshita	1989	Choral	Unaccompanied
AVC	Bass part from *Ave verum corpus* in D Major, K. 618	Wolfgang Amadeus Mozart	1791	Choral	Accompanied

1.2.3. Choral singing

Examining the spectral envelope is also a standard technique to investigate choral singing. For example, bass singers (N=8) showed smaller formant diagram (F1-F2 space) in choral singing than in normal speaking [8]. Soprano singers (N =30) showed stronger power in high frequency band in operatic singing, than in choral singing [9].

Rossing et al. compared the spectral envelopes of operatic and choral singing of eight bass/baritone singers who are experienced with both choral and solo singing [10]. The spectral envelope of the choral mode exhibited higher power in the low-frequency band and lower power in the high-frequency band than that of the operatic mode. This suggests that choral singing exhibits a smaller singer's formant than operatic singing.

1.3. Research questions

Considering the previous research, the interests in this study were (1) whether the O_q and SPR in choral and operatic singing differ and (2) whether the contrasts between operatic and choral modes are individual or sharing common strategies. By answering these questions, one can better understand the phonation–timbre relationship of choral singing in relation to the better-known operatic singing.

2. Experiment

In this experiment, acoustic and EGG signals were recorded during the operatic and choral singing, aiming at comparing the acoustical quality and vocal fold coordination between these two singing modes.

2.1. Participants and IRB

Quality of voice differs depending on the sex and voice types. To avoid such effects, the participants were limited to baritone singers.

Eight professional baritone singers with more than three years of training participated in the experiment. All participants majored in vocal performance at universities of music in Japan and professionally perform in operas and choirs. The mean age of the singers was 32.4 years, with the minimum age being 24 years and maximum age being 51 years. A moderate honorarium was provided upon the participation of the experiment.

The singers were informed about the experiment procedures beforehand and participated upon consent. This experiment is approved by the Institutional Review Board (IRB) at the University of Tsukuba.

2.2. Recording settings

The experiments were individually conducted in a sound-proof music studio in Tokyo. For the recording, the ECM8000 omnidirectional condenser microphone by Behringer was used. For the EGG, the EG2-PCX2 by Glottal Enterprises was used. The EG2-PCX2 amplifies the EGG and acoustic signals, converts to a digital signal, and transmits the signals to a laptop PC via a USB connection. Both signals were recorded at a 44.1 kHz sampling rate and 16-bit resolution. Audacity [11] was used to monitor and record the signals.

The microphone was placed in front of the singer, 50 cm away from the mouth and at the same height as the mouth.

The sound pressure level was calibrated by recording a pure tone of 1 kHz and measuring the sound level with a sound-pressure-level meter (LA-1440 by Ono Sokki).

For the songs having a piano accompaniment, a smartphone was used to play back the prerecorded piano part. The participant wore a pair of headphones connected to the smartphone in order to listen to the accompaniment. Each singer adjusted the volume level of the accompaniment as per their comfort. The experimenter verified the volume level to be quiet enough such that the piano sound did not invade the voice recording.

2.3. Procedure

After having an instruction and warming up his voice, a singer wore a pair of headphones in a comfortable manner, and a pair of electrodes for EGG measurement at the lamina of the thyroid cartilage (i.e., at the sides of Adam's apple).

The experimenter instructed the singer to sing songs in the standard way they would usually perform in a choir or as a soloist. The first phrases from the songs listed in Table 1 were sung in a random order, in the specified mode of singing. Each song was recorded five times. The experimenter simultaneously recorded both the EGG and the audio signal. The singers were allowed to rerecord the songs when they were not satisfied with the recorded performance.

2.4. Songs

The songs used for this experiment are listed in Table 1. Standard songs were selected from the solo and choral repertoires. The mode of singing was determined based on the standard practice in which the original composition is sung.

For operatic singing, *Libera me* (LM), composed by G. Fauré, and *Caro mio ben* (CMB), composed by T. Giordani, were selected. For choral singing, the bass part from *Ave verum corpus* (AVC), composed by W. A. Mozart, was selected.

It was considered desirable to have a song that can be sung in both modes: therefore, we selected *Yumimita mono wa* composed by M. Kinoshita, a Japanese standard repertoire sung in choral and solo performances. This song is denoted “YMO” when sung in operatic singing and “YMC” when sung in choral singing.

3. Analysis

From the recorded signals, both the SPR and O_q were calculated to analyze the acoustical and physiological characteristics for both singing modes.

3.1. Calculating singing power ratio

The SPR is a parameter extracted from a spectrum of vocal recording, and it represents the “ringing” quality of professional singers.

For each window of recorded voice signal, a spectrum is calculated. In the spectrum, the greatest harmonics peak between 2 and 4 kHz and the greatest harmonics peak between 0 and 2 kHz are determined. After taking the power of these peaks, SPR is calculated.

3.2. Calculating open quotient

The open quotient O_q was calculated for each window of the recorded EGG signal. An EGG signal represents the impedance change due to the adduction of the vocal fold. The impedance becomes higher when the vocal fold is opening and lower when closing. O_q is defined in terms of the time period of vocal fold opening T_o and the time period of vocal fold closing T_c.

$$O_q = T_o/T$$

where $T = T_o + T_c$, the cycle of the vocal fold vibration.

To estimate T_o and T_c from the EGG signal, the glottal closure instance (GCI) and glottal opening instance (GOI) need to be obtained. Because these instances exhibit discontinuity in the EGG signal, the first-order differentiation of EGG (dEGG) has abrupt peaks at GCI and GOI. These abrupt peaks are detected by complex wavelet analysis with cosine series envelope [12]. When the GCI and GOI were not detected from a given signal, that frame window was discarded from the O_q data.

4. Results

4.1. Open quotient

The open quotients for choral and operatic singing modes were compared to understand whether the vocal fold vibrations differ depending on the singing modes. O_q relates to the tense–lax coordination in singing: The lower the O_q is (i.e., closer to zero), the more tense the vocal fold coordination is; and the higher O_q is (i.e., closer to one), the laxer the vocal fold coordination is.

The mean O_q was first calculated for each song by averaging the instantaneous O_q in a song. One-way analysis of variance (ANOVA) with repeated measures was conducted; the factor of songs and the factor of singers showed the main effect ($F_{4,184}$ = 39.4, p < .00, $F_{7,184}$ = 122.3, p <.00, respectively), while the factor of repeated measurement trial did not ($F_{4,184}$ = 0.43, p = 0.79). This suggests that singers use voices of different O_q for each song.

Figure 1 shows the mean O_q for each song over five measurements across eight singers with the results of multiple testing corrected with the Benjamin-Hochberg (BH) procedure [13], with markers. This result suggests that songs in choral singing exhibit a higher O_q than songs in operatic singing — in other words, the singers use laxer vocal fold coordination in choral singing than in operatic singing.

Figure 2 shows the mean O_q for each song and each singer. In general, singers demonstrated a higher O_q for choral songs and lower O_q for operatic songs, which is in accordance with the trend found in Figure 1. However, the degree of increment of O_q across songs individually differs for each singer. Some singers (e.g., No. 1 and No. 7) do not differentiate O_q very much, while some others (e.g., No. 2 and No. 3) differentiate O_q dramatically.

4.2. Singing power ratio

The SPR represents the ringing quality of the voice, which is related to the presence of the singer’s formant. When the SPR is higher, 2-4 kHz of spectrum, the frequency band of the singer’s formant has more power.

The mean SPR was calculated for each song by averaging the instantaneous SPR in a song. One-way analysis of variance (ANOVA) with repeated measures was conducted; the factor of songs and the factor of singers showed the main effect ($F_{4,184}$ = 36.2, p < .00, $F_{7,184}$ = 92.5, p <.00, respectively), while the factor of repeated trial did not ($F_{4,184}$ = 0.79, p =

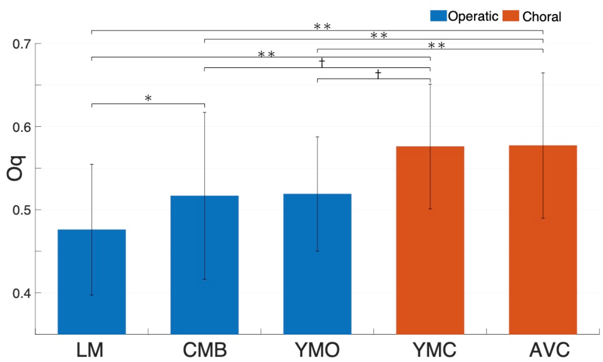

Figure 1: *Mean O_q for each song across singers, where **: p < 0.01, *: p < 0.05, †: p < 0.1, with error bar representing standard error*

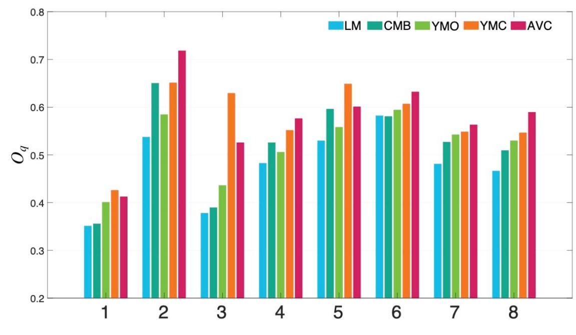

Figure 2: *Mean O_q for each song and each singer: the x-axis shows the participant number*

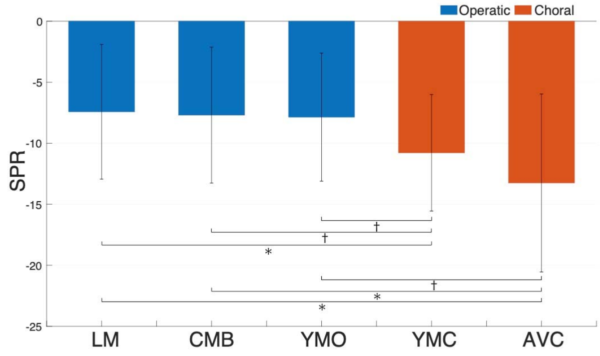

Figure 3: *Mean SPR for each song across singers, where *: $p < 0.05$, †: $p < 0.1$, with error bar representing standard error*

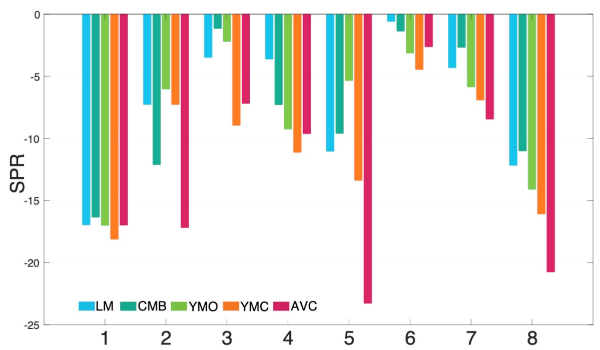

Figure 4: *Mean SPR for each song and singer: the x-axis shows the participant number*

0.53). This suggests that the singers change the power of the singer's formant for each song.

Figure 3 shows the mean SPR averaged for each song over five measurements across eight singers with the results of multiple testing (corrected with the BH method) with markers. This result suggests that operatic songs exhibit a higher SPR than choral songs.

Figure 4 shows the mean SPR for each song and each singer. This graph exhibits a great degree of individual differences for both the range and profile of SPR changes. Singer No.1 shows little change of the SPR across songs, while others change the SPR across songs, with the tendency to lower SPR for choral songs. Furthermore, singers No. 2 and No. 5 showed a remarkably low SPR for AVC, compared with the other songs.

5. Discussion

The mean O_q differed depending on the song, suggesting that singers control the degree of lax–tense coordination at the vocal fold for each song. High O_q values for choral songs suggest that singers took laxer vocal fold coordination. Meanwhile, the mean SPR also showed lower values for choral songs, suggesting a smaller amount of singer's formant in the choral mode than in the operatic mode. These observations are in accordance with previous research, and with the general impression about choral singing (i.e., soft, blending, and not-outstanding).

The individual differences of O_q and SPR suggest that the singers' coordination of vocal fold and vocal tract can be quite individual. Although O_q shows upward slopes for all the eight singers in Figure 2, the variety of SPR is prominent in Figure 4. For example, singer No. 1 shows almost a flat profile of mean SPR, although he increased O_q for choral songs. This means that he used the laxer vocal fold coordination in choral mode, but adjusted the singer's formant at the vocal tract, so that choral and operatic singing have a similar ringing quality. Meanwhile, singers No. 2 and No. 5 show extremely low SPR for AVC, even though the O_q for that song is not that high. This means that these singers adjusted the voice for choral songs rather at the vocal tract than at the vocal fold. These cases show that the coordination of the vocal fold and vocal tract, i.e., the balance of using the vocal fold or vocal tract to control the final sound, can be quite individual, meaning that each singer takes a unique strategy to achieve a desired timbre.

6. Conclusions

By recording the audio and EGG signals, it was observed that professional singers have a higher O_q for choral singing, suggesting that their vocal fold coordination is laxer for choral singing than in operatic singing. The SPR was lower for choral singing than operatic singing, which is in accordance with the previous research based on singer's formant observation. However, the O_q and SPR are not directly correlated: the degree of adjustment of SPR differs across singers, suggesting that the strategy to achieve a desired voice quality is individualistic in nature.

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8. References

[1] A. Fourcin, "Larynogographic examination of vocal fold vibration," *Ventilatory and Phonatory Control Systems,* B. Wyke, ed. London: Oxford University Press, 1974, pp. 315–326.

[2] A. Fourcin. "Precision stroboscopy, voice quality and electrolaryngography," *Voice quality measurement,* R. Kent and M. Ball Eds. San Diego: Singular, 1999.

[3] K. Stevens and H. Hanson. "Classification of Glottal Vibration from Acoustic Measurements," *Vocal fold physiology: Voice quality control,* O. Fujimura and M. Hirano Eds. San Diego: Singular, 1995, pp. 147–170.

[4] H. Yokonishi, H. Imagawa, K.-I. Sakakibara, A. Yamauchi, T. Nito, T. Yamasoba, and N. Tayama. "Relationship of various open quotients with acoustic property, phonation types, fundamental frequency, and intensity," *Journal of Voice*, Vol. 30, No. 2, pp. 145–157, 2016.

[5] J. Sundberg. "Articulatory interpretation of the singing formant," *Journal of the Acoustical Society of America*, Vol. 55, pp. 838–844, 1974.

[6] J. Sundberg. *The science of the singing voice.* De Kalb, IL: Northern Illinois University Press, 1987.

[7] K. Omori, A. Kacker, L. M. Carroll, W. D. Riley, and S. M. Blaugrund. "Singing power ratio: quantitative evaluation of singing voice quality," *Journal of Voice*, Vol. 10, pp. 228–235. Elsevier, 1996.

[8] S. Ternström and J. Sundberg. "Formant frequencies of choir singers," *Journal of the Acoustical Society of America*, Vol. 86, pp. 517–522, 1989.
[9] A. Godwin. "An acoustical study of individual voices in choral blend," *Journal of Research in Music Education*, Vol. 28, No. 2, pp. 119–128, 1980.
[10] T. D. Rossing, J. Sundberg, and S. Ternström. "Acoustic comparison of voice use in solo and choir singing," *The Journal of the Acoustical Society of America*, Vol. 79, No. 6, pp. 1975–1981, 1986.
[11] https://www.audacityteam.org
[12] H. Kawahara and K.-I. Sakakibara. "Simple method for detecting GCI and GOI based on complex wavelet analysis with cosine series envelope," *Technical Report of IEICE*, Vol. 118, No. 198, pp. 1–5, 2018. *(in Japanese)*
[13] Y. Benjamini and Y. Hochberg. "Controlling the false discovery rate: a practical and powerful approach to multiple testing," *Journal of the royal statistical society. Series B (Methodological)*, pp. 289–300, 1995.