Long Term Average Spectrum Characteristics of Head and Chest Register Sounds of Western Operatic Singers

−Possibility of a Second Singer's Formant−

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ABSTRACT

The purpose of this study was to analyze and compare head register with chest register of singers acoustically. Fifteen healthy tenor major students were participated . Fifteen healthy untrained adults were chosen as the control group for this study. Long term average (LTA) power spectrum using the Fast Fourier transform (FFT) algorithm and Linear predictive coding (LPC) filter response were made with /a/ sustained in both head (G4, 392 Hz) and chest registers (C3, 131 Hz). Statistical analysis was performed using the Mann−Whitney test. In the LTA power spectrum, head register of singers increased in the level of energy gain within the frequency of 2.2−3.4 kHz ($p<0.01$), and 7.5−8.4 kHz ($p<0.01$, $p<0.05$). Chest register of singers increased in the frequency of 2.2−3.1 kHz ($p<0.01$), 7.8−8.4 kHz ($p<0.05$) and around 9.6 kHz ($p<0.01$). The LTA power spectrum revealed a peak of acoustic energy around 2,500 Hz, known as the singer's formant and another peak of acoustic energy around 8,000 Hz in the singer's voice.

Keywords: Voice, Acoustics, Formants

1. Introduction

The term 'register' has been used to describe a particular series of tones, which are produced in the same way, having the same quality[1], and produced from perceptually distinct regions of vocal quality that can be maintained over some ranges of pitch and loudness[2]. However, subtle differences exist in the classification of this

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term depending on the researcher[3,4,5].

In traditional vocal training, lots of efforts are dedicated to bridging these registers. Thus, western operatic singers have been trained to smooth out their transitions. For this singing technique, the vocal processes can be spread apart to offset increased adduction by thyroarytenoid muscle activity. This must be coordinated with lung pressure, however, according to the amplitude of the vibration of vocal folds[3]. Titze[3] and Miller[5] insisted on the importance of a *messa di voce* exercise, a gradual crescendo followed by a decrescendo, which is a skill both technical and artistic; it is a facility that should be treated with great respect by the singer. This exercise appears register-free when adduction changes systematically with lung pressure.

Since the beginning of voice research, vocal registers have been discussed by many persons representing a variety of disciplines. In the early days of research, psychoacoustic analysis was the main method of reseach[6]. Recently, numerous research papers such as the spectral analysis of the modal and falsetto register on the speaking voice by Colton[7], research on the transition zone through inverse filtering and electroglottography by Vilkman et al[8], and changes in the glottal configuration as a function of register by Murry et al [9] have been published. However, there has been little work on the objective acoustic analysis of each register in the singing technique of western operatic singers, and so far, there is no published work regarding the differences in the acoustic analyses of the head registers and the chest registers in the singing techniques of western operatic singers. The authors thereby investigated the characteristics of the head register and the chest register voice, which are important aspects of western operatic singer's voice, through acoustic analysis.

2. Materials and Methods

Fifteen tenors attending a music conservatory, department of vocal music who could reliably produce the head and chest registers were participated for this study. The subjects trained a mean of 4.6 years of formal singing training, and the mean age of the subjects was 23.3 years (Table 1).

The voice samples were recorded in a sound treated room. Each subject was asked to produce an /a/ sound for at least five seconds on the G4 note (392 Hz) for the head register sound, and on the C3 note (131 Hz) for the chest register sound. A graduate of the music conservatory and a professor of the music conservatory listening to the voice sample recorded the head and chest register sounds that they considered appropriate. Subjects who produced a F4# or G4# for the head register, and B3b note for the chest register were asked to do so because it was considered that these subjects could produce the head register and chest register sounds more easily on those notes than the G4 or the C3 notes.

The notes were initially recorded on a DAT recorder TCD-D7 (Sony, Japan), then entered in a computer. The sampling rate was 20 kHz, and the sound pressure level was set at 70 dB. The sound data was analyzed using the long term average (LTA) power spectrum using the FFT of the Computerized Speech Lab. (CSL Kay elemetrics, Model 4300B, USA).

For the analyses using the LTA power spectrum, the energy gains for each frequency were compared with the frame size at 64 points (3.2 msec).

The control group was fifteen healthy male adults who had no laryngeal abnormalities, had no abnormalities in articulation, and were of similar age group as the study group. They were asked to produce G4 (392 Hz) notes and C3 (131 Hz) notes using their usual singing techniques. The samples were entered directly into a computer and then analyzed in the same manner as the study group.

Statistical analysis was performed using the Mann-Whitney test of the Statistical Package for Social sciences (SPSS). Results for each group are summarized as mean values standard deviation. Statistical significance were defined as $P< 0.05$, and 0.01.

3. Results

In the analysis using the LTA power spectrum, the energy gains for each frequency were as follows. For head register sounds, a significant increase was seen in the 2,200 Hz-3,400 Hz region ($p<0.01$) and the 7,599 Hz-8,400 Hz region ($p<0.01$, $p<0.05$) in trained singers compared with untrained singers (Fig. 1) (Tab. 2). For the chest register sounds, there was a significant increase in energy in the trained singer group compared with the untrained group in the 2,200 Hz-3,100 Hz region ($p<0.01$), the 7,800 Hz-8,400 Hz region ($p<0.05$), and the 9,600 Hz($p<0.01$) region for the chest register sounds (Fig. 2) (Tab. 3). In the figure 1 and 2, control spectra are not an average over all control subjects. They are one of the best spectra among the control subjects.

4. Discussion

Many definitions of a vocal register are to be found in the extensive literature available on the human voice. However, Colton [7] cumulated the opinions of numerous researchers to state that most of these definitions can be considered examples of one of two general categories. In one category, there are definitions describing the physiological variations which are characteristic of different vocal register, i.e. vibration patterns, vocal fold length/thickness, and/or aerodynamic patterns. The other type of definition emphasizes the voice quality characteristics of a vocal register.

Many classifications of the vocal register exist in the literature. Several decades ago, an attempt was made by a few American singing teachers to abandon the classic register terminology of singing voice and to substitute it with the terminology of speech investigators, thereby designating only "modal" and "loft" registers [5]. These terms, however, ignore the subtle differences in a number of register timbres recognized in the traditional school of singing. Currently this limiting terminology is less frequently encountered, even in investigative studies of the singing voice. There is a reemergence of interest in historic register phenomena, because they are a fundamental part of the art of elite vocalism. Baken supported Hollien's suggestions by classifying the register into modal, pulse, and loft registers, and then defining and explaining each term [4]. Later, Titze [3] combined the prior classifications of register to suggest that registration is observed in both speaking and singing. He also stated that typical speaking registers are pulse, modal and falsetto (Hollien, 1974), and that typical singing registers are chest, head and falsetto. However, there is still considerable controversy regarding the classification of vocal registers.

The typical features of the chest register and falsetto have been described by Johanes Müller based on anatomical and physiological study [8]. Numerous studies on the chest register and falsetto were conducted by Cohen [7,10] since then. He reported that the acoustic spectrum of phonation produced in the modal and falsetto registers show that modal register phonations exhibited a greater number of partials with significant energy. In another of his papers, he stressed the importance of frequency bandwidth, spectral differences in the amplitudes of the fundamental frequency, and differences between the modal and falsetto registers for the perception of the voice quality differences of these two registers.

Along with such acoustic investigations on the registers, Colton et al [6] described how accurately registers can be differentiated through psychoacoustic analysis. This implies that not only objective tests such as acoustic analysis, but also subjective tests that are dependent on listening and deciding, such as psychoacoustic analysis, constitute very important aspects of differentiating between registers. Psychoacoustic decision-making is considered important for opera singers, perhaps because in vocal performance, there is more emphasis on the artistic aspects of the sound than the quality of the sound itself. Investigations of register transitions have recently been reported. From their observations, Vilkman et al[8] reported the process of shift from breathy falsetto phonation to normal chest voice phonation using interactive adaptive inverse filtering and electroglottography, while Titze[2] explained register transition by classifying it into periodicity transition and timbre transition. Titze also suggested that strategies for register equalization be proposed on the basis of supraglottal formant tuning and adjustments in glottal adduction.

Other researchers made progress on the vocal ring (the Singer's formant). Bartholemew (1934) remarked that a good operatic voice needs a concentration of energy around 3000Hz. He also reasoned that this concentration must be produced with a special resonator in the larynx or lower pharynx[3]. About 40 years later, Sundberg (1972, 1978) offered a physiological explanation. He modeled the Singer's formant with a small resonator inside the vocal tract in the epilaryngeal region[3].

In this study, the authors attempted to find differences in the head register and the chest register, parameters that are representative of the voices of opera singers, in trained operatic singers, and differences of the same parameters between trained voices and untrained voices through advanced acoustic analysis equipment. The energy gain for each frequency and the distribution of formant frequencies were studied using the LTA power spectrum. The LTA power spectrum that was used for the acoustic analysis of each register is method of acoustic analysis through digital processing. In this study, the authors compared the energy gains for each frequency with the frame size 64 points. This frame size may give a poor frequency resolution (312.5 Hz), none the less we can see the regions of the energy gains. Although we do not showing in this paper, analysis of the LPC shows the spectral envelope, thus allowing clear visualization of the formants[11].

In this study, analysis of the LTA power spectrum revealed a significant energy gain in the 2,500 Hz region, a frequency already recognized as the singer's formant, in trained singers compared with the control group for both the head and chest registers.

This could mean that both the head and chest register sounds that were formed in an appropriate psychoacoustic manner are closely related to the formation of the singer's formant. The notable feature of this study is that in trained operatic singers, besides the conventional singer's formant in the region of 2,500 Hz, another energy peak was observed in the region of 8,000 Hz. The peak is interpreted as the second resonance of the epilarynx tube[12]. Explanation for this phenomenon will require further work involving physical or physiological modeling, but the authors believe that there will be a possibility of a formerly unrecognized singer's formant in the 8,000 Hz region.

5. Conclusions

When good vocal production was made for the head and chest registers, an energy peak was observed near 2,500 Hz, a frequency already known as the "singer's formant", in all subjects in the study group. Another region of increased energy was observed around 8,000 Hz that had not been noticed previously. The authors believe this region to be the second singer's formant. Further research needs to be pursued on what this increase in energy means, whether this occurs only in tenors, and what implications the increase in energy in this region has as an educational tool in western operatic singers.

References

[1] Leyerle, W. D. 1986.Vocal Development through Organic Imaginary. 2nd edition. Mt Morris, NY: Leyerle Publishing.

[2] Titze, I. R. 1988. "A framework for the study of vocal registers." *J. Voice*, 2, 183–194.

[3] Titze, I. R. 1994. Principles of Voice Production. Englewood Cliffs, NJ: Prentice-Hall Inc., 252–278.

[4] Sataloff, R. T. 1997. Professional Voice: The Science and Art of Clinical Care. 2nd edition. Sandiego. London: Singular Publishing Group Inc., 147–165.

[5] Miller, R. 1986. The Structure of Singing. New York, NY: Schirmer Books, A division of Macmillan, Inc.

[6] Colton, R. H. & H. Hollien. 1973. "Perceptual differentiation of the modal and falsetto registers." *Folia Phoniatr.*, 25, 270–280.

[7] Colton, R. H. 1972. "Spectral characteristics of the modal and falsetto registers." *Folia Phoniatr.*, 24, 337–344.

[8] Vilkman, E., P. Alku & M. laukkanen. 1995. "Vocal fold collision mass as a differentiator between registers in the low pitch range." *J. Voice*, 9, 166–173.

[9] Murry, T., J. J. Xu & G. E. Woodson. 1998. "Glottal configuration associated with fundamental frequency and vocal register." *J. Voice*, 12, 44-49.
[10] Colton, R. H. 1973. "Some acoustic parameters related to the perception of modal falsetto voice quality." *Folia Phoniatr.*, 25, 302-311.
[11] Kent, R. D. 1993. "Vocal tract acoustics." *J. Voice*, 7, 97-117.
[12] Titze, I. R. & S. M. Jin. 2003. "Is there evidence of a second singer's formant?" *J. Singing*, 59(4), 329-331.

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Table.1 Profile of volunteer

No.	Name	Birth of Date	Education periods (yrs.)	Notes for head register	Notes for chest register
1	SW Jin	09/12/77	6	G4	C3
2	YS Hwang	11/30/74	4	F4#	C3
3	HJ Kwon	01/19/77	4	G4	C3
4	SB Kim	03/07/72	5	G4	C3
5	JS Park	10/04/78	4	G4	C3
6	YH Shim	11/19/80	4	G4	C3
7	HY Yom	08/04/80	4	F4#	C3
8	JT Park	02/13/79	3	A4	C3
9	SS Choi	09/29/73	6	G4#	C3
10	SH Eom	05/05/75	6	G4	C3
11	TS Jun	12/23/73	3.5	G4	C3
12	IJ Yang	02/19/76	5	G4	B3*b*
13	JK Jo	05/30/79	5	A4	C3
14	HJ Kim	10/11/77	6	G4	C3
15	KM Park	04/05/78	6	G4	C3

Table.2 LTA power spectrum of head register

Frequency (Hz)	Singers Gain(dB)	Controls Gain(dB)	Variance Gain(dB)
312.5	34.82	39.26	−4.44
625.0	44.52	49.66	−5.14
937.5	47.42	51.70	−4.27
1250.0	48.12	52.95	−4.83
1562.5	43.59	49.81	−6.22
1875.0	35.72	41.59	−5.87
2187.5*	42.59	30.98	11.60
2500.0*	50.04	35.61	14.42
2812.5*	52.49	39.49	13.00
3125.0*	51.42	38.80	12.62
3437.5*	45.45	39.19	6.26
3750.0	35.96	39.59	−3.63
4062.5	27.98	37.11	−9.12
4375.0	23.96	30.93	−6.96
4887.5	21.89	31.67	−9.78
5000.0	20.14	30.25	−10.11
5312.5	20.27	33.41	−13.13
5625.0	20.91	32.07	−11.15
5937.5	22.05	31.15	−9.10
6250.0	24.01	29.16	−5.15
6562.5	25.13	25.36	−0.23
6875.0	24.22	24.87	−0.64
7187.5	23.87	23.92	−0.05
7500.0**	25.38	19.66	5.71
7812.5*	26.41	18.23	8.17
8125.0*	26.93	16.78	10.15
8437.5**	26.83	20.96	5.86
8750.0	25.63	21.33	4.29
9062.5	23.97	23.96	0.01
9375.0	22.31	22.81	0.00
9687.5	20.39	19.12	1.27
10000.0	15.87	15.97	−0.10

* $P<0.01$, ** $P<0.05$

Table.3 LTA power spectrum of chest register

Frequency (Hz)	Singers Gain(dB)	Controls Gain(dB)	Variance Gain(dB)
312.5	38.32	35.89	2.43
625.0	43.87	42.88	0.99
937.5	44.29	44.74	−0.45
1250.0	41.92	42.23	−0.30
1562.5	32.13	34.89	−2.76
1875.0	21.96	19.22	2.75
2187.5*	33.14	21.37	11.76
2500.0*	40.87	26.83	14.03
2812.5*	42.33	26.79	15.54
3125.0*	40.11	24.78	15.32
3437.5	35.11	28.71	6.39
3750.0	28.33	28.85	−0.52
4062.5	22.37	25.11	−2.73
4375.0	18.42	19.69	−1.27
4887.5	16.67	17.85	−1.17
5000.0	14.81	18.40	−3.26
5312.5	14.08	17.14	−3.05
5625.0	14.18	14.22	−0.04
5937.5	14.79	16.42	−1.63
6250.0	15.43	17.12	−1.68
6562.5	16.01	14.85	1.15
6875.0	15.73	16.10	−0.37
7187.5	15.82	14.05	0.76
7500.0	16.17	12.38	3.78
7812.5**	16.24	7.34	8.90
8125.0**	16.21	11.49	4.71
8437.5**	16.43	12.57	3.85
8750.0	16.43	12.66	3.77
9062.5	16.59	13.23	3.36
9375.0	16.79	13.30	3.48
9687.5*	16.73	11.33	5.40
10000.0	13.18	6.30	6.87

* P<0.01, ** P<0.05

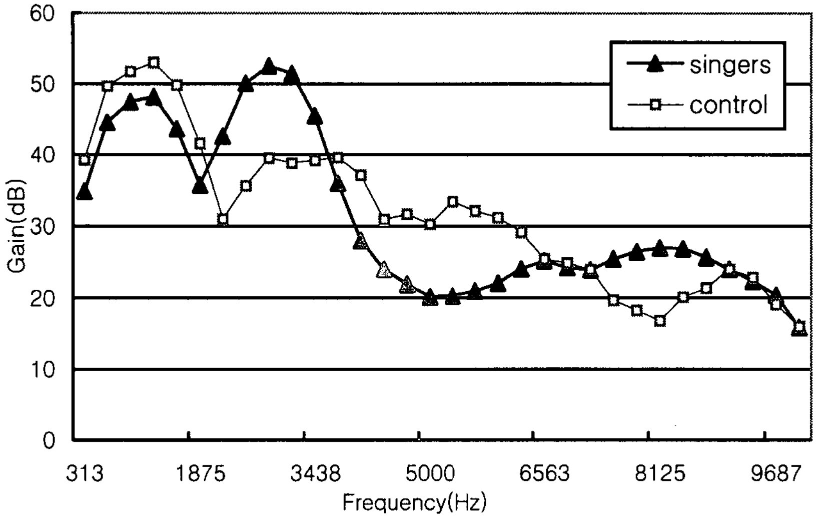

Figure.1 Long term average spectrum of 15 tenors singing (triangles) and 15 controls singing (squares) a sustained /a/ vowel at a high pitch (G4) in head voice.

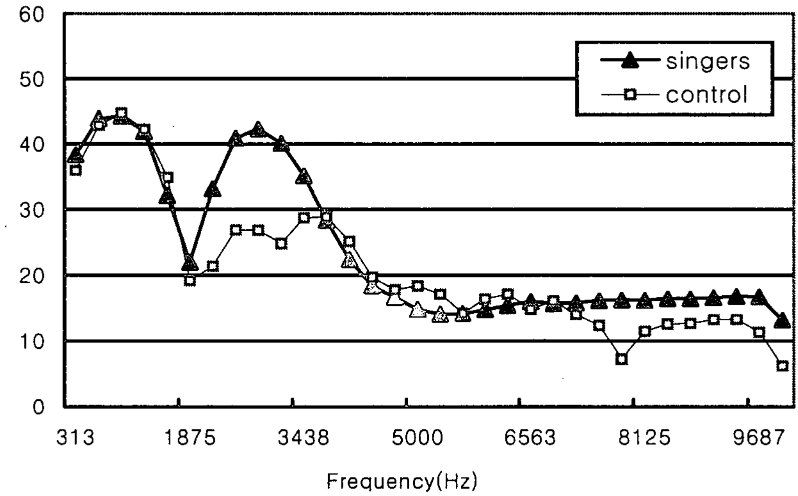

Figure.2 Long term average spectrum of 15 tenors singing (triangles) and 15 controls singing (squares) a sustained /a/ vowel at a low pitch (C3) in chest voice.