Proceedings of the International Symposium on Music Acoustics

(Associated Meeting of the International Congress on Acoustics)

25-31 August 2010, Sydney and Katoomba, Australia

Physiological and Acoustic Characteristics of the Female Music Theatre Voice in 'belt' and 'legit' qualities

Tracy Bourne (1,2) and Maëva Garnier (3)

(1) University of Ballarat, Australia
(2) University of Sydney, Australia
(3) University of NSW, School of Physics, Sydney, Australia

PACS: 43.70.Gr; 43.72.Ct; 43.75.Rs; 43.75.St

ABSTRACT

A study was conducted on six female Music Theatre singers. Audio and Electroglottographic (EGG) signals were recorded simultaneously with the vocal tract impedance while the singers produced sustained pitches on two different qualities ('chesty belt', 'legit'). For each quality, two vowels (/E/, /o/) were investigated, at four increasing pitches over the F#4-D5 range (~370-600 Hz). Measured values of glottal parameters (Open Quotient, Amplitude of the EGG signal) support the idea that 'chesty belt' is produced in the first laryngeal mechanism (M1) and 'legit' in the second one (M2). The frequency of the first vocal tract resonance (R1) was found to be systematically higher in 'chesty belt', close to the second voice harmonic ($2f_0$). These observations were consistent with greater intensities and energy above 1 kHz in 'chesty belt' compared to 'legit'.

INTRODUCTION

The past few decades have seen a growth in demand for the teaching of Contemporary Commercial Music (CCM) vocal styles, including Country, Pop, Broadway, Music Theatre, R&B, Jazz, Rock & Blues (Lovetri, 2008). However, many teachers lack experience and knowledge of appropriate training requirements (LoVetri and Means Weekly, 2003, Weekly and LoVetri, 2009), while others are concerned about apparent vocal health risks inherent to these styles (Osborne, 1979a, Osborne, 1979b, Howell, 1978). Further evidence-based information on these modes of production is required to inform singers and teachers of ways to avoid risk and prevent potential injury.

A number of studies on the CCM voice have established that there are key differences between the contemporary 'belt' voice and the more classically-based 'legit' sound. Perceptual studies have shown that CCM 'belt' is characterized by a 'bright' sound with 'ring' and 'forward', speech-like vowels (Edwin, 2004, Popeil, 2007), in contrast to the 'covered' sound and 'back' vowels of the classical voice (Estill, 1980). It is perceived as a more projected quality than classical singing (Estill, 1980, Edwin, 2002), with a less pronounced vibrato (Miles and Hollein, 1990). Although some studies define 'belt' as a sound with a 'high level of nasality' (Miles and Hollein, 1990), this need not always be the case (LeBorgne et al., 2009). A number of articles have argued that the female 'belt' voice is characterized by a prolonged use of the chest register at higher frequencies than the classical voice (Schutte and Miller, 1993, Miles and Hollein, 1990, Bestebreurtje and Schutte, 2000).

Physiologically, vocal registers are underpinned by different laryngeal behaviors and vocal tract adjustments (Henrich, 2006). At the laryngeal level, chest and head/falsetto registers are underlined by two different laryngeal mechanisms (M1 and M2), differing by the participation or not of the vocalis muscle to the vibration of the vocal folds (Roubeau et al., 2009). Vocal production in mechanism M1 typically shows lower open quotient values than in M2, higher amplitude and greater asymmetry of the Electroglottographic signal (Henrich et al., 2005). Female classical singers almost exclusively use the laryngeal mechanism M2, while studies have shown that CCM 'belt' production demonstrates higher levels of subglottal pressure than classical singing (Sundberg et al., 1993), as well as higher closed quotient values (Schutte and Miller, 1993), supporting the idea that 'belt' may be produced in mechanism M1.

At the vocal tract level, CCM 'belt' production requires a higher larynx position (Sundberg et al., 1993, Yanagisawa et al., 1983, Lawrence, 1979, Estill, 1980, Miles and Hollein, 1990, Balog, 2005) and a higher and more relaxed, forward tongue than for classical singing (Estill, 1988, Balog, 2005, Lawrence, 1979, Miles and Hollein, 1990, Lovetri et al., 1999). CCM 'belt' singers typically adopt a more constricted pharynx in comparison with classical singers (Sundberg et al., 1993), possibly with a megaphone-shaped configuration of the vocal tract, compared to inverted-megaphone shapes observed in opera singers (Titze and Worley, 2009). As a consequence of this narrowed vocal tract, the spectrum of the 'belt' sound demonstrates strong high frequencies in the spectrum (Estill, 1980, Sundberg et al., 1993, Bestebreurtje and Schutte, 2000, McCoy, 2007), leading to the perception of brightness and ring in the sound.

The higher larynx and raised tongue that is characteristic of 'belt' singing is consistent with higher frequencies of the first formant (F1). Observations of a female music theatre singer suggest that the purpose of raising F1 may be to adjust it close to the second harmonic ($2f_0$) (Schutte and Miller, 1993). Further support for this hypothesis can be found in the tuning of the first vocal tract resonance (R1) on $2f_0$, which has also been observed on a Bulgarian singer who also uses the M1 mechanism for the 'teshka'; a quality similar in timbre to 'belt' (Henrich et al. 2007). By contrast, studies on classical singing have observed systematic tuning of R1 on the first voice harmonic (f_0) only from B4 (494Hz)-D5 (587Hz) (Joliveau et al., 2004, Wolfe et al., 2009), and R1:H2 tuning has been observed in some singers at lower pitches; A4 (440Hz) ~B4 (494Hz), on [a] vowels in M2 mechanism (Garnier et al., 2010). Previous studies indicate that there is no systematic tuning of the second vocal tract resonance (R2) for female classical singers (Garnier et al., 2010). R2:$2f_0$ tuning has been reported in some singers on [a] vowels between C5 (523Hz) and G5 (784Hz). There have been no studies of R2 tuning in the 'belt' sound.

Very few of these studies have specifically focused on the music theatre voice. The female music theatre voice includes a wide variety of voice qualities; not only "belt" but also "legit", "twang" and "mix" qualities (Bourne and Kenny, 2008, Popeil, 2007, Lovetri, 2002, Edwin, 2003, Bourne et al., 2010). There is no published research on professional music theatre singers that objectively compares the acoustical and physiological features of these different vocal qualities, and how they compare to CCM "belt" and classical singing.

A single subject study of a female singer in a 'non-classical' style found that her 'legit' demonstrated 'falsetto' characteristics at the laryngeal and spectral level, with a raised F1 just below, but not matching $2f_0$ (Schutte and Miller, 1993). Broader studies of the music theatre voice indicate that singers in these styles demonstrate many of the characteristics of the CCM 'belt' voice (Stone et al., 2003, Bjorkner, 2008, Bjorkner et al., 2006, Barlow and Lovetri, 2009, Bourne and Kenny, 2008), although none of these studies specifically measure 'belt' or 'legit'.

As a consequence, this study aims to compare the productions of 4 professional and 2 advanced student music theatre singers in 'Chesty belt' and 'Legit' qualities. We simultaneously measured audio and electoglottographic signals, as well as the vocal tract impedance (Epps et al., 1997), in order to characterize their differences in laryngeal behavior, vocal tract adjustment and radiated sound.

MATERIAL AND METHOD

The subjects for this study included four professional music theatre singers (Subjects PR1, PR2, PR3, PR4) and two advanced tertiary level students specializing in Music theatre singing (subjects AD1 and AD2). Singers were asked to sustain a single note for 4 seconds, with no change in pitch or loudness and with limited vibrato. Four ascending pitches, generally spaced by one tone, were recorded in this way, the top one chosen as the highest comfortable 'belt' note of each singer. Five measurements were made for each pitch, and for the two vowels [E] and [o]. This whole procedure was repeated 5 times for each of the qualities, 'Chesty belt' and 'Legit'.

Singers stood in front of a stand with a 1/4" pressure microphone (Brüel and Kjær 4944-A) and a small tube attached, side by side. A second identical microphone was placed 30 cm away from the stand, and in front of the singer. The audio signals from both microphones were pre-amplified (Brüel and Kjær Nexus 2690), then digitised at 16 bits and a rate of 44.1 kHz using a Firewire audio interface (MOTU 828).

The vocal tract was excited at the lips only during the last 3 seconds while the subject was singing, with a synthesised broadband signal, and the vocal tract response to that excitation was recorded with the microphone at the lips (Epps et al., 1997). The frequency of the first two vocal resonances was detected manually by two of the authors, from the maxima of the measured impedance ratios.

The mean Sound Pressure Level (SPL) and the Average Spectrum (LTAS, with NFFT=4096 points) were measured from the first "clean" second of audio signal (recorded 30cm away from the lips), when the vocal tract was not excited yet. The coefficient α, defined as the ratio between the energy above and below 1kHz, was computed from the LTAS (Sundberg and Nordenberg, 2006).

Table 1. Comparision of the amplitude of the EGG signal, the Open Quotient and the Ratio between Closing and Opening peaks of the DEGG signal between productions in 'chesty belt' and 'legit' qualities, for the two vowels [E] and [o].

		EGG Amplitude		OQ		Ratio Cl/Op peaks	
		'Chesty belt'	'Legit'	'Chesty belt'	'Legit'	'Chesty belt'	'Legit'
PR1	[E]	0.22 ± 0.03	0.2 ± 0.02	0.40 ± 0.02	0.67 ± 0.07	4.16 ± 0.46	2.81 ± 0.9
	[o]	0.30 ± 0.03	0.37 ± 0.03	0.44 ± 0.01	0.7 ± 0.03	4.66 ± 0.4	2.45 ± 0.34
PR2	[E]	0.16 ± 0.01	0.24 ± 0.04	0.42 ± 0.09	0.65 ± 0.06	2.53 ± 0.36	2.24 ± 0.2
	[o]	0.15 ± 0.02	0.29 ± 0.03	0.38 ± 0.08	0.64 ± 0.04	2.28 ± 0.5	2.56 ± 0.17
PR3	[E]	0.13 ± 0.02	0.11 ± 0.04	0.6 ± 0.08	0.78 ± 0.04	2.44 ± 0.22	2.13 ± 0.36
	[o]	0.09 ± 0.01	0.09 ± 0.03	0.62 ± 0.09	0.84 ± 0.06	2.13 ± 0.24	1.77 ± 0.5
AD1	[E]	0.11 ± 0.02	0.1 ± 0.01	0.44 ± 0.03	0.60 ± 0.04	2.16 ± 0.4	1.23 ± 0.03
	[o]	0.11 ± 0.02	0.09 ± 0.01	0.42 ± 0.02	0.6 ± 0.02	2.04 ± 0.4	1.3 ± 0.09
AD2	[E]	0.14 ± 0.01	0.16 ± 0.02	0.42 ± 0.04	0.64 ± 0.05	2.75 ± 0.26	1.93 ± 0.2
	[o]	0.16 ± 0.02	0.16 ± 0.03	0.43 ± 0.06	0.67 ± 0.05	2.9 ± 0.47	2.09 ± 0.1

The contact of the vocal folds was measured using a 2-channel electroglottograph (Glottal Enterprise EG2) over the 4 seconds of phonation. We detected the mean amplitude of the EGG signal. Opening and closing peaks were detected from the derivative of the EGG signal (or DEGG signal) and were used to estimate the mean Fundamental frequency (f_0), the mean Open Quotient (OQ) and the Ratio between the amplitude of closing and opening peaks ('Ratio Cl/Op peaks'). This last parameter gives an estimation of the asymmetry of the EGG waveform.

RESULTS

Larynx

The laryngeal data of Singer PR4 could not be analysed because the quality of her EGG signal was poor.

Table 1 summarizes the laryngeal observations from the 5 singers, disregarding the pitch factor. In all 5 singers, OQ values were always lower in 'chesty belt' than in 'legit'. All singers demonstrated a higher ratio of opening to closing peaks in 'chesty belt' than in 'legit' for both vowels. This difference was particularly marked for singer PR1. Three of the five singers (PR1, PR2, AD2) showed a significantly higher amplitude of the EGG signal in 'legit' than in 'chesty belt" production; for both vowels for subject PR2, for [o] only in subject PR1, and [E] only for subject AD2.

Vocal Tract

On average over the different pitches considered, all singers demonstrated a higher first resonance frequency (R1) for 'chesty belt' productions than for 'legit' ones, for both [o] and [E] vowels (see Figure 1). This result extended to the second resonance frequency (R2) for half of the singers (PR2, PR3, and AD1). The three remaining singers PR1, PR4 and AD2 still presented higher R2 values in 'chesty belt' than 'legit', but for [o] vowels only (see Figure 1).

For all singers but one (PR3), R1 values followed the frequency of the second harmonic ($2f_0$) for increasing pitch on both vowels in 'chesty belt' (see example in Figure 2). For Singer PR3, R1 matched $2f_0$ only for the low pitches (G4-A4 ~400Hz) of [E] vowels. In 'legit', however, no systematic tuning of R1 was observed with increasing pitch (see Figure 3). Some proximity between R1 and $2f_0$ was observed for singers PR2, PR4 (on [E]) and PR3 (on [o]) but only on the lower pitches.

No consistent pattern was found in the tuning of the second resonance frequency (R2), neither in 'chesty belt' nor in 'legit'.

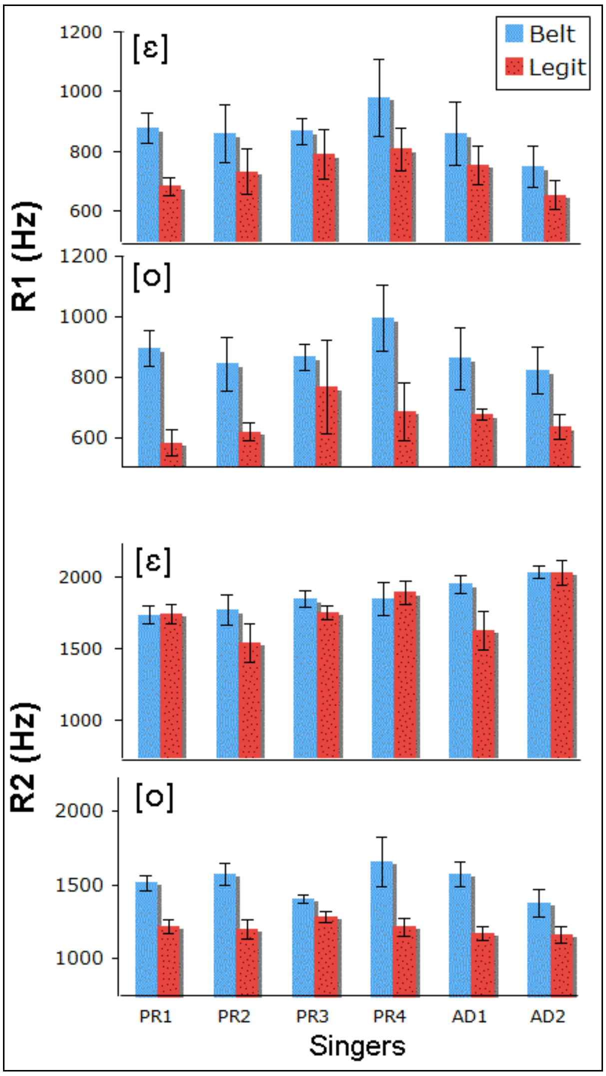

Figure 1. Comparison of the first two resonance frequencies (R1 and R2) in 'chesty belt' and 'legit' qualities produced on the vowels [E] and [o] by the 4 professional singers (PR) and the 2 advanced students (AD).

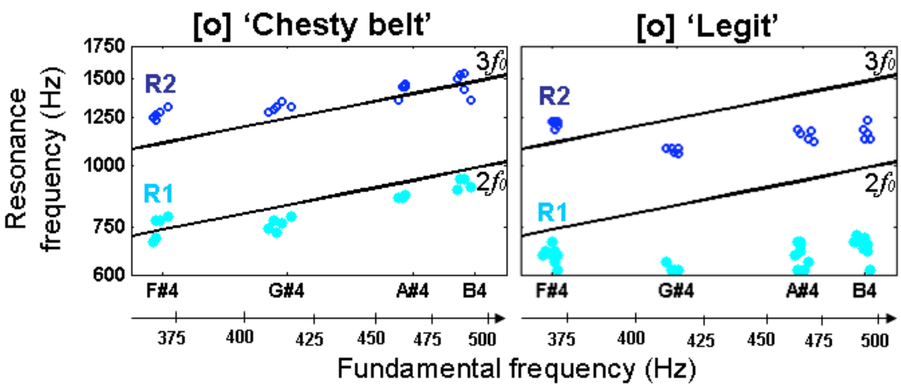

Figure 2. Details of the resonance adjustements observed in one singer (AD2). In 'Chesty-belt'(a), R1 follows $2f_0$ and R2 tends to follow $3f_0$, whereas no specific adjustement of R1 is observed in 'Legit'(b).

Spectrum

Table 2 summarizes SPL and α coefficient results for the 6 singers in both ‘chesty belt’ and ‘legit’. All singers in this study produced ‘chesty belt’ louder than ‘legit’, with higher sound pressure levels recorded in all singers for both vowels at every pitch. Values of the α coefficient were also demonstrably higher in ‘chesty belt’ than for ‘legit’ in all singers for both vowels.

Table 2. Comparision of the Sound Pressure Level and the α coefficient in ‘chesty belt’ and ‘legit’ qualities, produced on two vowels ([E] and [o]) by the 6 singers

		SPL (dB)		α coefficient	
		‘Chesty belt’	‘Legit’	‘Chesty belt’	‘Legit’
PR1	[E]	113 ± 2	103 ± 3	1.66 ± 2.79	3.12 ± 2.53
	[o]	124 ± 4	113 ± 4	-5.2 ± 2.27	1.15 ± 2.43
PR2	[E]	121 ± 9	112 ± 3	-0.62 ± 1.25	1.53 ± 0.63
	[o]	125 ± 5	113 ± 3	-1.91 ± 1.09	1.81 ± 1.45
PR3	[E]	117 ± 2	112 ± 1	-1.53 ± 1.2	3.98 ± 1.55
	[o]	118 ± 1	114 ± 1	-1.13 ± 0.83	1.70 ± 1.24
PR4	[E]	122 ± 3	108 ± 3	0.73 ± 1.52	6.34 ± 3.30
	[o]	121 ± 2	108 ± 3	-0.55 ± 2.02	5.49 ± 2.15
AD1	[E]	120 ± 5	104 ± 3	-2.06 ± 1.91	3.23 ± 2.05
	[o]	122 ± 3	105 ± 3	-1.9 ± 1.17	1.82 ± 2.23
AD2	[E]	112 ± 4	106 ± 2	-2.31 ± 2.72	3.23 ± 1.21
	[o]	115 ± 4	105 ± 2	-3.73 ± 2.43	1.51 ± 1.34

DISCUSSION AND CONCLUSION

Observations indicate a clear difference between the ‘chesty belt’ and ‘legit’ vocal qualities at both physiological and acoustic levels.

The values observed for OQ and for the ratios of closing peak to opening peak provide strong arguments to support the idea that the female music theatre ‘belt’ is produced in laryngeal mechanism M1, while ‘legit’ is produced in M2. This idea is contradicted by the tendency towards greater amplitude of the EGG signal in ‘legit’ than in ‘chesty belt’. However, the amplitude of the EGG signal is not only affected by the amount of contact between vocal folds, but also by other factors such as vertical movements of the larynx. As a result, the difference in EGG amplitude observed here between ‘chesty belt’ and ‘legit’ productions may not be a good indicator of the laryngeal mechanism used, but may just be the artifact of a higher position of the larynx in ‘belt’ often described in the literature (Sundberg et al., 1993, Yanagisawa et al., 1983, Lawrence, 1979, Estill, 1980, Miles and Hollein, 1990, Balog, 2005). The abrupt vocal fold closure, greater degree of contact between the vocal folds and stronger amplitude of vocal fold vibration that is characteristic of M1, also relates to the higher levels of SPL and the richer acoustic spectrum in the high spectral frequencies that all singers demonstrated in ‘chesty belt’ quality.

‘Chesty belt’ and ‘Legit’ qualities have also shown clear differences in vocal tract adjustments: Over the examined pitch range; G4-D5 (392-587Hz), ‘Chesty-belt’ quality was characterized by a tuning of R1 to $2f_0$ whereas ‘Legit’ did not show any particular resonance adjustment. All singers demonstrate higher R1 frequencies for ‘Chesty belt’.

No real differences were found between the professional singers and students in this study, so it is not possible to indicate differences between experience or expertise, or indeed ways that ‘Chesty belt’ or ‘Legit’ may be produced more efficiently for these subjects.

The findings of this study support arguments by CCM experts that ‘Chesty belt’ requires a different pedagogical approach than classical singing. In particular, developing the skill of singing in ‘chest’ register to relatively high pitches with a bright, forward timbre may require different technical exercises than those from classical methodologies.

REFERENCES

1 J. E. Balog, “A Guide to Evaluating Music Theater Singing for the Classical Teacher” *J. Singing* **61,** 401-406 (2005).
2 C. Barlow and J. Lovetri, “Adolescent Singers in Different Singing Styles” *J. Voice* (in Press).
3 M. Bestebreurtje and H. K. Schutte, “Resonance Strategies for the Belting Style: Results of a Single Female Subject Study” *J. Voice* **14,** 194-204 (2000).
4 E. Bjorkner, “Musical Theatre and Opera Singing - Why so Different? A Study of Subglottal Pressure, Voice Source, and Formant Frequency Characteristics” *J. Voice* **22,** 533-540 (2008).
5 E. Bjorkner, J. Sundberg, T. Cleveland and E. Stone, “Voice Source Differences Between Registers in Female Musical Theatre Singers” *J. Voice* **20,** 187-197 (2006).
6 T. Bourne, M. Garnier, & D. Kenny “Music Theatre Voice: Production, physiology and pedagogy”. In S. D. Harrison (Ed.) *Perspectives on Teaching Singing: Australian Vocal Pedagogues Sing Their Stories*. Brisbane, Australian Academic Press (2010).
7 T. Bourne and D. Kenny, “Perceptual descriptions of legit and belt voice qualities in music theatre” in *Proc. of the ANATS Conf.* (Perth, Australia, 2008).
8 R. Edwin, “Belting: bel canto or brutto canto” *J. Singing* **58,** 67-68 (2002).
9 R. Edwin, “A Broader Broadway” *J. Singing* **59,** 431-432 (2003).
10 R. Edwin, “Belt Yourself” *J. Singing* **60,** 285-288 (2004).
11 J. Epps, J. Smith and J. Wolfe, “A novel instrument to measure acoustic resonances of the vocal tract during speech” *Meas. Sci. Technol.* **8,** 1112-1121 (1997).
12 J. Estill, “Observations about the quality called belting” in *Proc. of* the *Ninth Symposium, Care of the Professional Voice* eds. B. Weinberg and V. Lawrence *(T*he Juilliard School, New York City, Voice Foundation, 1980).
13 J. Estill, “Belting and Classic Voice Quality: Some Physiological Differences” *Med. Probl. Perform. Art.* **3,** 37-43 (1988).
14 M. Garnier, N. Henrich, J. Smith and J. Wolfe, “Vocal Tract Adjustments in the High Soprano Range” *J. Acoust. Soc. Am.* **127** (in press).
15 N. Henrich, M. Kiek, J. Smith and J. Wolfe, “Resonance Strategies used in Bulgarian Women's Singing Style: A Pilot Study” *Log. Phon. Vocol.* **32,** 171-177 (2007).

16 N. Henrich, "Mirroring the voice from Garcia to the present day: Some insights into singing voice registers" *Log. Phon. Vocol.* **31,** 3-14 (2006).
17 N. Henrich, C. d'Alessandro, B. Doval and M. Castellengo, "Glottal open quotient in singing: Measurements and correlation with laryngeal mechanisms, vocal intensity, and fundamental frequency" *J. Acoust. Soc. Am.* **117,** 1417-143 (2005).
18 E. Howell, "Chest voice-belting" *Equity News* **April** *(1978)*
19 E. Joliveau, J. Smith and J. Wolfe, "Vocal Tract Resonances in Singing: The Soprano Voice" *J. Acoust. Soc. Am.* **116,** 2434-2439 (2004).
20 V. Lawrence, "Laryngological Observations on Belting" *J. Res. Sing.* **2,** 26-28 (1979).
21 W. D. Leborgne, L. Lee, J. C. Stemple and H. Bush, "Perceptual Findings on the Broadway Belt Voice" *J. Voice* (2009, in Press).
22 J. Lovetri, "Contemporary Commercial Music: More than One Way to Use the Vocal Tract" *J. Singing* **58,** 249-252 (2002).
23 J. Lovetri, "Contemporary Commercial Music" *J. Voice* **22,** 260-262 (2008).
24 J. Lovetri, S. Lesh and P. Woo, "Preliminary Study on the Ability of Trained Singers to Control the Intrinsic and Extrinsic Laryngeal Musculature" *J. Voice* **13,** 219-226 (1999).
25 J. Lovetri, E. M. Weekly, "Contemporary Commercial Music (CCM) Survey: Who's Teaching What in Non-Classical Music?" *J. Voice* **17,** 207-215 (2003).
26 S. Mccoy, "A Classical Pedagogue Explores Belting" *J. Singing* **64,** 545-549 (2007).
27 B. Miles and H. Hollien, "Whither Belting?" *J. Voice* **4,** 64-70 (1990).
28 C. Osborne, "The Broadway Voice: Just Singin' in the Pain (Part 1 and 2)" *High Fidelity* **29,** 53-65.
29 L. Popeil, "The Multiplicity of Belting" *J. Singing* **64,** 77-80 (2007).
30 B. Roubeau, N. Henrich and M. Castellengo, "Laryngeal Vibratory Mechanisms: The notion of vocal register revisted" *J. Voice* **23,** 425-438 (2007).
31 H. K. Schutte and D. G. Miller, " Belting and Pop, Nonclassical Approaches to the Female Middle Voice: Some Preliminary Conclusions" *J. Voice* **7,** 142-150 (1993).
32 R. E. Stone, T. Cleveland, J. Sundberg and J. Prokop, "Aerodynamic and Acoustical Measures of Speech, Operatic and Broadway Vocal Styles in a Professional Female Singer" *J. Voice* **17,** 283-297 (2003).
33 J. Sundberg, J. Gramming and P. Lovetri, "Comparisons of Pharynx, Source, Formant, and Pressure Characteristics in Operatic and Musical Theatre Singing". *J. Voice* **7,** 301-310 (1993).
34 J. Sundberg and M. Nordenberg, "Effects of vocal loudness variation on spectrum balance as reflected by the alpha measure of long-term-average spectra of speech" *J. Acoust. Soc. Am.,* **120,** 453–457 (2006).
35 I. Titze and A. Worley, "Modeling source-filter interaction in belting and high-pitched operatic male singing" *J. Acoust. Soc. Am.* **126,** 1530-1540 (2009).
36 E. M. Weekly and J. Lovetri, "Follow-up Contemporary Commercial Music: Who's Teaching What in NonClassical Music?" *J. Voice* **23,** 367-375 (2009).
37 J. Wolfe, M. Garnier and J. Smith, "Vocal tract resonances in speech, singing, and playing musical instruments" *HFSP Journal* **3,** 6-23 (2009).
38 E. Yanagisawa, J. Estill, S. Kmucha and S. Leder, "The Contribution of Aryepiglottic Constriction to "Ringing" Voice Quaity-A videolaryngoscopic Study with Acoustic Analysis" *J. Voice* **3,** 342-350 (1983).