# Closed Quotient and Spectral Measures of Female Adolescent Singers in Different Singing Styles

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**Summary:** Although quantifiable assessment of the singing voice is now commonplace, research on young (child and adolescent) voices is still in its infancy. There is still insufficient data on young people's voices based on which, "norms" in behavior could be modeled, particularly for contemporary commercial music (CCM), such as musical theater (MT). The objective of this study was to assess if quantifiable differences in vocal production and acoustic output of young singers exist between "classical" and "MT" styles. The study was a prospective cohort study of 20 adolescent female singers aged 12–17 years training their voices using a system, which includes both "classical" and "MT" styles. The study examined laryngographically derived closed quotient (CQ), average vowel spectra (AVS) and long-term average spectra (LTAS) measures of the sung voices of singers in "classical" and "MT" styles. The spectral slope was shallower for the MT voice, and the mean CQ was significantly higher across the pitch range when singing in an MT style than in a "classical" style. The second to fifth harmonics were stronger in the MT style than in classical, with a significant difference between the two styles. The increase in intensity in the first five harmonics was disproportionately higher than the increase in CQ. Results, therefore, suggested that MT singing primarily uses change in resonance strategy rather than raised vocal tension to achieve the tonal changes associated with the genre.

**Key words:** Singer–Adolescent–Musical theater–Closed quotient–LTAS–AVS.

## INTRODUCTION

The quantification of the singing voice has been of increasing interest to the voice science community for a number of years now, and the use of techniques, such as electroglottography/laryngography (EGG) (eg, Howard et al[1] and Howard[2]), inverse filtering (eg, Rothenberg[3]), long-term average spectra (LTAS) (eg, Mitchell and Kenny[4]) have been widely used to assess vocal production in adult singers, primarily from the western classical tradition.

Outside this particular demographic group, the data on singers' voices is still limited, with only a relatively small amount published on contemporary commercial music (CCM),[5] such as musical theater (MT), Pop, Folk, Rock, Gospel, and many other genres. Although there are studies in these areas, particularly on MT (eg, Evans and Howard[6] and Björkner et al[7]), as yet, these are few in number.

The study of young, particularly adolescent, voices has also been distinctly limited. A number of studies have examined quantifiable aspects of young singers' voices from a variety of perspectives. These have included using laryngographically derived vocal fold closed quotient (CQ) (eg, Pedersen[8] and Barlow and Howard[9]), inverse filter-derived CQ (Mecke and Sundberg[10]), and voice range profile (VRP) (McAllister et al[11]). However, despite this, quantifiable voice analysis of young singers to inform use of biofeedback tools is still limited in scope and quantity. There is an overall lack of a comprehensive corpora of data[12] that can be used to assess "norms" of young voices.

Of the available data, most of the studies have focused on the young "classical" (bel canto) chorister—particularly the male voice (eg, Cooksey[13]), with a smaller number of studies focusing on female choristers, for example, Welch[14] and Gackle.[15] There is a particular lack of research on young voice production for CCM despite the fact that young people are still the most likely demographic group to undertake training in singing,[16] particularly CCM. The Theatre Arts Organisation Stagecoach alone has over 39,000 students training in acting, dancing, and singing,[17] yet there is currently very little published research on the voices of young theater singers.

This study examines measurable parameters of 20 female students from the Brooklyn Youth Chorus Academy (BYCA)[a] who train for both classical and MT styles of singing. The study aims to ascertain if quantifiable differences occur in voice production by the same student singing in both classical and MT styles, and also aims to develop the beginnings of a model of the voices of young theater singers.

## METHODS

Twenty BYCA subjects aged between 12 and 17 years were recorded speaking and singing. Recordings were made using a Laryngograph headset mounted electret reference microphone to record the speech (Sp) signal, at a distance of 9 cm from the mouth, and a laryngograph, which was used to record the laryngographic (Lx) signal. The Lx signal was viewed on an oscilloscope during the recording to ensure that an adequate amplitude of the Lx signal was maintained. If the Q7

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[a]The BYCA is a uniquely positioned organization, working with a large number of international names from both the CCM and classical music worlds. The chorus regularly performs alongside artists as disparate as Elton John and the New York Philharmonic Orchestra. As such, the singers need to be able to adapt their vocal style according to the musical genre being performed.

signal dropped to a low level, the electrodes were repositioned and the protocol repeated. Recordings were made using the Digital Laryngograph directly onto a Toshiba Libretto micro-laptop with 1-Gb RAM and a Pentium Mobile processor running at 1.2 GHz. Sampling rate was 22.05 kHz and bit resolution was 16 bit. Approval of the research was given by the Ethics Committee of Southampton Solent University, and both subject and parental/guardian permissions were given.

Subjects were recorded singing a verse of "happy birthday" in a "classical" (chorister) style in the key of C Major and then repeating it in an "MT" style. The verse was sung between C4 (261 Hz) and C5 (522 Hz).

Students were given a key note and a tempo (90 BPM) before singing the piece unaccompanied. To control loudness variation, subjects were asked to sing the song mezzo-forte in both vocal styles. If considered too loud or too quiet, the singer was asked to repeat the verse.

Using a "universally" known piece ensured that all subjects were familiar with the song. Audio files were normalized for analysis and SpectraLab® was used to generate LTAS of the entire verse for all 20 students using a 3rd octave filter bandwidth, Hanning window with 75% overlap and an FFT size of 2048 samples. A mean spectrum for each style was plotted across the group.

Recordings of the 10 most experienced students, with 4–9 years' training under the Cross-Choral Training (C-CT) system, all aged between 14 and 17 years were analyzed in more detail. Five notes from the song at 3rd octave intervals (root, 3rd, 5th, 7th, and octave) were extracted for detailed laryngographic and acoustic analysis. Notes were chosen across the range to analyze relationships between pitch and production. These notes were chosen to be at 3rd octave intervals, as this frequency resolution is commonly used for spectral analysis. This interval would also allow effective separation of the fundamental frequencies for the purpose of analysis, allowing a more detailed comparison of the different styles than available using the LTAS of the entire song.

Average vowel spectra (AVS) were also derived from a 500-ms steady-state portion of each of the specified notes, to give a direct comparison between styles of notes across the pitch range of the song. The AVS used a narrowband filter with FFT size of 4096 samples, Hanning window and overlap of 75%.

The relative amplitude of harmonic partials up to the 6th (referenced to the fundamental) for each note was calculated from this data. Mean CQ was also calculated for each note, from which, AVS was extracted using the same sample to give a direct comparison of vocal function and resultant acoustic output.

From the notes selected for analysis, two notes were on the vowel æ ("happy"), one on the vowel ɝ ("birth") and two on the vowel u ("to" and "you"). The musical phrase is shown in Figure 1.

## RESULTS

The mean LTAS curves are shown in Figure 2. Although mean spectral slope is very similar between the styles over the lowest notes, from around 350 Hz, spectral slope for the "classical" voice is considerably steeper than for the "theater" voice, with a mean intensity 3 dB higher than the "classical" voice across the range, with a maximum difference of around 6 dB (double the intensity) and a range of variation up to 30 dB. A one-tailed, paired Student's t test in XLStat demonstrates a significant difference between the mean LTAS of the two vocal styles (P = 0.00029).

From the analysis of AVS, the "theater" voice demonstrated higher relative amplitudes than "classical" across all harmonics up to the sixth (Table 1), and particularly, in the first three harmonics. For many notes sung in "theater," the first three harmonics are stronger than the fundamental, and the spectral slope is relatively shallow over the first five harmonics, with a mean slope of 6 dB/octave, compared with 11 dB/octave for the "classical" voice. A one-tailed paired Student's t test of the means demonstrated a significant difference between the two data sets (P = 0.010). The "classical" voice shows much weaker harmonics, particularly above the third harmonics, and a much steeper spectral slope.

Mean CQ for each note in each style was derived, and the results are shown in Figure 3. The mean CQ for four of the five notes analyzed is higher for the "theater" voice than the classical voice, with the mean for C5 being nearly identical. Analyzed as individual singers across all notes, 76% of mean CQs were higher in "theater" voice than in "classical" voice.


FIGURE 1. "Happy birthday"—syllables selected for analysis circled.

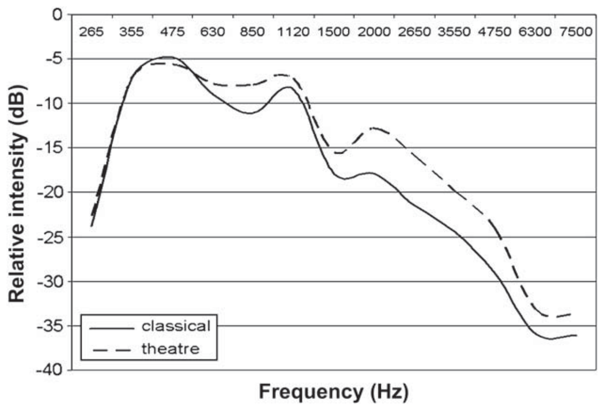


FIGURE 2. Third octave normalized LTAS curves for "classical" and "theater" voices.

TABLE 1.
Mean CQ% and Relative AVS for Specified Pitches/Vowels in Each Style

| Voice | Note/Vowel | Frequency (Hz) | CQ (%) | SD $F_0$ | Mean Intensity (dB) of Harmonic Partial | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2nd | 3rd | 4th | 5th | 6th |
| “Classical” | C4/æ | 262 | 26.2 | 0 | −3.10 | −0.45 | −2.49 | −7.08 | −17.95 |
| “Theater” | C4/æ | 262 | 31.1 | 0 | −1.05 | 5.66 | 7.62 | −3.76 | 8.84 |
| “Classical” | C5/ɝ | 523 | 28.2 | 0 | −2.10 | −7.99 | −19.55 | −22.91 | −27.86 |
| “Theater” | C5/ɝ | 523 | 31.1 | 0 | −1.38 | −6.77 | −12.90 | −11.13 | −17.97 |
| “Classical” | Bb 4/æ | 466 | 28.3 | 0 | 3.70 | −0.55 | −10.81 | −23.98 | −29.65 |
| “Theater” | Bb 4/æ | 466 | 33.6 | 0 | 6.91 | 0.35 | −2.37 | −16.57 | −12.08 |
| “Classical” | G4/u | 329 | 24.6 | 0 | −12.71 | −21.21 | −24.14 | −29.86 | −30.03 |
| “Theater” | G4/u | 329 | 29.4 | 0 | −11.03 | −22.88 | −13.50 | −19.59 | −18.44 |
| “Classical” | E4/u | 329 | 25.6 | 0 | −16.05 | −20.33 | −21.70 | −26.91 | −43.72 |
| “Theater” | E4/u | 330 | 31.1 | 0 | −11.58 | −24.61 | −23.42 | −11.09 | −12.84 |

C-CT is BYCA’s program for developing vocal and musicianship skills in a choral setting. C-CT enables the singers to intentionally perform in a variety of co-ordinated adjustments and vowel sound qualities so that the chorus can easily respond to the musical and expressive demands of diverse repertoire, including both CCM and “classical” styles of performance and can sing any style of music appropriately.

A one-tailed paired Student’s t test of the means demonstrated a significant difference between the two data sets (P ¼ 0.018).

There is a relationship between the mean CQ and sung pitch for each style. For the “classical” voice, mean CQ starts at 26.2% and decreases slightly with increased pitch up to G4 (24.6%), and then rises with pitch to B4 and C5 (28.3%). Mean CQ of the “theater” voice is higher at C4 (31.1%), but otherwise shows a similar pattern, again decreasing slightly with increased pitches to G4 (29.2%), and rising to B4 (33.6%), although CQ drops slightly again at C5 to 31.1%.

## DISCUSSION

Previous studies by the authors on classically trained choristers in the United Kingdom[18] demonstrated a relationship between CQ and pitch for this style of singing. The pattern of mean CQ against pitch for the classical voice is almost exactly replicated in this sample group, in which, CQ falls with increasing pitch up to G4 and rises above G4. This suggests a register transition around G4, which is supported by the findings of Wurgler,[19] who identified this point as a register transition for young voices. These results suggest that the “classical” singing style used by the BYCA is the same as that used by other conventionally “classical” youth choirs. The “theater” style appears to have much the same relationship between CQ and pitch as the “classical,” with a decrease in CQ up to G4 followed by a slight increase again. The key difference is that the “theater” voice uses higher mean CQ values for most pitches.

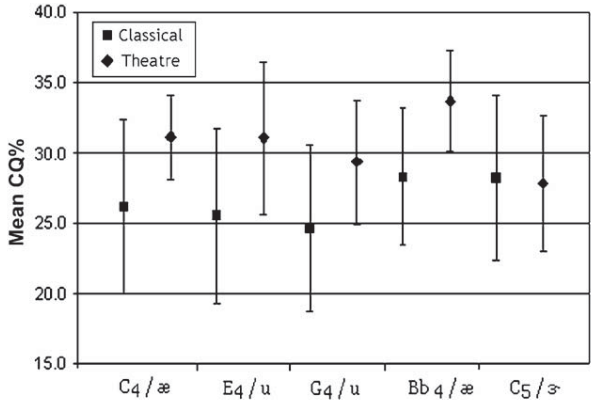


FIGURE 3. Mean CQ% and standard deviation for selected pitches in each style.

The results clearly show consistent differentiation in both vocal function and acoustic output between the two different singing styles. The AVS show stronger harmonics relative to the fundamental for the “theater” voice compared with the “classical” style of singing.

The variations in amplitude across the spectrum indicate potential differences in both voice source and resonance strategies for the performer between the two different singing styles. Nordstrom and Sundberg[20] indicate that spectral tilt can be caused by variation in vocal loudness. As each subject in this study performed mezzo-forte in both styles, loudness variation was minimized. The degree of effect of vocal loudness on spectral tilt also decreases with increased volume, particularly for young voices,[10] so that this effect is minimized for the subjects in the study.

Scherer[21] suggested that increased vocal tension increases the strength of harmonics and decreases the spectral slope of the glottal waveform. Evans and Howard[6] demonstrated that adult “belt” voices use significantly more vocal tension in phonation than classical “bel canto” voices, which was evidenced by raised CQ values.

The CQ results appear to support this finding, showing a slightly raised CQ for “theater” singing compared with “classical” singing. This possibly suggests that there would be a flatter spectrum from the glottal waveform. However, although a statistically significant increase in CQ between the two styles is evident, the difference in CQ is relatively small (5%) and the effect that this would have on vocal production is negligible.

The existence of a positive slope over the first three harmonics suggests the use of vocal tract resonances in “theater” singing to enhance this part of the spectrum, possibly a form of formant "tuning." This is supported by the spectrum of certain vowels—for example, the vowel æ sung at C4 has a peak amplitude, indicating a first formant at 800 Hz for the "classical" voice (indicated by Kent and Read to be within the expected region for adolescent voice[22]), but a peak amplitude around 1000 Hz for the theater voice (Figure 4). This higher formant frequency could give the characteristically "bright" and "edgy" sound to the voice of the young MT singers compared with the "rounded" tone of a classically trained singer.

A key point of interest here is that there is a relatively small increase in CQ when there is considerably higher amplitude of harmonics 1–6 relative to the fundamental series of the acoustic output. The mean increase in CQ between "classical" and "theater" is 4.1%, from 26.6% to 30.7%, considerably lower than the voices exhibited by adult "belt" voices.[6,7] Overall, the CQ values for both voice types are generally lower than those displayed by adults analyzed in similar studies.[2,6] The mean difference in relative amplitude between genres across the first six harmonics is 7 dB (123% increase).

## CONCLUSIONS

Results indicate that there are significant and quantifiable differences in vocal production and acoustic output of young singers between the "classical" and "MT" styles of singing.

Results demonstrate an higher vocal fold CQ, although it is suggested that this increase is of such a small amount that it would make little functional difference to the voice, although it is possible that it may slightly reduce the spectral slope of the glottal waveform.

However, as the increase in relative strength of the first six harmonics is disproportionate to the change in CQ, it is suggested that the primary factor in the difference between MT styles of singing and classical style for this age group is in the use of a different voice resonance strategy, which is used to enhance any slight changes in the acoustic waveform caused by a slightly increased CQ. This resonance is used to enhance the harmonics to increase projection, change the tone, and

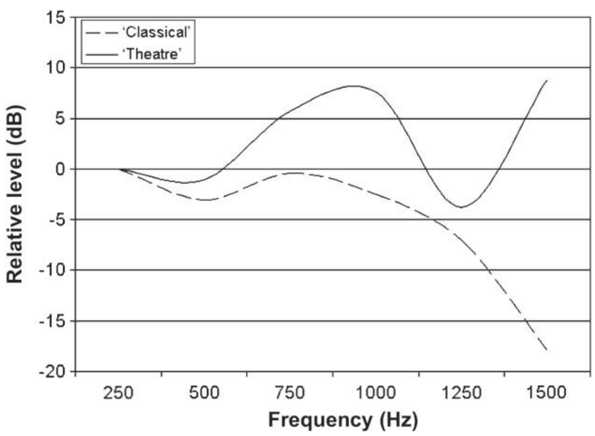


FIGURE 4. Relative intensity of spectrum relative to fundamental for æ at C4.

The results suggest that a combination of acoustic analysis and voice source analysis could be used to give detailed model of the progression of young voices with training within a vocal genre, which could be used to differentiate between the effects of training and musical genre for young singers. Further research will be required to develop a comprehensive model of young MT singers, which takes into account differences in age, gender, and level of training.

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