A STUDY OF TWO VOCAL QUALITIES EXHIBITED BY PROFESSIONAL FEMALE SINGERS

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1. ABSTRACT

This paper reports on singing analysis research being carried out at York University using standard speech analysis techniques. The work concentrates on the experimental comparison and modelling of two vocal qualities used by professional female singers: the classical opera quality (Bel Canto), and the loud brassy vocal quality known as "Belting" which can be heard in rock, gospel, ethnic and music theatre.

The standard analysis techniques used include spectrography, linear predictive coding, electrolaryngography and closed quotient measures. Many of the techniques used are available on the Speech Filing System, a software package originally from University College London, which is being further developed at York. The vocal quality models are being tested by comparative recordings of real and resynthesized sound data using a Klatt speech synthesizer modified to include parameters relating to the singing voice. This paper will present some results from the experimental analysis of the voice source waveforms.

2. INTRODUCTION

This study compares two contemporary female singing qualities heard in western music; belting quality and opera quality. These two qualities are briefly described below.

Belting Quality

Belting has been described as "yelling set to music" (Yanagisawa et al., 1989). It can be heard in many Broadway musicals today, and in much ethnic world music. Famous exponents of this technique include Ethel Merman, Judy Garland, and Liza Minelli. Belting as an artform has been heavily criticised in the past. One definition has described it as chest voice range extended upwards and over the break (Ruhl, 1986). Howell (no reference) uses the term "belting" to describe "the forced vocal muscles, pushed-air oversinging of anyone in any material, whether it's opera or rock." It is only through the scientific work of Jo Estill and her associates that belting is now slowly becoming regarded in the western world as a legitimate and safe form of singing (even though other folk cultures, some in the west, have a long tradition of this type of singing).

Estill (1992) shows that the production of opera and belting qualities share some common vocal tract settings. Estill believes that the the "singer's formant", the spectrum amplitude peak around 3kHz and perceived as a ringing quality is common to opera quality and belting, and is best achieved with an elevated larynx with aryepiglottic sphincter constriction, since lowering the larynx masks the tone making it darker and softer.

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Female Opera Quality

The "singer's formant" found in the singing voice of Western male opera and concert singers is a spectrum amplitude peak around 3kHz resulting from a clustering of the 3rd 4th and 5th formant frquencies. This peak is known as the "singer's formant" (Sundberg, 1987). An increase in loudness increases the level of the singer's formant. The amplitude of the singer's formant is lower in female singing voices than in male singing voices, especially in soprano voices (Bloothooft, 1985). The soprano employs "pitch dependent tuning" more than the "singer's formant" to project the sung tone (Sundberg, 1987). This enables the soprano to utilise the resonant effects of the first formant which often lies below the sung pitch and would otherwise not be used. The effect of formant shifting is most apparent in high pitched singing where often projection of the sung tone is achieved at the expense of vowel intelligibility.

3. BACKGROUND

Differences in vocal quality arise from supralaryngeal settings, subglottic pressure and also different modes of vocal fold vibration. The object of this work was to investigate voice source differences between belting and opera qualities in female singing.

The approximated vocal folds are set into vibration when the airstream from the lungs is forced past. This results in the rapid opening and closing of the glottis, the air passage between the vocal folds, which chops up the airstream into tiny pulses. Each vocal fold closure results in an acoustic excitation/pressure pulse set up at the glottis which is transmitted via the vocal tract, and a series of such pulses, produced by periodic vocal fold closures result in the buzz-like voice-source. The tensions within the vocal folds and arising from the positioning of the artenoids varies the mode of vibration, the vibration frequency, and the spectral components of the voice-source waveform.

Vocal fold vibration can be monitored non-invasively using a device known as an electrolaryngograph (Fourcin and Abberton, 1971). A small constant high frequency voltage is applied between a central conductor and an outer guard ring of one electrode.The other electrode acts as a receiver and picks up the high frequency current flow. The electrodes are strapped either side of the larynx at the level of the vocal folds, and the current flowing between the electrodes is measured, which increases in amplitude when the vocal folds are closing, and decreases in amplitude when the vocal folds are opening. Figure 1 represents the output waveform of the laryngograph (Lx). There are four distinct portions of this waveform relating to the degree of conductance between the vocal folds: closing, closed, opening, (all three contained within the "closed phase" (CP) of figure 1, and open phase (OP in figure 1). Successive points of closure of the laryngograph signal determine the duration of each cycle, called the Tx, from which fundamental frequency (F0) can be estimated. Larynx closed quotient (CQ), is defined as the percentage of each larynx cycle for which the vocal folds are in contact (Davies et al, 1986). It is calculated as follows:

$$CQ = ((CP/Tx)*100)\%$$

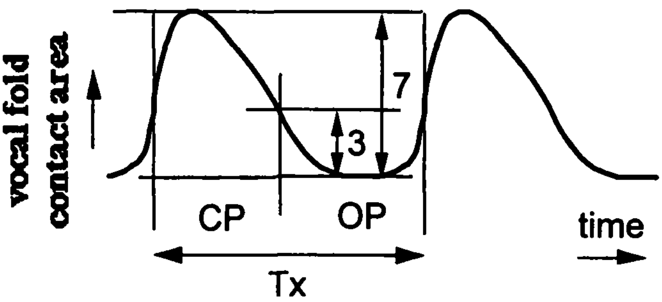

Figure 1 showing a typical lx waveform with open and closed phases, and how they are calculated.

The SVHS data is digitally transferred into a Viglen 486 PC and stored in data files using The EdDitor (Digital Audio Display Editor by Digital Audio Labs, Minnesota, U.S.A.) software and Soundblaster software.

Data Manipulation: The Speech Filing System (SFS)

The computer software used for manipulating the recorded audio data is the Speech Filing System (SFS) (Edgington et al., 1992). This tool allows convenient storage and handling of an original single voice data file which also contains the processing history of any subsequent manipulations by adding a header to the original file. A variety of utility programs are present in the SFS. This project utilises the major analysis software associated with the SFS. The main programs provide spectrographic analysis, formant frequency estimations using LPC analysis, larynx closed quotient analysis, and fundamental frequency estimation. At present the general purpose graphics program allows for SFS data display of files no longer than 2 seconds duration. The data files captured from SVHS into the computer are converted into SFS format by adding a header and by arranging the stereo patterning.

4. SUBJECTS AND RECORDING

The aim of this study was to investigate whether there is any statistically significant difference in CQ measures between female opera quality and belting quality for an adequately sized database of singers.

Seven West End musical singers and eight soprano opera singers served as subjects. The recordings were undertaken in a sound proof booth in the Sound Acoustics Laboratory within City University's Department of Clinical Communication Studies. A multi-channel recording setup including a cardioid microphone, a Glottal Enterprises MC2-1 two-channel electroglottograph and an eight-track Alesis ADAT recorder to capture the acoustic output, the averaged lx data and larynx height data from the voice source, was used. The following tasks were carried out:

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1. become comfortable with wearing the electrodes and neck band and find larynx resting position by monitoring the laryngeal tracking meter whilst also producing a maximum amplitude lx signal.
3. stand 10 cm infront of the microphone and sing the a maximum amplitude tone. A maximum amplitude reading on a sound pressure level meter was noted and all signals were then adjusted so that they would not overload the ADAT recorder.
4. read a spoken passage then sing through a series of vowel exercises at different pitches in opera or belt quality.
5. three vowels /i:/ pronounced "ea", /ɜ/ pronounced "er", and /ɑ:/ pronounced "ah", were extracted from the words /bead/ /bird/ /bard/ sung at up to six pitches C4, E4, G4, C5, E5, and G5.
6. the laryngograph data from the extracted vowels were subjected to CQ analysis and statistical analysis using the Wilcoxon rank sum Test.

5. RESULTS AND DISCUSSION

The average CQ values for each singer across the singing range and vowels are listed in table 1. The average CQ across singers for each vowel and pitch (the final column in table 1) is presented graphically in figure 2. The most striking feature of this graph is the consistent difference in patterns between opera and belt. The opera CQ patterns are lower in value than for belt, with a prominent dip rising upwards as pitch increases. This is in agreement with previous single-case studies (Estill (1988), Evans & Howard (1992)) However, the belt patterns take on an "M" pattern. These results depart from those referenced above which have shown that belt values are at a consistently high level across the singers' ranges. A closer look at table 1 will reveal that CQ values vary widely within the opera and belt sets. This indicates that the subjects may not be belting through all of the vocal range, even though they were directed to do so.

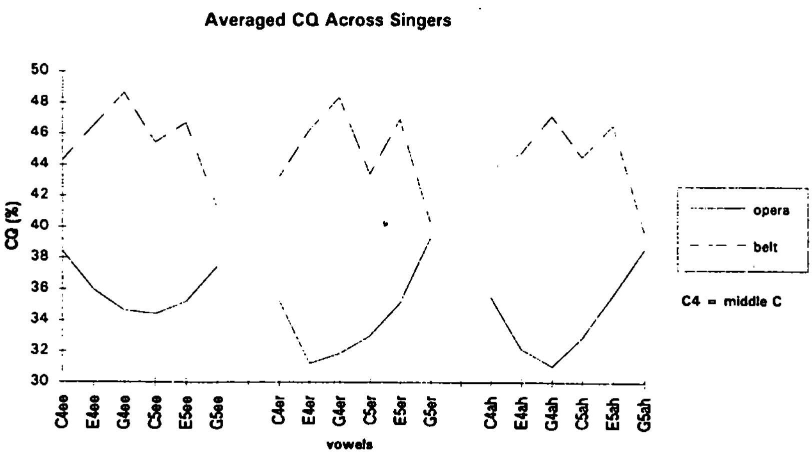

Figure 2 showing the average CQ values for the opera and belt groups at different pitches and vowels.

		closed quotient values for sung vowels at different pitches							
vowel				subject					
	o1	o2	o3	o4	o5	o6	o7	o8	average
C4ee	43.73	51.83	40.65	33.38	34.65	32.76	41.02	29.52	38.4425
E4ee	38.45	44.67	40.34	32.69	38.51	36.83	24.71	31.64	35.98
G4ee	37.28	35.16	40.4	24.96	39.46	40.66	25.77	33.45	34.6425
C5ee	32.19	34.88	40.73	29.89	33.6	44.57	21.99	37.52	34.42125
E5ee	31.83	41.69	36.72	27.08	39.43	42.25	23.93	38.61	35.1925
G5ee		46.36	37.47	26.44	45.72	45.94	20.47	39.66	37.43714
C4er	38.2	51.52	34.63	32.01	28.66	38.24	33.29	26.28	35.35375
E4er	31.77	47.79	33.95	29.09	28	29.3	23.02	26.76	31.21
G4er	34.47	29.84	37.26	26.36	36.75	33.33	25.55	31.33	31.86125
C5er	30.82	29.77	36.23	31.31	36.21	42.69	18.75	38.52	33.0125
E5er	32.87	39.09	35.51	27.48	40.03	44.26	22.26	39.61	35.13875
G5er		45.21	39.79	30.84	49.49	44.76	24.75	39.98	39.26
C4ah	37.87	47.65	35.01	31.21	31.23	39.3	34.82	27.23	35.54
E4ah	35	47.3	35.51	29.49	29.12	31.68	23.67	25.47	32.155
G4ah	33.95	29.73	34.88	25.49	34.56	34.63	21.6	33.45	31.03625
C5ah	30.94	30.69	35.17	30.28	37.76	42.72	18.31	37.31	32.8975
E5ah	33.14	38.17	32.61	29.03	44	45.57	21.91	40.76	35.64875
G5ah		46.79	37.22	30.89	49.5		25.05	42.04	38.58167
vowel				subject					
	b1	b2	b3	b4	b5	b6	b7		average
C4ee	41.03	47.92	52.5	40.57	44.69	40.54	42.87		44.30286
E4ee	47.94	56.7	55.16	41.28	46.33	41.35	36.9		46.52286
G4ee	53.64	63.69	57.8	47.07	37.33	40.36	40.71		48.65714
C5ee	50.44	44.92	59.55	40.18	36.84	40.27	46.11		45.47286
E5ee	49.91	63.49	58.08	45.07	35.08	35.66	39.76		46.72143
G5ee		48.02	46.07	45.42	34.79	32.1			41.28
C4er	40.23	50.41	44.96	43.4	43.88	37.69	41.61		43.16857
E4er	50.02	50.72	51.4	46.54	42.26	44.88	37.53		46.19286
G4er	54.39	63.15	53.9	53.8	31.76	44.77	36.55		48.33143
C5er	50.06	37.85	56.73	41.87	31.73	41.25	44.33		43.40286
E5er	40.91	59.65	59.39	44.77	35.17	40.69	47.97		46.93571
G5er		50.81	46.2	40.64	33.31	30.6			40.312
C4ah	42.4	51.61	46.54	46.84	43.61	33.86	41.04		43.7
E4ah	47.04	45.27	54.33	47.42	43.09	41.47	34.69		44.75857
G4ah	54.44	60.32	56.24	51.67	28.6	42.16	36.54		47.13857
C5ah	55.47	37.86	56.62	44.81	33.46	39.47	43.72		44.48714
E5ah	39.91	64.51	59.74	42.04	35.27	39.22	45.07		46.53714
G5ah		48.3	44.48	42.66	33.22	29.77			39.686

o1 = opera subject 1
b1 = belt subject 1

Table 1 displaying the average CQ values for individual singers and for the belt and opera groups.

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A statistical analysis of these average CQ values provides a mathematical comparison of the opera and belt sets. A Wilcoxon rank sum test statistical analysis of the results in figure 2 are shown in figure 3. It represents the normalised statistical values for the lowest scoring set as compared with the standard 5% and 2.5% statistical threshold levels: a statistical value below the 5% statistical threshold level indicates statistical difference between the two sets; a score below the 2.5% statistical threshold level means that the difference between the two sets is highly significant; and above the 5% threshold value, there is no statistically significant difference. The more negative the values in figure 3, the greater the statistically significant difference between the opera and belt groups.

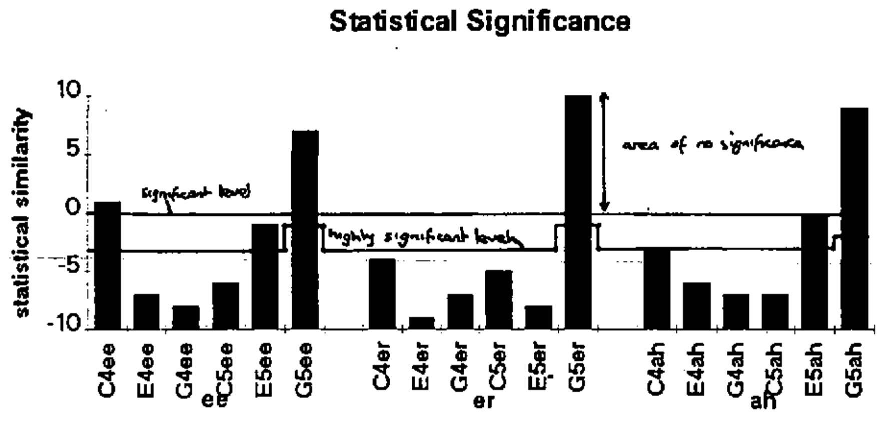

Figure 3 showing the significance between the opera and belt groups for each vowel and pitch.

Figure 3 shows that most of the vowels fall within the highly significant level. This means that the vowels produced in belt quality have a significantly different value of average CQ than for opera quality, and the two sets can be described as mutually exclusive for most of the singing range.

The extremes of the range (C4ea, all vowels at G5) show no significance. Looking at figure 2 and figure 3 together suggests that the belt tessituras for most of the belt singers does not extend up to pitch G5. This is confirmed from listening to the samples. The singers use a vocal quality which has a lower CQ value than is normal for belt.

For the opera group, the higher than average CQ values across the vowels at middle C suggest that, on average, the opera singers are "chesting" this lowest note. All of the opera singers are sopranos and it is not uncommon to have a register break around middle C between the chest and middle registers. Singing in their middle register quality at about this pitch is extremely difficult and produces a low CQ value. A choice has to be made by the singers. It appears that most of them have opted for the chest quality since at these lowest pitches in the soprano range, the action of the set of adductor muscles utilised in

"chesting" is naturally stronger than the action of the set of adductor muscles used in the production of middle register quality. A strong CQ value indicates that the glottal waveform spectrum will have a good frequency spread of harmonics which can be transimitted by the vocal tract, resulting in a strong sound. A poor CQ indicates that the glottal waveform spectrum could be lacking in components in the high frequency range, thus making it potentially more difficult for the vocal tract to transmit the higher frequency information required for voice projection at the lowest range. Opera singers are trained to mix registral qualities on and around the register breaks in order to achieve a homogenity of sound. It is likely that these singers are mixing a little middle register quality in with the chest sound on pitch C4.
At middle C, of the three vowels only C4ee displays no significance. If one looks at figure 2, the CQ values for all of the pitches up to E5 for vowel /i:/ are consistently higher than for the other vowels (which have a rise in CQ upwards through the middle register) suggesting that the production of this vowel within the middle register range in opera is associated with a longer closing phase of the vocal folds. For the highest pitch G5, usually sung in the "head" register, the more open vowels /ɜ/ and /ɑ:/ have higher CQ values than the closed vowel /i:/. One may speculate that the mechanisms used to project the sound at high pitches favour open vowels and a rise in CQ. However, singers tend to sing louder at high pitches. This may be partly responsible for the rise in CQ across the opera singers' range.

6. CONCLUSIONS AND FUTURE WORK

This paper shows that this method of analysis is useful for differentiating between two vocal qualities. It suggests that the closed quotient measure is an appropriate indicator of singing voice quality, but it must be seen in the context of other parameters. The results above indicate that the articulation of different vowels may possibly affect vocal fold vibration throughout the vocal range in opera quality. This knowlege may be of some use in singing training.

The next stage in this study will be to undertake some perceptual studies to reduce the database to pure opera and belt vocalisations only. The statistical study can then be retried with the pure qualities.

7. ACKNOWLEDGEMENTS

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