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Electrolaryngographic assessment of the effect of training and sex on the voice source of prepubertal male and female singers

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Introduction

Over recent years a number of researchers have attempted to provide a quantifiable analysis of the effect upon the adult singing voice of formal vocal training (Howard, 1991,1995, Rossiter, 1995, Evans and Howard, 1991). The results of a number of these studies appear to indicate that formal training in singing has a measurable effect upon vocal production, particularly at the voice source. It has been further indicated that such analysis when used in a biofeedback device could provide a training tool which can increase the rate at which singers improve their vocal technique . (Rossiter, et al, 1996).

By far the greatest amount of analysis of singers has been performed upon adult, usually classically trained (in what is often known as the 'bel canto' style) performers, with some work having been undertaken with 'belt' style singers. Remarkably little work has studied the effect of formal training upon children and younger teenagers, whose voices are still in the process of developing.

Background

In the UK, there are 40 Anglican (Episcopal) cathedrals, each of which maintains the traditional pattern of choral worship, in which a considerable part of the service is set to music and sung by the Cathedral Choir. The choir usually sings two to three services on a Sunday, as well as at least one service per day every weekday. In these choirs the Bass and Tenor lines are sung by adult, professional male singers, and the alto line is in most cases also made up of adult male counter-tenors. With little exception, the soprano (or 'treble') line of the choir is sung by children.

This tradition has been maintained for hundreds of years - for example the choir school at York Minster can date its antecedents back to 627AD. For most of this period the treble line has been sung by boy trebles, but in recent years a number of cathedrals have admitted girl choirs as well as the traditional boy choirs. These singers, despite their age, are ‘professional’ in every sense of the word. They sing six days a week with a professional conductor, performing ‘live’ on most of those days, with a rapidly changing repertoire, in addition to which they perform on radio broadcasts, concert tours and recordings. In return for this, the choristers usually receive scholarships towards the cost of fees at the choirschool, most of which are specialist music schools, providing tuition in a number of musical instruments as well as voice training.

In addition to cathedral choristers, a large number of other children also train their voices with professional teachers. While singing in state schools has drastically decreased in recent years some schools still maintain excellent choirs. Many private schools also specialise in music tuition and singing is still considered to be an excellent way to develop musicianship skills.

Despite this tradition of child singers, there are many schools of thought as to how singing tuition should be approached for child singers. A child’s vocal system undergoes rapid and dramatic change during adolescence, during which many singers are making demands on their voice as great as that of any adult. During the pubertal growth spurt, both male and female larynxes change dimensions rapidly, necessitating a constant reassertion of the muscle control skills needed for speech and singing. There are as many conflicting ideas on how child singers should be treated during this period as there are vocal pedagogues who deal with child singers. In spite of this, there has been very little research undertaken to attempt to determine the effect of regular singing and vocal training on the voice production of children and adolescents.

Methodology

43 Female and 60 Male young trained singers and untrained singers from 7 schools took part in the study. These included choristers from 5 Cathedral Choirschools around Britain, in addition to which further subjects were taken from one school specialising in music, and one non-specialist school. Criteria for inclusion in the ‘trained singers’ were that the subject must have undertaken regular individual formal singing training with a professional coach/singing teacher for at least two years, or who sang at least twice per week in a group environment with a professional singing

coach or choral director, and had done so for the same minimum time period. (This did not include singing in school choirs). The choirmaster or music teacher of the children confirmed this information. Untrained singers were pupils of the same age who had never undergone singing training and had not sung in a choir or other form of formalised singing, discounting school music lessons.

All subjects were of White European background and spoke British English. Each subject was recorded by the researcher in the songschool or music department of their school. The youngest subjects recorded were at least 8 years old, and the eldest not more than 14. The 6 schools were visited over a period of 1.5 years between February 2000 and July 2001.

The subjects voices were recorded a) reading aloud a passage of spoken text approximately 90s in duration to determine mean spoken f_0 and b) singing a 2 octave scale to the vowel of /a/ covering the pitch range of G major. The spoken text was a section of the phonetically recognised short story 'Arthur the Rat', which has been used in a number of similar studies to determine mean spoken f_0.

In the case of females or boy trebles the scale was sung from G3 (196 Hz) to G5 (784 Hz). In the case of changed male voices , the scale was sung from G2 (98 Hz) to G4 (392 Hz), or as near to G4 as the subject could reach. Subjects were asked to project the sound at a consistent mezzo-forte level, 'as if they were singing a solo'. If they were considered to be singing too loud or too quietly, or if there was considerable fluctuation in volume they were asked to repeat the scale. They were not required to sing the entire scale in one breath, but asked to breathe when necessary to maintain as regular a volume as possible. In the event of a subject running out of breath whilst singing, the subject was asked to repeat the scale.

The output waveform from an electrolaryngograph (Lx) and the speech pressure waveform (Sp) from an AKG CK77 omnidirectional condensor microphone were recorded onto the two channels of a Fostex DA-5 DAT (Digital Audio Tape) recorder. The microphone was powered by a Mackie 1402 VLZ-PRO low noise mixer. The Lx signal was viewed on an oscilloscope during the recording to maintain correct electrode positioning. The microphone was mounted on a headset to ensure constant distance from the mouth. This allows the monitoring of SPL so that consistent volume levels can be ensured as closely as possible.

Data analysis was undertaken using the Speech Studio™ and Quantitative Analysis™ software running on a PC with PIII 450 Hz processor fitted with the Laryngograph™

processor card. The recordings were digitally transferred to the PC for storage and analysis.

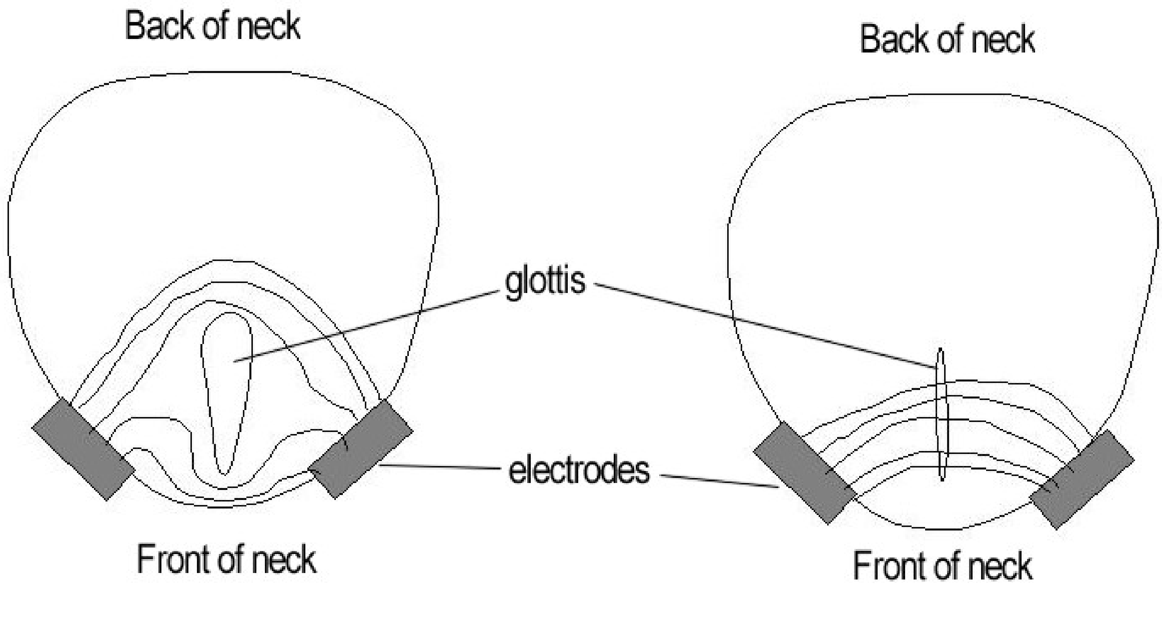
The Speech Studio software was used to output a text file of sample number, derived F_0, and CQ for each subject, which was then analysed in a spreadsheet.

Electrolaryngography (a.k.a. Electroglottography, EGG)

Electrolaryngography uses the measurement of electrical impedance to give a direct measurement of laryngeal activity. It is widely used for f_0 estimation in laboratories and clinics (Hess and Indefrey, 1984).

Human tissue is a moderately good conductor of electricity, and the electrolaryngograph uses a constant voltage high frequency electric current passed between two electrodes placed externally either side of the neck at the level of the larynx. (Figure 1).

The output waveform represents the current flowing between the electrodes. When the vocal folds are apart, the current must flow along a longer path between the electrodes, increasing impedance of the signal. (Garner, 2000). (Figure 1)



Open Glottis Closed Glottis

Open glottis: Current path has to move around open glottis, resulting in loss of signal through increased inter-electrode path length.

Closed glottis: Current path may flow directly across the vocal folds resulting in relatively greater signal amplitude.

Figure 1 - Horizontal cross section of the neck at the level of the larynx, indicating current path across the vocal folds for open and closed glottis.

(Derived from Garner, 2000:45)

The current will thus be higher when the vocal folds are in contact than when they are apart. The current variation can therefore be analysed in terms of changes in vocal fold contact area.

The typical Lx waveform is shown here, indicating the various phases of the vocal fold excitation (fig 3).

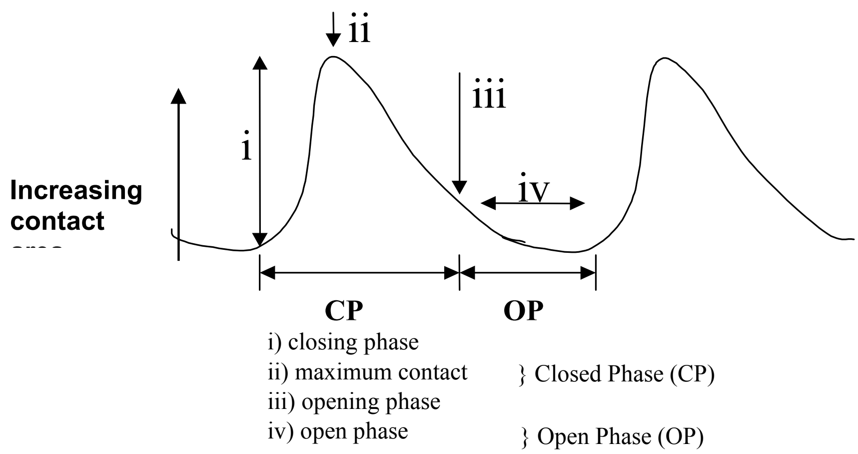


Figure 3 - Idealised electrolaryngograph output waveform showing closed and open phases (derived from Howard *et al*, 1990a:206)

The electrolaryngograph has been accepted as a valid method of voice source analysis (Fourcin and Abberton, 1971) particularly due to its immunity to extraneous acoustic noise and acoustic modification of the signal by the local environment (such as room reverberation). It can also give a more accurate estimation of the boundaries of silence, voiced and voiceless sound than can be obtained from many microphone based devices.

Analysis

Barlow and Howard (2002) found that scatterplots of CQ/log f0 indicated particular differences in the voice source of child and adolescent females which could be attributed to training. In order to examine further how training and sex differences affect voice source in children, a further study was undertaken to include detailed analysis of closed quotient values of unchanged male and female singers, with and without training.

The method of analysis chosen was the analysis of mean sung CQ in third octave bands. This method of study has previously been used for the analysis of adult voices (Howard, 1995), so makes an important comparison with the data for child subjects.

The particular boundaries used were chosen because of their close relationship with the critical bands of the basilar membrane in the hearing system, and therefore for their perceptual salience (Howard, 1995:169, Howard and Angus, 1996). They also have a relative ease of calculation, being points on the G major scale that was used in the protocol.

The boundaries of the bands for female and unchanged male voices are shown in table 1.

	Band 1	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**
Pitch Frequency range	(G3-B3) 196.0Hz – 247.0Hz	(B3-D4) 247.1Hz – 311.0Hz	(D4 – G4) 311.1Hz – 392.0 Hz	(G4 -B4) 392.1Hz – 494.0Hz	(B4 – D5) 494.1Hz – 622.0Hz	(D5 – G5) 622.1Hz – 784.0Hz

Table 1 – Frequency boundaries of third octave bands for female/unchanged male voices

One and two tailed student t-tests were carried out for results of each band between groups under comparison. Paired T-tests were also carried out on the mean of means values to examine the overall trend of each group across the 6 bands under comparison. The mean CQ for each group in each band was also plotted on charts for visual analysis.

Male voices

Mean spoken f_0 has been demonstrated by Cooksey to be an indicator of the stage of pubertal development of the male voice (Cooksey, 1993:34) While there are insufficient subjects in this study to subdivide into the 6 stages of Cooksey's classification, unchanged male subjects were classified as voices with a mean spoken f_0 of 220 Hz or higher. Subjects recorded who exhibited lower mean spoken f0 were not used in this analysis.

Female voices

Data relating spoken f0 to the changing female voice is more limited. However, Pedersen (1997: 73) found that unchanged female voices had a mean spoken f_0 of 256 Hz, pubertal voices had a mean spoken f0 of 248 Hz and changed female voices had a mean spoken f0 of 241 Hz.

Mean spoken f_0 for subjects aged 12.9 or under in this study (Pedersen's 'child' group) was found to be 249 Hz – slightly, though not significantly different from Pedersen's results.

In light of this, female voices with a mean spoken f_0 of 249 Hz and above were classified as unchanged and used in this study. After disregarding subjects whos voices were deemed to be pubertal, result from 30 female and 48 male subjects were analysed for the study.

Results

Female subjects

Female voices were analysed for effect of training on Closed Quotient in each of the 6 pitch bands.

Tables 2 and 3 show descriptive statistics for changed and unchanged female voices.

	age	tuition	spoken f0	band 1	band 2	band 3	band 4	band 5	band 6
Upper limit of band (Hz)				**247.00**	**311.00**	**392.00**	**494.00**	**622.00**	**784.00**
Mean	10.77	0.22	274.79	45.24	42.49	40.85	44.95	44.42	50.45
Standard Error	0.63	0.09	5.62	2.15	2.04	1.44	3.38	4.05	4.44
Median	10.00	0.00	277.18	46.95	43.93	41.36	41.37	45.31	50.87
Standard Deviation	2.28	0.32	20.25	7.76	7.37	5.19	11.70	12.82	8.88
Count	13.00	13.00	13.00	13.00	13.00	13.00	12.00	10.00	4.00

Table 2 - Mean CQ in pitch bands for unchanged female voices: Untrained

	age	tuition	spoken f0	band 1	band 2	band 3	band 4	band 5	band 6
Upper limit of band (Hz)				**247.00**	**311.00**	**392.00**	**494.00**	**622.00**	**784.00**
Mean	11.88	3.19	262.67	46.66	42.64	40.77	40.48	39.78	44.32
Standard Error	0.44	0.31	2.28	1.08	1.65	1.67	1.89	2.34	1.73
Median	11.00	2.70	261.63	47.32	44.48	42.12	43.12	43.52	44.17
Standard Deviation	1.83	1.29	9.41	4.46	6.80	6.88	7.80	9.65	6.48
Count	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	14.00

Table 3 - Mean CQ in pitch bands for unchanged female voices: Trained

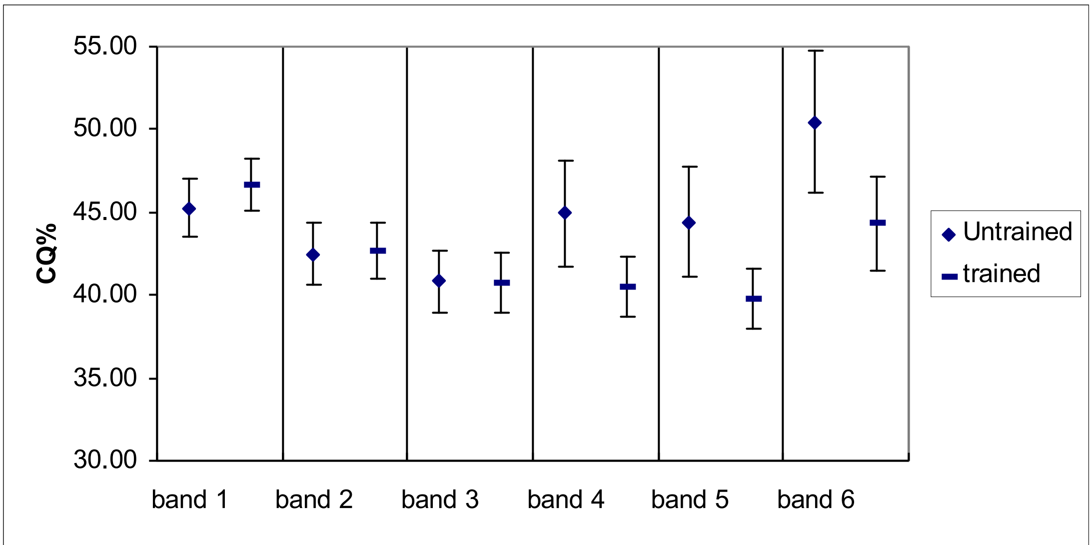


Figure 4 – Mean of CQ means with standard error for trained and untrained unchanged female voices in third octave bands

As can be seen from figure 4, the lower octave (bands 1 to 3) demonstrates very similar closed quotient values between trained and untrained voices of unchanged subjects. Bands 1 to 3 show distinct similarity between trained and untrained voices, while in bands 4 to 6 the similarity decreases, with untrained singers demonstrating considerably higher mean CQ values in the upper octave than trained singers. While this appears to show a trend, analysis of the trends does not demonstrate a significant difference between the two groups ($p>0.05$).

One particular trend is evident, however. The standard error values for the untrained singers across the bands are significantly higher ($p=0.031$) than the standard error values for the trained singers, suggesting far lower variation in vocal production in trained compared to untrained singers. This is particularly the case in the upper octave. There is also a markedly higher CQ value, though still not significant, for untrained singers compared to trained singers in the 3 highest bands, with the difference becoming greater with increased pitch band. This could potentially be demonstrative of 'pushing' or 'forcing' in the upper end of the range. This would benefit from further investigation in a future study, as the evidence of higher CQ in higher bands for untrained singers is a direct opposite to the results for adult female singers demonstrated by Howard (1995) in which he found significantly higher mean CQ values demonstrated by trained singers in bands 5 and 6.

Male singers

A similar analysis was done on the voices of male subjects in the study. Tables 4 and 5 show descriptive statistics for changed and unchanged male voices:

	age	*tuition*	*spoken f0*	*band 1*	*band 2*	*band 3*	*band 4*	*band 5*	*band 6*
Upper limit of band (Hz)				**247.00**	**311.00**	**392.00**	**494.00**	**622.00**	**784.00**
Mean	10.83	0.02	241.32	46.31	43.63	43.86	41.63	40.22	35.57
Standard Error	0.40	0.02	4.42	1.33	1.39	1.54	2.12	2.30	3.82
Median	11.00	0.00	239.91	46.58	44.01	44.47	40.94	38.05	36.08
Standard Deviation	1.69	0.09	18.76	5.62	5.89	6.55	8.98	8.92	10.12
Count	18.00	18.00	18.00	18.00	18.00	18.00	18.00	15.00	7.00

Table 4 - Mean CQ in pitch bands for unchanged male voices: Untrained

	age	*tuition*	*spoken f0*	*band 1*	*band 2*	*band 3*	*band 4*	*band 5*	*band 6*
Upper limit of band (Hz)				**247.00**	**311.00**	**392.00**	**494.00**	**622.00**	**784.00**
Mean	11.07	3.58	251.77	45.31	40.56	38.30	38.59	37.63	39.59
Standard Error	0.18	0.26	4.18	1.26	1.06	1.24	1.28	1.52	1.97
Median	11.00	3.60	254.18	43.63	40.24	39.11	37.80	36.98	40.10
Standard Deviation	0.98	1.43	22.88	6.91	5.80	6.82	6.89	8.06	10.25
Count	30.00	30.00	30.00	30.00	30.00	30.00	29.00	28.00	27.00

Table 5 - Mean CQ in pitch bands for unchanged male singers: Trained

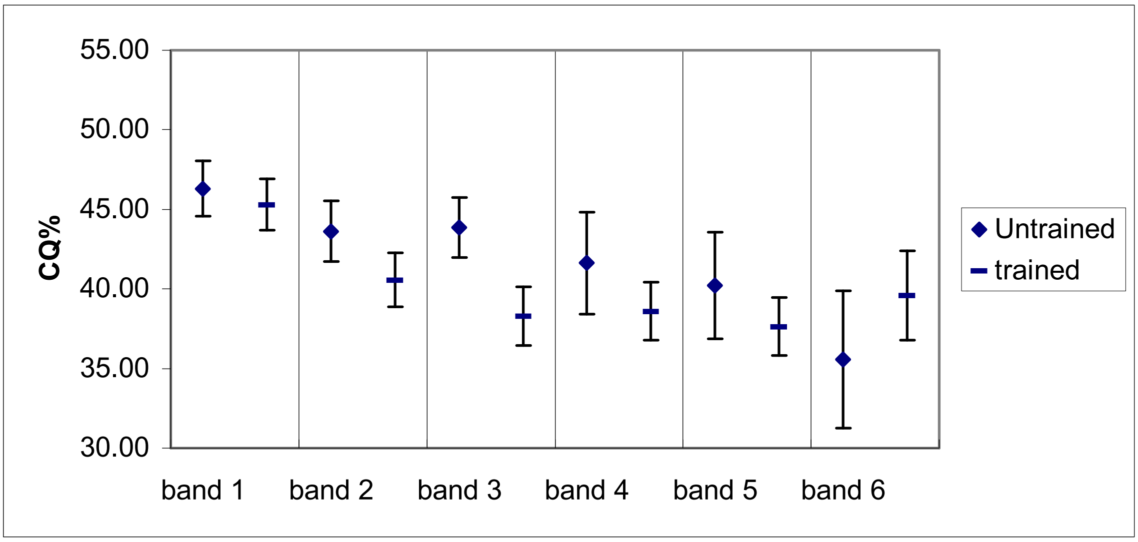


Figure 5 – Mean of CQ means with standard error for trained and untrained unchanged male singers in third octave bands.

As can be seen in figure 5, there are slight differences between CQ means in each third octave band between trained and untrained singers.

While in band 1 trained and untrained voices show no significant difference (p=0.21), in bands 2 and 3 untrained voices show a significantly higher mean CQ than do untrained (p=0.41 and p=0.001 respectively). Bands 4 and 5 also demonstrate higher mean CQ for untrained signers, although insignificantly so (p>0.05), while in band 6 mean CQ for untrained singers drops below that of trained signers. There is a general negative slope with decreasing mean CQ in increased pitch bands for untrained singers, while the trained singers exhibit a slight rise in the upper band in a similar manner to female subjects.

Differences in voice source between biological sexes

Figure 6 compares male and female untrained unchanged voices, while figure 7. compares male and female trained unchanged voices.

Untrained voices: (figure 6) The mean CQ for both untrained male and female voices is similar in each of the lower 3 bands. A comparison of the bands shows the insignificant differences (p>0.4) between male and female. However in the upper octave the mean values differ, as male subjects demonstrate continual decrease of mean CQ in higher bands, while the female subjects demonstrate increased mean CQ with increased pitch over the upper octave. By band 6 this difference becomes significant with a one tailed test showing the female subjects to have significantly (p=0.01) higher mean CQ than the male subjects.

The differences in trend are also important, with the male subjects exhibiting a continual decrease in mean CQ with increased pitch, while the female subjects exhibit a decrease over the lower octave, but an increase in mean CQ over the upper octave. This is an indicator of a definite difference between male and female voice source even amongst unchanged voices, in particular at higher pitches.

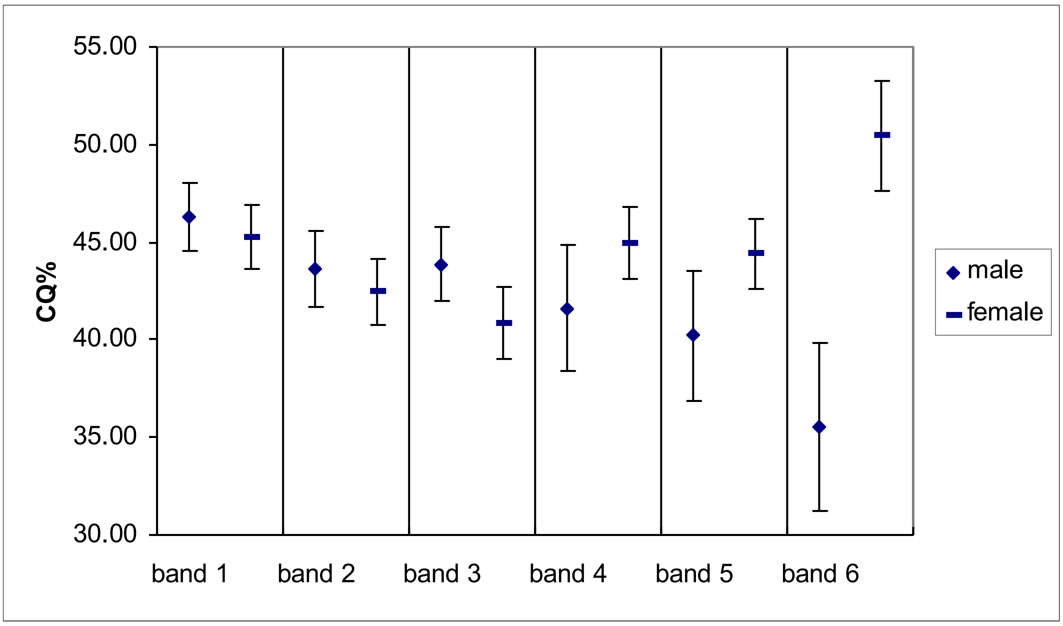


Figure 6 – Mean of CQ means with standard error for unchanged male and female untrained singers in third octave bands.

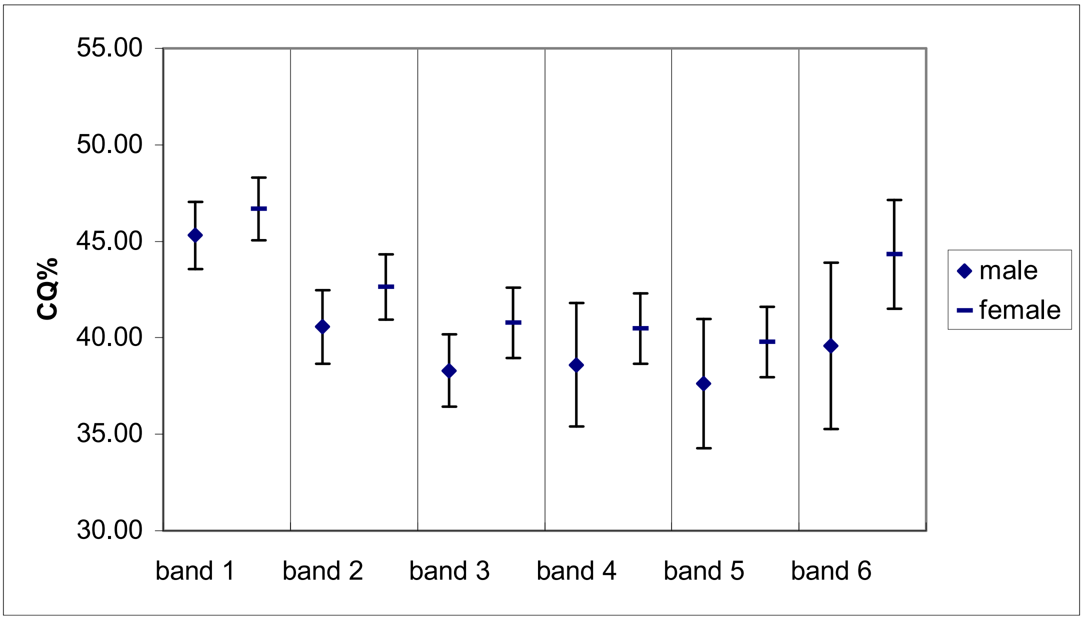


Figure 7 – Mean of CQ means with standard error for unchanged male and female trained singers in third octave bands.

Trained singers: (figure 7) There appears to be little difference between the male and female trained singers in this development group, with a distinct similarity to the pattern of change of mean CQ between bands for male and female trained singers. Female singers maintain an insignificantly higher mean CQ in all pitch bands ($p>0.14$ in all bands). Apart from that, there are distinct similarities between the two groups. Both have a decrease in mean CQ over the low octave, which stabilises from band 3 to band 5, with a slight rise in mean CQ in band 6.

These results would appear to indicate that slight differences do exist between the production of voice at source of male and female unchanged voices, but that training alters voice source and minimises the difference.

Conclusion

- Female prepubertal untrained singers demonstrate an insignificantly higher (p,0.05) CQ value compared to trained singers in the 3 highest 3rd octave bands, with the difference becoming greater with increased pitch band. The lowest 3 bands show significantly similar values between the two groups. The evidence of higher CQ in higher bands for untrained singers is a direct opposite to the results for adult female singers demonstrated by Howard (1995) in which he found significantly higher mean CQ values demonstrated by trained singers in bands 5 and 6.
- Amongst female untrained singers there is a general trend for changed voices to have lower mean CQ values than unchanged in all bands, although the difference between unchanged and changed voices amongst untrained singers is insignificant ($p>0.05$) in the lowest 3 bands. Bands 4 to 6 show significantly higher ($p<0.015$) mean CQ values amongst unchanged voices than changed voices.
- In bands 2 and 3 untrained prepubertal male voices show a significantly higher mean CQ than do trained ($p=0.41$ and $p=0.001$ respectively). Bands 4 and 5 also demonstrate higher mean CQ for untrained signers, although insignificantly so ($p>0.05$), while in band 6 mean CQ for untrained singers drops below that of trained signers. There is a constant negative slope with decreasing mean CQ in increased pitch bands for untrained male singers, while trained male singers show an increase in mean CQ in the highest band in

a similar manner to female subjects resulting in a higher mean CQ for trained singers in the highest band.

- The mean CQ for untrained prepubertal male and female voices is similar in each of the lower 3 bands. A comparison of the bands shows insignificant differences ($p>0.4$) between male and female. However in the upper octave the mean values differ, as male subjects demonstrate continual decrease of mean CQ in higher bands, while the female subjects demonstrate increased mean CQ with increased pitch over the upper octave. By band 6 this difference becomes significant with female subjects displaying a significantly ($p=0.01$) higher mean CQ than male subjects.
- Prepubertal Female trained singers maintain an insignificantly higher mean CQ in all pitch bands ($p>0.14$ in all bands) than male. Aside from this, there are distinct similarities between the two groups, which display very similar trends in the pattern of mean CQ values against increased pitch band. The implication is that there is a slight natural difference between the voice source of prepubertal male and female voices, but that training can reduce this to an insignificant level.

These results appear to demonstrate that there are quantifiable differences in the singing voice source of male and female children, and that training has a significant effect on the voice source. Classical 'Cathedral' Training would appear to reduce the difference between male and female voices to an insignificant level.