Results from a pilot longitudinal study of electrolaryngographically derived closed quotient for adult male singers in training

David M Howard and David Rossiter
Signal Processing: Voice and Hearing Research Group,
Electronics Department, University of York, Heslington, York YO1 5DD

1. Abstract

Measures of electrolaryngographically derived vocal fold closed quotient (the closed phase in each vocal fold vibrational cycle expressed as a percentage of the period of that cycle) for adults with varying degrees of singing training has indicated that there is a patterned variation of closed quotient with fundamental frequency as a function of the number of years singing training/experience. This variation has been established for adult groups of both males and females. The purpose of this paper is to report the results of a pilot experiment to investigate if such a variation can be observed on a longitudinal basis to establish whether the effect can be at all attributed to the training process itself. Closed quotient/fundamental frequency measurements have been made for two adult male singing students at York University based on recordings taken at regular intervals over seven months. Results indicate that changes do occur with singing training and it is suggested that the use of a real-time visual display of closed quotient against time could therefore be beneficial in the training process.

2. Introduction

Pupils of singing rely on their teachers to provide feedback on the developing sung sound during formal lessons. Pupils have to become used to their own perception of what their teacher describes as a sung sound appropriate for them, in order that they might monitor their own vocal output during practice and performance. Traditional singing training relies on a close communicative relationship in which the pupil must build up both trust and confidence in the skills and experience of the teacher, and through this relationship the teacher is enabled to modify and develop the vocal output of the pupil.

One of the goals of our present research is the quantification of aspects of the developing professional voice which are subject to change during vocal training. At present, this work is based on the developing singing voice due to the availability of suitable subjects. One of the goals of the work is the provision of real-time visual displays to be used during vocal training to supplement the subjective feedback provided by the teacher, particularly during individual practice sessions between formal lessons. In order that such feedback is of any practical value, it must be *appropriate* for the subject, i.e. according to Welch et al., [1] it must be ".. in a form which is accessible to the developing singer. Singers must be able to extract and use the information offered."

Suitable quantifiable aspects of the developing singing voice have to be defined as potential candidates for use in such feedback systems. We are investigating the relationship between the number of years singing training/experience and changes in the percentage of each vocal fold vibratory cycle for which the folds remain in contact, known as the larynx closed quotient (CQ), as measured from the electrolaryngograph output (e.g. [2]). It has been demonstrated for adult males that there appears to be a direct correlation between CQ and the number of years singing training/experience [3, 4] while for adult females, it is the *pattern* of variation of CQ with fundamental frequency (F0) which appears to change as a function of the number of years singing training/experience [5].

In these experiments both subjects had different singing training/experience backgrounds. While the results serve to demonstrate that CQ/F0 changes might be an important parameter in the developing singing voice, they do not confirm whether such changes occur as a direct result of vocal training. It could, for example, be the case that these trends result from natural physiological differences between the voices of the subjects. The purpose of the present work is to carry out a longitudinal study of subjects taking regular singing lessons to investigate these phenomena.

3. Method

Two adult males took part in this pilot investigation which began in October 1991. Subjects are students in the Music Department at the University of York who are receiving regular singing lessons in which traditional methods of the Bel Canto School are used. Subjects were recorded at approximately three week intervals with the exact interval between recordings being varied as appropriate to fit in with their other work. Recordings were made in the laboratory of the signal processing research group in the Electronics Department. Stereo recordings were made on a Sony TCD-D10-PRO digital audio tape (DAT) recorder, with the output from a Sennheiser MKH/40/P48 cardiod microphone on one channel and the output from an electrolaryngograph on the other.

The following data were recorded in each session:

(a) name of subject and date of recording,
(b) a read passage: "The story of Arthur the rat"
(c) the following words *spoken*:

BOOED	**BEAD**	**BAD**	**BUD**	**BED**	**BIRD**	**BARD**	**BOARD**
MOON	**MEAN**	**MAN**	**MUN**	**MEN**	**MERN**	**MARN**	**MORN**

(d) the utterances used in (c) *sung* on C(128Hz), E(165Hz), C(256Hz), and E(330Hz),
(e) a two octave ascending and descending major scale on the vowel of *baa* - from G (98Hz) for subject M1 (baritone) and from C(128Hz) for subject M2 (tenor).
(f) a snippet from a song or a singing exercise currently being studied.

The electrolaryngograph output (Lx) was transferred digitally from the DAT tape directly to a Silicon Graphics Indigo computer (sampling rate = 48kHz), and converted into speech filing system (SFS) format [6]. Larynx closed quotient and fundamental frequency measurements were made for each cycle of the Lx waveform using method (a) of Davies et al., [7], which is summarised with reference to figure 1 elsewhere in these proceedings [8] as follows. The polarity of the Lx is first checked to ensure that positive changes reflect increased inter-electrode current flow. The detection of the start of the closed phase is based on the assumption that the vocal fold contact area changes more rapidly when it is increasing than when it is decreasing (i.e. the folds snap together more rapidly than they part). These points on the Lx waveform can be readily located as the positive peaks in the time differentiated Lx waveform. These points are used to define the start of the closed phase (CP) in each cycle, and the time between these peaks is used to provide a measure of the fundamental period (Tx). The end of the CP is the instant when the negative-going Lx waveform crosses a fixed ratio (7:3) of the current cycle's amplitude. Electrolaryngographically derived CQ is defined as follows: $CQ = ((CP/Tx)*100)\%$.

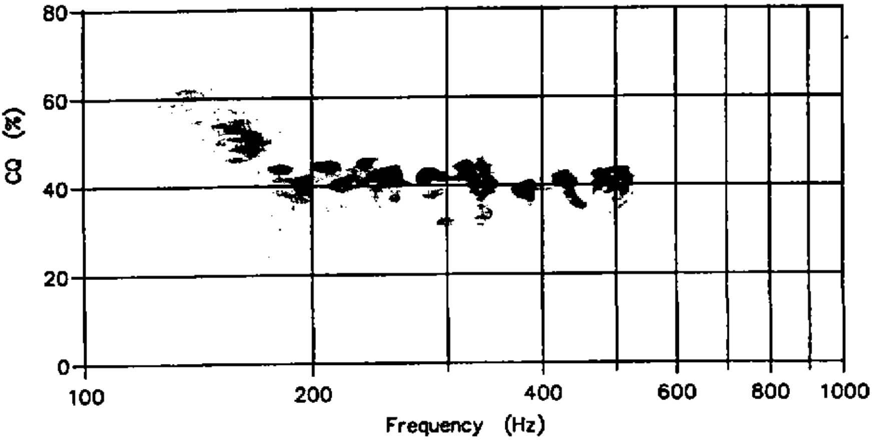
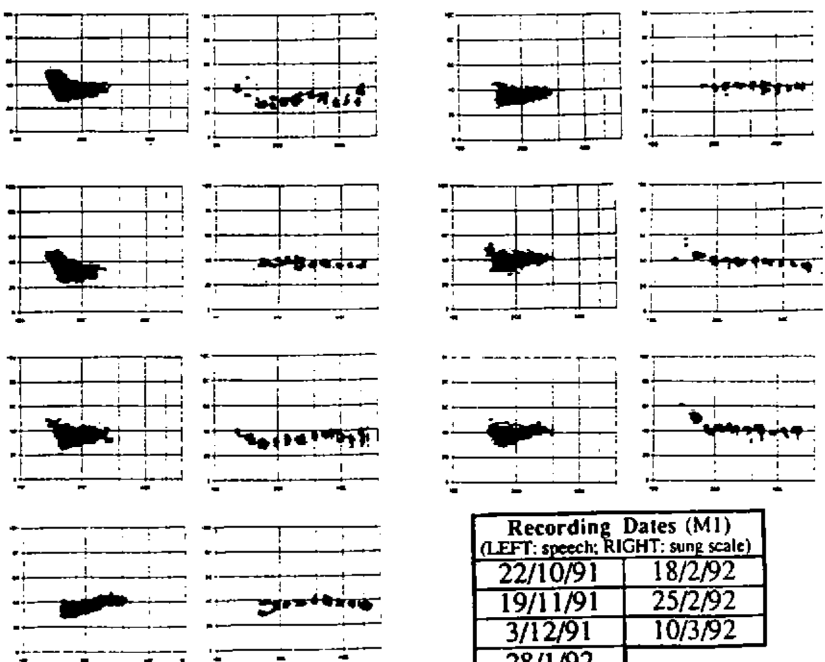
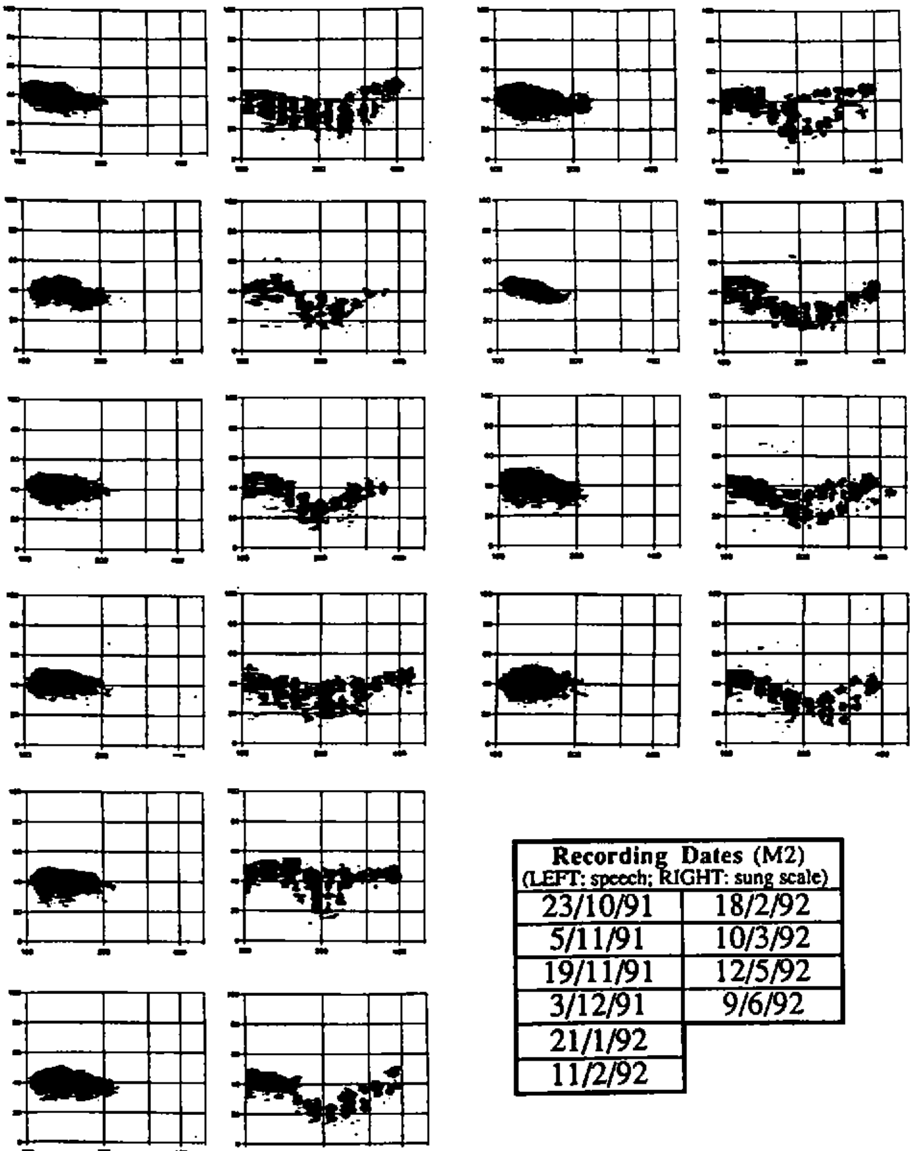


Figure 1: *Gray scale CQ/F0 scattergram recorded on 10/3/92 for subject M1 singing a two octave ascending and descending C major scale (nominal equal tempered frequency of start note is 128Hz).*



Recording Dates (M1) (LEFT: speech; RIGHT: sung scale)	
22/10/91	18/2/92
19/11/91	25/2/92
3/12/91	10/3/92
28/1/92	

Figure 2: *Gray scale CQ/F0 scattergrams recorded on the seven dates as shown for subject M1 for the read passage (left) and the sung scale (right).*



Recording Dates (M2) (LEFT: speech; RIGHT: sung scale)	
23/10/91	18/2/92
5/11/91	10/3/92
19/11/91	12/5/92
3/12/91	9/6/92
21/1/92	
11/2/92	

Figure 3: *Gray scale CQ/F0 scattergrams recorded on the ten dates as shown for subject M2 for the read passage (left) and the sung scale (right).*

The results are plotted as a scattergram (Qx) of closed quotient (CQ) against the logarithm of F0 (where F0 = (1/Tx) Hz), for each cycle. The values on the scattergram are mapped to a gray scale (e.g. see figures 1 and 2) with the darker levels representing greater accumulation of values at that CQ/F0 position.

4. Results

Figure 1 shows a Qx plot for the sung scale by subject M1 recorded on 10/3/92. The F0 range covered is that of a two octave C major scale starting on the nominal equal-tempered fundamental frequency of C(128Hz). The data relating to individual notes in the scale are discernable with a spread in F0 due to vibrato and pitching inaccuracies. His CQ values are constant across the majority of the F0 range at 40% with falling CQ values with rising F0 for F0 values lower than about 190Hz.

A series of Qx plots have been made for the read passage and sung scales at various times between October 1991 and March 1992 and these are shown in figures 2 and 3 for subjects M1 and M2 respectively. It can be seen that subject M1 exhibited CQ values for his sung scale which rise over the period under consideration, remaining essentially constant with F0 in each case apart from a tendency for a lowering of CQ with rising F0 when F0 is less than about 190Hz (most clearly seen in the plot for the latest recording repeated as figure 1). The Qx plots for his read passages also exhibit a falling CQ with rising F0 over an approximately similar F0 range.

The data for subject M2 (see figure 3) show changes in the patterning of CQ with F0 over the period, with a tendency for a fall in CQ values with rising F0 up to about 200Hz, and rising CQ with F0 above 200Hz. It is clear that for some of the recordings, CQ is higher overall than for others. This is particularly noticeable in the recordings of 3/12/91 and 21/1/92 for the sung scale but not for the read passage. It appears to relate especially to CQ values for notes around 200Hz; the overall effect being to make all the CQ values more constant, thereby occupying a narrower range across the sung two octave range.

5. Discussion and Conclusions

In order to make the trends in CQ somewhat clearer, the mean and standard deviation CQ values are given in table 1 for all analyses and presented graphically in figure 4.

The graph for subject M1 (lower graph of figure 4) exhibits signs of trends noted by Howard et al. [4] for adult males with varying singing training/experience as follows: (i) the mean CQ values for the sung scale increase with training, (ii) the mean CQ values for the sung scale occupy a narrower range than their read passage counterparts (note the lengths of the standard deviation bars), and (iii) they become progressively higher with respect to their read passage counterparts. The graph for subject M2 (upper graph of figure 4) shows no such trends. The mean CQ values for the sung scale increase with training over sessions 2 to 5 but elsewhere show some decrease, the mean CQ values for the sung scale occupy a wider range in every case than for their read passage counterparts, and the mean CQ for the sung scale remains lower than the mean CQ for the read passage (except for session 5), by about one standard deviation. Thus the trends for subject M2 appear to be rather different to those exhibited by subject M1.

These differences cannot, at this stage, be regarded too highly since this data is sparse both in terms of (A) the number of subjects - human subjects often exhibit individual differences in their vocal outputs and two subjects is no basis for a rigourous experiment - and (B) the time scope

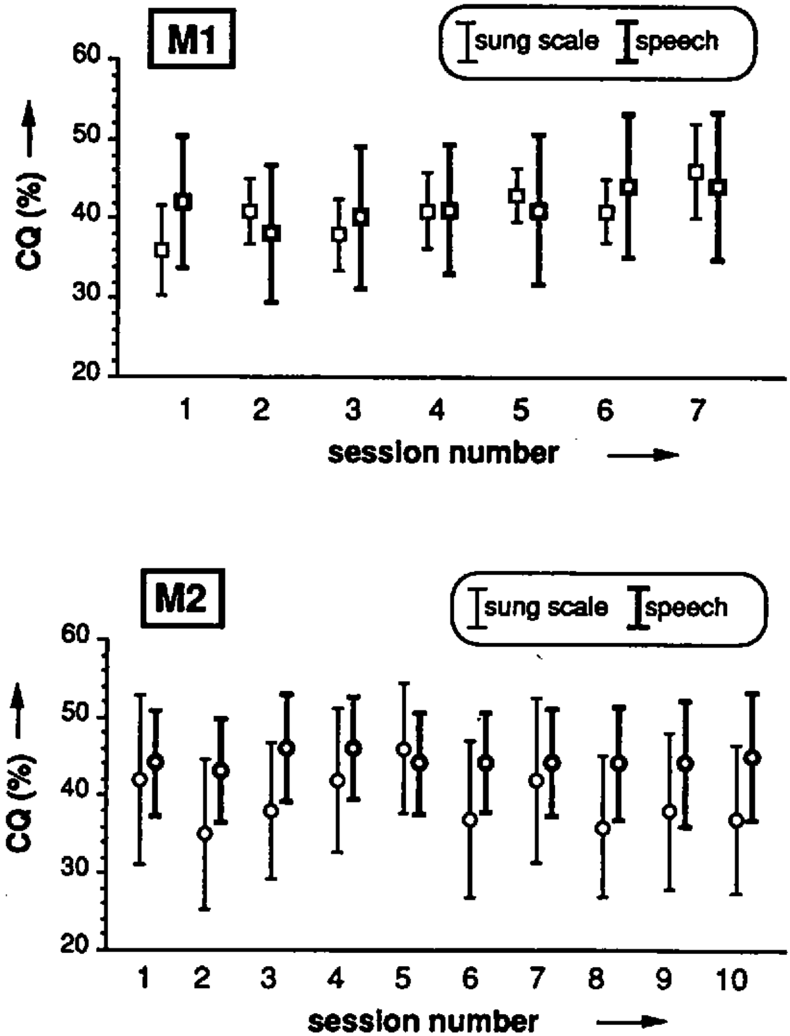


Figure 4: *Mean CQ values for speech and sung scales of subject M1 (UPPER) and M2 (LOWER) against recording session number. One standard deviation each way is shown by the vertical bars.*

(5 and 7 months) - no indication of the possible time scale over which these changes might be observed can be gained from previous work. The data serve to demonstrate that variations in CQwith F0 do occur longitudinally with traditional singing training methods, and that the changes appear to bear some relationship to previously noted trends for one subject and in some respects with the other. Some of the reverse trends noted for subject M2 could be indicative of a learning process in which progress in the desired direction is followed by retrograde steps, or a lack of concentration during the recording, or a lack of confidence to perform in front of the microphone in the absence of his teacher.

Further recordings are in progress and the data base is to be expanded in terms of the number of subjects. Also, the development of a real-time display of both CQ and F0 with time [8] and investigations into various visualisation methods for their display [9] will enable changes in CQ and F0 to be observed directly as a function of vocal exercises with direct feedback on vocal progress from the teacher.

6. Acknowledgements

The authors would like to thank both the singers who took part in these experiments. This work was supported by SERC research grant number GR/H14878.

7. References

[1] GF WELCH, C RUSH & DM HOWARD. 'The SINGAD (SINGing Assessment and Development) system: First applications in the classroom', *Proceedings of the Institute of Acoustics*, 10, (2) pp179-185 (1988).

[2] ERM ABBERTON, DM HOWARD, & AJ FOURCIN. 'Laryngographic assessment of normal voice: A tutorial', *Clinical Linguistics and Phonetics*, 3 pp281-296 (1989).

[3] DM HOWARD, & GA LINDSEY. "New laryngograms of the singing voice", *Proceedings of the 11th International Congress of Phonetic Sciences*, USSR: Tallinn, 5 pp166-169 (1987).

[4] DM HOWARD, GA LINDSEY & B ALLEN. "Towards the quantification of vocal efficiency", *Journal of Voice*, 4 pp205-212 (1990) (See also Errata, *Journal of Voice*, 5 pp93-95 (1991)).

[5] DM HOWARD, GA LINDSEY, & SK PALMER. 'Larynx closed quotient measure for the female singing voice', *Proceedings of the 12th International Congress of Phonetic Sciences, France: Aix-en-Provence*, 5 pp10-13 (1991).

[6] MA HUCKVALE, DM BROOKES, LT DWORKIN, ME JOHNSON, DJ PEARCE, & L WHITTAKER. 'The SPAR speech filing system', *Proceedings of the European Conference on Speech Technology*, 1 pp305-317 (1987).

[7] P DAVIES, GA LINDSEY, H FULLER, & AJ FOURCIN. 'Variation in glottal open and closed phase for speakers of English', *Proceedings of the Institute of Acoustics*, 8 pp539-546 (1986).

[8] DM HOWARD, & P GARNER. "DSP-56000 based real-time electrolaryngographically derived closed quotient", *these proceedings*, (1992).

[9] D ROSSITER, and DM HOWARD. "Cyberspace visualisation of vocal development data", *these proceedings*, (1992).