The science of singing and seeing

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Background in singing pedagogy. Singing teaching is commonly based on a master-apprentice model, relying on good modelling and feedback. Visual feedback technology (VFT) has been investigated as a tool in singing teaching by a number of researchers and its benefits for skills learning long advocated. However, its uptake in the singing teaching community has been slow, partly because of the cost, which has been very high until recently, but also because of real and perceived shortcomings of the technology and the lack of pedagogical guidelines incorporating VFT.

Background in vocal acoustics. Perceptual characteristics of the singing voice include the pitch, loudness, and vocal timbre—with corresponding acoustic correlates fundamental frequency (Fo), sound pressure level, and spectral characteristics. For the purposes of singing training, acoustic quantities must be presented in musically relevant terms.

Aims. In order to develop new VFT for use in singing teaching, the aims of our continuing research are to:
1. develop new acoustic algorithms to better meet the needs of singers
2. design on-screen displays to present the feedback in musical terms
3. evaluate the usefulness of VFT in the singing studio.

This paper reports on an investigation into use of VFT in the singing studio.

Method. VFT commercially available for voice analysis was maximised for singing voice and four singing teachers used it in lessons with a number of their regular students (21 students in all).

The learning effectiveness of the VFT was assessed by means of a within-subject research design, where recordings were made for each subject within the framework of 1-4 weeks baseline, 4-6 weeks intervention, and 1-4 weeks follow-up. These recordings formed the basis for acoustic and perceptual measures of changes in singing performance. Prior to implementing the protocol, the teachers were given a brief training session on use of the VFT, and collaborated with the researchers in setting appropriate singing tasks for each student. On completion of the protocol, all teachers and students (25 participants) were interviewed to collect data on how the technology was used in the pedagogical process, their perception of the strengths and weaknesses of the VFT, and their suggestions for possible modifications. An analysis of the interview data is reported in this paper.

Results. Analysis of the interview data showed positive reactions from both teachers and students. Students were enthusiastic about the immediacy of the feedback and its precision. Many felt that they made quicker progress. Teachers used the VFT for onset, pitch accuracy, vibrato, and vowel quality. Both students and teachers had suggestions for improvements to the VFT and for how it could be incorporated into the learning process.

Conclusion. The results suggest that VFT can provide a useful tool for singing teachers in providing immediate and precise feedback about particular aspects of the voice that are otherwise difficult to explain to the student.

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"It may seem to many that every perfect singer must also be a perfect instructor, but it is not so; for his qualifications (though ever so great) are insufficient if he cannot communicate his sentiments with ease and in a method adapted to the ability of the scholar."

So said the eminent teacher and writer Pier Francesco Tosi in 1723 (Galliard/Pilkington, 1987, p. 73). The teaching of singing skills is commonly based on a master-apprentice model, relying on good modelling and feedback (Callaghan, 2000). The process of skill acquisition can be broken down into three stages: the cognitive stage, the associative stage, and the autonomous stage (Anderson, 1982). In both the cognitive and associative stage, modelling and external feedback have been identified as important. Traditional methods for learning to sing have relied heavily on auditory imagery. Many students in our very visually-oriented society are more visually than aurally aware, and that visual awareness is part of the bodily-kinaesthetic intelligence which plays such an important part in singing. In talking about acting students, Barton (1997) claims that, at the introductory levels, the vast majority (often up to 80 percent) are visual learners; at more advanced levels more have become kinaesthetic or auditory learners. Using visual feedback is thus one method adapted to the ability of the majority of scholars.

Learning to sing involves training in two fundamental elements: musical concepts and psychomotor skills. These are interdependent in that content (e.g. pitch) cannot be studied without applying some specific level of skill (e.g. the ability to co-ordinate the vocal mechanism to produce the requisite pitch). Kemp (1996) summarises three particular issues which cause difficulty in this learning process: firstly, singers cannot hear themselves as others hear them; secondly, each sound they produce will be accompanied by a particular sensation; and, thirdly, singers have to learn to detect particular body sensations that connect with their more desirable sounds, as identified by their teachers.

Feedback which is both unambiguous and timely is central to the learning of all musical performance skills, but is of even more importance in the learning of singing, where the process is confused by the identification of the performer with the instrument. In conventional singing training, interpretation of the teacher's feedback can be problematic, partly because of the difficulties in verbally explaining perceptual and production aspects of the voice, but also because of the delay between when the student produces the vocalisation and when the feedback is made. This delay makes it difficult to learn the motor control programs because the feedback provided by the teacher is disassociated from the proprioceptive and auditory sensations accompanying vocalisation (Welch, 1985).

In attempting to help students build a perception of the interrelationship between their body sensations and desirable vocal performance, teachers commonly give feedback in metaphoric language which links sensation to tone. However, between teacher and student there may well be disparities in perceptual style, and teaching/learning style, in addition to great differences in life experience, making allusive language at best ambiguous, and at worst, misleading. There is also the difficulty that the teacher's verbal feedback may be interpreted by the student as personal criticism and therefore do more harm than good, or that repetition of the same feedback may cease to have any impact on the student's performance. In any case, the student is required, after the event, to recall an accurate and detailed memory of his or her own performance, interpret the feedback provided in the light of that memory, and apply the feedback to modify subsequent performance. In such a scenario, it is perhaps not surprising that learning to sing can be a slow process (Welch, 1985).

Recent research suggests real-time visual feedback enhances cognitive development and skills learning (Welch, Howard & Rush, 1989; Howard, 1993; Nisbet, 1995; Weidenbach, 1996; Nair, 1999) and may therefore be profitably employed in the teaching of singing. If there is a way to present clear, instantaneous feedback which comes from an impartial machine, and cannot be misread as personal criticism or nagging, then the feedback information is more readily assimilated.

This paper reports aspects of a continuing investigation into the use of computer-assisted visual feedback in the teaching of singing (Thorpe, Callaghan & van Doorn, 2001). In a preliminary study conducted in 1999 teachers used commercially available speech technology in singing lessons, incorporating the VFT in whatever way they found useful. Interview data from teachers and students indicated that it is certainly both feasible and productive to utilise computer technology in singing training (Callaghan, Thorpe & van Doorn, 1999). That study also clarified areas in which further investigation was needed and aspects of the speech technology which needed modification for application to singing. In 2000 further research examined how computer technology can assist in the teaching of singing (Callaghan, Thorpe & van Doorn, 2001). The results indicated that such technology can provide useful assistance to the teacher and student, but the teacher needs to be able to interpret what the computer is showing and incorporate that understanding into the learning environment.

Our current more extended study is focused on developing new VFT for use in singing teaching, through investigation of:

1. acoustic analysis techniques for extracting perceptually relevant characteristics from the singing voice;
2. methods of presenting acoustic information in meaningful visual displays; and
3. pedagogical approaches that integrate this technology into the practice of singing teaching.

Both quantitative data (recordings) and qualitative data (reactions to the feedback) were collected. This paper reports on the qualitative aspects of the study.

Visual feedback operation

For visual feedback to be successful in assisting students, it must provide information about acoustic properties of the singing voice that are relevant to the perceptual qualities required in good singing performance. The acoustic properties of the singing voice include characteristics relating to qualities of pitch, vowel identity, and timbre.

The perceptual quality of pitch is reasonably well correlated with the acoustic measure of fundamental frequency and it is relatively straightforward to estimate from the voice signal. Visual representations of pitch can therefore be presented to the singer. One difficulty with the display of pitch information however is the disparate requirement of wide range and high accuracy. A singer's voice may range over two or more octaves, but demands for pitch accuracy are in the order of 1% (<¼ semitone). It is therefore necessary to arrange that the display is able to represent both large pitch intervals and fine target accuracy. One way to accomplish this is to superimpose a scale of guidelines, at

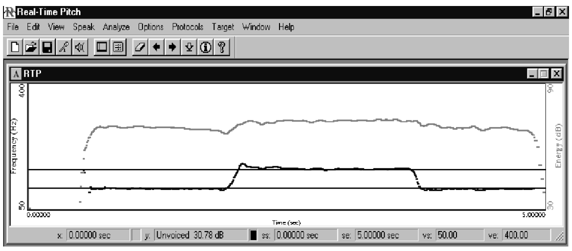

Figure 1. Example of pitch profile (Kay Real-time pitch) showing simultaneous presentation of pitch (dark line) and loudness (gray line) contours, with guidelines illustrating appropriate interval (5th).

appropriately spaced intervals, on the simple representation of pitch value (see Figure 1). This display can be enlarged to allow for accurate targeting of a single pitch, or compressed to show larger interval steps.

Vowel identity is somewhat problematic because of its dependence on pitch, and indeed the fundamental limitations on vowel identification at high pitch (Scotto Di Carlo & Germain, 1985). At low pitch it is feasible to invoke the source-filter model of speech production and associate vowel identity with the frequencies of the first two formants (resonance peaks) in the voice spectrum. The formant frequencies (F1 and F2 respectively) estimated from the voice signal can be represented diagrammatically on a two-dimensional display of F1 versus F2 (see Figure 2). This two-dimensional display approximates the articulatory space, with the F1 dimension correlating with jaw opening and the F2 dimension with front or back placement of the tongue. It is therefore possible to associate the position at which vocalisation appears on the display with the position of the articulators. Also, as the singer adjusts his or her jaw and tongue position, the resulting point shown on the display moves accordingly. Students can therefore practise attempting to achieve a target vowel

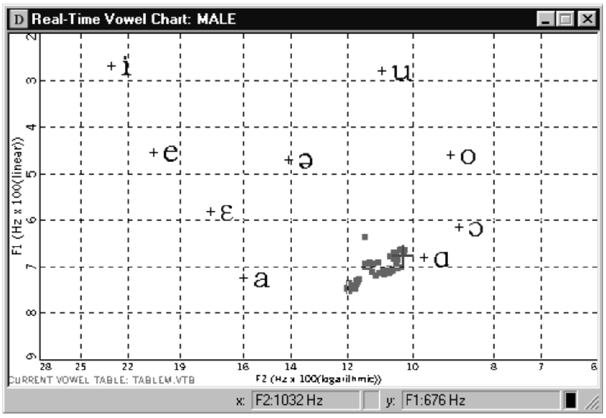

Figure 2. Vowel chart generated by plotting the frequencies of the first two formants F1 (vertical) against F2 (horizontal). Also depicted are the positions of (American) English vowels, together with a series of points arising from acoustic analysis of a short vocalisation of /a/.

identity, and once they have attained it by visual matching, learn to identify it both aurally and with respect to how the articulators are positioned to effect its pronunciation.

Vocal timbre covers a range of perceptual qualities other than pitch and vocal loudness. These are generally referred to qualitatively in descriptive terms such as “colour”, “warmth”, “ring”, “brightness”, etc (Ekholm, Papagiannis & Cagnon, 1998).). Although there is still some uncertainty about the precise acoustic correlates of these various qualitative descriptors, in general the qualities of timbre correspond to the overall distribution of sound energy across the spectrum. For instance, a strong concentration of acoustic power at a frequency of around 3kHz (the so-called singer’s formant) is strongly associated with perceptual qualities of vocal brightness, ring, and warmth. Other acoustic manifestations of vocal timbre include the pattern of vibrato in the voice and the temporal structure of note

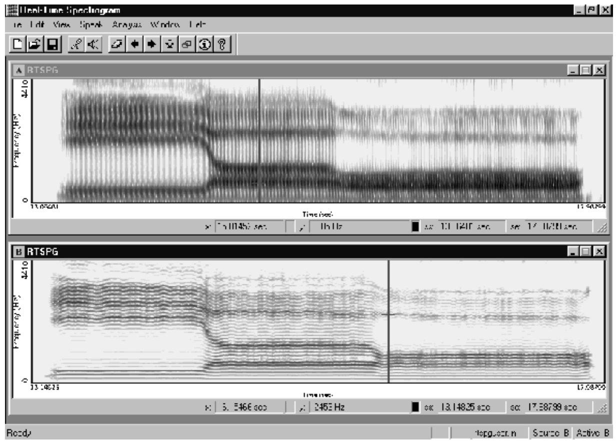

Figure 3. Example of spectrographic display showing both wideband and narrowband representations of the sequence /i/-/e/-/a/ sung at a constant pitch.

and vocalisation onsets. All of these quantities can be displayed via the medium of the spectrogram, which is a pseudo three-dimensional representation of the spectral distribution of sound energy and its temporal evolution (Figure 3).

Method

Commercially available VFT from Kay Elemetrics (Computer Speech Lab) was installed on a dedicated computer to give feedback on pitch (Visi-Pitch), vowel identity (Sona-Match), and timbre (CSL). We relied on the results of our earlier research to optimise the program settings for singing voice and to make the operation as simple as possible for use in the singing studio. A good quality headset microphone was used, to minimise problems associated with students adapting body alignment to suit the position of a fixed microphone. Teachers were provided with written instructions on use of the program and initial training was provided to each teacher in the use of the system and interpretation of the visual displays in terms of singing concepts.

The study followed a within-subject research design, with 21 students followed over a baseline period of 1-4 (weekly) lessons, a series of 4-6 lessons incorporating visual feedback, and a follow-up period of 1-4 lessons with visual feedback withdrawn. Four teachers trialled the VFT, one with eight students, one with three students, one with four students, and one with six students. The teachers chose which aspects of the program to use and how to incorporate the feedback into the lesson. The study was approved by The study was approved by the Human Ethics Committee of the University of Sydney.

At the beginning of each lesson, an assessment exercise was recorded, comprising one or more sets of vowels sung over scales or arpeggios, followed by a vocalise. The specific details of the exercise differed according to the level appropriate for each student, but the same exercise was recorded over all visits by each individual student.

The visual feedback intervention for each student was specified by consultation with the teacher, having regard for the student's pedagogical needs and stage of development. Typically it included one or two of the three modes of feedback (pitch, vowel, and spectral), provided during the course of the lesson.

Following the intervention, all participants (four teachers and 21 students) were interviewed to collect qualitative data on their characteristics and their reaction to the feedback. A semi-structured interview schedule was used for both teachers and students to examine individual familiarity with computer technology and reaction to the use of VFT in lessons. For the teachers, questions also covered personal characteristics such as gender, age, musical and pedagogical training, and teaching setting. For the students, questions also covered personal characteristics such as gender, age, and learning stage. The interviewer was the chief researcher who is a singing teacher, and thus able to use the common language of the singing studio and to prompt as needed during the interview. Interviews were transcribed verbatim and the text entered into NU.DIST analysis software. The data were analysed by searching for common ideas, words, or themes; using these groupings to construct categories and sub-categories; and searching for links between categories.

Results

Teachers

Three of the teachers were female, ranging in age from 58 to 67. One was male, aged 37.
All teachers had qualifications (some more than one) in teaching, in addition to their musical training and performance experience. Three had Trinity College of Music teaching diplomas, one had a conservatorium Associate Diploma of Music Teaching, one a Graduate Certificate in Singing Pedagogy, and one a Diploma of Education as well as a Masters degree containing some education subjects. All taught in private studio in the Sydney metropolitan area, with one also teaching in a fee-paying school. Three use computers in other aspects of their work, but

	Age	Gender	Teaching Qualifications*	Computer Skills	Familiarity with Acoustic Analysis Displays
Teacher F1	64	female	DipEd, MA, LTCL Enrolled MSc in voice	Yes	Yes
Teacher F2	58	female	ADipTeach., ATCL Enrolled MSc in voice	Yes	Yes
Teacher F3	67	female	Some tertiary-level psychology subjects GradCertSingPed	No	Yes
Teacher M1	37	male	LTCL	Yes	Yes

*In addition to musical qualifications and performing experience

Table 1: Details of participant teachers

one does not. (See Table 1.)
All teachers found some aspects of the VFT useful. How they used it depended on their individual teaching style, the length of lessons, and the students they were working with. Teachers F1 and F3 were working largely with adolescent singers and felt that the pitch feedback was the most useful. Neither felt that it was appropriate to use the spectrogram for singer's formant with these students, but they did both use it for onset. Teacher F1 used it for teaching young singers vibrato and, with one student particularly,

found it useful in teaching her to distinguish between amplitude vibrato and pitch vibrato. Teacher F2 was working with beginners in the first couple of years of their tuition and felt that for these students the spectrogram had limited application. She found the pitch feedback useful, particularly with one student who is slightly deaf.

Teacher M1 found the VFT "phenomenal", saying that "the visual thing is far more specific than I can be. … On the machine we can see where the resonance is not strong and they just work on it again and again." He was working with adult students only and found it very useful with beginner adults, with whom he felt that "it clearly explains things I have been telling my students to do … they have confidence in me when they are starting out … because it's all objective—like the computer can't lie." He relied entirely on the spectrogram, using it to give feedback on vowel quality, the singer's formant, and onset. Both Teacher M1 and Teacher F1 were concerned that some adult beginners were so keen to get the right visual feedback that they became very tense and forced the voice. As F1 said, "They worked so hard to get the right visual feedback that often they overdo it. … One has to be really careful that when they are using visual feedback they are doing it the right way."

Teachers F3 and M1 used the spectrogram for dynamics.

All the teachers felt that if the VFT were commercially available at reasonable cost they would like to use it, but not for every lesson. They would like the screen display to be less scientific, more musical. Some saw the VFT as a useful practice tool at the right stage of development, but emphasised the importance of teacher supervision, or the teacher providing a recorded model. One suggested that it would be ideal to "have it in the other room so the kids could come early and work on different little programs". This teacher taught half-hour lessons with adolescents preparing for examinations and felt that, while the VFT was very useful, to use it in lessons took would take too much time from work on repertoire and musicianship.

Teachers felt that student response to the VFT varied, but could identify no pattern related to age, gender, or computer experience. One attributed the difference in response to learning style, saying "The self sufficient ones had less interest. Those who like to ask for help really liked the machine and those who like to work things out for themselves weren't so impressed. They would use it once or twice and would say, 'Oh well, that was interesting and now I will get back to … .' "

All the teachers were disappointed with the vowel quadrilateral, finding it unreliable at high pitch, and therefore only suitable for use with adult males. Plainly a vowel quadrilateral that gave accurate feedback at high pitch would be a valuable enhancement to the program. Other suggestions for improvements were a longer time frame for the feedback/recording, a greater choice of colours for the spectrogram display, and more obviously musical pitch displays.

Students

Of the students, eight were male and 13 female. They ranged in age from 14 to 58.
Their singing experience varied from complete beginner to students who had been learning singing for many years. Only one (male) was a semi-professional performer. (See Table 2.)

While all but one of the students used computers for word processing, internet, and other applications, only four had any familiarity with acoustic displays. Of these, two were music students, one a speech pathology student, and one a journalist. Ninety percent of the student participants had a positive response to the VFT, ranging from “I was quite happy about it” to “It’s really amazing!”, while ten percent were lukewarm in their response and felt they would prefer to learn in other ways (using the flute or piano as a reinforcement). Those who found it useful attributed this to the fact that the feedback was visual. One volunteered: “It helped me know how the voice sounded and gave me a method of singing”, another that “it is another way of learning” and another that it “gets two senses going and programs the brain”. One commented favourably on the fact that feedback was immediate and another said “It was very useful for reinforcing what I knew but it did it so dramatically. … It reinforced the things that you knew but it did it so instantly that I think it was like somebody prodding you when you make a mistake.” Two teenage males were particularly enthusiastic about using technology: “It was a good experience; society’s now based on computer technology.”; “I was excited. I thought it was really good and it was kind of nice to have part of the lesson dedicated to recording this protocol and be looking at it back.”

Students	**Number**	**Percent**
Total Number	21	100
Gender		
Male	8	38
Female	13	62
Age Range		
14-19	8	38
20-29	6	29
30-39	1	5
40-49	4	19
50+	2	10
Years of Training		
1	4	19
2	3	14
3	6	29
4	5	24
5+	3	14
Computer Skills		
Yes	20	95
No	1	5
Familiarity with Acoustic Displays		
Yes	4	19
No	17	81

Table 2: Participant students

Some students felt they learnt quicker, but others just that the VFT gave them a better understanding of their voice production and helped them to focus their practice outside lessons. One summarised: “I sing, and see what it looks like, and then remember the way it was sung.” The oldest participant felt that “it helped reinforce things I knew and because I am coming to singing older and because I am trying to change how to do something, that is a lot harder than changing something intellectually because you are trying to change the body; so I think it sharpened my understanding of where I was losing those things that I knew”.

Since the teachers determined how they used the VFT for individual students, it was not surprising that different students identified different applications of the feedback as particularly useful. Many found it useful for maintaining a consistent vibrato, or—in the case of young students with changing voices—for cultivating vibrato: “it’s the idea of actually seeing the vibrato … and you can remember it after you’ve done it”.

Many commented on its use in sustaining a vowel on a single pitch, and for cultivating clear onset and offset of tone. While some found the VFT useful for maintaining the singer’s formant across different vowels, others did not really understand this display. Six students used the VFT when they were singing arpeggios. Two felt it was not much help, but one was particularly enthusiastic about its use in maintaining voice quality across the major register change while singing arpeggios.

Six students found the VFT particularly useful for correcting intonation problems and identified that as being linked to breath management.

Two students felt the VFT was not much help. With one this is probably attributable to her preferred mode of learning. She found the immediate visual feedback distracting, commenting "I found that when I was singing and recording it it was sort of distracting to actually see it coming out on the screen and I was trying to adjust what I was doing as I was singing. I didn't find it useful to try and adjust as I saw it because you start tensing up and trying to force yourself into a change."

The other, a high soprano, found that the VFT did not respond well to notes high in her range (E5 and above).

Students too would like a reliable vowel chart to be incorporated into the software. Some also suggested that it would be useful to have print-outs or recordings from the lesson to use as models when practising at home. Three suggested an instruction manual and two teenage boys were very keen on incorporating games into the package.

Summary and Conclusions

Teachers used the VFT for pitch, onset, vowels, dynamics, vibrato and timbre (see Table 3)

Use	Teacher
Pitch	F1, F2, F3, M1
Onset	F1, F3, M1
Vowels	F2, F3, M1
Vibrato	F1
Timbre	F2, F3, M1
Dynamics	F3, M1

Table 3: Usage of VFT by individual teachers

All found the pitch displays useful and two were very enthusiastic about the spectrogram. One of these teachers (M1) used the spectrogram for teaching vowel quality, but the teachers who tried the vowel quadrilateral were disappointed that it was not adequate for use with adolescent voices or adult female voices.

All teachers, and the great majority of students, found the VFT useful. Its most effective use depends on the teacher having a clear understanding of the relationship between singing production and the acoustic features displayed, as well as being able to identify the best applications for students with different learning styles and at different stages of vocal development. From teacher responses, it was clear that developing more musically meaningful visual displays would be helpful.

While many students were keen to have VFT as a practice tool, teachers were more cautious, emphasising that unsupervised practice with the VFT could lead to the pursuit of a result in one aspect of voice, with accompanying bad habits in another.

The provision of real-time visual feedback about the singer's performance can provide information directly to the student, and because it is provided simultaneously, the information can be immediately incorporated into the singer's vocal production. Ideally, students will learn through this feedback, and internalise the knowledge of how to produce the required performance, so that they eventually no longer require the supplementary external information (whether provided by the teacher or by real-time visual display).

We have used the results of this study in developing a specialised computer system, Sing&See, that gives more accurate real-time visual feedback on the singing voice in more musically meaningful visual displays (see Figures 4 and 5). Currently Sing&See gives feedback on pitch, loudness and timbre. We have recently published a pedagogy manual for use with the software (Callaghan & Wilson, 2004) and are working on incorporating an accurate vowel chart into the software.

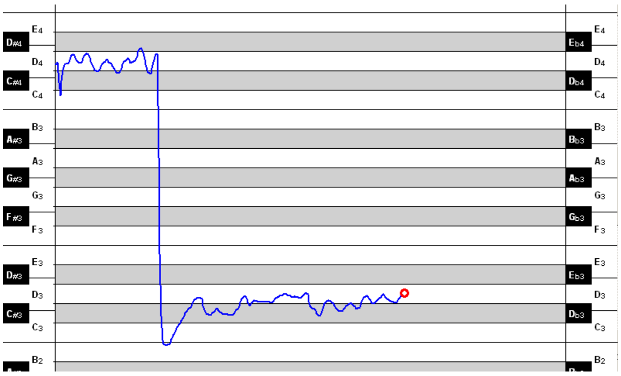

Figure 4 Example of Sing&See pitch profile showing presentation of pitch (blue line), with guidelines illustrating musical intervals.

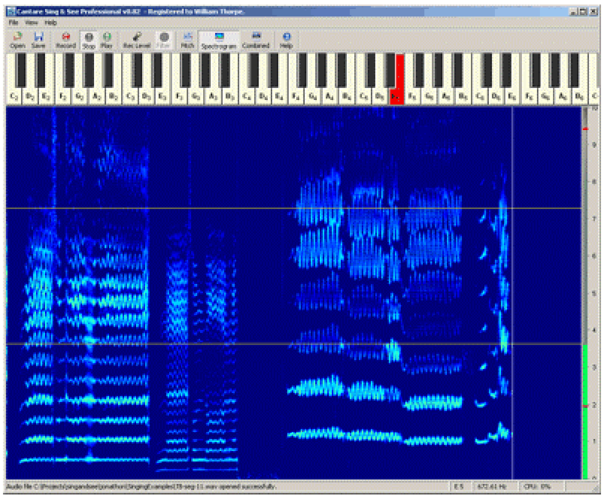

Figure 5. Example of Sing&See spectrographic display showing feedback of harmonic structure together with pitch (on piano keyboard) and total loudness on level meter.

References

Anderson, J.R. (1982). Acquisition of cognitive skill, *Psychological Review*, 89, 369-406.

Barton, R. (1997). Voice in a visual world: A neuro-linguistic programming perspective on vocal training. In M. Hampton & B. Acker (Eds.), *The Vocal Vision: Views on Voice*, 81-92.

Callaghan, J. (2000). *Singing and voice science*. San Diego, CA: Singular Publishing Group, Inc.

Callaghan, J. & Wilson, P. (2004). *How to sing and see*. Sydney: Cantare Systems Pty Ltd.

Callaghan, J., Thorpe, W. & van Doorn, J. (1999). Computer-assisted visual feedback in the teaching of singing. In M.S. Barrett, G.E. McPherson & R. Smith (Eds), *Children and Music: Developmental Perspectives*, pp. 105-111. Proceedings of the 2nd Asia-Pacific Symposium on Music Education Research and the XXI Annual Conference of the Australian Association for Research in Music Education. Launceston: University of Tasmania.

Callaghan, J., Thorpe, W. & van Doorn, J. (2001). Applications of visual feedback technology in the singing studio. *Proceedings of the XXIII Annual Conference, Australian Association for Research in Music Education*. Newcastle, September. Melbourne: AARME.

Ekholm, E, Papagiannis, GC, & Cagnon FP. (1998). Relating objective measurement to expert evaluation of voice quality in Western Classical Singing: Critical perceptual parameters. *Journal of Voice*, 12(2):182-96.

Howard, D.M. (1993). Real-time visual displays in speech and singing. *Defence Science Journal*, 43(3), 211-221.

Kemp, A.E. (1996). *The musical temperament. Psychology and personality of musicians*. Oxford: Oxford University Press.

Nair, G. (1999). *Voice tradition and technology: A state-of-the-art studio*, San Diego, CA: Singular Publishing Group, Inc.

Nisbet, A. (1995). Spectrographic analysis of the singing voice applied to the teaching of singing. Australian Voice, 1: 65-68.

Scotto Di Carlo, N. & Germain, A. (1985). "A perceptual study of the influence of pitch on the intelligibility of sung vowels", *Phonetica* 42:188-197.

Thorpe, C.W., Callaghan, J. & van Doorn, J.L. (2001). *Real-time visual feedback of acoustic characteristics of the singing voice and its use in enhancing singing teaching.* Australian Research Council Large Research Grant.

Tosi, P.F. (1987). *Observations on the florid song* (Galliard, Trans., M. Pilkington, Ed.). London: Stainer & Bell. (Original work, *Opinioni de'cantori antichi e moderni*, published in 1723).

Weidenbach, V. (1996). *The influence of self-regulation on instrumental practice.* PhD thesis, University of Western Sydney, Nepean.

Welch, G.F. (1985). A schema theory of how children learn to sing in tune, *Psychology of music*, 13(1), 3-18.

Welch, G.F., Howard, D.M. & Rush, C. (1989). Real-time visual feedback in the development of vocal pitch accuracy in singing. *Psychology of Music*, 17, 146-157.