Open throat: acoustic and perceptual support for pedagogic practice

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Music and song permeate every facet of human experience and play a significant role in cultural and social life. How are beautiful singing voices developed? What features of the singing voice define vocal beauty? Are listeners reliable in their assessments of these features? Can these features be accurately measured and taught? This paper reports on the first body of work of its kind to define and assess one feature of the technique of the classical singing voice – open throat. Such is its prominence in vocal pedagogy, Richard Miller commented 'It would be hard to find a voice teacher who recommended singing with a closed throat' (Miller 1996b) (p.58). The fact that a technique is universally practiced does not in itself provide justification for its continued use; it must be validated empirically. Accordingly, we examined the acoustic and perceptual features of the classical singing voice while singers used and then reduced usage of open throat in a series of five studies. We confirmed that open throat technique is a useful and valid pedagogic technique that enhances vocal quality in the female classical voice. The methods and procedures developed to assess open throat can be used to assess other pedagogic training techniques, thereby contributing to the science of voice and vocal pedagogy.

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INTRODUCTION

"Open throat" is a term regularly used in the singing studio. It is a pedagogic concept transmitted through the oral tradition of singing. Mitchell and Kenny (Mitchell et al. 2003; Mitchell and Kenny 2004a, 2004b, in press; Kenny and Mitchell in press, 2004) examined the technique in the modern singing studio using qualitative, acoustic, perceptual and statistical analyses to relate singing instructions, terminology and spectra to the sound qualities produced by instruction in this technique and validated its role in singing pedagogy.

Achieving vocal mastery

How are beautiful singing voices developed? What features of the singing voice define a voice of quality? Can these features be measured accurately and more importantly, specifically taught? Historically, teaching and evaluating singing has been guided by an oral tradition in which pedagogic techniques are handed down from one generation of singing teachers to the next. Today, empirical research into the singing voice has the potential to benefit the singing community by documenting and systematically assessing the acquisition of vocal mastery.

Since the 1980s technology to measure vocal acoustics has become steadily more sophisticated and has been increasingly used in experimental research, with the findings of such research now being incorporated into texts on singing (Miller 1996b; Nair 1999; Sundberg 1977; Thurman and Welch 2000). International authority Richard Miller asserts "It is the responsibility of the singing teacher in a scientific age to interpret and expand vocal traditions through the means of current analysis so that the viable aspects of tradition can be communicated in a systematic way" (Miller 1998,p. 299).

However, it is often difficult to see how the general principles established in scientific studies can be applied to the subtleties of developing individual vocal quality. To date, few studies link the vocal strategies used by singers to acoustic studies and perceptual judgments by pedagogues. This makes it difficult to draw firm conclusions about the implications of these scientific studies for singing pedagogy as they rarely identify the teaching/learning approach of the subjects (Miller 1998; Callaghan 2000).

In this paper, we report the first body of work to track a singing technique as practiced in the singing studio using a comprehensive approach to all aspects of singing research (Mitchell and Kenny

2004a, 2004b, in press; Mitchell et al. 2003; Kenny and Mitchell in press, 2004). As it is pedagogically informed and verified, this series of studies has the potential to substantially progress the fields of acoustic and perceptual assessment of voice in order to benefit the wider singing community and enhance pedagogic approaches.

DEFINING OPEN THROAT TECHNIQUE

Concepts relating to open throat can be traced throughout pedagogic and scientific singing literature (Burgin 1973; Fields 1947; Monahan 1978). It is defined as a complex process that is both a pedagogic instruction and a perceived sensation or action that results in a specific sound quality. Use of the technique makes a difference to vocal quality. Indeed, Vennard defined open throat as the 'condition agreed upon by most voice teachers as desirable for resonance' (Vennard 1968, p.252). Current support for the use of open throat in singing technique is widespread (Miller 1996a; Reid 1975, 1983). It elicits a sound quality which is perceived as resonant (Miller 1996b; Vennard 1968), round (Joiner 1998), free (Ware 1998), pure, (Marafioti 1981) rich and warm (McKinney 1982) and is attributed to freedom from 'constrictor tensions' (Reid 1983)(p. 83). The sound quality is linked to vocal actions: the preparation to sing or inhalation (Hemsley 1998; Manèn 1987; Miller 1997b, 1997a); through the surprise breath or smelling the rose imagery (Hemsley 1998; Miller 1996b; Puritz 1956); and visualizing space within the throat, through an 'air-ball' or 'soap bubble' (Herbert-Caesari 1951; Manèn 1987).

Do expert singing teachers actually agree on the definition of open throat technique, and if so, on what such a technique was meant to achieve? Subjective terminology used in singing pedagogy does not always indicate a specific vocal instruction or action. Often terminology and meaning are not the same for each teacher. Communication of techniques in singing pedagogy can be improved by attempts to gain consensus on the use of terminology. This was the goal of our first study on open throat. We interviewed fifteen expert singing pedagogues to explore current thinking regarding terminology, pedagogy, sound quality and the perceived physiology associated with open throat technique (Mitchell et al. 2003).

Terminology of open throat

The majority of our fifteen vocal pedagogues interviewed agreed that open throat was essential to good singing and more specifically to classical singing. Most included the technique as fundamental in their singing training. Freedom, collar and depth were suggested as alternative terms to clarify meaning or to refer to an action. Pedagogues were aware of the need to tailor their terminology and instructions in the singing studio to each student's vocal needs and learning styles. Despite the use of different terminology to describe the technique, there was consistency in the vocal instructions to achieve it and with respect to the sound qualities it produced. Pedagogues taught conscious control of open throat using laugh, sob, correct inhalation or maintaining the posture of inhalation.

Sound quality

Open throat produces a distinctive sound quality recognised by most singing pedagogues. Table 1 [after (Mitchell et al. 2003)] identifies the most common terms used to describe the sound quality. Pedagogues associated open throat with both a sound quality that was characterized by freedom, warmth and openness and an action that produced balance, coordination, evenness and consistency. The terms related to vocal 'quality' such as 'warm', 'full' or 'round', as well as the 'functional' terms such as 'easy' or 'clean' were used interchangeably by participants in this study. Although the 15 participants offered 18 terms to describe sound quality, there were clear associations or similarities in their usage and application.

Physiological action

Singing pedagogues relied on their perceptions of sound qualities to determine the physiological processes at work in the production of the sound quality. Open throat was defined as a technique to maximize pharyngeal space and/or abduct the ventricular folds. Participants who consistently mentioned a presumed "abduction" or retraction of the false vocal folds or ventricular folds reported seeing the action of endoscopy and linked the technique to the term retraction. Those participants who used the term and technique of retraction did so to reduce constriction or tension to achieve a healthier sound quality as well as to achieve a specific sound quality.

Recommendations

This study advanced previous work in clarifying terminology related to open throat (Burgin 1973; Fields 1947; Monahan 1978). In this study, pedagogues' use of open throat confirmed the perceived value of the technique. Pedagogues did not sepa-

Table 1: Sound qualities associated with open throat – pedagogues' individual choices indicated by □.

Pedagogue	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	%
Balanced/Coordinated	□		□	□	□	□	□	□	□	□	□	□	□	□	□	93
Free	□		□			□	□	□	□		□	□	□		□	67
Open	□		□		□	□	□	□	□					□		53
Even/Consistent	□				□	□		□		□	□		□	□		53
Warm	□	□	□			□		□	□	□					□	53
With space	□			□			□	□	□	□			□	□		40
Healthy/Safe	□	□	□				□					□				33
Round	□	□	□						□					□		33
Overtones/formants			□			□							□	□	□	33
Easy/Flexible	□				□	□		□					□			33
Clear		□	□			□						□				27
Full	□			□					□							20
Efficient	□						□					□				20
With depth	□									□	□				□	20
Clean						□	□					□				20
Sexy/Juicy/Lusty		□									□					13
Natural Voice					□						□					13
Relaxed				□												7

rate quality and function descriptors and seemed comfortable with their use interchangeably in the studio. The research highlighted the usefulness of qualitative research as a tool for the generation of research questions and clarification of terminology used to describe vocal quality and to encourage the use of anatomically correct terms in vocal pedagogy. For example, de-constriction is a more accurate term than retraction.

Having established the widespread usage of the term 'open throat' and its practice in the singing studio, the next challenge was to assess whether open throat had identifiable acoustic and perceptual characteristics.

ACOUSTIC AND PERCEPTUAL VERIFICATION OF OPEN THROAT TECHNIQUE

The musical community has become increasingly fascinated with the link between acoustic measures of vocal quality and perceptual judgments of listeners. Prior to the work of Mitchell and Kenny (Mitchell and Kenny 2004a, 2004b; Kenny and Mitchell 2004, in press), two studies examined this link. Wapnick and Ekholm (Wapnick and Ekholm 1997) established 12 generally accepted perceptual criteria for the assessment of voice quality in classical singing (appropriate vibrato, color/warmth, diction, dynamic range, efficient breath management, evenness of registration, flexibility, freedom throughout vocal range, intensity, intonation accuracy, legato line, and resonance/ring). Ekholm, Papagiannis and Chagnon (Ekholm, Papagiannis, and Chagnon 1998) used four of these criteria ("appropriate vibrato", "resonance/ring", "color/warmth", and "clarity/focus") and related them to objective measurements taken from acoustic analysis of the voice signal. Both studies required listeners to focus on specific vocal dimensions, as well as making an overall judgment of vocal quality. In both studies, analysis of the listener rating scales of vocal quality revealed that the specific dimensions outlined above were collinear and hence likely to be tapping into a single underlying construct, that of (overall) vocal quality, thereby rendering individual assessments on each dimension at least partially redundant. While focusing listeners by using a number of criteria may improve the consistency of judges' responses, (Wapnick et al. 1993), studies have reported very high correlations between all dimension of voice quality studied (Ekholm, Pa-

pagiannis, and Chagnon 1998; Robison, Bounous, and Bailey 1994; Wapnick and Ekholm 1997). All of these dimensions were found to converge with the overall judgment of vocal quality. It may not be possible to separate individual features of good singing from the overall perception of a "good voice".

Assessing acoustic and perceptual characteristics of open throat

Our next challenge was to determine whether this pedagogic technique could reliably produce desirable acoustic and perceptual changes in voices.

Six advanced female opera students, [3 sopranos, 3 mezzo-soprano] were asked to sing in three conditions: 'optimal' (O), using maximal open throat, 'sub-optimal' (SO), using reduced open throat and loud sub-optimal (LSO), which was the same as SO but with the additional instruction to sing as loudly as in O. Singers performed three musical tasks: messa di voce (a crescendo-diminuendo on a single note of long duration) on three pitches across their range, portions of an aria (Mozart: Ridente la Calma, K 152, bars 1-27) and a lied (Schubert: Du bist die Ruh D. 776 Op. 59, No. 3, bars 54 to 80) (Figure 1a and b). These were chosen as they require vocal skill and technical mastery (Miller 1996b) within the capacity of tertiary level students of opera (Ekholm, Papagiannis, and Chagnon 1998).

Singers' voices were recorded to CD (Marantz CDR 630) using a high-quality microphone (AKG C-477) positioned on a head boom a constant 7 cm distance from the singer's lips. This ensured we recorded only the voice energy, not the room reflections. We calibrated each recording in order to compare each singers' recording with the others at the same SPL, heard as 'loudness'. Recordings were anaysed with Soundswell (Hi-tech, Sweden) and Cool Edit software.

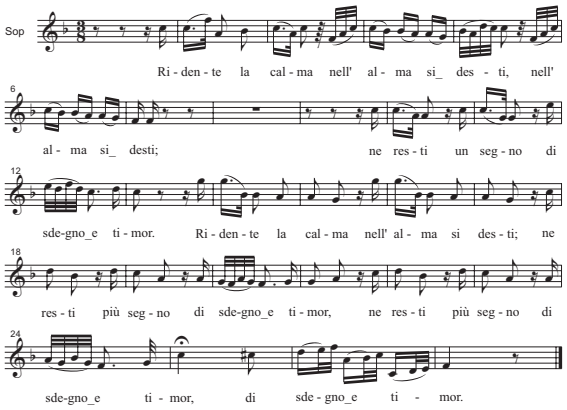

Figure 1a: The Mozart Task, Ridente la Calma, K 152, bars 1-27.

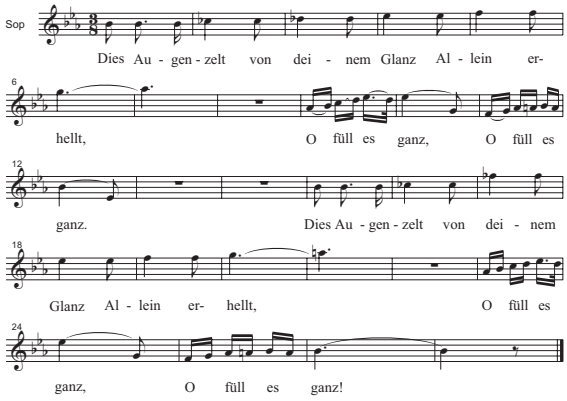

Figure 1b: The Schubert Task, Du bist die Ruh D. 776 (Op. 59, No. 3), bars 54 to 80.

PERCEPTUAL DIFFERENCES OBSERVED IN OPEN THROAT

In this study, we explored whether particular sound qualities were associated with one vocal technique, open throat.

We asked singing pedagogues to judge the singing of our sample of female classical singers as O (maximal open throat) and SO (reduced open throat) in 48 messa di voce and 30 song samples (including 6 repeated samples to test judges' response reliability). Fifteen expert singing pedagogues made a forced choice decision (O or SO) on each sample they assessed. Correctly identified responses were counted by condition (O/SO), by judge and by singer.

The majority of listeners correctly recognised the use of open throat when it occurred. Collectively, judges were accurate in their identification of O (81.1% correct) and SO (91.0% correct) in messa di voce samples. In the individual song samples, listeners identified the use of open throat in 84% of O samples, and 69% of SO [Table 2 after (Mitchell and Kenny in press)]. They were more likely to make a correct identification in the Mozart task (85% correct) than in the Schubert task (68%). Listeners identified >83% of Mozart O and SO, and Schubert O. They were least reliable in judging Schubert SO (53%).

The 15 judges identified the experimental condition in 372 of 450 messa di voce samples (82.7%). Twelve of fifteen judges were moderately consistent in their judgments ($k \geq 0.600$); and three judges

Table 2: Song responses. Percentages of correct (hit) and incorrect (miss) responses to the song task, by condition (optimal and sub-optimal) and by condition and task (Mozart and Schubert).

Task	Hit %	Miss %
All O	84%	16%
All SO	69%	31%
Mozart O	86%	14%
Mozart SO	84%	16%
Schubert O	83%	17%
Schubert SO	53%	47%

were inconsistent in their judgements. Listeners demonstrated reliability (fair to highly consistent) in their judgements through the duration of the song task, repeating their judgement of O or SO in an average of 86% of the six repeated samples in the perceptual test.

Conclusions

Listeners recognised a specific vocal quality in singers' sound that they associated with the use of open throat technique. These findings suggest that there is a specific vocal quality in classical singing associated with the use of open throat technique, which is a perceptual reality to singing pedagogues. Perceptual verification of a single vocal technique indicates that other pedagogic strategies can be assessed and evaluated making it feasible to track the methods by which good singers are trained and which produce the most effective outcomes in terms of vocal quality.

Singers rely on expert listeners' judgments in auditions, competitions and examinations. Research indicates that listeners show some degree of reliability and consistency in their perceptual judgments of timbre, between vocal genres (from opera to music theatre) (Sundberg, Gramming, and Lovetri 1993), and between good and poor vocal and instrumental performance (Ekholm, Papagiannis, and Chagnon 1998; Geringer and Madsen 1998; Saunders and Holahan 1997; Wapnick et al. 1993), in the assessment of excellence in overall voice quality (Wapnick and Ekholm 1997) and in rankings and ratings of performers in competitive situations (Davidson and Da Costa Coimbra 2001).

ACOUSTIC CHARACTERISTICS OF OPEN THROAT TECHNIQUE

Having verified that open throat technique has reliable perceptual qualities, we then investigated whether these were associated with consistent acoustic characteristics. A number of voice qualities [loudness, vibrato and long term average spectra (LTAS)] were assessed for their acoustic features. .

Loudness

Pedagogues suggested that the use of open throat resulted in 'loudness' (Mitchell et al. 2003). We used SO and LSO in experimental conditions to demonstrate that voice quality changes from O to SO were not simply the result of changes (i.e. reductions) to sound pressure levels (SPL) (Foulds-Elliott et al. 2000; Rossing, Sundberg, and Ternstrom 1986). A pilot test found that LSO did not produce a sufficiently discernible voice quality to be reliably distinguished from SO and was therefore not included in the perceptual studies.

Vibrato

Vibrato is taken for granted as an intrinsic quality of the classical singing voice and in pedagogic literature, as a component of tone quality in coordination (Vennard 1968) richness (Seashore 1938; Vennard 1968) and vibrancy (Miller 1996b). Despite acoustical, physiological and perceptual studies (Vennard 1968; Prame 1994, 1997; Shipp, Sundberg, and Hadlund 1984; Sundberg 1995), it has been difficult to define its most desirable parameters. Consistent vibrato occurring within specified parameters, has been associated with a beautiful sound (Robison, Bounous, and Bailey 1994) and to listeners' overall preference (Ekholm, Papagiannis, and Chagnon 1998). In the classical singing literature, a steady and even vibrato is universally promoted (Miller 1996b) while poor vibrato is considered indicative of poor technique (Vennard 1968; Miller 1996b) and inferior sound quality. In classical singing, sound without vibrato, or straight-tone, has been described as dull or spread (Vennard 1968) and lacking freedom, power (Miller 1996b) and ring (Vennard 1968). In fact, delay in vibrato onset is argued to be indicative of a faulty technique and an unnatural voice quality (Miller 1996b).

Few studies compare the same singers' vibrato in

different tasks. When they do, they find it changes across musical styles (Easley 1932; Hakes, Shipp, and Doherty 1987), as a result of emotion (Sundberg 1997; Rothman and Arroyo 1987; Gabrielsson and Juslin 1996), drama (Sundberg, Iwarsson, and Hagegard 1995) or indeed variations in 'loudness' (SPL) (Titze et al. 1999) or dynamics (Prame 1994). Our study is the first to assess the impact of a specific singing technique i.e. open throat on vibrato. As pedagogues associated evenness and consistency with the technique, we hypothesized that frequency modulations associated with vibrato rate, extent and onset would vary outside acceptable or desirable parameters for SO and LSO compared to O, that is rate (VR) would be less consistent, extent (VE) would be reduced and onset (VO) would be delayed.

Vibrato results

We demonstrated reliable differences in vibrato parameters as a result of varying the degree to which singers applied the technique of open throat. Figure 2 [after (Mitchell and Kenny 2004b)] illustrates the changes to vibrato parameters observed in spectrographs of the three experimental conditions. Hypotheses were confirmed for vibrato extent and onset, that is, a reduction of open throat technique for these singers produced a significant decrease in VE in SO/LSO and a significant increase in VO in both SO/LSO. There was no statistically significant change for VR. However, visual inspection of the spectrographs (Figure 2) shows that reduction of open throat in the SO and LSO conditions was associated with greater irregularity of the vibrato pattern compared to O. There were no significant differences between SO and LSO on any of the vibrato parameters.

As vibrato is considered a key indicator of good singing, these findings suggest that open throat is important to the production of a good sound in classical singing. Since vibrato parameters largely define good singing technique in the literature, open throat would appear to be an essential element of sound vocal pedagogy. Inappropriate vibrato is indicative of poor singing in general; therefore further acoustic tests were required to test the differences in timbre.

Long-term average spectra (LTAS)

LTAS is widely used to represent singers' sound (Sundberg 1974; Borch and Sundberg 2002) and its different vocal qualities based on energy changes that occur during different vocal tasks. Early researchers in this field have used LTAS to develop

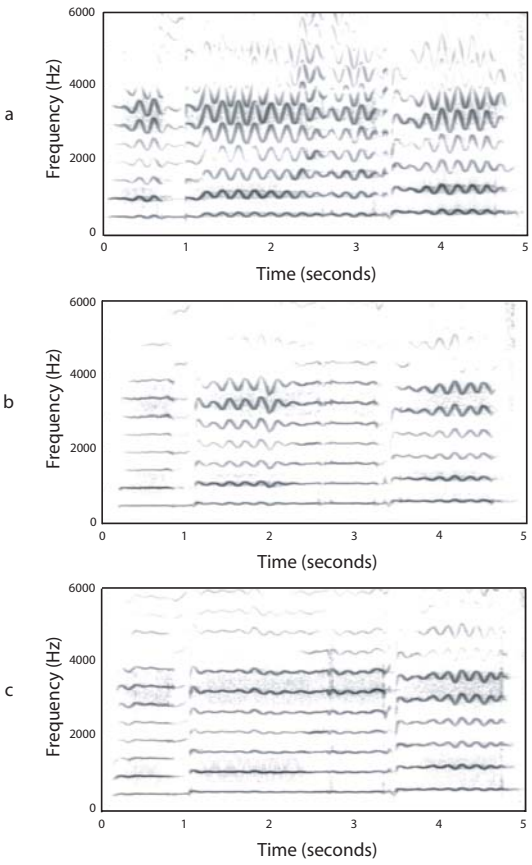

Figure 2 a-c: Examples of vibrato from subject 3 singing 'Von deinem Glanz' in each of the three conditions, optimal (O), sub-optimal (SO), and loud sub-optimal (LSO).

exemplars of voice types (Sundberg 1974) or singing genres (Cleveland, Sundberg, and Stone 2001; Borch and Sundberg 2002). LTAS curves have also been used to differentiate male and female voices (Mendoza et al. 1996), to note differences between singing and speaking voices (Barrichelo et al. 2001), solo and choral voice (Rossing, Sundberg, and Ternstrom 1987) and pop or country from opera singers (Borch and Sundberg 2002; Cleveland, Sundberg, and Stone 2001). Some LTAS have become exemplars of particular vocal qualities and of voices of quality. In classical or operatic voice, for example, an LTAS presents an energy boost around 3 kHz and this has been linked to carrying power over an orchestra or audibility in an opera theatre (Sundberg 1974; Barnes et al. 2004; Thorpe et al. 2001; Vurma and Ross 2000).

In research, we perform two simple measurements on LTAS. Figure 3 illustrates how the ratio measurements of singing power ratio (SPR) (Omori et al. 1996) and energy ratio (ER) (Thorpe et al. 2001) are derived from the LTAS curve. From the LTAS plots, the highest peaks in the 0-2 kHz and 2-4 kHz regions were labeled P1 and

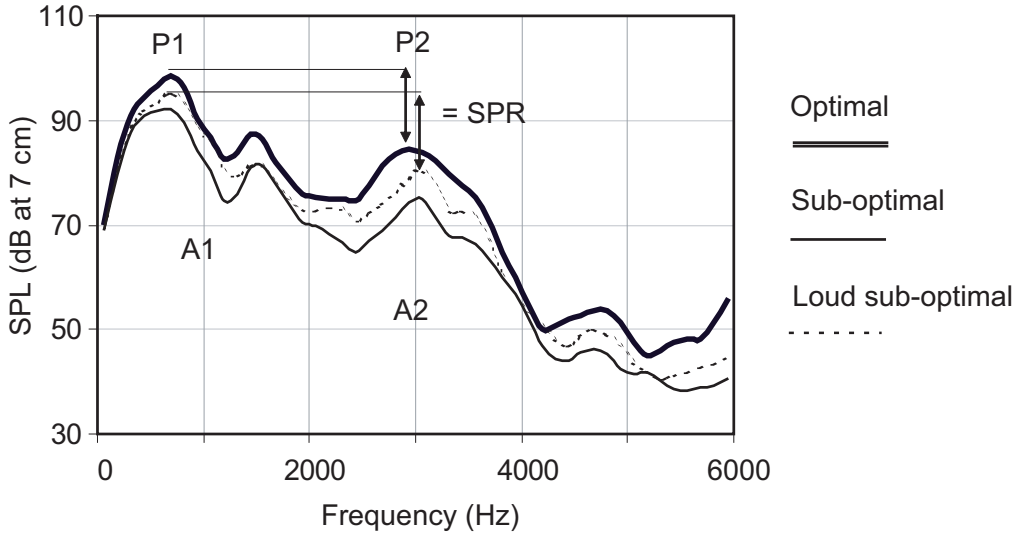

Figure 3: Long term average spectra of singer 3 singing Mozart's Ridente la calma in three experimental conditions, optimal, sub-optimal and loud sub-optimal (O, SO, LSO). Singing power ratio (SPR) is the difference between the spectral peaks (P1 and P2) and energy ratio (ER) is the difference between the area under the peaks (A1 and A2).

P2 respectively and the areas below the peaks, A1 and A2. The SPR (Omori et al. 1996) is the difference between the energy peaks P1 and P2 while the ER (Thorpe et al. 2001) is the difference in energy area between 0-2 kHz and 2-4 kHz. A low ER or SPR represents a greater reinforcement in the 2-4 kHz region and better balance between the spectral energy 0-2 and 2-4 kHz. When there is less reinforcement in the 2-4 kHz region, ER results follow SPR.

As inconsistent vibrato is considered indicative of poor singing, it was hypothesized that testing the energy distribution in our singers' voices in each condition would identify the timbral changes associated with open throat. Hypotheses were generated regarding the LTAS plots in O compared to SO: that peaks P1 (0-2kHz) and P2 (2-4kHz) would be reduced, that overall LTAS shape would demonstrate smaller or multiple energy peaks above 2 kHz in SO/LSO compared to O. Differences between spectral peak height (SPR: singing power ratio,) and spectral area (ER: energy ratio) between the 0-2 and 2-4 kHz frequency ranges were performed to assess the effect of open throat on carrying power in the voices.

LTAS results

Visual inspection of long term average spectra (LTAS) confirmed differences between O and SO/LSO, and the O condition produced a rounder peak between 0-2 kHz indicating a warmer sound quality compared to SO (Figure 3). Despite these findings, there was no significant difference in measurements of SPR (peak height) (Omori et al. 1996) or ER (peak area) (Thorpe et al. 2001) between O and SO/LSO. There were however, significant differences between SO and LSO for P2, SPR and ER but hypotheses were not confirmed for O. These findings did not accord with differences in vibrato extent and onset between O and SO/LSO.

As these results were not consistent with the vibrato findings they suggest that while LTAS provides information on energy distribution, measurements performed on the LTAS were unable to differentiate between experimental conditions, whereas the human ear produced the most reliable assessment of vocal quality. Plotting the differences between O and SO/LSO pairs of LTAS clearly indicates the areas of spectral change (Figure 4). This appears to be the most sensitive measure of energy distribution differences between conditions, but we have no way of capturing and quantifying such data at this time.

DO ACOUSTIC MEASURES MATCH PERCEPTUAL JUDGMENTS?

The conflicting results from the perceptual and acoustic studies of open throat technique highlighted potential problems with these conventional analyses as measures of vocal quality. In the final study, we compared perceptual ratings of vocal quality with acoustic measures performed on

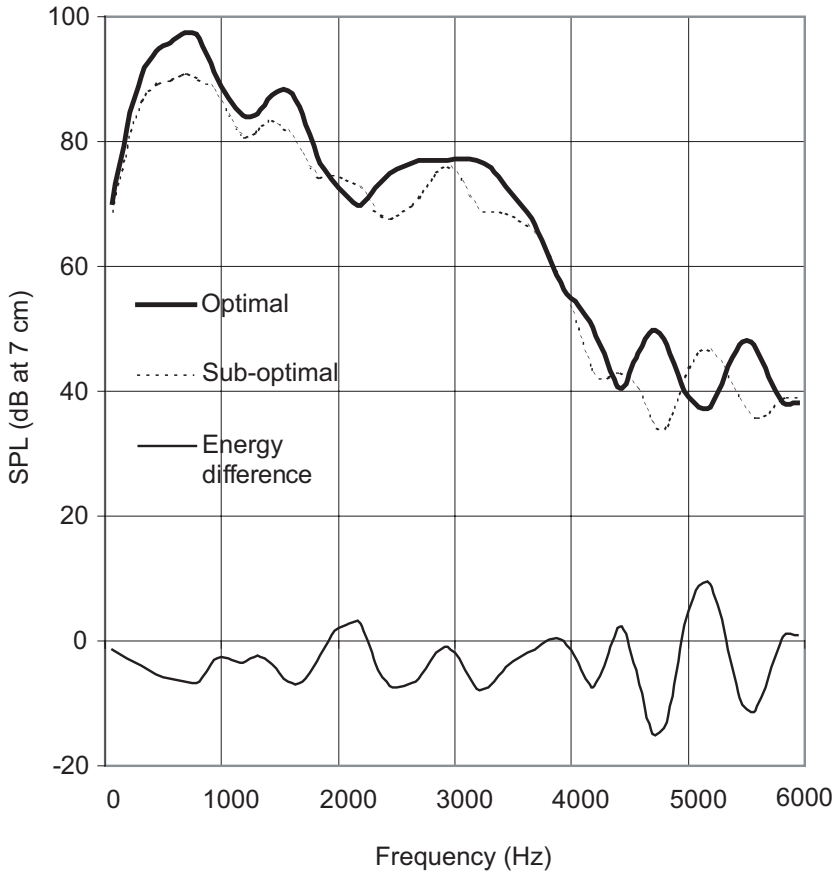

Figure 4: Example of singer 1's LTAS plots in the optimal and sub-optimal condition for the Mozart task. Below is an example of the calculation of energy difference between the optimal and sub-optimal conditions.

LTAS to assess whether SPR and ER were sufficiently sensitive to evaluate LTAS or vocal timbre and whether acoustic measures can predict a voice of quality?

Characteristic LTAS shapes, particularly of classical or operatic voices of performers of the highest regard have been accepted as an accurate visual representation of good sound. Operatic singing is positively associated with an increase in energy between 2-4 kHz (Omori et al. 1996; Thorpe et al. 2001; Vurma and Ross 2000; Barnes et al. 2004). While measures of SPR (Omori et al. 1996) and ER (Thorpe et al. 2001) are not intended to give information about singer's formant, they should illustrate differences in energy distribution, or carrying power. However, Vurma & Ross (Vurma and Ross 2000) found that increased energy above 2 kHz did not necessarily represent vocal quality judged perceptually.

To test the value of acoustic measures, we matched pedagogues' perceptual ratings to acoustic measures of each perceptual sample. Perceptual scores, SPR and ER were rank ordered for overall quality as defined in the singing literature (Omori et al. 1996; Thorpe et al. 2001; Barnes et al. 2004; Vurma and Ross 2000). We then compared perceptual rankings with rankings of acoustic measures (SPR and ER) to assess whether the acoustic characteristics matched the perceptual judgments of overall timbre.

Table 3 [after (Kenny and Mitchell 2004)] presents the rankings of each singer and the respective musical task and experimental condition, ordered by perceptual rank from highest to lowest. While we found the expected significant relationship between SPR and ER, there was no relationship between perceptual rankings of vocal quality of singers based on SPR or ER. LTAS measures were not consistent with perceptual ratings of vocal quality, and could not therefore be used to define a voice of quality in our studies.

Measurements of comparative energy (SPR and ER) were inconclusive indicators of vocal quality. A science of the singing voice cannot progress without addressing the problem inherent in accepting long-term average spectra as analogues for vocal quality without providing a link between perceptual cues and a visual representation of 'quality in singing. This presents a major challenge to the current wisdom that acoustic parameters of voice

Perceptual Rank	SPR Rank	ER Rank	Singer	Task	Condition
1	16	9	5	S	O
2	13	3	5	M	O
3	10	10	1	M	O
4	5	2	3	M	O
5	9	11	1	S	O
6	21	20	4	S	O
7	6	13	4	M	O
8	23	23	2	S	O
9	19	19	3	S	O
10	8	6	2	M	O
11	11	14	6	S	O
12	4	4	5	S	SO
13	3	12	1	M	SO
14	24	24	2	S	SO
15	15	8	6	M	O
16	7	7	5	M	SO
17	20	21	3	S	SO
18	18	18	6	S	SO
19	12	16	1	S	SO
20	1	5	3	M	SO
21	22	22	4	S	SO
22	17	15	2	M	SO
23	14	17	4	M	SO
24	2	1	6	M	SO

Table 3: Singer, task, condition and rankings for perceptual score, singing power ratio (SPR) and energy ratio (ER), sorted by perceptual score ranking from highest to lowest.

must emulate the established acoustic norms in order to achieve overall vocal excellence.

In Figure 5a-d, we compared exemplars of LTAS sampled from voices ranked high, middle or low on the perceptual rating scale. LTAS of the highest-ranking singers [Figure 5a-b after (Kenny and Mitchell in press)] showed an increase in energy between 2-4 kHz, whereas LTAS of middle and low ranked singers (Figure 5c-d) lacked the unified peak of energy increase above 2 kHz. Previous similar findings (Borch and Sundberg 2002; Miller 1998; Vurma and Ross 2000) have interpreted these visual cues in singers' LTAS as a good sound. However, as third equal ranking singers 1 and 3, singing in the O condition produced this unified energy peak > 2 kHz (the most 'masculine' LTAS shape) they should have had the 'best' voices perceptually. However, their LTAS were different to the highest-ranking singer (singer 5), who had a wider distribution of energy above 2 kHz. The SO plots of the lower ranked singers (Fig 3d) showed a spectral roll-off more consistent with plots for speech than singing.

CONCLUSIONS AND FUTURE DIRECTIONS

In this series of studies, we have demonstrated that open throat is a technical and perceptual reality to singers and singing pedagogues and produces a specific vocal quality in classical singing that can be reliably identified by expert listeners. Through qualitative, acoustic and perceptual studies, we have defined the term 'open throat' as a technique, an action and a sound quality.

While we know that singing improves over time and through training specific components of the training that produce improvements in vocal quality have not hitherto been isolated (Ekholm, Papagiannis, and Chagnon 1998; Mendes et al. 2003; Robison, Bounous, and Bailey 1994; Vurma and Ross 2000; Wapnick and Ekholm 1997). This series of studies presents a first attempt to study a single technique, to identify its perceptual and acoustic characteristics, and its effect on vibrato.

Vocal quality results from a complex combination of acoustical parameters. To date, no single objective evaluation captures or characterizes vocal quality in a systematic way (Omori et al. 1996; Thorpe et al. 2001). We have demonstrated that acoustic analyses such as LTAS do not reliably match perceptual judgments by expert listeners and therefore cannot be used to define or predict vocal quality. We recommend that any future acoustic analyses or visual representations of voice must emulate the human ear. A new generation of acoustic recording equipment and analysis software is emerging that has the potential to provide much finer acoustic and psychoacoustic representations of vocal quality. Voice research will benefit from other areas of acoustic research (e.g. room acoustical quality (Nannariello, Osman, and Fricke 2002) and audio systems (Zwicker and Fastl 1999)) oriented to listener sensation and will use binaural measurements (using a dummy head microphone) to virtually place the listening subject in the same acoustical environment as in the original recording(Møller et al. 1996). A singing quality model will be more appropriately derived

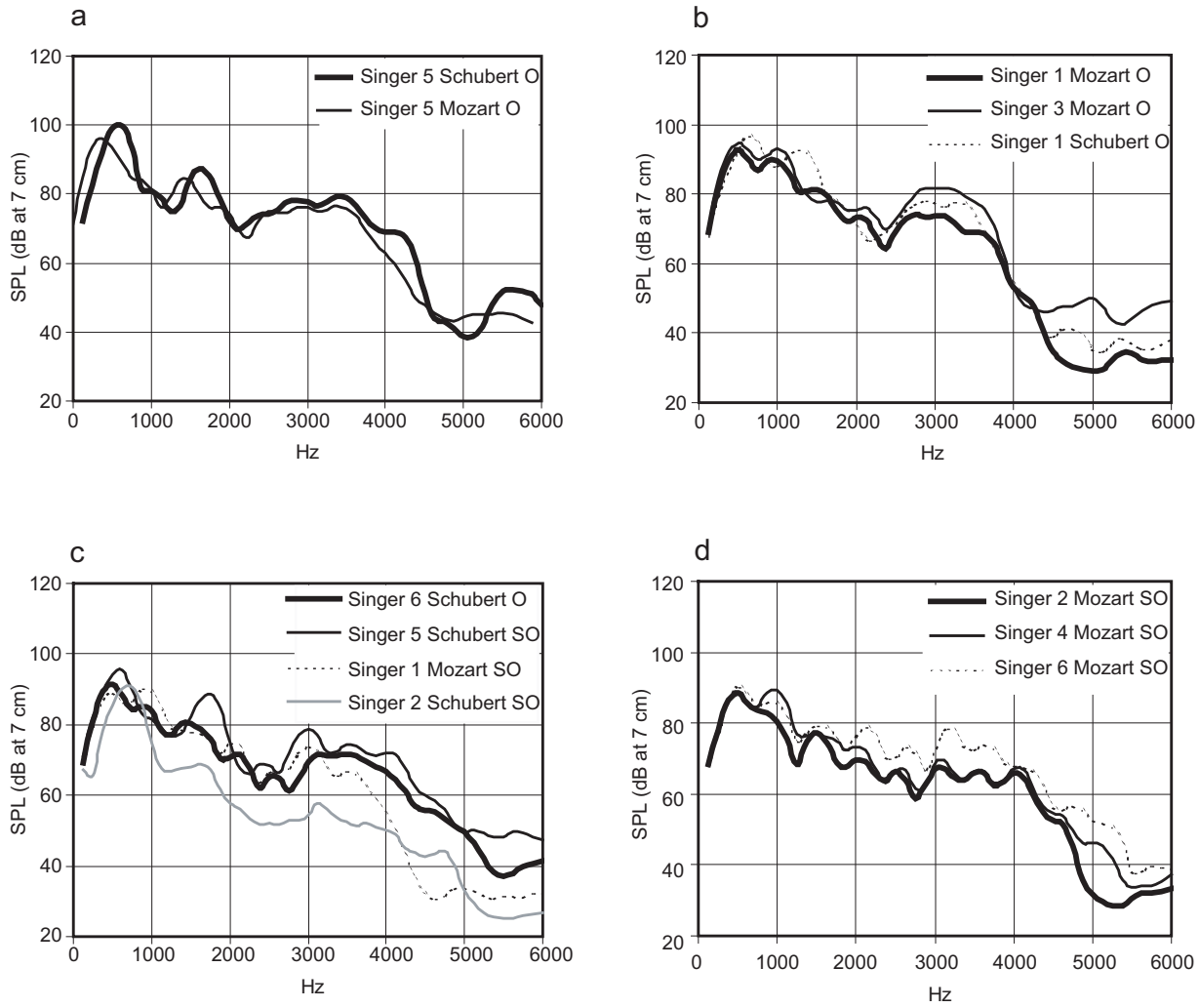

Figure 5: LTAS of highest (a), 3= (b), middle (c) and lowest (d) perceptually ranked singers. Legends correspond to task, Mozart (M) or Schubert (S), and singer number.

by representing listener experience.

REFERENCES

Barnes, J.J., P.J. Davis, J. Oates, and J. Chapman. 2004. The relationship between professional operatic soprano voice and high range spectral energy. J Acoust Soc Am 116 (1):530–538.

Barrichelo, V.M.O., R.J. Heuer, C.M. Dean, and R.T. Sataloff. 2001. Comparison of singer's formant, speaker's ring and LTA spectrum among classical singers and untrained normal speakers. Journal of Voice 15 (3):344-350.

Borch, D Z, and J Sundberg. 2002. Spectral distribution of solo voice and accompaniment in pop music. Logopedics Phoniatrics Vocology 27:37-41.

Burgin, John Carroll. 1973. Teaching singing. Metuchen, N.J.: Scarecrow Press.

Callaghan, Jean. 2000. Singing and voice science. San Diego, California: Singular Pub. Group.

Cleveland, T. F., J Sundberg, and R.E. Stone. 2001. Long-Term-Average-Spectrum characteristics of country singers during speaking and singing. Journal of Voice 15 (1):54-60.

Davidson, J.W., and D Da Costa Coimbra. 2001. Investigating performance evaluation by assessors of singers in a music college setting. Musicae Scientiae 5 (1):33-53.

Easley, E. 1932. A comparison of the vibrato in concert and opera singing. In The vibrato, edited by C. E. Seashore. Iowa: University of Iowa Press.

Ekholm, E., G. C. Papagiannis, and F. P. Chagnon. 1998. Relating objective measurements to expert evaluation of voice quality in Western classical singing: critical perceptual parameters. Journal of Voice 12 (2):182-96.

Fields, V.A. 1947. Training the singing voice: an analysis of the working concepts contained in recent contributions to vocal pedagogy. New York: King's Crown Press.

Foulds-Elliott, SD., CW. Thorpe, SJ. Cala, and PJ. Davis. 2000. Respiratory function in operatic singing: effects of emotional connection. Logopedics

Phoniatrics Vocology 25 (4):151-68.

Gabrielsson, A., and P.N. Juslin. 1996. Emotional Expression in Music Performance: Between the Performer's Intention and the Listener's Experience. Psychology of Music 24:68-91.

Geringer, J.M., and C.K. Madsen. 1998. Musicians' ratings of good versus bad vocal and string performances. Journal of Research in Music Education 46 (4):522-534.

Hakes, J., T. Shipp, and E. T. Doherty. 1987. Acoustic properties of straight tone, vibrato, trill and trillo. Journal of Voice 1 (2):148-156.

Hemsley, Thomas. 1998. Singing and imagination: a human approach to a great musical tradition. Oxford; New York: Oxford University Press.

Herbert-Caesari, Edgar F. 1951. The voice of the mind. London: Robert Hale.

Joiner, James Richard. 1998. Charles Amable Battaille: pioneer in vocal science and the teaching of singing. Lanham, Md.: Scarecrow Press.

Kenny, D.T., and H.F. Mitchell. 2004. Visual and auditory perception of vocal beauty: conflict or concurrence? Paper read at 8th International Conference on Music Perception & Cognition (ICMPC8), August, at Evanston, IL, USA.

———. in press. Acoustic and perceptual appraisal of vocal gestures in the female classical voice. Journal of Voice.

Manèn, Lucie. 1987. Bel canto: the teaching of the classical Italian song-schools its decline and restoration. Oxford: Oxford University Press.

Marafioti, P. Mario. 1981. Caruso's Method of Voice Production. New York: Dover Publications. Original edition, 1922.

McKinney, James C. 1982. The Diagnosis and Correction of Vocal Faults. Nashville, Tennessee: Broadman Press.

Mendes, A.P., H. B. Rothman, C. M. Sapienza, and W. S. Brown, Jr. 2003. Effects of vocal training on the acoustic parameters of the singing voice. Journal of Voice 17 (4):529-543.

Mendoza, E, N Valencia, J Munoz, and H Trujillo. 1996. Difference in voice quality between men and women: use of the long-term average spectrum (LTAS). Journal of Voice 10 (1):59-66.

Miller, R. 1998. The singing teacher in the age of voice science. In Vocal Health and Pedagogy, edited by R. T. Sataloff. San Diego, CA: Singular.

Miller, R. 1996a. Sotto Voce: Vocal Timbre in Piano Dynamic. Journal of Singing - The Official Journal of the National Association of Teachers of Singing 52 (5):23-24, 52.

Miller, Richard. 1996b. The structure of singing: system and art in vocal technique. New York: London: Schirmer Books.

———. 1997a. National schools of singing: English, French, German, and Italian techniques of singing revisited. Rev. ed. Lanham, Md: Scarecrow Press.

———. 1997b. The Open Throat (La gola aperta). In On the Art of Singing, edited by R. Miller. New York: Oxford University Press.

Mitchell, H.F., and D.T. Kenny. 2004a. The effects of open throat technique on long term average spectra (LTAS) of female classical voices. Logopedics Phoniatrics Vocology 29 (3):99-118.

———. 2004b. The impact of "open throat" technique on vibrato rate, extent and onset in classical singing. Logopedics Phoniatrics Vocology 29 (4):171-182.

———. in press. Can experts identify "open throat" technique as a perceptual phenomenon? Musicae Scientiae.

Mitchell, H.F., D.T. Kenny, M. Ryan, and P.J. Davis. 2003. Defining open throat through content analysis of experts' pedagogical practices. Logopedics Phoniatrics Vocology 28 (4):167-180.

Møller, H., M.F. M.F. Sørensen, C.B. Jensen, and D. Hammershøi. 1996. Binaural technique: do we need individual recordings? J. Audio Eng. Soc. 44:451-469.

Monahan, Brent Jeffrey. 1978. The art of singing: a compendium of thoughts on singing published between 1777 and 1927. Metuchen, N.J.: Scarecrow Press.

Nair, Garyth. 1999. Voice tradition and technology: a state-of-the-art studio. San Diego: Singular Publishing Group.

Nannariello, J, M.R. Osman, and F.R. Fricke. 2002. Recent developments in the application of neural network analysis to architectural and building acoustics. Acoustics Australia 29:103-110.

Omori, K., A. Kacker, L. M. Carroll, W. D. Riley, and S. M. Blaugrund. 1996. Singing power ratio: quantitative evaluation of singing voice quality. Journal of Voice 10 (3):228-35.

Prame, E. 1994. Measurement of the vibrato rate of ten singers. J Acoust Soc Am 96 (4):1979-1984.

———. 1997. Vibrato extent and intonation in professional Western lyric singing. J Acoust Soc Am 102 (1):616-621.

Puritz, Elizabeth. 1956. The teaching of Elisabeth Schumann. London: Methuen.

Reid, Cornelius L. 1975. Voice: psyche and soma. New York: Joseph Patelson Music House.

———. 1983. A dictionary of vocal terminology. New York: Joseph Patelson Music House.

Robison, C.W., B Bounous, and R Bailey. 1994. Vocal Beauty: A study proposing its acoustical definition and relevant causes in classical baritones and female belt singers. Journal of Singing 51:19-30.

Rossing, T.D., J Sundberg, and S. Ternstrom. 1986.

Acoustic comparison of voice use in solo and choir singing. J Acoust Soc Am 79 (6):1975-1981.

———. 1987. Acoustic comparison of soprano solo and choir singing. J Acoust Soc Am 82 (3):830-836.

Rothman, H. B., and A. Antonio Arroyo. 1987. Acoustic variability in vibrato and its perceptual significance. Journal of Voice 1 (2):123-141.

Saunders, T.C., and J.M. Holahan. 1997. Criteria-specific rating scales in the evaluation of High School instrumental performance. Journal of Research in Music Education 45 (2):259-272.

Seashore, Carl E. 1938. Psychology of music. New York and London: McGraw-Hill Book Company.

Shipp, T., J. Sundberg, and S. Hadlund. 1984. A model of frequency vibrato. Paper read at Transcripts of the Thirteenth Symposium: Care of the Professional Voice, at New York.

Sundberg, J. 1977. The acoustics of the singing voice. Scientific American (March):82-91.

Sundberg, J. 1974. Articulatory interpretation of the "singing formant". J Acoust Soc Am 55 (4):838-44.

———. 1995. Acoustic and psychoacoustic aspects of vocal vibrato. In Vibrato, edited by P. H. Dejonckere, M. Hirano and J. Sundberg. San Diego: Singular Publishing Group.

———. 1997. Expressivity in singing. TMH-QPSR 2 (3):13-19.

Sundberg, J., P. Gramming, and J. Lovetri. 1993. Comparisons of pharynx, source, formant, and pressure characteristics in operatic and musical theatre singing. Journal of Voice 7 (4):301-10.

Sundberg, J., J. Iwarsson, and H. Hagegard. 1995. A singer's expression of emotions in sung performance. In Vocal Fold Physiology: Voice Quality Control, edited by O. Fujimura and M. Hirano. San Diego, California: Singular Publishing Group, Inc.

Thorpe, CW., SJ. Cala, J. Chapman, and PJ Davis. 2001. Patterns of breath support in projection of the singing voice. Journal of Voice 15 (1):86-104.

Thurman, L, and G. F. Welch, eds. 2000. Bodymind & voice: foundations of voice education. Rev. ed. ed. Collegevile, Minn: VoiceCare Network.

Titze, I. R., R. Long, G. I. Shirley, E. Stathopoulos, L. O. Ramig, L. M. Carroll, and W. D. Riley. 1999. Messa di voce: an investigation of the symmetry of crescendo and decrescendo in a singing exercise. J Acoust Soc Am 105 (5):2933-40.

Vennard, William. 1968. Singing: the mechanism and the technic. 5th ed. New York: Fischer.

Vurma, A., and Y. Ross. 2000. Priorities in voice training: carrying power or tone quality. Musicae Scientiae 4 (1):75-93.

Wapnick, J., and E. Ekholm. 1997. Expert consensus in solo voice performance evaluation. Journal of Voice 11 (4):429-36.

Wapnick, J., P Flowers, M Alegant, and L Jasinskas. 1993. Consistency in piano performance evaluation. Journal of Research in Music Education 41 (4):282-292.

Ware, Clifton. 1998. Basics of vocal pedagogy: the foundations and process of singing. New York: McGraw-Hill.

Zwicker, E, and H Fastl. 1999. Psychoacoustics: facts and models. Berlin: Springer.