The impact of 'open throat' technique on vibrato rate, extent and onset in classical singing

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Mitchell, Kenny *et al*. (2003) identified 'open throat' as integral to the production of an even and consistent sound in classical singing. In this study, we compared vibrato rate, extent and onset of six advanced singing students under three conditions: 'optimal' (O), representing maximal open throat; 'sub-optimal' (SO), using reduced open throat; and loud sub-optimal (LSO), using reduced open throat but controlling for the effect of loudness. Fifteen expert judges correctly identified the sound produced when singers used open throat with 85% accuracy. Having verified the technique perceptually, we used a series of univariate repeated measures ANOVAs with planned orthogonal contrasts to test the hypotheses that frequency modulations associated with vibrato rate, extent and onset would vary outside acceptable or desirable parameters for SO and LSO. Hypotheses were confirmed for vibrato extent and onset but not for rate. 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.

Key words: open throat, singing technique, vibrato, vocal pedagogy.

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INTRODUCTION

The principal goal of classical and operatic singing pedagogy is the production of a voice of quality that is achieved through instruction in specific vocal techniques and exercises to achieve the desired overall sound. Instruction in the use of 'open throat' technique to achieve a good sound is widespread (1–4). Historically, the term 'open throat' can be traced throughout the vocal pedagogy literature (5–7) as a way of describing freedom or lack of tension in the area of the throat, resulting in a lack of constriction and a better tone quality. As early as 1935, Bartholomew commented: 'If the various tricks of the trade that voice teachers use to improve quality are analyzed, most or all of them will be found to be a device for directly or indirectly enlarging the throat.' (8)

According to the singing literature, 'open throat' is a complex maneuver that involves a pedagogical instruction and a perceived sensation or action that results in a specific sound quality. Previous pedagogical strategies have linked 'open throat' to an indirect action in the preparation to sing, on inhalation in the *imposto* (9, 10), *appoggio* or as part of 'breath management' (3, 11), or in the surprise breath or smelling the rose (3, 9, 12). Pedagogues also used imagery though visualization of space within the throat, through an 'air ball' or 'soap bubble' to achieve the posture of 'open throat'. The action of yawn (13, 14) or yawn-sigh (2) was recommended, but pedagogues cautioned against yawning to the point of distortion of sound through unnecessary tension (2, 3).

Perceptually, open throat produces a tone 'free of constrictor tensions' ((2), p. 83). The sound quality attributed to open throat is perceived in resonance (3, 15), roundness (16), freedom (17), purity (18), richness and warmth (19). Use of the technique facilitates technical dexterity and better use of other techniques, such as 'ring' (1, 2).

There are differing pedagogical perspectives of the vocal mechanics involved in 'open throat' technique. Pedagogues who explain their pedagogy in physiological terms link their preferred strategy to achieving open throat to lowered larynx, pharyngeal width and raised soft palate (3, 11, 15, 20). Singing pedagogy also hypothesized that 'open throat' counters constriction

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which may result in a reduction of pharyngeal space (2). Pedagogues generally understand that open throat is not necessarily an 'enlarged pharynx' or action that may excessively depress the hyoid bone, tongue (2) or larynx (3) as that may cause tension, and limit resonance in the sound quality.

A recent study examined current understanding and use of open throat in the classical singing studio. Mitchell *et al*. (4) interviewed 15 singing pedagogues and results indicated that all 15 pedagogues described 'open throat' technique as fundamental to singing training. Although some pedagogues preferred different terms, such as 'retraction', 'freedom' or 'collar', they were in fact describing the same underlying phenomenon of 'open throat'. They recognized it in the final sound as balanced and coordinated, free, even or consistent, warm and open. Expert pedagogues in this study believed that open throat maximizes pharyngeal space and/or abducts the ventricular folds (4). While some vowels, for example [a], cannot be produced without pharyngeal constriction (21) and hence pharyngeal space cannot be maximized to the same degree on every vowel, in the bel canto (Western classical singing) tradition, the ideal is to achieve the same warm, open voice quality on every note (10).

Story *et al*. (22) using MRI (magnetic resonance imaging) techniques have confirmed that different vocal postures are associated with different vocal qualities such as 'yawny' and 'twangy'. 'Yawny' involves widening of the oral cavity and lengthening of the vocal tract while 'twangy' is produced by slight constriction of the oral cavity and shortening the vocal tract. Open throat is related to the 'yawny' quality (2, 11) but pedagogically the yawn is considered too exaggerated for classical singing. A pre-yawn or cry/sob instruction is preferred by most pedagogues (2, 3, 23, 24). Story *et al*. (22) analyzed these physiologically established vocal qualities acoustically but not perceptually, but recommended that perceptual assessment was necessary to complement the acoustic and physiological findings.

It may be possible to understand good classical singing through acoustic features associated with subjective descriptions of acceptability or beauty in singing. Vibrato, for example, is widely accepted as a component of singing, but despite acoustical, physiological and perceptual studies (15, 25–28), it has been difficult to define its most desirable parameters. It is, however, possible to trace different preferences over the century (29) and also to assess its defects or undesirable qualities (3, 15). However, acoustic studies of undesirable qualities of vibrato have not achieved consensus in their definitions (30, 31).

In this study, we investigated the technique of open throat by identifying acoustic differences from the same singers when they consciously manipulated the technique in their singing. As pedagogues in a previous study by these authors (4) reported that singers normally use open throat in good singing, and were conscious of using the technique, we believed that experienced singers could manipulate their use of this technique. The aim of this study was 1) to test the perceptual distinctiveness of the sound produced by singers using open throat and 2) to determine the measurable differences between a sound quality using maximal open throat and a sound that used a lesser degree of open throat, while holding other aspects of singing technique or sound quality constant.

METHOD

Participants

Six female singers (three sopranos and three mezzo-sopranos) volunteered to participate in this study. They were advanced students with excellent technique of an experienced singing pedagogue, who is a Lecturer in Vocal Studies and Opera at a state Conservatorium of Music in Australia. It is the premier institution for musical education in the country and has produced singers of international repute. The pedagogue had 30 years' teaching experience, a private studio consisting of international and national singers (32) and is considered to be one of the top five singing teachers in Australia. Criteria for participant selection included, through this pedagogue's assessment, singers who: 1) had a good classical singing technique for their level of training and experience; and 2) understood and demonstrated skillful control of 'open throat' or 'retraction' techniques in their singing. The institutional human ethics committee approved the study.

Prior to the voice recording, participants completed a questionnaire seeking information on age, years of singing study, number of years of study with each singing teacher and highest qualifications attained or currently undertaken in music and/or singing, and singer type (soprano or mezzo-soprano). The participants were also asked to classify the genres of singing they performed in public (opera, classical, choral, music theatre and contemporary) in accordance with the Bunch and Chapman taxonomy (32) and to estimate the percentage each style played in their total performing career.

The demographic information of the participants is presented in Table 1. Participants were aged between 23 and 30 years, with a mean of 26 years. All had studied singing for at least 7 years (average 9.8 years) and had spent an average of 5 years studying with their present singing teacher. Each singer held a

Table 1. *Summary of subject characteristics. Description of subject number, age, the number of years each subject has taken singing lessons, the number of teachers each subject has had, the number of years each subject studied with their three most recent teachers (T1–T3), the highest level of education completed by each subject, the current level of education undertaken, voice type, proportion of each subject's career spent singing opera, classical, choral, music theatre, contemporary or other styles of music.*

Subject	Age (years)	Years of lessons	No. of teachers	T1	T2	T3	Highest education	Current education	Voice type	Opera	Classical	Choral	Music theatre	Contemp	Other
1	26	8	4	1	1	3	Bachelor	Bachelor	Mezzo	80%	20%				
2	25	7	3	1.5	3	4.5	Bachelor	Postgraduate	Soprano	80%	20%				
3	30	12	2	10	2		Diploma	N/A	Soprano	97%			3%		
4	23	10	2	4	5.5		Bachelor	Postgraduate	Soprano	50%	45%				5%
5	25	10	2	7.5	2.5		Diploma	Postgraduate	Mezzo	73%	25%		2%		
6	28	12	6	5	1.5	1.5	Bachelor	Bachelor	Mezzo	50%	35%	5%		10%	

qualification in singing or music (four had Bachelor of Music degrees and two had diplomas, in music and/or singing) and five of six were currently undertaking a second degree in singing (three postgraduate Diploma of Opera and two Bachelor of Music degrees). All defined the majority of their singing as operatic (>50%), with the second most common style classical (>20%), in accordance with the Bunch and Chapman taxonomy (32) of singing voices. All reported that they were in good health and able to perform the tasks.

Procedure

Singers were sent information about the project and were invited to take part in an acoustic and perceptual study of singing technique. They were required to attend a single recording session lasting approximately one hour. They were advised that the object of the study was to investigate the acoustical and perceptual features of the use of open throat in singing and to investigate the sound qualities associated with the use of open throat.

Experimental protocol for assessing sound qualities produced by open throat

A protocol was developed to assess the effect of 'open throat' technique in singing. Two musical tasks were chosen to investigate the use of the technique in two song excerpts. Prior to singing, each singer selected the sequence of their tasks before commencing the experiment by selecting a blank card, the reverse side of which represented one of the tasks, to reduce the possible effects of task-order.

Singers sang each of the two song excerpts under three conditions: optimal, sub-optimal and loud sub-optimal. 'Optimal' (O) condition was necessary to provide a sound quality with the best technique that they could. This involved the maximal use of open throat. 'Sub-optimal' (SO) condition involved the use of a reduced (open throat) technique but still with an acceptable singing technique and without consciously altering any other aspect of their technique. It was hypothesized, from interviews with pedagogues (4), that the SO condition would result in a reduction of sound pressure level (SPL), so a third condition 'loud sub-optimal' (LSO) involved the same instruction as the SO condition, but with the added instruction that the singer should try to achieve a louder dynamic than in SO. This addressed SPL as an additional variable to the SO condition and was similar to technical conditions established by Foulds-Elliot *et al*. (33) when SPL was a variable of degrees of emotional connection in operatic singers.

Each task was performed twice in the O and SO conditions while the LSO condition was performed only once. In total, each singer performed each musical task five times.

Instructions

A pedagogue was present during the recording sessions to provide accompaniment for warm-ups and practice of the tasks where necessary and to instruct singers to achieve the required vocal postures for each experimental condition. For example, she instructed them to pay attention to producing the most open sound in their throat in the O condition, and a lesser degree in the SO and LSO conditions. Some singers asked how to produce the LSO condition and the pedagogue instructed them to 'use more twang', as taught in their lessons (23).

Reliability check

Prior to the commencement of the study, the participating students and pedagogue had several practice sessions in which the singer was instructed to use either O or SO at random. The pedagogue indicated which technique she thought the singer had used. Practice with each singer continued until both the singer and the pedagogue reached 100% agreement on the occasions that the technique was applied.

The musical tasks

Musical tasks were chosen in order to test different demands of good singing, but were not musically difficult. They were designed to test the use of open throat, and contained musical features derived from a previous qualitative study on the use of the technique, where use or lack of the technique was deemed to be particularly valuable or noticeable (4). These features were: high tessitura, sustained or legato singing, dynamic range control, and vocal agility.

The Mozart song *Ridente la Calma*, K 152, bars 1–27 (Fig. 1a) was selected as it is a nominally simple song in the Italian language (34) with a mixture of common musical statements involving repeated legato lines as well as the initial stylized leaps of a major 4, and short scale figures. All six singers sang this aria in the same key (F-major).

The third verse of the Schubert lied, *Du bist die Ruh* D. 776 (Op. 59, No. 3) (Fig. 1b), bars 54–80 was chosen for its demanding vocal control, sustained musical line and high climactic tessitura. The three sopranos and three mezzo-sopranos sang this in an

Fig. 1a. The Mozart task, *Ridente la Calma*, K 152, bars 1–27 with the numbering of 37 notes selected for analysis.

appropriate key depending on soprano or mezzo-soprano voices (E-flat, D-flat and C-major).

Recording

Participants were given time to warm up in the singing studio and become familiar with the room before recording. Recording levels for each singer were set during this time. The acoustic signal was recorded digitally (Behringer Ultragain preamplifier/Marantz CDR 630) via a high-quality microphone (AKG C-477) positioned on a head boom a constant 7 cm distance from the subject's lips. This ensured that direct energy of the performers' voices was recorded rather than room reflections, enabling us to use a studio environment with low ambient noise rather than an anechoic studio (35).

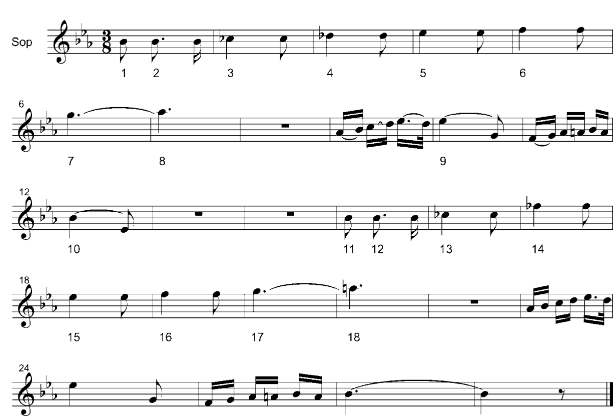

Fig. 1b. The Schubert task, *Du bist die Ruh* D. 776 (Op. 59, No. 3), bars 54–80 with the numbering of 20 notes selected for analysis.

Calibration was carried out in each recording by using a recording of two pink noise samples on audiotape played immediately following each recording session at the same recording gain used for recording the singer's voice. Pink noise is a broadband steady state signal which enables calibration of an audio playback system across the frequency range for tasks such as subjective testing and, if the analysis is just done on computer, the noise is at least as good as any other steady-state known signal. For calibration of absolute sound pressure levels (SPL), the microphone of a sound level meter (Rion NL-06 SPL) was held adjacent to the AKG microphone from a speaker (Bose Lifestyle) from which the pink noise was played. The SPL (in dB at 7 cm) recorded by the sound level meter was noted for the two noise signals and used later for calibration.

The CDs of the recordings were marked by subject number. The audio recordings were acquired to computer at 16 kHz with a Loughborough Sound Images PC/C32 board using Phog Version 2.0 and analyzed using Soundswell Version 4.00 (Hitech, Sweden) software to produce nine channels of raw and calculated data. A real-time digital SPL meter was used to set a recording gain so that the pink noise calibration level recorded in Phog was the same (+ 0.5 dB) as the SPL level noted during recording.

Perceptual test of open throat

Because open throat is a pedagogical concept that has not yet been verified empirically, it was necessary to determine whether expert pedagogues could reliably distinguish the sound quality associated with this instructional technique. Accordingly, a perceptual test was designed to determine the degree to which expert pedagogues agreed that a sound was indicative of the application of open throat. Judges who assessed singers were not the singers' pedagogues and did not know any of their identities.

Listeners assessed 30 tracks (6 singers $\times$ 2 conditions (O and SO) $\times$ 2 musical tasks) in random order, including six repeats, also selected at random. (A pilot test found that LSO did not produce a sufficiently discernible voice quality to be correctly distinguished from SO. As LSO was created as acoustic confirmation of SO, it was considered unreasonable to expect the human ear to detect so small a difference in timbre. The LSO condition was therefore not included in the perceptual study.)

The perceptual test was conducted in a quiet environment and samples were played from a Sony CD Walkman (DEJ885W) via circum-aural closed-back stereo monitoring headphones (Sennheiser HD 270). Prior to presentation of stimuli, participants were given information on the two singing conditions, O and SO, and were presented with the musical score of each musical task. They were asked to judge whether or not the singer was using open throat technique in each sample.

Measurement of sound pressure level (SPL)

To calculate mean SPL, the SPL channel of the Soundswell program was calibrated with the two known SPL levels of the pink noise samples for each singer. The histogram function was applied to the SPL channel in the Soundswell program for each complete rendition of musical task and generated the mean, standard deviations (SD), and percentile values of SPL in dB.

Vibrato measurement

Vibrato cycles were measured manually from the spectrogram feature in the Soundswell program using a fine resolution Hamming analysis window, FFT length 1024, with a bandwidth of 30 Hz. A cursor point logged the time and frequency of each vibrato peak and trough and the data exported to spreadsheets. Frequency was measured on a high harmonic across all subjects, as resolution increases with the partial number (26). Fundamental frequency of each logged point was calculated by dividing it by its partial number. Data were manipulated within spreadsheets (Excel, Microsoft 2000). Thirty-seven notes were measured in the Mozart task and 20 in the Schubert.

The vibrato onset (VO) in seconds (s) was measured from the initiation of phonation on the particular note until the first conclusive peak of the vibrato cycle. Onset was only considered following the start of a word or after a break in phonation; 18 VO occurrences were studied in the Schubert task and 23 in the Mozart task.

The vibrato rate (VR) in hertz (Hz) and vibrato extent (VE) in semitones (ST) were measured from the first identifiable peak until the last trough of the note. The VR of each cycle was measured as the time difference between adjacent vibrato peaks and calculated in Hz. The VR for each note was calculated as the mean of all successive VR cycles of the note. If vibrato peaks and troughs could not be discerned by visual inspection of the spectrograph, a nil result was recorded.

Vibrato extent in semitones (ST) was calculated by dividing the peak-to-trough ST values by 2 (28). A frequency point in Hz of a peak or trough was calculated in ST using the formula:

$$F_0 \text{ in ST} = \frac{12(\log_{10}(F_0) - \log_{10} 16.35)}{\log_{10} 2} \quad [1]$$

The semitone difference between adjacent cycle peaks and troughs was calculated as:

$$\text{Peak-to-trough(ST)} = \frac{12(\log_{10}(\text{peak } F_0) - \log_{10}(\text{trough } F_0))}{\log_{10} 2} \quad [2]$$

In this study, VE in ST represents the distance from peak to the mean F_0 of the vibrato cycle or from the mean F_0 of the cycle to the next trough (28). Frequency values from successive vibrato cycles were averaged for each note studied.

Study 1: Perceptual verification of open throat. The total number and percentages of correct responses for each O and SO sample for each listener and for the group as a whole were calculated. Intra-rater reliability was also assessed by calculating the percentage of each repeated pair that was correctly identified by each judge.

Study 2: Vibrato parameters of open throat. The study design was a repeated measures (three dependent measures: vibrato rate (VR); vibrato extent (VE); vibrato onset (VO)) randomized complete block with a 2 (task (Mozart *versus* Schubert)) × 3 (condition (optimal, sub-optimal and loud sub-optimal)) factorial structure with planned orthogonal contrasts on each of the three dependent variables.

Data were analyzed firstly through a series of fixed and mixed effect univariate ANOVAs with three factors (task, condition, subject). In the first series, all three factors were entered as fixed effects; in the second, subject was entered as a random effect. Finally, the data were subjected to analysis using the general linear model (GLM) with planned orthogonal contrasts. Since all analyses yielded the same outcomes, only the results of the contrasts are presented. Main effects for task and condition and interaction effects (contrasts) were calculated for each dependent measure (VR, VE and VO). In the first contrast, O was compared to SO and LSO and in the second contrast SO was compared to LSO.

Hypotheses

The following hypotheses were generated:

1) Study 1: Expert judges would reliably identify the use of open throat in samples of classical singing.
2) Study 2: SPL would decrease from O to SO.
3) Study 2: Frequency modulations associated with vibrato rate, extent and onset would vary outside acceptable or desirable parameters established in singers' O singing for SO and LSO.

RESULTS

Hypothesis 1: Perceptual verification of open throat

Expert listeners correctly identified 85.3% O and 80.0% SO. Intra-judge reliability using the six repeated samples was 83.33% (that is to say, judges, on average, rated five out of six singing sample pairs correctly).

Hypothesis 2: SPL would decrease from the O to SO condition

Hypothesis 2 stated that SPL would decrease from the O to SO condition. Hypothesis 2 was not confirmed from O to SO $F_{(1,5)} = 0.010$, $p = 0.924$). The mean SPL for O was 97.38 dB (SD 1.86) in the Mozart task and 97.65 dB (SD 2.61) in the Schubert task. In the SO condition, the mean SPL was lower (96.18 dB in Mozart and Schubert). In LSO, each singer's SPL was associated with SPL levels that were either similar to the O condition (6 examples <2 dB different) and in 9 of the 12 LSO, samples increased SPL from the level of the original O in the LSO condition (LSO means: 99.18 dB, 98.92 dB).

Vibrato

Data screening. The distributions for each dependent measure (VR, VE, and VO) were assessed for normality and outliers. Examination of skewness and kurtosis statistics indicated that the distributions were relatively normally distributed. Univariate tests for homogeneity of variance (Levene's Test of Equality of Error Variances) for each of the dependent measures (VR: $F = 5.7$, $p < 0.001$; VE: $F = 2.65$, $p < 0.001$; VO: $F = 9.699$, $p < 0.001$) indicated that this assumption was violated for all three measures. Univariate F-tests (with Bonferroni adjustment for three tests: $p < 0.017$) indicated that task, condition and subject were all significant, hence a very conservative p-value of $p < 0.005$ was set for all subsequent analyses.

Descriptives. The complete vibrato data are presented in Table 2, showing the overall means from averaging all measured notes sung by each singer, in each condition, for vibrato rate (VR), vibrato extent (VE) and vibrato onset (VO) in each musical task (Mozart and Schubert).

Differences in VR, VE and VO were considered separately for effects of condition and task.

Table 2. *Mean vibrato rates in Hz, mean vibrato extent in semitones and mean vibrato onset in seconds, for the Mozart and Schubert musical tasks in each condition, optimal (O), sub-optimal (SO) and loud sub-optimal (LSO); standard deviations (SD) are given in parentheses.*

		Rate			Extent			Onset		
		Condition			Condition			Condition		
Task	Subject	O	SO	LSO	O	SO	LSO	O	SO	LSO
Mozart	1	5.96	5.93	5.92	1.16	0.68	0.63	0.09	0.22	0.21
		(0.22)	(0.28)	(0.40)	(0.15)	(0.14)	(0.16)	(0.07)	(0.17)	(0.17)
	2	5.63	5.32	5.36	1.26	0.77	0.73	0.15	0.16	0.21
		(0.28)	(0.40)	(0.29)	(0.14)	(0.16)	(0.15)	(0.17)	(0.17)	(0.09)
	3	5.58	5.58	5.58	1.63	0.81	0.81	0.19	0.24	0.24
		(0.40)	(0.29)	(0.27)	(0.16)	(0.15)	(0.21)	(0.17)	(0.09)	(0.12)
	4	5.65	5.60	5.51	1.48	0.60	0.60	0.12	0.28	0.27
		(0.29)	(0.27)	(0.31)	(0.15)	(0.21)	(0.17)	(0.09)	(0.12)	(0.10)
	5	6.80	6.78	5.51	1.00	0.72	0.60	0.09	0.22	0.27
		(0.27)	(0.31)	(0.24)	(0.21)	(0.17)	(0.20)	(0.12)	(0.10)	(0.07)
	6	7.27	6.28	6.63	0.85	0.52	0.67	0.10	0.27	0.25
		(0.31)	(0.24)	(0.36)	(0.17)	(0.20)	(0.24)	(0.10)	(0.07)	(0.11)
	Mean	6.15	5.93	5.97	1.23	0.68	0.67	0.12	0.23	0.24
		(0.71)	(0.53)	(0.61)	(0.29)	(0.10)	(0.08)	(0.04)	(0.04)	(0.03)
Schubert	1	5.79	5.57	5.63	1.00	0.58	0.61	0.12	0.56	0.63
		(0.31)	(0.33)	(0.28)	(0.20)	(0.15)	(0.15)	(0.13)	(0.43)	(0.47)
	2	5.23	5.06	5.18	1.32	1.19	0.88	0.22	0.26	0.42
		(0.32)	(0.14)	(0.14)	(0.14)	(0.21)	(0.25)	(0.10)	(0.12)	(0.16)
	3	5.68	5.67	5.63	1.32	0.60	0.51	0.13	0.32	0.46
		(0.23)	(0.26)	(0.44)	(0.25)	(0.19)	(0.15)	(0.09)	(0.27)	(0.44)
	4	5.66	5.70	5.65	1.44	0.61	0.58	0.13	0.22	0.10
		(0.23)	(0.49)	(0.37)	(0.24)	(0.19)	(0.16)	(0.10)	(0.17)	(0.07)
	5	6.70	6.77	6.68	1.07	0.85	0.71	0.18	0.18	0.23
		(0.25)	(0.26)	(0.51)	(0.19)	(0.18)	(0.12)	(0.08)	(0.13)	(0.16)
	6	5.96	5.50	5.88	0.90	0.77	0.81	0.18	0.20	0.15
		(0.73)	(0.52)	(0.75)	(0.20)	(0.14)	(0.19)	(0.10)	(0.12)	(0.11)
	Mean	5.84	5.71	5.78	1.18	0.77	0.68	0.16	0.29	0.33
		(0.49)	(0.57)	(0.50)	(0.22)	(0.23)	(0.14)	(0.04)	(0.14)	(0.20)

Hypothesis 3: Frequency modulations associated with vibrato rate, extent and onset would vary outside acceptable or desirable parameters established in singers' O singing for SO and LSO

Hypothesis 3a: For vibrato extent, singers' F_0 would show greater variation from the mean in SO/LSO compared to O

Hypothesis 3a stated that VE would show greater increases or decreases from mean fundamental frequency in SO and LSO compared to O. Hypothesis 3a was confirmed as overall means of VE by condition indicated a significant reduction from O to SO/LSO in both musical tasks. For VE, there was a main effect for contrast 1 ($F_{(1,5)}=20.821$, $p=0.006$) but not for contrast 2 ($F_{(1,5)}=1.448$, $p=0.283$). There was no effect for musical task ($F_{(1,5)}=0.032$, $p=0.865$). Fig. 2 presents these data. There was also a significant interaction between musical task and contrast 1 ($F_{(1,5)}=12.136$, $p=0.018$), but not for musical task and contrast 2 (see Fig. 2); that is, VE was wider for both Mozart and Schubert in the O condition, but the same for both musical tasks in the SO and LSO conditions. Table 2 shows that all subjects' mean VE decreased in both the SO and LSO conditions by 0.09 ST to 0.92 ST, with an average reduction of 0.50 ST.

Inspection of the narrow standard deviations confirmed that singers' reductions of VE in SO and LSO were similar for all subjects. Although VE in semitones changed overall in each condition, the singers' variability remained slight (SD $\leq$0.25) for notes within a condition. The time plots in Fig. 3 plot the consecutive VE of the notes measured for vibrato cycles in each musical task (37 in Mozart, 20 in Schubert) in the O and SO conditions for subjects 4 and 5. These present data from subject 4, who showed a typical decrease from O to SO, and subject 5, who showed a smaller reduction in VE. In some SO vibrato cycles, there was no measurable VE. Subjects 3 and 4 maintained the

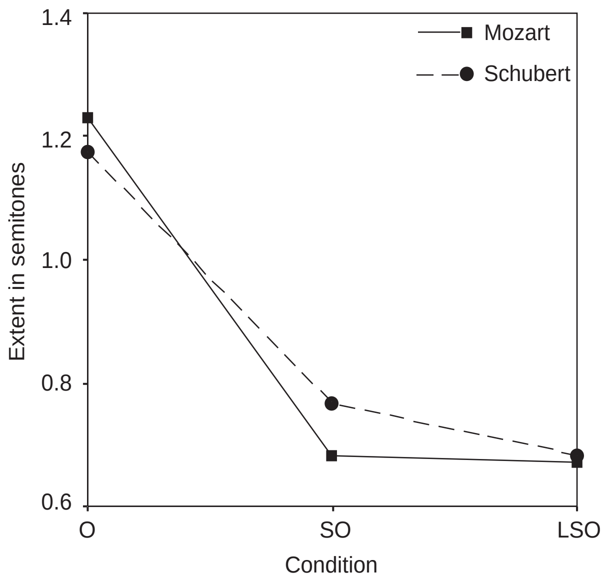

Fig. 2. Vibrato extent. Main effect of condition in contrast 1, that is to say, between optimal (O) and sub-optimal (SO)/loud sub-optimal (LSO). Interaction effect of musical task (Mozart and Schubert) for contrast 1, that is, between optimal (O) and sub-optimal (SO)/loud sub-optimal (LSO).

two highest mean VEs overall, but also the greatest variance (SD 0.25 and 0.24 ST respectively) but only in the Schubert task (Table 2). The greatest VE seems to be in the Mozart task, not the Schubert task (Table 2).

Hypothesis 3b: Vibrato rate would show greater variations in SO/LSO compared to O

For VR, the hypothesis that vibrato would show greater variations in SO and LSO compared to O

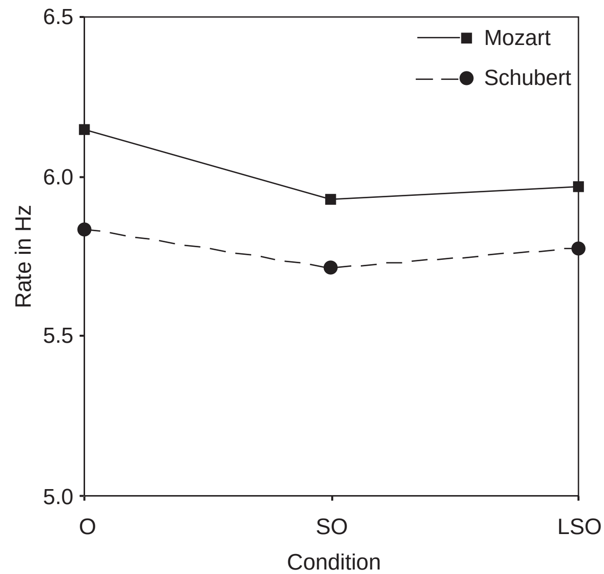

Fig. 4. Vibrato rate: no statistical effects of task (Mozart and Schubert) or condition (optimal (O) and sub-optimal (SO)/loud sub-optimal (LSO)).

was not confirmed for task or condition. Overall means of VR were not significantly different in each task ($F_{(1,5)}=2.415$, $p=0.181$). There was no effect of condition for contrast 1 ($F_{(1,5)}=2.828$, $p=0.153$) or contrast 2 ($F_{(1,5)}=0.629$, $p=0.464$), that is, VR in O, SO and LSO conditions was not significantly different. There were no interaction effects for task and condition. Fig. 4 presents the results of this analysis graphically.

The mean VR across all subjects, conditions and tasks was 5.92 Hz (SD 0.11). Four of the subjects displayed a relatively similar mean VR across all conditions and tasks (5.3–5.8 Hz), whereas two

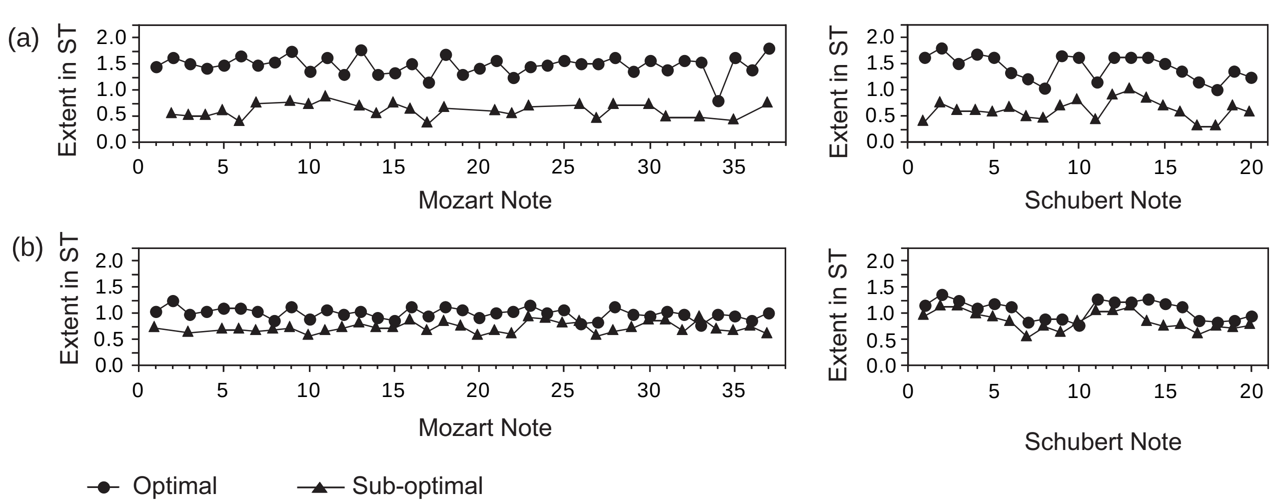

Fig. 3. Time plots of mean vibrato extent in semitones in the Mozart task, notes 1–37 and the Schubert task in the optimal and sub-optimal conditions: a = subject 4; b = subject 5.

subjects each showed a higher mean VR of 6.8 Hz as shown in Table 2. Subject 6 was an outlier.

Hypothesis 3c: Vibrato onset would be longer in SO/LSO compared to O

Hypothesis 3c stated that VO would be longer in SO/LSO compared to O. Hypothesis 3c was confirmed as overall means indicated a significant increase from O to SO/LSO in both musical tasks. For VO, there was a main effect for contrast 1 only ($F_{(1,5)} = 13.118$, $p = 0.015$), that is, VO was significantly less in the O condition than in either SO or LSO. There were no differences in VO between SO and LSO ($F_{(1,5)} = 0.905$, $p = 0.385$) and there was no effect for musical task ($F_{(1,5)} = 1.559$, $p = 0.267$) There were no interaction effects between task and contrasts, and VO was affected by condition in the same way in each task. Fig. 5 presents the results of this analysis graphically.

A visual example of the changes to vibrato parameters by condition is given in Fig. 6. Each panel of Fig. 6 represents the same singer and the same 3-second portion of '*Von deinem Glanz'* in the Schubert musical task across each condition (O, SO and LSO). The vibrato cycles are less regular or consistent in each of the SO and LSO conditions, and in the LSO in particular, the cycles are erratic and unstable.

There was no vibrato on 75 of a total of 684 notes chosen for measurement. In the Mozart condition, 73 notes had no vibrato and 46 of these occurred in SO. An example of this is shown in Fig. 6c.

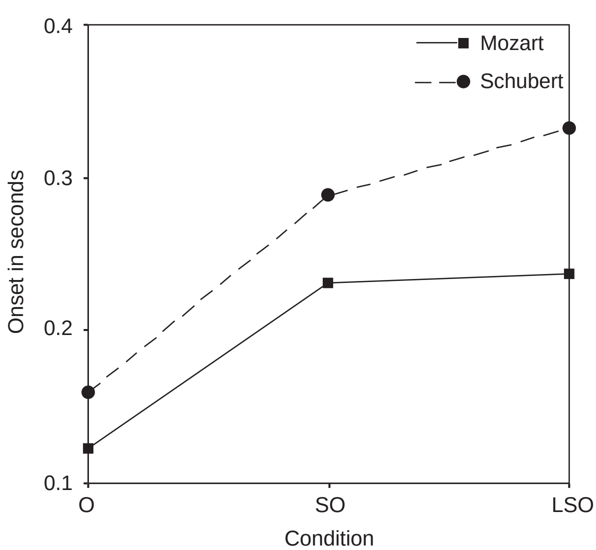

Fig. 5. Vibrato onset: main effect of condition in contrast 1, that is to say, between optimal (O) and sub-optimal (SO)/loud sub-optimal (LSO).

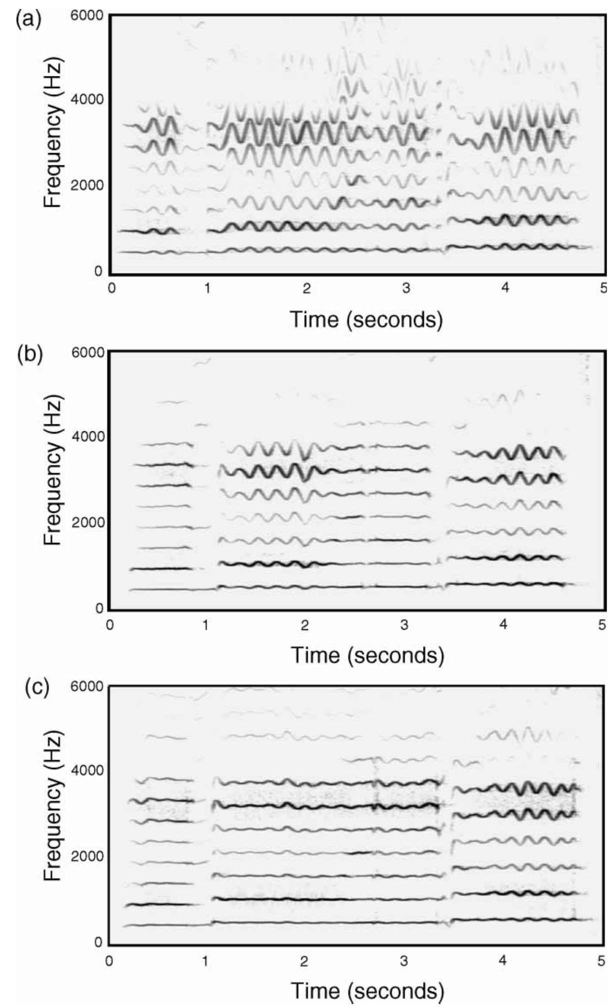

Fig. 6a–c. Examples of vibrato from subject 3 singing 'Von deinem Glanz' in each of the three conditions, optimal, sub-optimal and loud sub-optimal (O, SO, LSO) respectively.

DISCUSSION

We hypothesized that open throat technique would produce audible differences in vocal quality and this was confirmed by the perceptual study. Listeners were reliable in their judgements and consistently identified the technique in repeated samples. Singers' vocal quality produced discernable sound quality differences in 85.3% of O and 80.0% of SO samples, which listeners attributed to the pedagogical instruction of 'open throat'. This study confirmed pedagogues' recognition of a fundamental technique in classical singing previously defined by expert pedagogues by a specific sound quality (4). Further analysis of the perceptual qualities of this technique is the subject of ongoing research by these authors.

This study had a number of methodological strengths. For example, we considered it important to demonstrate that voice quality produced during SO was not simply the result of changes (that is to say, reductions) in SPL. The inclusion of a second comparison group, LSO, indicated that SPL did not account for differences between O and SO. Foulds-Elliot (33) and Rossing (36) have used similar study designs. The hypothesized reduction in SPL did not in fact occur; however, there were differences in the energy distributions of each condition that will be explored further in future studies on this technique. A second methodological strength was the use of a homogenous group of singers of similar skill and training who could consistently apply the technique. While other studies have used the same sex subjects (37, 38), singers in previous studies have ranged from novice to advanced students. Studies assessing voice qualities in which subjects vary in amount of singing training or experience associate certain qualities with levels of training, and find differences in vibrato or energy which could be attributed to training. In some cases, singing studies are unable to correlate length of training with improved sound quality or any measurable acoustic feature of voice (39), suggesting it is not length of training per se but quality or type of training that is the critical factor.

Having established that the overall sound quality of open throat technique is perceptually identifiable, we subsequently assessed vibrato, a major defining feature of vocal quality. Although vibrato is taken for granted as a feature of the classical singing voice, as a component of tone quality, 'richness' (15), 'vibrancy' (3) or 'resonance' (40), it is widely accepted in the singing literature that vibrato outside acceptable rate and extent parameters is indicative of poor technique (3, 15) and inferior sound quality. Vibrato rate and extent are important ways to communicate emotion in singing. For example, deep, slow vibrato is perceived as sad, while fast, irregular vibrato communicates fear (41). Vibrato may vary for other reasons; for example, for dramatic purposes (42); in response to stylistic requirements of particular genres (43, 44); or as a result of changes to SPL in messa di voce (45); or for dynamic variation (25) towards the ends of notes. However, consistent vibrato within specified parameters has been linked to beautiful sound (38) and to listeners' overall preference (37). In the classical singing literature, a steady and even vibrato is universally promoted (3).

In this study, we demonstrated reliable differences in vibrato parameters as a result of varying the degree to which singers applied the technique of open throat. Reduction of open throat technique for these singers produced a significant decrease in VE in SO/LSO and increase in VO in both SO/LSO. Singers spanned the conventional VR parameters, from 5 Hz to >6 Hz, and although visual inspection showed that VR was less even in SO/LSO, this was not statistically significant. While singers vary vibrato for emotional reasons, or suitability in different musical genres, these six singers' vibrato changed as a result of using optimal or insufficient open throat technique. Since vibrato parameters largely define good singing technique in the literature, open throat would appear to be an essential element of sound vocal pedagogy.

Different genres require differing vibrato extent. For example, singers use a wider vibrato extent in operatic singing compared to concert singing (43) and in classical singing compared to baroque or early music style (44). Informal studies have found that the same singers increased vibrato extent in dramatic lied or Verdi operatic arias in comparison to Schubert's 'Ave Maria' (26). Changes to vibrato extent in an individual singer are normally associated with emotional intent (for example, agitated and peaceful in (42)). In this study, singers reduced VE by, on average, more than 40% from O to SO/LSO. Decreased vibrato extent associated with reduced open throat suggests that instruction and technique are also relevant to the production of classical voice quality, which was perceptually equated with poor singing technique. These findings suggest that open throat is indeed a specific technique used to achieve a classical or operatic quality. Our understanding of what produces changes in vibrato extent may need to be extended to include not only the demands of genre and emotional intention, and to a lesser extent, the production of particular vowels, but also its deliberate cultivation through instruction in particular pedagogical techniques such as open throat.

A singer's vibrato rate has been identified as an intrinsic component of his or her sound quality (28) and is the most consistent parameter (46, 47). The vocal system has a natural tendency to oscillate in the 5–6 Hz frequency range. Results from this study support this finding. Singers' rate did not vary outside of their O range, regardless of condition. Changes to VR have been identified in different musical genres (43), but even in these, VR was the most consistent factor when the same singers sang opera or concert songs. Our findings confirm previous data on vibrato rate. Visual inspection of the spectrographs shows that reduction of open throat in the SO and LSO conditions was associated with greater irregularity of the vibrato pattern compared to O, although these differences did not reach statistical significance when mean rates were compared across conditions. This is probably due to the fact that mean VR could not take into account occasions where no cycle was measured because singers did not produce vibrato. Such cycles occurred only in SO and LSO. Additionally, there were large inter-subject differences of up to 1 Hz across different tasks and conditions.

In pedagogical terms, if vibrato onset was delayed or absent in sustained pitches or during rapid syllables, then the voice was not 'natural' and this would indicate a faulty technique. This view concurs with Ekholm *et al*. (37) who associated late onset of vibrato (>0.5 seconds) with the overall perception of poor vibrato and this also was highly correlated with lower ratings of the overall voice quality. In terms of measurement, Prame (25) did not directly address VO, although he rejected the first vibrato cycle in the mean VR or VE, because the pattern had not stabilized. In our study, both SO and LSO conditions revealed a marked increase in VO (Table 2 and Fig. 6b–c), which is associated with poorer overall vibrato and inferior application of technique.

Pedagogical implications

The challenge for vocal pedagogues is to assess each individual voice and to devise a program of technical work to improve the basic sound. In Western classical singing, good technique is integral to vocal quality, and poor technique is identified by faults perceived within the overall sound (48, 49). Research into singing, by contrast, has hitherto focused on identifying acoustic parameters that characterize a 'good' voice by reference to findings that have been generated by averaging data from a number of voices. The dilemma and paradox in this approach is that the averaged findings may not adequately represent any of the individual voices used to generate the desirable acoustic parameters that become the benchmark of vocal quality. Pedagogy focuses on individual techniques to achieve the complete sound and evaluating teaching techniques individually is necessary to verify their effectiveness and reliability as teaching tools. This study extends previous work in its attempts to assess and verify the efficacy of specific teaching tools by reference to their acoustic and perceptual impact on vocal quality. While replication of these findings is required prior to confident recommendations that open throat technique be applied in singing studios, this study has demonstrated that individual teaching techniques can be empirically assessed and their effects verified both perceptually and acoustically.

CONCLUSION

Pedagogical and perceptual studies agree that substandard vibrato is immediately identifiable and indicates inadequate technique or poor vocal quality. Whether reduced vibrato extent and delayed vibrato onset are consequences of reduced 'open throat' technique specifically, or the primary factors perceived as 'open throat' or indeed any technique used in good singing needs further investigation. Vibrato alone does not necessarily carry the acoustic cues of 'vocal quality' to listeners (50), yet perceptually, in this study, the best quality was associated with open throat technique. Further acoustic analysis of O and SO sound qualities is necessary to identify which parameters most closely concur with the holistic perceptions of expert pedagogues.

Auditory-perceptual aspects of a voice represent a psychological reality for both the singer and the listener. Linking an acoustic parameter such as vibrato to a commonly used instruction, such as open throat, has the potential to provide a common terminology for ease of communication between singers, their teachers, and clinicians. Future research may also define 'open throat' as a set of physiological parameters.

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