Changes in Singer Performance in different acoustics

Christopher Barlow
School of Computing and Communications,
Southampton Solent University,
East Park Terrace,
Southampton,
SO14 0RD

e-mail: christopher.barlow@solent.ac.uk

Abstract

The majority of quantitative research on the singing voice has been undertaken in a laboratory environment, where analysis tools are frequently based on phonetically balanced texts and vowel vocalisations rather than 'real' repertoire. Most singers of music in the Western Classical tradition rely on the acoustics of the performance venue to provide aural feedback to control aspects of their vocal performance, and are therefore particularly vulnerable to changes in acoustic environment.

This pilot project examined quantitative measures of the performance of a singer in two different environments. The project analyzed a sung phrase of ~50 seconds duration taken from recordings by a solo unaccompanied mezzo-soprano singer performing in a hemi-anechoic chamber (RT60 = 0), and the same singer recorded in a large Victorian church with RT60 ~ 3.5 s. The phrase was recorded several times in each environment, and was part of a solo well known by the singer. A number of key parameters were analysed, including Mean frequency over a number of sustained notes, mean tempo, vibrato rate/depth, and pitch of formant frequencies of sustained vowels in the musical phrase evaluated using Long Term Average Spectra.

Significant variation was found between the recordings in each venue for the parameters of tempo, vibrato rate and depth, and the frequencies of formants F1-F3. Pitch variation was exhibited but not at a significant level.

Howard and Brereton (2008) analysed singers in a similar manner, examining different parameters, and found raised vocal fold closed quotients, a shallower spectral slope and increased intensity for the anechoic recordings, suggesting heightened effort and increased vocal load and a resultant change in singer tone quality.

This study supports these findings, indicating that significant changes in tone quality, and other key aspects of performance are highly likely where singers are assessed in anechoic spaces, and that researchers need to take into account this consideration when assessing vocal properties.

Key Words: Voice analysis, Acoustic, LTAS, Spectrum, Pitch, Vibrato

Introduction

In recent years there has been increasing interest in the use of technology to analyse the performance of singers in order to improve understanding of how the singer's voice works and in turn to improve techniques and rate of learning [2]. Several different forms of analysis have been used and have been demonstrated to have some effects on the acquisition of singing skills. Analyses have included direct monitoring of both the larynx and the acoustic output of the singer, glottal airflow, respiration rates and analysis of neural information using MRI and fMRI scanning.

However, there are a number of problematic aspects in the majority of the research on vocal performance. A particular problem is the lack of data from real performances and venues. Instead, the majority of research has been undertaken in a laboratory environment, where the analysis tools are frequently based on phonetically balanced texts and vowel vocalisations rather than ‘real’ repertoire. This is a disadvantage from both an acoustic and performance perspective, in terms of interpreting 'abstract' data to make generalisations on real practice and actual situations.

The major issue is that laboratory-based voice recording and analysis research entails an highly unrealistic performance environment, whether an anechoic chamber or MRI scanner [3], not only because of the sorts of vocal tasks involved, but also due to the absence of any kind of realistic room acoustic. Ternstrom [4] states *“It is widely acknowledged that room acoustics are of great importance to vocal performance”.*

Performers and composers alike have long understood that both different repertoire and different ensembles are suited to particular acoustic environments. In particular, it is recognised that a ‘good’ acoustic can significantly improve the perceived quality of a musical performance. **Reference.**

Performing in different acoustics not only changes the audience perception of the music, but research over recent years has shown that it also has a marked effect on the performer him- or her-self, and can change a large number of aspects of the actual performance, rather than just what reaches the listener’s ears. It has also recently been demonstrated that variations in acoustic environment cause significant alteration in performance, changing the way in which the performer interacts with the performance venue [5].

Most singers of music in the Western Classical tradition rely on the acoustics of the performance venue to provide aural feedback. Howard and Angus [6] state that singers receive instantaneous feedback in three ways: by kinaesthetic feedback from the larynx, head and chest, auditory feedback from bone conducted sound and auditory feedback from air conducted sound. The internal transmission of sound dominates – as opposed to the instrumental musician, for whom the feedback via the ear is generally strong. This means that for a singer, the degree of auditory feedback is fairly low **[reference]**, yet this is particularly important for determining loudness and intonation. Where auditory feedback is low, the singer finds it particularly difficult to accurately judge volume and effort in vocal production **[ref] Voice science and acoustics?**. Feedback on vocal tone is also largely auditory, so a lack of reverberation can have a significant effect on tone production, in particular of the vowel. Musicians from Contemporary Commercial Music (CCM) may be less subject to this effect due to the use of amplified feedback, however, this is as yet unstudied.

Other parameters which can affect the performance include: The presence of accompanying instruments, and even the type of instrument used [7] ; physiological and environmental temperature changes can cause hydration loss [9]; the act of performing in front of an audience can cause significant changes in the singer's performance in comparison to rehearsal, as the increased stress factor can cause changes in vasovagal control of the heart, increased cortisol and adrenaline and reduced breath control [10]. Finally, emotional engagement with repertoire can affect vocal technique [8] compared to abstract vocalisations or vowel sounds often used in research protocols.

Vocal performance is not separate from the acoustic and physical environment in which it was produced; it is intrinsically and irreversibly linked to its performance environment. As the majority of research studies do not take any of these parameters into account, they only show a limited picture of how the singer will act in a real performance. This is an area that requires a considerable amount of development in order for research to impact beyond academic interest and develop a practical application on performance techniques. This will allow the analysis of the interrelationship between psycho-physiological reactions and acoustic performance, and allow this data to be used in feedback and training.

Singers, particularly those on tour, are regularly asked to perform music in a variety of different acoustic conditions, from those which are considered optimal, to those which are anything but. A modern musician is frequently asked to adapt their performance to suit anything from a recording studio to a cathedral, so an understanding of the changes in performance in different environments is critical to the understanding of vocal performance, and therefore to the improvement of vocal technique and pedagogy.

This pilot study aimed to examine how much change between performances could be determined for a singer performing in both an anechoic room and an acoustically 'live' performance venue.

Method

The study analysed a sung phrase from an unconducted solo unaccompanied mezzo-soprano singer recorded in a hemi-anechoic chamber (RT60 = 0), and the same singer recorded in a large Victorian church with RT60 ~ 3.5s. In both cases the performances were recorded complete, and the phrase was part of a solo well known by the soprano, and which she had performed in a variety of different concert environments.

The church performance was taken from the spot mic track from the recording of the piece for a commercial release on compact disc, and so can be considered to have been made under ‘performance’ conditions. An impulse response was taken of the church during the recording session to measure the RT60 of the building.

The solo was designed to be performed unaccompanied, and utilised several sustained vowels over a range of 1.5 octaves. Each solo was performed 3 times.

Recording was done using a digital audio workstation running on a Toshiba Laptop with an external soundcard. The microphone used was a Neumann KM130 Omnidirectional condenser with a flat frequency response, placed on a stand ~1m in front of the singer. The microphone was powered by an M-Audio DMP3 low noise microphone preamplifier. Both recordings were undertaken at 48 kHz sampling rate and 24 bit resolution.

Quantitative analysis of the acoustic signal was undertaken using spectral analysis software. Eight sustained notes each on a single vowel in the solo (each ~1 to 3 seconds in duration) were selected for analysis. As a portion of the phrase was repeated several times in the solo, 5 of the selected notes were on the same pitch to allow for analysis of pitch drift during the solo. These notes were evently spread throughout the solo. The mean fundamental frequency (F0) over all selected notes was calculated for each version of the solo using a narrowband FFT in SpectraPlus™ spectral analysis software, using a Hanning window with 16384 points.

The overall duration of each solo was measured from the onset of the first word to the onset of last word (to eliminate the effect of reverberation lengthening the perceived duration). The rate of pitch variation (vibrato rate) and the depth of frequency variation (vibrato depth) was also measured for each of the selected notes. Praat™ software was used to determine formant frequencies for each of the sustained vowels.

Results

Pitch/Mean F0

In order to assess whether acoustic had a significant effect on unaccompanied pitching of notes, mean fundamental frequency over the sustained portion of each of the 8 notes was compared between the recordings in each of the venues (figure 1).

The mean frequency was not significantly different for any of the comparable notes analysed ($p<0.05$), indicating that the acoustic variation did not have a particularly strong effect on pitch accuracy in this case. There was also no significant pitch drift in either venue across the phrase.

Figure 1 – mean F0 of each of 8 notes analysed through phrase.

Tempo however varied by a marked amount, with the anechoic performance being slower by around 10% on an approximately 50 second long phrase. It is suggested that the lack of reverberation resulted in a slower performance tempo as the singer needed to sustain particular notes longer to process feedback regarding pitch and intensity.

The mean vibrato rate for a number of sustained notes was calculated for each performance, with the same note and duration from onset being selected for each analysis.

The performance in the reverberant environment resulted in a mean vibrato **rate** of 5.73 Hz across all notes, compared to 6.12 Hz for the anechoic environment, and increase in rate of about 7%. The vibrato rate in the anechoic environment was consistently higher than that in the reverberant environment by between 6-11%.
Vibrato **depth** was considerably smaller in the reverberant environment than in the anechoic, with a mean pitch variation across 3 sustained notes being 85.67 cents (hundredths of a semitone), compared to 131.59 cents in the anechoic performance. This is a particularly significant difference as it amounts to a 65% increase in vibrato rate between the different acoustics.

Vibrato is primarily a mechanism for determining and maintaining pitch. The significant difference in both rate and depth of vibrato shown here suggests that the singer is using the vibrato to present extra auditory feedback in order to maintain pitch, in order to compensate for the lack of feedback from the reverberation.
The first four mean formants of the mid-portion of a number of sustained vowels in the phrase were analysed for the recordings from the two venues (Table 1). Formant analysis showed a significant discrepancy of mean formants of the vowel sound between the two acoustics.

The /a/ vowel in the anechoic acoustic (figure 1) is a much harsher sound than for the reverberant sound, and the singer identified that it was not the sound she would expect normally expect from the /a/ vowel. In particular the formants F2 and F3 are considerably higher for the anechoic recording than for the reverberant recording, and it can be surmised that the singer is using the resonances to make the note easier to determine in the anechoic environment.

	F0	F1	F2	F3	F4
Reverberant	278.43 Hz	544.5 Hz	1160.9 Hz	2935.4 Hz	3472.1
Anechoic	277.2 Hz	508.3 Hz	1363.5 Hz	3163.3 Hz	3458.5 Hz

Table 1: Mean Fundamental frequency and formant positions for the vowel /a/ from the same note.

Pitch 1: (/i/ on Criosda)
373.47458319862403 Hz (mean pitch in SELECTION) (anechoic)
372.28205163175835 Hz (mean pitch in SELECTION) (reverberant)
Vibrato rate: 6.189 Hz anechoic
Vibrato rate: 5.88 Hz reverberant

(/a/ on Dalma)
277.22611787598765 Hz (mean pitch in SELECTION) (anechoic)
278.43840344903623 Hz (mean pitch in SELECTION) (reverberant)
Vibrato rate: 5.58 Hz (reverberant)
Vibrato rate: 6.05 Hz (anechoic)

Formants (reverberant)
544.5623688635011 Hertz (nearest F1 to CURSOR)
1160.9505647081128 Hertz (nearest F2 to CURSOR)
2935.384334528307 Hertz (nearest F3 to CURSOR)
3472.1109676775795 Hertz (nearest F4 to CURSOR)

Formants
508.34320324101327 Hertz (nearest F1 to CURSOR)
1363.522162173917 Hertz (nearest F2 to CURSOR)
3163.2841889169786 Hertz (nearest F3 to CURSOR)
3458.5655241139902 Hertz (nearest F4 to CURSOR)

Discussion

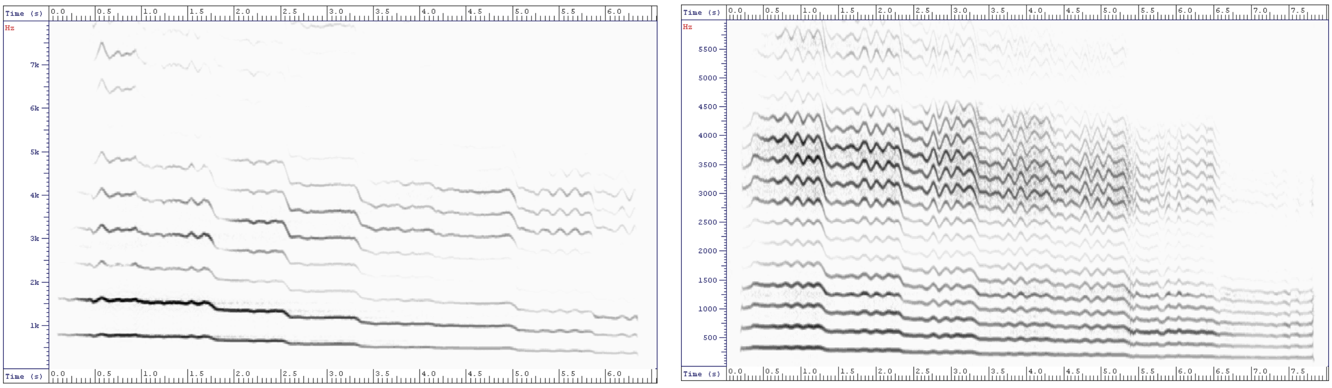
Brereton and Howard (2008) undertook a similar study, examining vocal fold closed quotient, output spectrum and pitch, tempo and vibrato of a mezzo-soprano and a tenor, recorded singing a G major decending scale in both York Minster Chapter House (RT60~8s) and an anechoic chamber.

The singers reported 'working harder' in the anechoic environment, and this was borne out by the analysis of peak sound pressure levels. SPL output at the mouth was 107.1 dB SPL for the anechoic environment compared to 95.2 dB in the Chapter House.

Again, it is suggested that the singer is overproducing the voice in order to compensate for a lack in auditory feedback. This change in singer output is sufficient to suggest that working for more than a short time in this environment will lead to singer fatigue and potential risk to vocal problems.

In addition, the vibrato rate and depth was again considerably higher for the singer in the anechoic environment than in the reverberant acoustic, supporting the results above.

Howard and Brereton also found raised vocal fold closed quotients and a shallower spectral slope for the anechoic recordings, both suggestive of a) heightened effort and increased vocal load and b) a resultant change in singer tone quality.



Spectrograms of one-octave G-major descending scale, sung by mezzo-soprano in Chapter House (left hand spectrogram) and anechoic chamber (right-hand spectrogram) (From Brereton and Howard, 2008)

Termstrom (1993) found similar results from the analysis of choirs performing in a number of different acoustic environments, demonstrating shallower spectral slope, higher intensities and raised formants of the Long Term Average Spectra (LTAS) of 3 choirs performing in a 'poor' acoustic compared to performing in a church with a subjectively 'good' acoustic.

6] Ternström, S. (1993). Long-term average spectrum characteristics of
different choirs in different rooms/./ /Voice/, *2*: 55-77.

7] Daugherty, J.F. (1999). Spacing, formation and choral sound: Preferences and perceptions of auditors and choristers/. Journal of Research in Music Education/, *47*(3): 224-238.

8] Daugherty, J.F. (2003). Choir spacing and formation: Choral sound preferences in random, synergistic and gender-specific chamber choir placements. /International Journal of Research in Choral Singing, /*1*
(1) 48-59

9] Marshall, A.H. and Meyer, F.-J. (1985). The directivity and auditory
impressions of singers. /Akustika/, *28*: 181-184.

11] Libeaux, A., Lentz, T. and Kob, M. (2007) Voice Assessment in Choir
Singers using Virtual Choir Environment, /19^th International Congress
on Acoustics, /Madrid, Spain, 2-7 September 2007//

12] Ternström, S. (1999). Preferred self-to-other ratios in choir singing. /Journal of the Acoustical Society of America, /*105 *(6):

3563-3574

2] Welch, G. F., Howard, D. M., Himonides, E., & Brereton, J.(2005) Real-Time Feedback in the Singing Studio: An Innovatory Action-Research Project Using New Voice Technology *Music Education Research,* 7(2), 225-249.
3] Kleber B., Veit R., Birbaumer N., Lotze M. (2007) Neural correlates of professional classical singing p. 335-343 In A. Williamon and D. Coimbra (Eds.), *Proceedings of the International Symposium on Performance Science*, Association of European Conservatoires.
4] Ternström, S. (1993) Long-term average spectrum characteristics of different choirs in different rooms, *Journal of Voice* 2, pp. 55–77
5] Brereton, J. and Howard, D.M, (2008). The Effect of Different Acoustic Environments on Singing Voice Performance*, British Voice Association Research Symposium*, Institute of Education, Feb 2008.
6] Howard and Angus (2005) . *Acoustics and Psychoacoustics*. Oxford: Focal Press.
7] Daffern, H. (2006) 'Pilot study: the effects of period instruments on the voice'. *Proceedings of the 3rd international Conference on the Physiology and Acoustics of Singing*, York.
8] Havas, K. (1978). *Tensions in the Performance of Music* London: Kahn & Averill.
9] Wilmore, Costill & Kenney (2008). *Physiology of Sport & Exercise.* 4th Edition. Human Kinetics.
10] Hamann, D. L. (1982) An Assessment of Anxiety in Instrumental and Vocal Performances *Journal of Research in Music Education 30 77-90*
11] Sataloff, R.T., (2005) *Voice Science*. San Diego: Plural Publishing
12] Sundberg, J. (1987) *The Science of the Singing Voice*. Illinois: DeKalb
13] Hirano, M. Sundberg, J and Dejonkhere, P (1995), *Vibrato.* Oxford: Singular
14] Mazzù M, Scalvini S, Giordano A, Frumento E, Wells H, Lokhorst K, Glisenti F. (2008) Wireless-accessible sensor populations for monitoring biological variables.*Journal of Telemed Telecare.* 2008;14(3):135-7