Spectral and Temporal Changes in Singer Performance With Variation in Vocal Effort

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ABSTRACT

A singer's vocal output has to vary depending on the musical work being performed, the size of the auditorium used for the performance and other factors. In the work reported on in this paper the *small hall* and the *large hall* voices of professional opera singers were investigated to determine the spectral and temporal changes in their vocal output. Recordings of 8 opera singers were made in an anechoic chamber. Singers were asked to imagine they were in a small hall for one set of recordings and in a large auditorium for another set. The recordings were then analysed to determine spectral changes between the large hall and small hall renditions. Temporal changes were investigated looking at performance timings of the songs (under different *projection* conditions). Psychoacoustical models were also used to evaluate the recordings.Overall, it was found that *large hall* song renditions produced greater amplitude in the 1kHz-4 kHz region as well as faster tempos compared to *small hall* performances.

INTRODUCTION

The ability of people to sing is, in itself, quite an achievement. While a classic model of singing relies on the singer's ability to project sounds that will be clearly heard and therefore audible in a pre-defined performance space, contemporary music usually relies on sound reinforcement for vocal audibility, especially when there is a loud backing band as an accompaniment. Thus, it is often the case that a singer who is singing softly, as required in a classical rendition of a song, is amplified. A singer who is not amplified has to sing loudly to be heard by a large audience or in a noisy auditorium. It is not uncommon for an operatic singing approach to be combined with modern sound reinforcement techniques in certain types of performance. While it may be relatively easy to make a singer loud with amplification, the nuances of the sung voice may be lost. The present work was undertaken to explore the changes in opera singers' spectral/temporal characteristics according to whether they sing in a small or large hall. It is hoped that this might lead to better audio techniques that would better preserve the feeling that a singer is trying to project when a sound system is used. The possible application is to use electronic amplification, compression, equalisation and perhaps even time-stretching/compression techniques to successfully reproduce changes that inherently occur with different levels of singing performance.

Previous studies (Bartholemew 1934, Sundberg 1974) have shown that opera singers produce high energy in the frequency region at around 3 kHz. Hence, this is taken as roughly the centre frequency of the *singer's formant*. A formant can be described as a frequency range where the vocal tract resonates at higher sound amplitudes. Normal speech has formants in the range of approximately 250 Hz to 4000 Hz for vowel sounds. Sung vowels have formant frequencies as spoken vowels but while the amplitudes of the first and second formants are often about the same, the amplitude of the higher formants in the range between 1 kHz and 4 kHz, have much larger amplitudes when sung. This allows the singer to be heard without amplification over sounds of accompanying music (Sundberg 1974). Such formants appear to be more prominent in trained singers, contraltos rather than sopranos, and in solo rather than choral singers. Rossing et al found that a trained singing subject will sing with more power in the singer's formant region in solo mode (Rossing et al 1986) and Sundberg also strongly suggested that a solo singer will greatly utilise his or her singer's formant region to improve voice projection (Sundberg 2001). However, the precise location of the formant frequency varies. The frequency of singers' formants may be affected by individual voice types and ranges as well as the environment they are singing in, amongst other factors. J.Y. Jeon's work on temporal changes for musicians (1993) found that louder levels of singing resulted in a shorter duration compared to softer sung levels of the same song under the same performance conditions. While there is a lack of data on temporal changes in singing, this paper also found that in most cases, the duration of louder levels of singing were shorter. In general, the sung notes and the spaces between the notes were shorter for the *large hall* renditions compared to *small hall*.

METHOD

Singers were recorded using the one song excerpt in the same key in all conditions. The song was the final 16 bars of "Torna a Surriento" (traditional Italian song) with a duration of approximately 50 seconds. The B&K 4190 model free field microphone was used on axis at a distance of 2.1 metres from the subject in an anechoic room utilising flat layers of graded density fibres material providing anechoic conditions down to 250 Hz. The abovementioned distance was used because of the larger microphone array and anechoic room configuration for other aspects of this measurement project (primarily to measure horizontal directivity of the singers (Cabrera and Davis, 2004). A microphone calibration tone was recorded along with the singer recordings (1 kHz @ 93.8 dB using the B&K Sound Level Calibrator Type 4231). Recordings were made on a digital hard disc recorder (Alesis HD-24) using a 24-bit pulse code modulated format with a sampling rate of 48 kHz.

The singer's task relevant to this study was to sing the excerpt imagining that they were in a small auditorium (i.e.*small hall*), or imagining that they were in a large auditorium (i.e.*large hall*). There were other singing conditions i.e. intonation, emotion, large theatre with headphones as well as recordings made in another room (reverberation chamber) as part of the recording session which are not looked at in this paper. Singers were professional opera singers, including some soloists who perform with the Australian Opera.

The length of the respective song renditions were measured using a number of professional audio hard disk editing packages such as Sadie, Pro-Tools and Adobe Audition software. Spectral analysis primarily used the Pulse system utilising 1/3 octave band analysis over the whole song for large and small hall song renditions. Measurements were made in dB (A) measuring LEQ and in the case of loudness LMAX (Instantaneous Loudness).

RESULTS

In all cases, subjects clearly showed greater levels for *large hall* renditions compared to *small hall*.

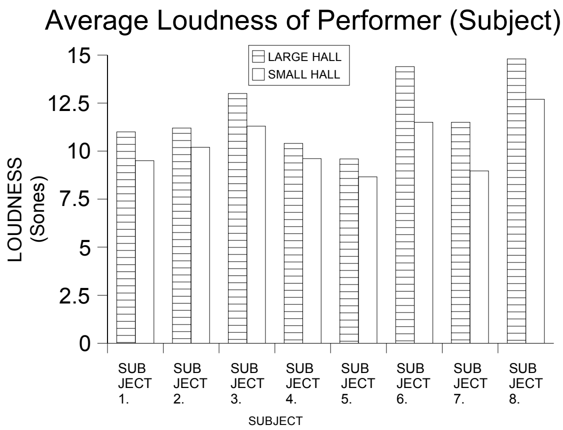

Figure. 1. Display of loudness (based on Leq values of performer) of *large* hall (shaded columns) and *small* hall (clear columns) on a per subject basis.

While it can easily be seen that subjects were louder for *large hall* singing compared to the *small hall* case further spectral analysis showed non-uniformity of spectral behaviour. A comparison of sound level (dB SPL) differences between *large theatre* and *small theatre* relevant to 1/3 octave bands shows a more prominent rise in the frequency range typically associated with the *singer's formant* region.

Figure 2 displays the 1/3 octave level differences i.e. *Large hall-Small hall* as 1/3 octave scaling between relevant singing frequencies in the range of 250 Hz and 8 kHz.

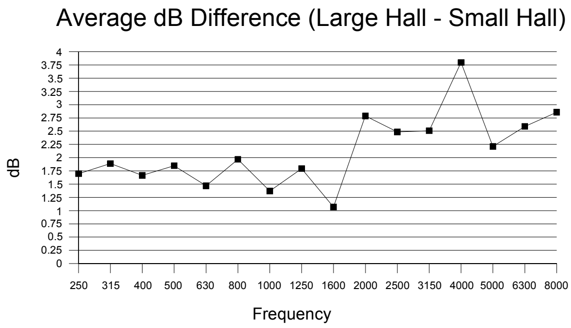

Figure. 2. Average Leq 1/3 octave frequency sound level difference(dB) between *Large Hall* and *Small Hall renditions*.

Song Performance Duration lengths of *large hall* and *small hall are* represented in Figure 3. In almost all subject cases (except for subject 5), *small hall* renditions are longer than *large hall* performance. An average of 3.3% greater duration time exists for *small hall* song renditions compared to *large* hall with subject 8 exhibiting the longest duration (*small* hall) of 5.8%.This suggests perhaps that the greater vocal effort required for *large hall* conditions utilises greater energy reserves by the singer and as such loudness cannot be sustained for as long a period compared to *small hall conditions*. While the longest duration timing (*small hall*) exists for subject 8, the shortest duration timing (also *small hall*) exists for Subject 1. Comparing loudness levels (Figure 1) with duration measurements (Figure 3), it can be seen the highest average loudness occurs for subject 8 who also had the longest (*small hall*) duration [as previously mentioned].

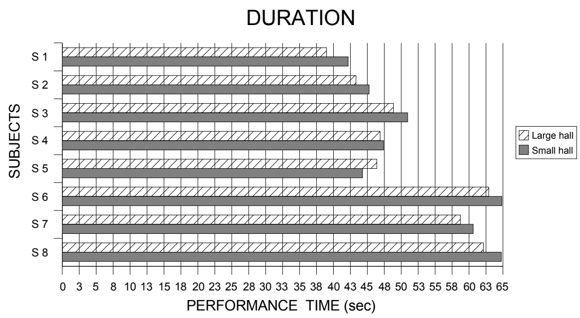

Figure.3. Display of Large Hall and Small Hall song performance durations for each subject.

This analysis of singing data supports Jeon's duration studies where playing a musical instrument at a louder level requires more energy and all other things being equal, the performance will be of shorter duration as a result (J.Y. Jeon 1993).

DISCUSSION

While an overall increase of 2-3 dB in the 2kHz-4 kHz region may appear insignificant, it's important to note this is an average result and individual cases can show greater magnitude. Although most subjects expressed some difficulty adjusting to the *unusual* anechoic room conditions, spectral differences are obvious when comparisons between *large hall* and *small hall* renditions are made. This suggests that the singing voice is accustomed to using formants regardless of room acoustics present.

While the average A-weighted level of *large hall* song renditions is +1.7dB(A) compared to *small hall* renditions, an average rise of 2.9 dB (A) in the 2 kHz-4 kHz bandwidth (compared to *small hall* singing levels) takes place. Statistically, at 2 kHz, 2.5 kHz, 3.15 kHz and 4 kHz average levels (dB SPL) for *large* hall were +2.9 dB, 2.5 dB, 2.5 dB and 3.8 dB respectively. All other 1/3 octave frequencies below this range were less than +2 dB increase for *large hall* compared to *small hall* performances. The most notable individual difference occured for subject 1 registering +10.3 dB more (large theatre) at 4 kHz. The smallest dB difference occured for Subject 8 at 1.6 kHz registering only +0.01 dB (large theatre).

CONCLUSION

In comparing SPL's, a significant rise in frequencies between 2 kHz and 4kHz exists for *louder* levels of singing performance. When using a sound reinforcement/playback system, the typical "loudness" control (commonly found in home hi-fi systems) should be modified to respond dynamically (between 2 kHz-4 kHz) for sung performances in order to enhance subjective loudness. This will provide a more realistic reproduction of dynamics. In addition, with results predominantly showing large hall renditions to be shorter for the sung notes and the gaps in between (compared to the small hall renditions), the tempo of the performance should be increased when played loudly. While this may not be possible for live performance, playback of pre-recorded material is technically viable thus increasing radio airplay time for example. However, an increase of up to 5% (approximately) may not be significant for program managers or subjective notions of loudness. It is known that reverb can influence the loudness of a singer due to extra reflections that lead to a more diffuse field. By exercising song renditions in anechoic room conditions, all subjects performed *large hall* and *small hall* renditions of the song without the acoustic benefits of singing in an actual theatre. While this provided a constant for recording conditions, further research will analyse spectral and temporal results between large and small theatre song renditions in reverb chamber conditions. Furthermore, there is a need to examine subjective response to shorter duration in relation to perceived loudness for sung performances.

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REFERENCES

Bartholemew, W.T. (1934). A physical description of "good voice quality in male voice," J.Acoust. Soc. Am 6. U.S.A.

Jeon, J.Y. (1993) Perception and Production of Tonal Sounds: Duration Studies, Department of Architectural and Design Science. University of Sydney

Rossing, T.D; Sundberg, J; Ternstrom, S. (1986) Acoustic comparison of voice use in solo and choir singing J.Acoust. Soc. Am. 79. U.S.A.

Sundberg, J., (2001) Level and center frequency of the singer's formant, J. Voice, Vol.15

Sundberg, J. (1974). Articulatory interpretation of the "singing formant," J. Acoust. Soc. Am. 55. U.S.A.

E. Zwicker, H. Fastl. (1991): Psychoacoustics, Facts and Models. Springer Verlag Berlin.