PERFORMANCE CHANGE IN VOCALISTS WITH VARIATION IN HEADPHONE FOLDBACK AND REVERBERATION LEVELS

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1 INTRODUCTION AND BACKGROUND

The relationship between acoustics and quality of performance spaces has been documented for thousands of years. A number of acoustic effects which allowed unamplified actors in the ancient theatre of Epidaurus to be clearly heard at the rear of the theatre have been identified (1), while Vitruvius Pollio developed theories of acoustic design as far back as the Roman period (2). The advent of the concert hall and opera house from the Renaissance onwards engendered an interest in acoustic design (3), although the science was initially poorly understood.

Performers and composers alike have long understood that both different repertoire and different ensembles are suited to particular acoustic environments. In particular, it is recognized that a ‘good’ acoustic can significantly improve the perceived quality of a musical performance (4), and concert halls are typically rated using a number of subjective (e.g. ‘clarity’) and objective (e.g. C_{50}) measures to determine their quality (5).

It is well known amongst the classical singing community that the acoustic of a performance space has an impact on the performance given by a singer. Relationships between acoustic environment and performance have been discussed by a number of authors. Research over recent years has shown that performing in different acoustics not only changes the audience’s perception of the music, but 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 (6), (7), (8). Variations in acoustic environment cause significant alteration in performance, changing the way in which the performer interacts with the performance venue (9).

Most singers of music in the Western Classical tradition rely on the acoustics of the performance venue to provide aural feedback. Howard and Angus (10)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 for the singer, in contrast to the instrumental musician, for whom the feedback via the ear is generally strong. This means that for a singer, the proportion of auditory feedback compared to bone conduction is fairly low, 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 (11). 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.

The level of reverberation (12), (6), critical distance and proximity to reflecting surfaces (13), have all been shown to have impact on parameters such as timing, volume and spectral content of the voice signal, while occlusion of the ear (preventing the singer getting auditory response from their own voice) has significant impacts on loudness and pitch intonation (14).

In the popular music field, performance and recording generally takes place in acoustically dry environments, in which reverberation time is low (typically around 0.3s). This allows control of the recording, and enables the addition of artificial reverberation to the sound to suit the creative requirements of the artist and producer. Artificial reverberation has been used in recorded music since the 1947 number one hit 'Peg O' My Heart' by the Harmonicats (15), and is used in the majority of popular music recordings.

Performers also typically perform and record to backing tracks in which the accompaniment is fed through headphones. In order to prevent problems caused by occlusion of the ear by the headphones, the performer's own voice is generally sent back to them through the headphones (known as foldback). Given that the acoustic feedback of their own voice to the performer has a substantial impact on performance, this means that variations in this foldback, such as level and use of reverberation effects could have a substantial effect on the popular music performer, with concerns expressed by some artists regarding whether the resulting sound was reflective of the artist's intent (16). Understanding this variation is important both to enable performers to improve their performance when in a situation requiring headphone foldback, improve vocal analysis and feedback systems (17) but will also be essential for the understanding of new 'virtual' acoustic spaces being developed for music rehearsal and collaborative performance (17) (18). This study assessed the impact of variation in foldback of both voice level and reverberation setting on a group of singers of varying levels of experience.

2 METHOD

Twelve singers of varying levels of experience were recorded unaccompanied, performing the song 'Amazing Grace', which is commonly performed as part of both popular music and classical repertoire. Of these, four were experienced
singers from a classical background, four were from popular music and musical theatre backgrounds, and the remaining four singers were amateur choral singers with little formal training. Recordings were made in either a hemi anechoic or a fully anechoic room, in order to prevent potential acoustic feedback from the room having an impact on the performance or measurements.

An initial pilot study using a single singer indicated that the singer underwent significant changes in level, pitch, tone, intensity, vibrato depth and performance tempo with the changes in acoustic foldback. In particular, average sound pressure level increased with a strong correlation to reverberation 'wetness', while pitch and tone correlated strongly with foldback level. Low levels of foldback caused the singer to go flat, while high levels caused the singer to go sharp.

This led to the research hypothesis that both the level and reverberation 'wetness' would independently affect the measured parameters of performance, specifically tone (as defined by average spectrum), timing and sound pressure level.

In order to examine this hypothesis, it was necessary to record a larger sample, and a total of twelve singers were recorded for the main study.

2.1 Equipment and setup

Recordings were made using a DPA d:fine headset mounted omnidirectional condenser microphone, positioned about 5cm from the mouth. This enabled the singer to move their head while singing, without significant impact on the recording levels. The audio was recorded digitally using a low noise Alice™ microphone preamplifier into a Dell XPS 15 laptop computer running Adobe Audition digital audio workstation, using an AVID Fast track C600 audio interface. Recordings were made at a sampling rate of 96 kHz and bit depth of 24 bits.

The output signal was run through an Alesis Microverb effects processor, set to a 'room' reverb, with predelay of 150ms and a decay time of 1.3secs. The signal was then relayed back to the singer via

Behringer headphone amplifier, with Beyerdynamic DT150 closed back headphones. The recording system setup is shown in figure 1.

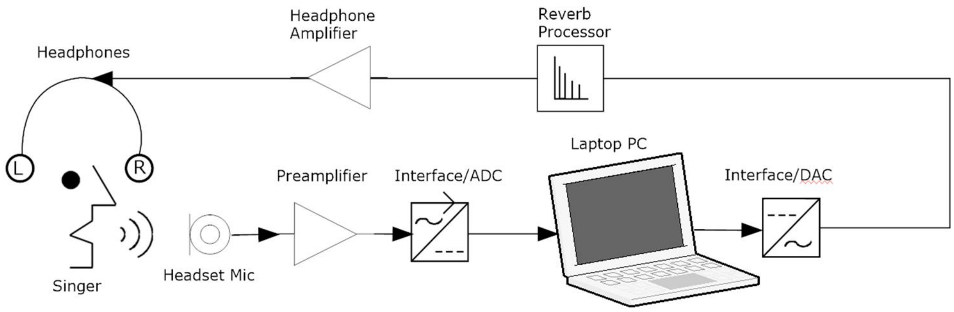

Figure 1: Recording setup

It was important to ensure that both recording levels and headphone foldback levels were the same for all singers. A calibration signal of a 1kHz pure tone was played through a loudspeaker with the microphone mounted next to the microphone of a Class 1 sound level meter (NTi XL2 with measurement microphone M2230). Levels were set so that the input signal was $94dB_{SPL}$ at 1kHz. This signal was recorded onto the beginning of the recorded track in order to give a reference for sound pressure level, allowing 8 dB of headroom in the recording system. Gain controls were then left locked in position so that gain variation did not occur between recordings.

In order to set the headphone foldback levels, the calibration tone was played back through the headphones placed on a Bruël and Kjaer Head and Torso Simulator type 4128, the output of which was attached to an NTi XL2 sound level meter. This was calibrated before each recording using a Bruël and Kjaer type 4231 calibrator. Figure 2 shows the calibration setup.

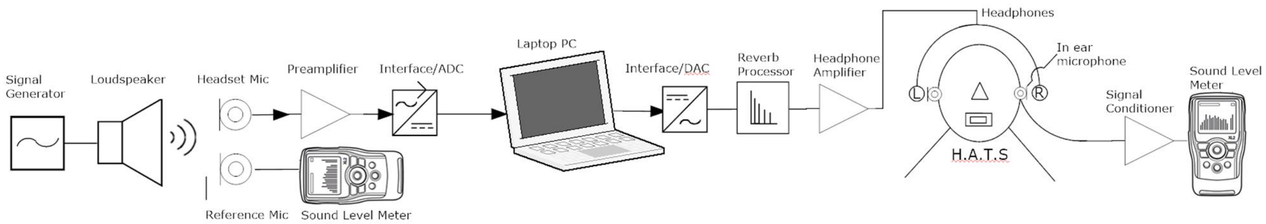

Figure 2 - Calibration setup

Output levels were adjusted at the headphone amplifier to give 3 possible levels at the ear for a 94 dB_{SPL} output from the system. The highest level was set at 94 dB_{SPL} so that the singer experienced a level as high as would be likely in an acoustic environment. A mid-level was set with the foldback at 74 dB_{SPL} and a 'low' level was set with foldback at 54 dB_{SPL}.

The artificial reverberation applied to the headphone signal was set at 3 different positions: 100% dry (unprocessed signal); 50% Wet/Dry (50% processed, 50% unprocessed signal) and 100% Wet (100% reverberated signal). Decay time and predelay were left the same for all recordings.

2.2 Recordings.

A total of eleven variations of foldback and reverberation were recorded for each singer, including no foldback and singing without headphones. The singer performed unaccompanied, with no click track or other timing information, so could perform at their chosen tempo. They chose a suitable pitch range before the recording and were played a starting note based on the key they had chosen before each take.

Each singer sang each variation 3 times, giving a total of 33 versions per singer. In order to mitigate against learning effects, a random number generator was used in order to randomize the order in which each variant of level and reverberation was recorded.

Analysis of the sound files focused on the average sound pressure level (L_{EQ}), Long Term Average Spectra (LTAS) for each recording, and duration/tempo and timing for each recording, while each singer was also asked to give a subjective assessment of the 'ease' of performance in each scenario.

Individuals will vary considerably in their performance, so analyzing absolute levels and timing is not appropriate, as the research question is to examine whether varying foldback affects the individual. In order to account for individual variations in performance sound pressure level and timing, all recordings were therefore analysed by considering the variation in each parameter from that of the first recording at 54 dB_{SPL} level with no reverberation.

The various combinations of level and reverberation are shown in table 1 below.

Recording	Foldback level	Reverberation level
1	No headphones	N/A
2	No foldback (headphones on)	N/A
3	54 dB_{SPL}	100% Dry
4	74 dB_{SPL}	100% Dry
5	94 dB_{SPL}	100% Dry
6	54 dB_{SPL}	50% Wet/50%Dry
7	74 dB_{SPL}	50% Wet/50%Dry
8	94 dB_{SPL}	50% Wet/50%Dry
9	54 dB_{SPL}	100% Wet
10	74 dB_{SPL}	100% Wet
11	94 dB_{SPL}	100% Wet

Table 1: Foldback settings

3 RESULTS

3.1 Duration.

Duration for each recording (i.e. the tempo at which the piece was sung) was calculated by measuring the time from the voice onset of the first word to the voice onset of the last word. This avoids calculation error due to holding the last note for different lengths. Variation in duration was expressed as a percentage and mean variation for each parameter setting was plotted (figure 3).

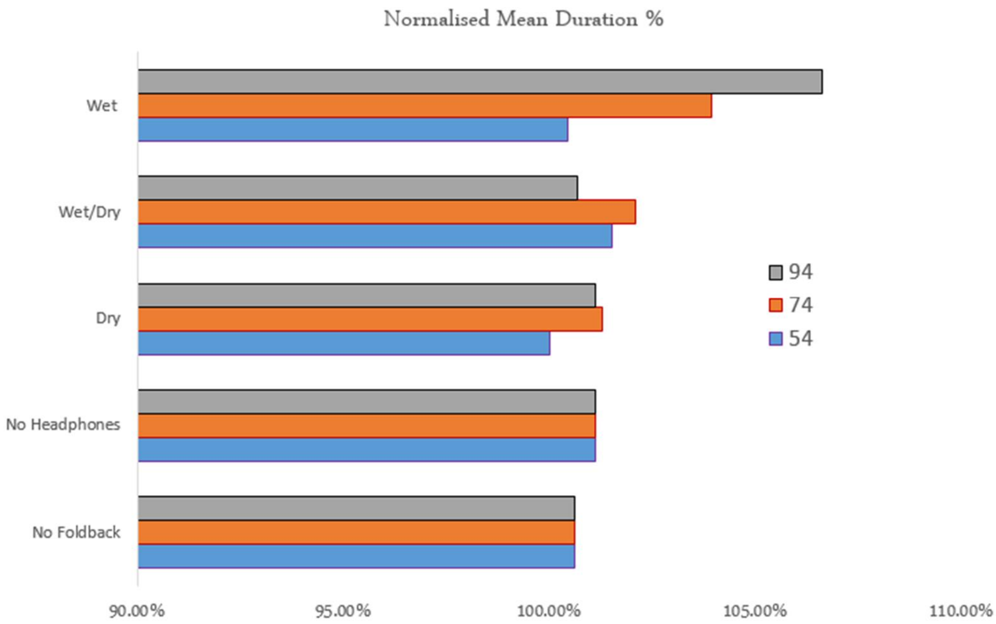

Figure 3 - Variation in mean duration.

3.2 Sound Pressure Level

Sound pressure level was calculated using an average RMS level of the digital signal, again from the voice onset of the first word to the onset of the last word. The variation of average RMS from the reference recording was calculated in decibels for each recording (figure 4).

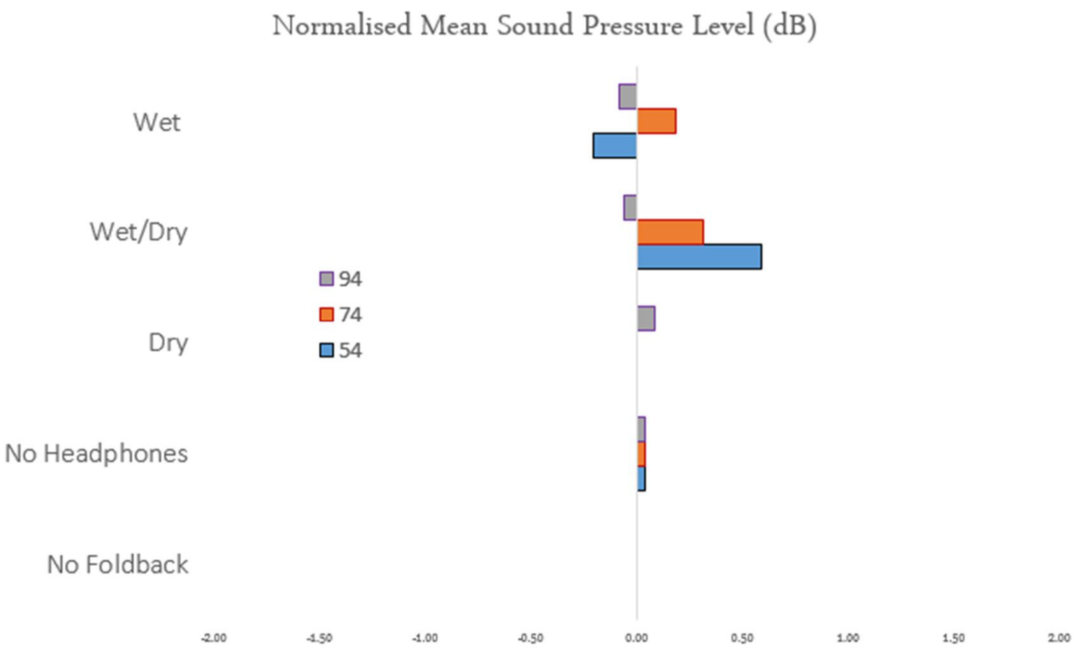

Figure 4 - Variation in mean sound pressure level

3.3 Long Term Average Spectra.

Long term average spectra were measured using a MATLAB script for each recording, again from voice onset of the first note to voice onset of the last note. LTAS were averaged across all takes and all subjects for each condition and are shown in figure 5.

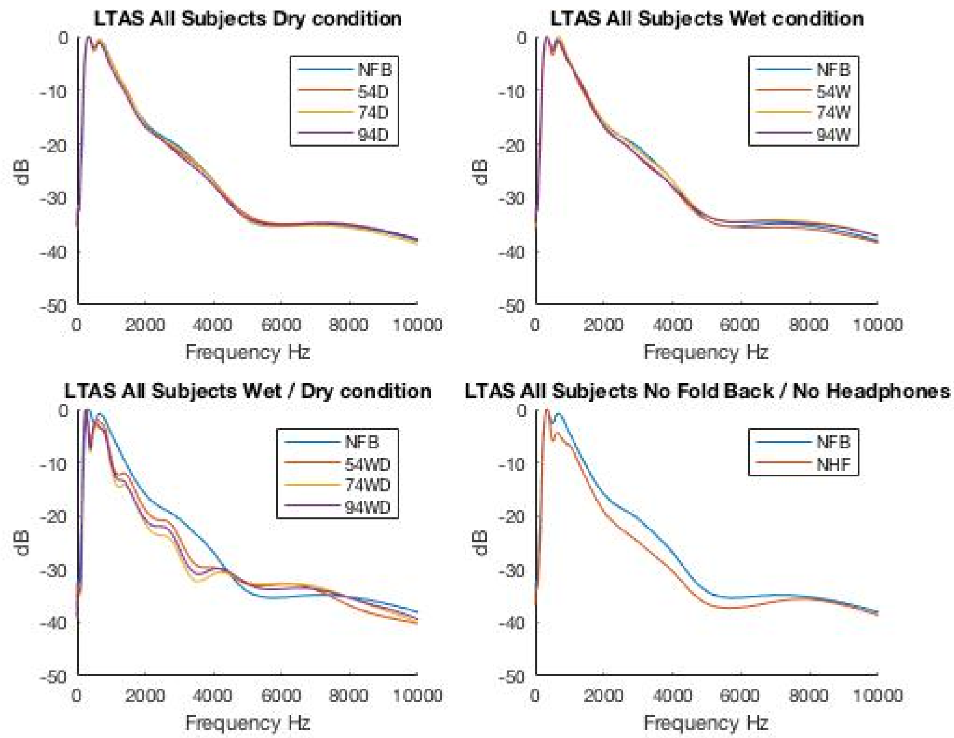

Figure 5 - LTAS for all conditions and levels

4 DISCUSSION

When all subjects were averaged there was an overall increase in duration from the least reverberant condition (no foldback, headphones on, in which the ear is occluded) to the most reverberant condition for the 74 and 94 dB_{SPL} levels, with an increase of 6% in the mean duration for a 100% wet signal at 94 dB_{SPL}, and an increase in 4% for a 100% wet signal at 74dB_{SPL}. Both 74 dB_{SPL} and 94 dB_{SPL} foldback levels exhibited a positive correlation between reverb state and duration (R^2 of 0.5 for 94 dB_{SPL} foldback and R^2 of 0.86 for 74 dB_{SPL}). There was no correlation between duration and reverb setting for foldback presented at 54 dB_{SPL}.

This suggests that the presence of reverberation affects the tempo of performance, and corresponds with the results of other studies (6) (12) which found that more reverberant acoustic environments led to singers performing at a slower tempo. This could suggest that singers in a reverberant acoustic slow down to improve the clarity of their own perception of the note, so that they are 'interacting' with the virtual acoustic, in much the way that singers interact with a real space.

When the mean sound pressure level of the voice for all subjects under each condition are averaged, there is no overall correlation between average sound pressure level and either reverberation condition or foldback level. There is however a measurable variation in sound pressure level for the

Wet/Dry condition between the three foldback levels, with voice sound pressure increasing by around 0.7 dB at the 94 dB_{SPL}.foldback level in this condition. This is a very small change, and the difference between the measurements at the 54 and 94 dB_{SPL} foldback levels are not significant ($p<0.05$). However, although the mean differences are low, there is a marked variation in level between the voice sound pressure level with 54 dB_{SPL} foldback, with an increase of 0.7 dB to the Wet/Dry condition, and a reduction of 1dB between Wet/Dry and Wet reverberation. This runs contrary to studies based on real rather than simulated acoustics (6), (12) in which sound pressure level was found to increase significantly in an anechoic environment. However this may be down to individual variability, particularly between trained and untrained singers, and further investigation is required to ascertain the relationship between training and this parameter.

Once averaged across all subjects, there is little variation in LTAS across the different foldback levels in each reverberant condition (figure 5). The condition for which a noticeable change in spectral energy is observed is in the LTAS for the Wet/Dry reverberation, in which an additional three peaks are present below 5kHz compared to Dry, Wet and No Foldback / No Headphones. These results are reflected in the findings for voice sound pressure level where there is a difference in sound pressure level for the Wet/Dry condition compared to the other reverberation settings. This is particularly apparent with a notable increase in mean voice sound pressure level at the 54dB_{SPL} foldback and a small decrease in sound pressure level at the 94dB_{SPL} foldback. The Wet/Dry reverberation condition also presents the least consistent LTAS and voice sound pressure level results across the levels, whilst for the other conditions there is little difference between LTAS results with different levels of foldback. The LTAS and voice sound pressure level results could be directly connected, in that the increased variation in sound pressure level production with the Wet/Dry condition causes the variability in the spectral content of the sound produced, reflected in the LTAS results. However, the consistent pattern of peaks observed in all Wet/Dry LTAS curves compared to the positive and negative differences in voice sound pressure level for the same conditions suggests that there are spectral characteristics specific to the Wet/Dry condition independent from sound pressure level. This may be due to vocal timbre or other performance parameters, such as level and duration of consonant production. Further analysis is needed to consider the implications of the performance elements contributing to these results.

The consistency of LTAS and sound pressure level results in the most extreme environments would seem unexpected, in that there is no obvious link between increasing level or depth of reverberation and performance. However, the use of the anechoic/hemi-anechoic space to perform this experiment means that the condition with no headphones does not necessarily elicit a ‘natural’ performance: removing the headphones places the performer in an unnaturally dry and alien acoustic (12). Similarly, the extreme conditions produced in this study (100% Wet, 94dB), would represent an unusual real performance environment. These finding are also consistent with previous studies in this area: When analysing cello performance in different acoustic environments, researchers found that tempo and timbre were similarly affected by reverberation time, with both short and long reverb times leading to slower tempi and lower timbral bandwidth. In later studies investigating more instruments these authors found highly individual responses to acoustic conditions by performers and suggest that anechoic environments might elicit particular performer responses that skew the potentially linear relationship between reverberation time and tempo (19). Also supporting the findings of similar tempi in very dry and very reverberant conditions, another study by Kalkandjiev *et al* found that the musical material contributed to the impact of the room acoustics on performance (20). The use of only one song in this study restricts the generalisability of the findings: However, the direct comparison of the same material across all subjects and conditions provides robust data to test the hypothesis of this study.

5 CONCLUSION.

The results indicate that certain elements of the performance were affected by changes in the foldback provided to the subjects of this study. However, that both the level and reverberation ‘wetness’ independently affect the measured parameters of performance, as was hypothesised, is not clear from the data analysed. Initial analysis, as presented in this paper, suggests that the wetness has more of an impact on the performance than the level and that extremes of foldback condition (including none in an anechoic environment) were treated similarly by this cohort of subjects. The findings of this experiment illustrate the need for more research in this area, with a particular focus on performance parameters affected by different foldback conditions and the impact of different singing styles and levels of experience, which could have direct implications on recording environments and studio techniques utilised for the singing voice.

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