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Further investigation of ensemble singers' preferred sound fields

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ABSTRACT

In the winter of 1984 Sir Harold Marshall spent a sabbatical leave from the University of Auckland in a joint research project with Prof. Dr. Jürgen Meyer in the Musical Acoustics section of the Physikalisch-Technische Bundesanstalt (PTB) at Braunschweig in Germany. That study explored the preferred acoustical environment of vocal ensembles. The preference for the reverberated field vanished if the 'reflections' were centred around a delay of 40 ms. This paper reports efforts to repeat that experiment but in a different laboratory, as suggested by Prof. Lothar Cremer.

Compared to the PTB study, the experiments as carried out in the laboratory from Auckland University (AU) have led to some similar but also some other insights regarding the singers' preferred sound field. Although a slightly different methodology has been used for the AU experiment, the '40ms effect' seems to be present for ease of ensemble. However, it does not seem to be as strong as in the PTB experiment. To get a better understanding of these results, the authors of this paper intend to perform a similar experiment in a more realistic environment in which actual stage elements can be moved to create different delays instead of simulating delays and levels.

Keywords: Singer, Ensemble, Stage

We dedicate this paper to the memory of Professor Claus Ocker whose voice provided the source for measurements on directivity in 1984. He sang arpeggios, over two octaves, with three different vowels and two different vocal styles in anechoic conditions, and for two hours. A feat! He died in 2015 at the age of 92.

1. INTRODUCTION

The acoustical conditions on stage preferred by musicians and singers for symphonic music and small vocal ensembles have been thoroughly investigated through objective measurements and subjective experiments since the mid '70s. These researches indicate that appropriate early reflections are essential for performers on stage. These early reflections are provided by the stage environment, including the stage floor and potential risers, the stage walls, the stage ceiling and potential (overhead) reflectors.

One of those researches on singers' preferred stage acoustics is discussed in the paper "The Directivity and Auditory Impressions of Singers" (1) by A.H. Marshall and J. Meyer. It focuses on addressing the singer's comfort and ease of ensemble. The directivity of professional singers in anechoic conditions was measured. In a separate experiment, the auditory impression of singers in vocal ensembles and as soloists was explored. The obtained results from those experiments indicated that while the early reflections are so important to instrumentalists, the singer's auditory impression is dominated by reverberation. The sound fields with reverberation were strongly preferred, 'with or without reflections', except for a 40 ms delay of reflections relative to the direct, when the preference for the reverberated field disappeared.

The 40 ms delay corresponds with a 13.7 m delay distance. Any objects in the close stage environment, in particular overhead reflectors, could cause a 13.7 m delay. The reduced preference at 40 ms could have significant architectural implications. Therefore, it is important to get a better understanding of this effect.

Prof. Lothar Cremer suggested that the same experiment be performed in a different laboratory to eliminate the possibility that the '40 ms effect' was an artefact caused by the laboratory. This paper reports the efforts to repeat the experiment to explore the acoustical environment of vocal ensembles in a different laboratory.

2. EARLY REFLECTIONS ON STAGE

Various researches discuss the preferred acoustic conditions on stage for singers and musicians, based on measurements and questionnaires. They all conclude that early reflections on stage are preferred.

In the paper "The Directivity and Auditory Impressions of Singers" (1) assessments of 'ease of singing' and 'ease of ensemble' were solicited for two groups singing in anechoic conditions but supported by synthetic sound fields which simulated realistic stage conditions. Various stage configurations were created by acoustic delay and level of 'reflections' plus reverberated signal - all close-miked from the participants. In general, the reverberated fields were strongly preferred with or without the simulated reflections except when the delay of the reflections was about 40 ms. Then the preference for the reverberated field vanished. See also Figure 1.

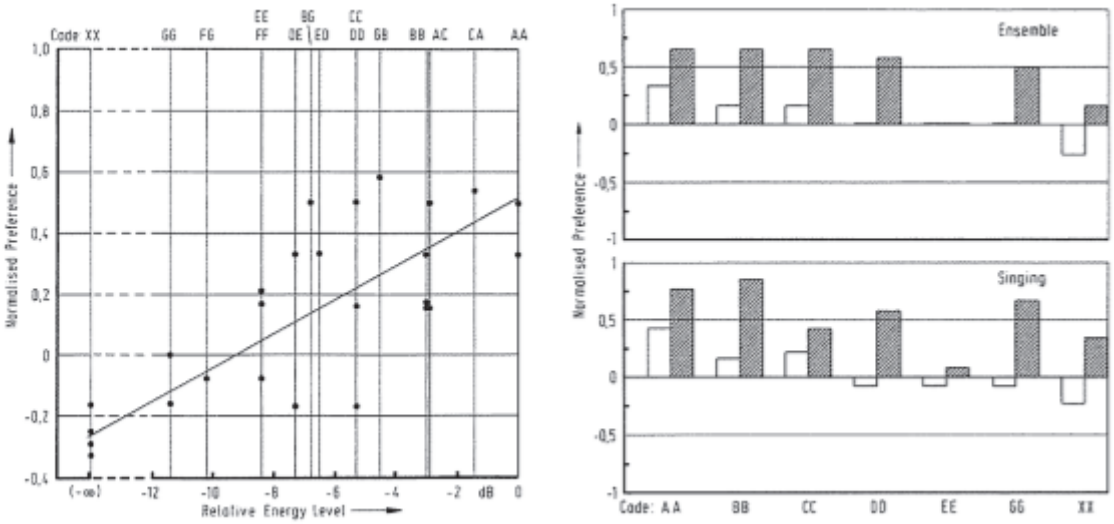


Figure 1 – Figure 11 and Figure 12 from (1). Left: Normalised preference (ensemble) for the quartette for reverberation-free simulated reflections; Right: Normalised preference for the quartette for sound fields with (dark areas) and without (light areas) reverberation component.

This effect seemed to be so strong and independent of group size and reflection configurations (symmetrical or asymmetrical) that further investigation was carried out by varying the Reverberation Time and onset delay time. Similar results were found. The conclusion was that "energetic early reflections do contribute positively to the singing comfort if they are early enough but at about 40 ms delay reduce preference well below that of a reflection-less reverberant field".

In Figure 2, from "Acoustics and the Performance of Music" by J. Meyer (2), the delay of reflections is presented for different distances between musicians and distance to wall/ceiling elements. This figure summarises results from several authors. For short distances between musicians (such as one would expect in quartets), unfavourable reflections are indicated at 10 ms and 40 ms, and favourable at 20 ms (to 35 ms).

D. Noson et al conclude that the preferred delay averages 20 ms, when singing faster-tempo music (4). They also concluded that the consensus of preference is statistically significant when singing fast-tempo music, while with a slow-tempo piece the singers were not consistent in their judgment of preference.

Although the singers in the experiment for the paper "The Directivity and Auditory Impressions of Singers" were in the same room, there was no usual visual contact between the singers. The ease of playing for musicians without visual contact was investigated by A. Gade in (3). Unlike the singers in the experiment who also seemed to like the reflections at 60 ms, the musicians' preference for sound fields with reflections decreased with the delay time of the reflections, and the sound fields with reflections fell into disfavour after 35 ms. See also Figure 3.

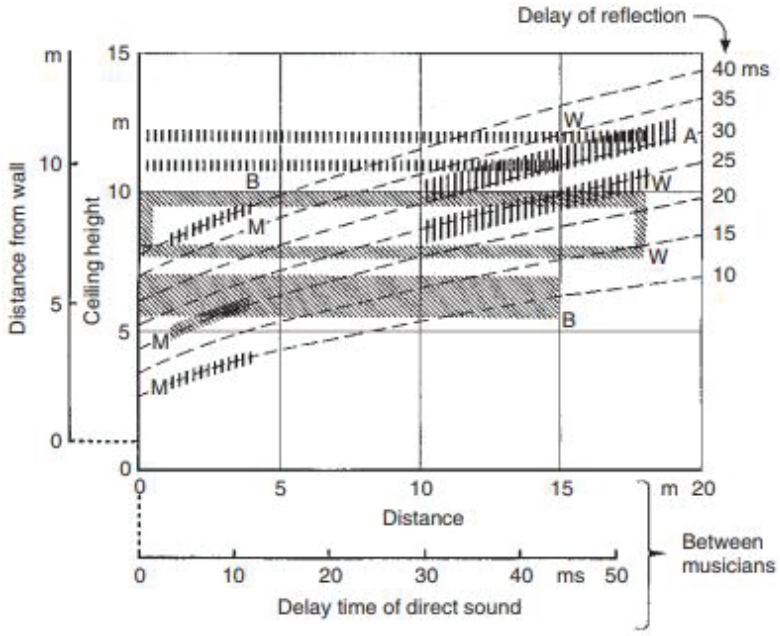


Figure 2 – Fig 6.12 from (2): Influence of hard reflection surfaces on mutual hearing (after Allen, 1980; Barron, 1978; Marshall and Meyer, 1978; and Winkler, 1979). Angled shading: favorable reflections; vertical shading: unfavorable reflections

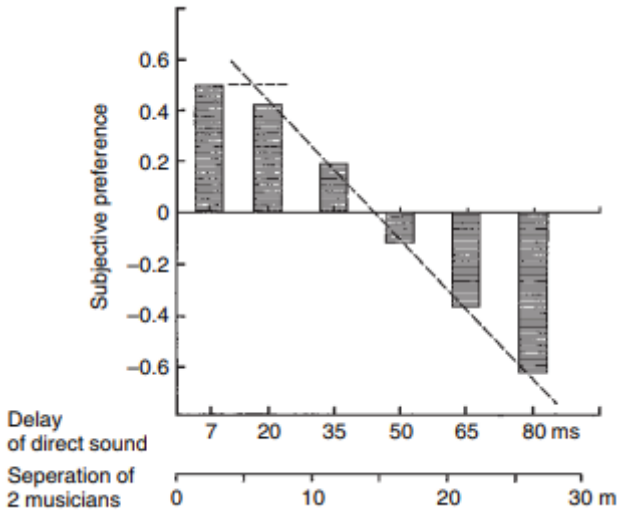


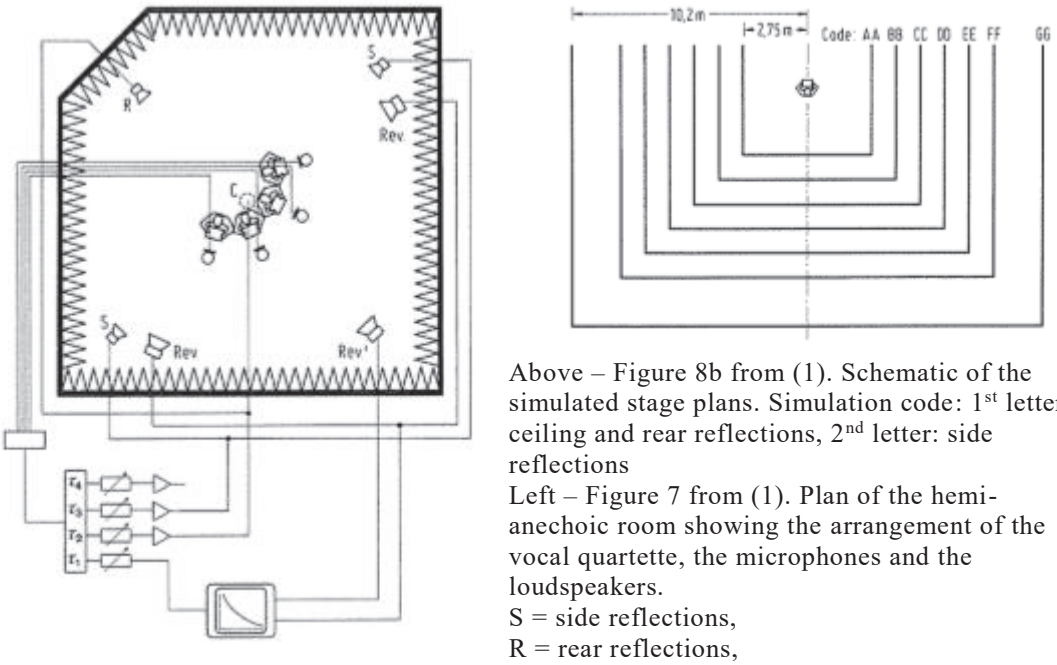
Figure 3 – Figure 7.2 from (2): Ease of playing together without visual contact, in dependence on distance between performers (after Gade, 1989a (3))

3. METHODOLOGY

The experiments for the paper "The Directivity and Auditory Impressions of Singers" (1) were carried out in the hemi-anechoic room of the Physikalisch-Technische Bundesanstalt (PTB) at Braunschweig in Germany.

35 years later the experiment was repeated in the laboratory at Auckland University (AU) in New Zealand. Most of the original measurements' setup has been maintained, with a few alterations due to technical developments and new insights since the original work.

For both experiments, a digital delay-line simulated side, overhead and rear reflections corresponding to a variety of stage sizes (AA-GG: 15-60 ms delay relative to the direct sound), with configuration XX representing 'no reflections'. While the reverberance started abruptly at 85 ms in the PTB experiment, it was decided to gradually (envelope time 15 ms) introduce the reverberance in the AU experiment. An abrupt onset might have been perceived as an additional reflection. Figure 4 shows the measurement setup, with the singers' positions to the sources and receivers and the schematic of the simulated stage plans. Table 1 provides the total delay of the reflections.



Above – Figure 8b from (1). Schematic of the simulated stage plans. Simulation code: 1st letter: ceiling and rear reflections, 2nd letter: side reflections
Left – Figure 7 from (1). Plan of the hemi-anechoic room showing the arrangement of the vocal quartette, the microphones and the loudspeakers.
S = side reflections,
R = rear reflections,
C = ceiling reflections,
Rev, Rev' = reverberation.

Figure 4 – Schematic of the layout (left) and simulated stage plans (above right), for both PTB and AU experiments

Table 1 – Total delay of reflections in ms

Code	XX	AA	BB	CC	DD	EE	FF	GG
Total Delay	-	16.25	22.5	28.75	35	41.25	47.5	60

Delayed signals were presented at levels consistent with the spherical divergence relative to each delay time. For the AU experiment, the reverberant portion of the signal had a 1.5 s mid-frequency reverberation time, and was presented at a level 12 dB lower than the driving source heard at a distance of 1 m – consistent with the reverberant level for a 4000 m^3 concert chamber with that reverberation time.

Directional microphones were placed 0.2 m in front of each singer, instead of 0.5 m in the PTB experiment. The target reverberant level at greater microphone distances could not be achieved without significant regeneration of the signal.

For the AU experiment, the configurations AA to GG and XX were presented in six rounds in a random order (in total 48 trials), randomly with and without reverberation. During the experiment, singers faced away from each other to maximise dependence on the simulated 'reflected' sound. Approximately 30 seconds were sung from the quartette "Elijah-15" by Mendelssohn. After each presentation, the four singers rated the 'ease of singing' and 'ease of ensemble' on 7-points scales. Due to the type of questionnaire and the restricted number of trials for each configuration, median values have been calculated for the responses in the AU experiment. Figure 5 shows the singers in the PTB experiment (left) and the AU experiment (right).

Figure 5 – Left: Singers in PTB experiment (1); Right: Singers in AU experiment

4. RESULTS

4.1 General observations

The general observations for the experiment in AU are quite similar to the general observations as discussed in (1) for PTB. These are as follows: the singers seemed to prefer the reverberant conditions, and found that singing in ensemble was possible without it but more challenging than in normal situations.

4.2 Ease of singing

For the ease of singing, it is clear that the trials with reverberation were rated with a higher score than the trials without reverberation. See also Figure 6, which includes the median ratings and all responses as given by the singers. The singers rated the trials with reverberation (indicated by black shapes in Figure 6) as 'good' to 'very good', and the trials without reverberation (white shapes) as 'mediocre' to 'reasonable'.

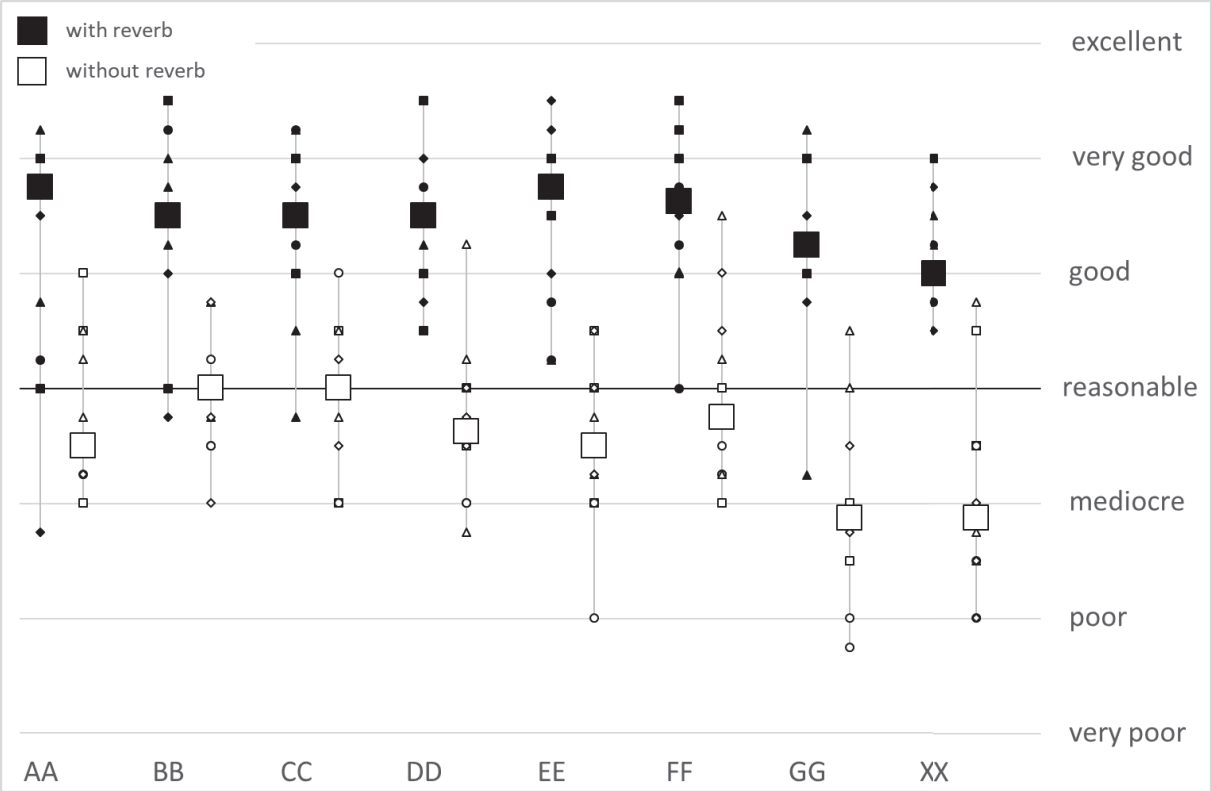


Figure 6 – Ease of singing median ratings (indicated by big black and white squares), including all responses, as given by the singers

Configuration GG (with delayed reflection at 60 ms) and XX (no reflection) with and -in particular- without reverberation were given the lowest rating. In fact, GG received almost the same rating as having no reflections at all (XX) for ease of singing. Some other observations are:

- For configurations BB (with delayed reflection at 22.5 ms) and CC (28.75 ms), the difference between the median values for with and without reverberation is the smallest (reasonable to good / very good).
- For configuration GG, the difference between the median values with and without reverberation is the biggest (mediocre to good / very good).
- The ratings for configuration XX with reverberation and BB without reverberation seem to be the most consistent (i.e. smallest difference between minimum and maximum).

4.3 Ease of ensemble

The difference between with and without reverberation for 'ease of ensemble' (median values) is much smaller than for 'ease of singing'. The trials with reverberation are rated as 'reasonable' to 'good', and without reverberation as 'mediocre' to 'good' (most: 'reasonable'), as can be seen in Figure 7.

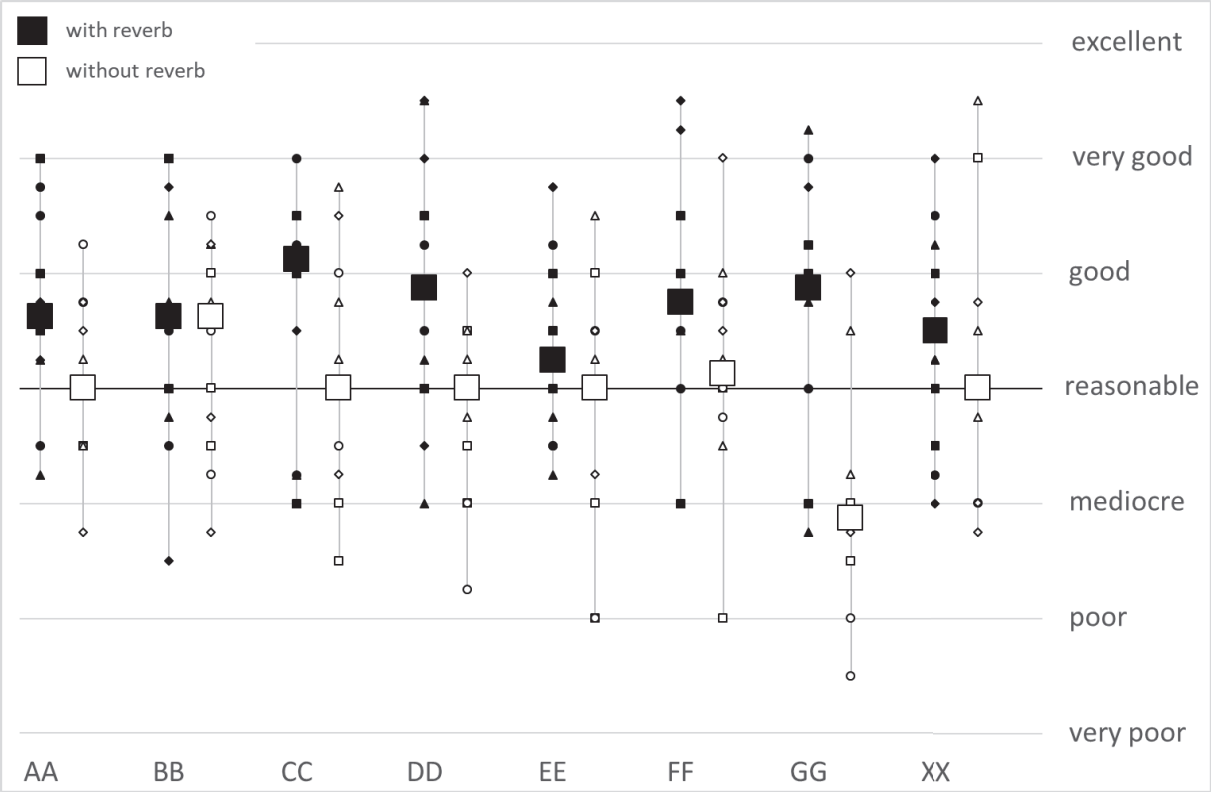


Figure 7 – Ease of ensemble median ratings, including all responses, as given by the singers

Configuration EE (reflection at 41.25 ms delay) with reverberation seems to have the lowest rating for 'ease of ensemble' compared to the other measured configurations. Some other observations are:

- The difference between 'with reverberation' and 'without reverberation' is largest for configuration GG (with delayed reflection at 60 ms), and smallest for configuration BB (22.5 ms) and EE (41.25 ms) ('reasonable to good', respectively 'reasonable').
- It is clear that -of the tested delays- a sound field without reverberation is least preferred for reflections arriving at 60 ms delay relative to direct (configuration GG). Having no reflections at all even receives a higher median rating than these 'late' early reflections.
- Early reflections at approximately 28.75-47.5 ms delay (CC to FF) seem to be the most preferred for ensemble in fields with reverberation, with the exception of 41.25 ms.

The latter may have implications for stage design: introducing elements providing reflections at the 30-35 ms delay (5-6 m surface distance) is recommended, whereas elements providing reflections at 40 ms delay (7 m surface distance, such as ceiling reflectors) may not contribute to the ease of singing and ensemble.

4.4 Evaluation of responses

There is a moderate to strong correlation between 'ease of singing' and 'ease of ensemble' for all AU trials (0.61). The ratings from three singers seem to correlate strongly (0.65-0.71) for 'ease of singing' and 'ease of ensemble', from one singer weakly (0.40).

The correlation between 'ease of singing' and 'ease of ensemble' for configuration BB, CC, DD, EE and GG is strong to very strong for the trials with reverberation (0.75-0.90), and weak to moderate for configuration AA, FF and XX (0.38-0.46). For the trials without reverberation, the correlation is very weak to moderate (0.19-0.57) for most configurations, except for GG and XX (0.81-0.84, very strong). From this we conclude that only one judgment was being made for most of the trials 'with reverberation', and two judgments for most of the trials 'without reverberation'.

As can be seen in Figures 6 and 7, the individual responses for each configuration vary. It is not yet clear what has caused this spread. An increase of trials per each configuration may reduce the spread, and increase the reliability of the results. This will need to be further investigated.

4.5 Comparison with results from "The Directivity and Auditory Impressions of Singers"

The correlation between the judgments of 'ease of singing' and 'ease of ensemble' for all trials is stronger for the PTB experiment (0.82-0.90, i.e. very strong) than for the AU experiment (0.61, i.e. moderate-strong).

While the responses in the PTB experiment have been presented as normalised preference values (see Figure 1), the results from the AU experiment are presented as median values. It makes exact comparison slightly more difficult, but strong effects can still be compared.

Both experiments indicate that the sound field with reverberation (dark areas) is strongly preferred and well rated for singing. For most configurations, the results from the AU experiment also indicate a preference for reverberation for ensemble, but it seems to be less strong than in the PTB experiment.

For 'ease of ensemble' in both experiments, there is little difference between a sound field with and without reverberation for reflections at approximately 40 ms delay relative to the direct. Additionally, configuration EE (reflection at 41.25 ms delay) with reverberation has the lowest rating for the AU ensemble response. A similar effect was found in the PTB results (disappearance of preference for reverberation at 40 ms delay), but which was far stronger than in the AU results.

The effect at about 20 ms (BB) in the AU experiment, i.e. same rating for with and without reverberation, does not show in the PTB experiment. Other researches (2, 4) indicate the preference of singers for about 20 ms delay relative to the direct.

5. DISCUSSION

5.1 Acoustic environment of experiments

Although the benefit of a laboratory is that the acoustic environment can be controlled, there are still a few aspects that could influence the singers' response, and therefore the outcome of the experiment.

One would be the simulations of the sound field by using software, introducing only one reflection and onset of reverberation time at certain levels. While the gently introduced reverberation in the AU experiment may be more realistic than a sudden onset (as used in the PTB experiment), it is still quite artificial. It is uncertain exactly what level of presentation of delay and reverberance was used in the original experiment. Our difficulty obtaining sufficient gain before feedback to achieve a representative reverberant level at the 0.5 m microphone distance as used in (1), suggests that the presentation of delays and reverberance in the AU experiment may have been louder than the original experiment (1).

Another aspect would be the visual environment, in which the experiment takes place. A hemi-anechoic room is visually an entirely different environment than on a real stage. The quartet layout with the singers facing away from each other is also less realistic and could influence the ease of singing and ensemble.

The authors of this paper intend to perform a similar experiment in a more realistic environment in which actual stage elements can be moved to create different delays instead of simulating the delays and levels.

5.2 Difference in methodology

Exact comparison of the AU results with the PTB results is challenging, due to a slightly altered test procedure, different test subjects and different evaluation and presentation of the singers' responses. The (visually) large variation in the singers' response for the same configuration asks for further investigation into the consistency and reliability of the singers' responses related to the experiment's setup and variables.

6. CONCLUSION

Prof. Lothar Cremer suggested that the same experiment as reported in (1) be performed in a different laboratory to eliminate the possibility that the '40 ms effect' was an artefact caused by the laboratory.

Efforts to repeat that laboratory experiment (1), to explore the acoustical environment of vocal ensembles in a different laboratory (i.e. the Auckland University laboratory), has led to some similar but also some other insights regarding the singers' preferred sound field compared to the PTB study.

6.1 Experiment in Auckland University laboratory

For the ease of singing, it is clear that the trials with reverberation were rated with a higher score than the trials without reverberation.

The sound field with delays arriving at 60 ms after the direct sound (configuration GG) was the least preferred of the tested sound fields without reverberation, for both ease of singing and ease of ensemble.

For ease of ensemble, configurations BB (22.5 ms) and EE (40 ms) received a similar rating for the sound field with and without reverberation. This effect is not clearly present in the results for ease of singing.

The latter two conclusions are based on the median values, and may need some more investigation regarding reliability due to the number of trials.

6.2 Comparison with experiment in Physikalisch-Technische Bundesanstalt laboratory

Although a slightly different methodology has been used for the AU experiment, the ’40 ms effect’ seems to be present for ease of ensemble here. However, it is not as strong as in the PTB laboratory.

Additionally, the AU results also indicate a similar effect at 22.5 ms (BB), i.e. a similar rating for sound field with and without reverberation. This effect did not occur in the PTB laboratory.

While for the PTB experiment, there was a very strong correlation between ease of singing and ease of ensemble, this correlation seems to be less strong for the AU experiment.

7. ACKNOWLEGDEMENTS

We would like to thank the four singers for their participation in the experiments in the Auckland University laboratory. The measurements were made possible by Auckland University and Auckland Testing Service by providing us access to the laboratory and the equipment.

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