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ANALYSIS OF CHANGES TO THE EARLY AND LATE RESPONSE IN AN EXISTING ORCHESTRAL REHEARSAL STUDIO

Peter Exton

Creative Acoustics, 128 Faraday Street, Carlton, VIC 3053, Australia

Abstract

Successful rooms for orchestral and chamber music allow the musicians to balance their own playing as part of the full ensemble. Work by Marshall et al. in 1978 [1] inspired Gade [2] to propose measures in 1989 that addressed these two factors.

Recent work by Kahle [3] has verified that both the early and late room response have a significant effect on what musicians hear and can respond to while playing.

Tuning a 7,500m^3 orchestral rehearsal studio in Brisbane in late 2025 provided an opportunity to analyse the subjective impressions of 70 musicians with repertoire ranging from a Shostakovich symphony to a wind quintet and a string quartet.

The early reflection strength and late room response were independently varied by changing the height and orientation of an existing array of large overstage reflectors and varying the extent of operable absorption banners.

This paper describes the creation of a loosely coupled reverberant volume in the upper part of the studio following the design theory of reflection sequence halls. This was activated by directing some of the early energy from the reflectors.

Subjective responses and objective data have been analysed to provide insight into preferred conditions.

Keywords: *rehearsal studio, orchestra, measurements, impressions from musicians, tuning*

***Corresponding author**: peterexton25@gmail.com*

1. Introduction

This project was commissioned by the Queensland Symphony Orchestra with the goal of establishing preferred settings in the studio for different musical uses.

The analysis presented below extends an earlier presentation [4] which was limited to the subjective responses from the musicians.

2. The studio

The studio is a rectangular shoebox form approximately 28m x 21m x 14m. It has raked upholstered seats for an audience of 206 at one end, facing temporary orchestral risers for woodwind, brass and percussion sections on the flat floor area. The design of this studio satisfies the recommendations of ISO 23591: Acoustic quality criteria for music rehearsal rooms and spaces for a symphony orchestra of up to 80 musicians.

The studio has the following finishes:
- Lower level walls - moderate diffusion to a- height of 4m formed from timber battens
- Mid-level walls – non-parallel plasterboard facets
- Ceiling – areas of low frequency absorbers
- Floor - timber

Additional drapes were installed to provide absorption behind the percussion and brass sections.

Operable finishes in the studio included:
- 4 large, curved reflectors each approx. 15m x 3.5m suspended above the flat floor
- Double layer roller banners with a drop of 5m on the upper walls.

The reflectors are nearly full width. They are installed on chain motors and can be raised to a height of 11m and tilted ± 15 degrees from the horizontal.

The studio is used for:

- Rehearsal of the full orchestra (up to 80 musicians plus choir as required)
- Performance of chamber music (including chamber orchestra of 30 musicians, string quartet, wind quintet, brass quintet)

The studio is illustrated in Figure 1.

Figure 1. Photo of the studio showing the large reflectors above the orchestra and deployed absorption above the audience seating.

3. Acoustic analysis

A previous acoustic survey conducted by us showed that varying the height of the reflectors and extent of absorption changed the measured parameters as shown in Table 1. The values shown are for mid frequency averaged for the same source and 4 receiver positions for each configuration, measured in general accordance with *ISO 3382-1:2009 Acoustics – Measurement of room acoustic parameters – Part 1: Performance spaces.*

Table 1. The range of parameter values with varied configurations of reflectors and absorption measured during the previous survey.

Configuration	T (s)	C80 (dB)	Ts (ms)	ST Early (dB)	ST Late (dB)
Full absorption, low reflectors	1.1	4.1	65	-12.8	-16.2
Full absorption, high reflectors	1.1	3.9	65	-17.0	-18.0
No absorption, high reflectors	1.6	1.3	99	-16.4	-14.4
50% absorption, intermediate reflectors	1.3	2.6	77	-14.5	-15.5

The survey showed that:

- The changes in configuration led to wide variation in parameters.
- The reverberation time T correlates with the extent of banner absorption
- The clarity C80 and corresponding centre time Ts varies with the height of the reflectors
- The early support ST Early varies with the height of the reflectors
- The late support ST Late varies with both the height of the reflectors and the amount of exposed absorption.

The orchestra had recently been using the studio with all the reflectors at a height between 7.5 and 8.5m tilted towards the centre of the orchestra, and the upper wall absorption fully deployed as shown in Figure 1.

A 3-D model of this original setting as shown in Figure 2 was constructed to illustrate the coverage of early reflections.

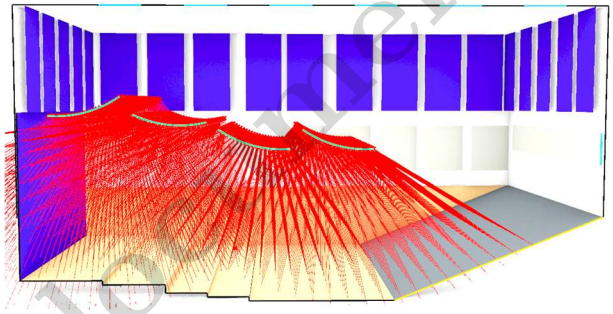

Figure 2. Coverage from the original reflector positions illustrated in a 3D model of the studio.

It was observed that the reflectors created a loosely coupled volume above the musicians. Figure 2 indicates that early sound energy doesn't easily flow into this upper volume and it can be readily absorbed when it gets there.

Members of the orchestra described the sound quality in this original setting as:

- Too muddy and loud
- Harsh and unappealing
- Difficult to achieve a warm blend
- The deadness of the acoustic entices many players to force their sound
- The sound becomes too loud and overpowering
- People feel like they need to play louder to hear themselves which further decreases their ability to hear others.

These comments are consistent with excessively strong early response from the overhead reflections and a weak late response in the studio.

The orchestra management was aware of the high sound levels for the musicians and on their recommendation the use of earplugs during rehearsals was widespread.

4. Tuning strategy

The strategy to change the acoustic conditions for the musicians involved:

- Varying the intensity of the early reflected sound - by tilting and raising the reflectors
- Increasing the energy in the reverberant field in the upper part of the studio volume - by directing and retaining more reflected energy there.

8 additional settings were created. These involved the different reflector heights and amounts of absorption in the volume above the orchestra shown in Table 2. All of them angled the reflectors to project early sound more evenly into the studio and removed the absorption above the fixed audience seats.

Table 2. Details of the different settings used in the tests with musicians.

Setting	Reflector height	Reflector angle	Audience banners	Orchestra banners
0 Original	Varied between 7.5m – 9.0m	Varied between -15º and +15º	100%	100%
1	8.5m	+15º	0%	100%
2	Raked between 6.5m and 9.5m	+15º	0%	50%
3	Raked between 7.5m and 9.0m	+15º	0%	50%
4	11m	+15º	0%	50%
5	9.5m	+15º	0%	50%
6	10.5m	+15º	0%	50%
7	8.5m	+15º	0%	50%
8	7.0m	+15º	0%	50%

Setting 7 with its distribution of early reflections is shown as Figure 3.

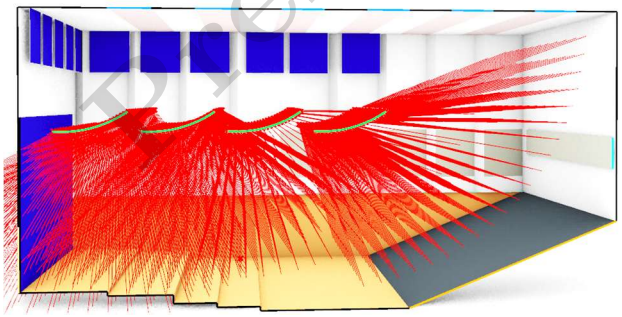

Figure 3: Reflection study for setting 7.

The orchestra musicians were scheduled for two full days of rehearsal in the studio while different settings were tested.

Six different groups of musicians took part:

- Chamber orchestra of 30 string players
- String Quartet
- Brass quintet
- Wind quintet
- Large orchestra (81 musicians)
- Classical orchestra (47 musicians)

Each group repeated repertoire with several different settings selected from those shown in Table 2.

All groups started with the same original setting shown in Figures 1 and 2.

5. Responses

Feedback was received from the musicians in discussion during the tests. The evaluations were formalised using written questionnaires which included sliding scale evaluations on reverberance, clarity, projection and overall acoustic impression. Musicians were encouraged to provide additional comments and impressions of the different configurations.

Preferred settings were determined by averaging the values of the sliding scale responses. These are indicated in the highlighted rows in the Tables below.

5.1 Chamber orchestra

Repertoire:
Shostakovich Chamber Symphony Op. 110a

4 settings were tested with the chamber orchestra.

Table 3. Measured parameters for the settings used for the chamber orchestra – Setting 1 is the preferred.

Setting	T (s)	C80 (dB)	Ts (ms)	ST Early (dB)	ST Late (dB)
0	1.00	5.9	52.3	-12.1	-14.1
1	1.08	6.0	55.2	-13.1	-14.7
2	1.17	5.2	60.8	-12.7	-14.5
3	1.16	5.3	59.8	-13.0	-15.0

Selected comments from the musicians from the chamber orchestra are shown in Table 4.

Table 4. Representative comments from the chamber orchestra musicians.

Setting	Comments from musicians
0	Less ensemble clarity - could hear myself a lot Feels loud under the ear, like it's not projecting to the audience Hard to hear the violins from the violas Hard work - sounds like the pit
1	Seems the best

	A lot fuller and more vibrant. Easier to hear others parts of the ensemble. Perhaps not as crisp? It still feels a bit dry but the clarity is great More clarity Much easier to hear but not too loud
2	Less reverberant than 1 but clearer. Less big ensemble sound than 1 Dryer - I can hear the announcements more clearly
3	Felt less resonant overall. Ensemble less homogeneous. Felt slightly muddier - more resonance but less clarity Clarity probably better, definitely better than original Lots of energy in the room

Setting 1 increased the blend of the ensemble and allowed the musicians to hear their own sound as part of the group. This is indicated by a longer reverberation time T and lower early stage support ST Early.

Settings 2 and 3 involved raking the reflectors creating a ceiling that was lowest at the rear of the ensemble. Overall, this increased subjective clarity, particularly for setting 2. Raising the reflectors 1m for setting 3 increased the room presence compared to setting 2 but with reduced subjective clarity.

5.2 String Quartet

Repertoire:
Mendelssohn Quartet No. 2 in A minor Op. 13

3 settings were tested with the string quartet.

Table 5. Measured parameters for the settings used for the string quartet – Setting 7 is the preferred.

Setting	T (s)	C80 (dB)	Ts (ms)	ST Early (dB)	ST Late (dB)
0	1.00	5.9	52.3	-12.1	-14.1
1	1.08	6.0	55.2	-13.1	-14.7
7	1.15	4.9	61.2	-12.7	-14.3

The comments from the members of the quartet are shown in Table 6.

Table 6. Comments from the members of the string quartet.

Setting	Comments from musicians
0	Unsupported, no blend, no depth Felt like 4 individual players, unable to blend
1	Missing support in soft passages, bass resonated warmly, treble thin Much better, could blend more easily Definitely better, fuller, warmer but still clear
7	Very forgiving, well supported, easy to sink into the sound Nicest, the room gave back Preferred this more reverberance, could explore softer dynamics more Easier to play softer, more clarity, more support

Removal of some of the absorption in the upper chamber created above the reflectors between settings 1 and 7 resulted in;

- Slightly increased reverberation time T
- Decreased C80 (1 difference limen)
- A small increase in the support parameters (0.5 difference limen)

However, the combination of these factors was strongly audible and welcomed by the musicians.

The studio became significantly more responsive.

5.3 Brass Quintet

Repertoire:
Carols and short band pieces

5 settings were tested with the brass quintet by adding more extreme settings of the reflector heights.

Table 7. Measured parameters for the settings used for the brass quintet – Setting 7 is overall the preferred.

Setting	T (s)	C80 (dB)	Ts (ms)	ST Early (dB)	ST Late (dB)
0	1.00	5.9	52.3	-12.1	-14.1
1	1.08	6.0	55.2	-13.1	-14.7
7	1.15	4.9	61.2	-12.7	-14.3
8	1.17	5.6	56.2	-11.7	-14.3
4	1.24	4.9	63.4	-13.7	-14.5

The comments from the brass quintet are shown in Table 8.

Table 8. Comments from the members of the brass quintet.

Setting	Comments from musicians
0	Loud but not resonant Lots of my own sound but not in a good way. Very bright and loud. Softs aren't easy. Everything is a little too bright and loud. Very hard to get a good pianissimo and it sounds overwhelmingly loud very quickly.
1	Better but still too bright and very loud. It has more resonance and it is easier to hear the ensemble. Definitely better than setting 0. Brightness has relaxed, ensemble is better. A little easier to play in. Still very loud with limited dynamic range.
7	Best so far. Much more resonance and less brightness. Can hear the ensemble well, both soft and loud.

	Best one yet. The ensemble sounds rich and warm. It's easy to play!
8	Lost some warmth. Very clear though. Not quite as good as the previous.
4	Nice to play in. Maybe good for a large brass ensemble. Enjoyable - easy to play. Very reverberant. Also very good. Clarity is great. Pianissimos easy to play.

As for the string quartet, the musicians of the brass quintet appreciated the additional reverberance of setting 7 which was achieved by reducing the absorption on the walls of the upper volume above the reflectors.

For setting 8 the reflectors were lowered by 1.5m. The clarity and early stage support were increased, but the sense of ensemble and the blend of sound was reduced.

Raising the reflectors to 11m (the maximum allowed by the mechanism) added more energy to the reverberant field, reduced early stage support but retained the C80 of the preferred setting. The blend of instruments and room response was enhanced at the expense of hearing detail of each part.

5.4 Wind Quintet

Repertoire:
Works for wind quintet by Ibert and Malcolm Arnold

The wind quintet tested the same settings as the string quartet.

Table 9. Measured parameters for the settings used for the wind quintet – setting 7 is the preferred.

Setting	T (s)	C80 (dB)	Ts (ms)	ST Early (dB)	ST Late (dB)
0	1.00	5.9	52.3	-12.1	-14.1
1	1.08	6.0	55.2	-13.1	-14.7
7	1.15	4.9	61.2	-12.7	-14.3

Table 10. Comments from the members of the wind quintet

Setting	Comments from musicians
0	Too dry, sound remains within the ensemble
1	This was better than setting 1 but still feels a little dead
7	Can play dynamics easily The best acoustic, lovely resonance, clarity of sound independently and as an ensemble, best blend

As for the string quartet, setting 7 provided more lively and musically responsive conditions which were preferred by the musicians.

5.5 Large Orchestra

Repertoire:
Shostakovich Symphony No. 10, movements 1 and 2

5 settings were tested with the large orchestra. The Shostakovich 10th Symphony was selected because it is one of the largest and biggest sounding works performed recently by this orchestra.

Table 11. Measured parameters for the settings used for the large orchestra – setting 5 is the preferred.

Setting	T (s)	C80 (dB)	Ts (ms)	ST Early (dB)	ST Late (dB)
0	1.00	5.9	52.3	-12.1	-14.1
1	1.08	6.0	55.2	-13.1	-14.7
5	1.19	5.6	58.6	-13.4	-15.1
6	1.20	4.9	63.5	-13.3	-15.5
7	1.15	4.9	61.2	-12.7	-14.3

Due to the large number of responses a few selected representative comments from the 70 returned questionnaires are presented.

Table 12. Selected comments from the members of the large orchestra.

Setting	Comments from musicians
0	Poor balance between sections, too loud in forte Good clarity but too loud. Would be unbearable for a full day Dead, a hard sound quality Bright and overbearing. Harsh and not blending
1	Much better, more reverberance, less overwhelmed in louder dynamics The sound as a whole was more colourful, darker, which made the musicians play better More balanced General sound better and rounder, but more muddy
5	Can hear everyone and didn't need earplugs. People played softer as the room invited dynamics I heard details that I had never heard before, Winds loud without being harsh Best so far, best blend between clarity and ensemble Love it! Definitely heading in the right direction. Way less bright and aggressive
6	A little more muddy, the orchestra more distanced from each other Hard to hear distant instruments, big sound, not strident, less clarity Loud, big sound but ensemble not as good Washy, loud and undefined
7	Too loud, bringing back the aggressive qualities Too loud, not enough space for the sound to flourish Sound hard and oppressed but a bit clearer Some clarity with reverberance - not bad

With the preferred setting 5 we identified a balance between clarity and the blend of the sounds of the many instruments. The intensity of the initial loudness felt reduced, and the conditions allowed an increased range of dynamics and colours without sounding overly loud or harsh.

From this setting raising the reflectors by only 1m to 10.5m resulted in noticeably less clarity despite all the changes in measured parameters being less than 1 difference limen.

Lowering the ceiling to 8.5m (setting 7) was preferred for smaller ensembles but resulted in problems with sound levels and tonal harshness with the large orchestra playing this repertoire.

5.6 Classical orchestra

Repertoire:
Beethoven Symphony No. 6, movements 2 and 3

Table 13. Measured parameters for the settings used for the classical orchestra – setting 1 is the preferred.

Setting	T (s)	C80 (dB)	Ts (ms)	ST Early (dB)	ST Late (dB)
0	1.00	5.9	52.3	-12.1	-14.1
7	1.15	4.9	61.2	-12.7	-14.3
1	1.08	6.0	55.2	-13.1	-14.7

Table 14. Selected comments from the 40 returned questionnaires from the classical orchestra.

Setting	Comments from musicians
0	Dry, no resonance My sound is too bright and isolated No help from the room I find it hard to blend in Harsh and unpleasant Too boxy and loud
7	Warmer More reverberant Some sections lacked clarity Easier to blend and sing but slightly swimming Slightly more resonance but still highlights the roughness
1	Nice clarity, easier to hear It was actually good to play in My sound felt present and a bit edgy. I could hear most things and it wasn't too swimmy.

The preferred setting for the classical orchestra with the Beethoven symphony was the same as that preferred by the chamber orchestra and is consistent with a preference for clarity over the fuller sound quality of a larger number of instruments with more dramatic repertoire.

6. Conclusion

The tests have shown that the acoustic conditions were noticeably changed by reconfiguring surfaces and materials within the studio, and a set of preferred conditions was established for each group.

Directing sound into the upper volume of the studio allowed the strength of the early overhead reflections to be weakened and the acoustic energy redeployed. This resulted in less harshness in the early sound for the musicians and less masking of the later sound.

The reverberant sound level could be controlled by adjusting the absorption above the reflectors and also by changing the volume of the upper loosely coupled space with changes to the height of the reflectors.

Many of the preferred conditions were identified after small changes in the room settings and were associated with changes in parameter values of less than 1 generally recognized difference limen.

We observed some correlation between the musicians' reported impressions and the changes in parameters generated from the limited set of room acoustic measurements.

However, the ability to predict the subjective acoustic response purely from the measured values was not shown. Further data and other studies would contribute to our understanding in this area.

7. Acknowledgments

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