INVESTIGATING CONCERT HALL ACOUSTICS FROM MUSICIANS' PERSPECTIVE: SUMMARY OF RESULTS FROM A SURVEY OF TWO TOURING CHAMBER ORCHESTRAS

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Abstract

Through a collaboration with the Australian Chamber Orchestra (ACO) and their sister group ACO2, subjective musician assessments of the acoustics in sixteen Australian concert venues have been obtained. The musicians were asked to rate venues on key acoustical aspects, including on Reverberance, Hearing Self, Support, Ensemble, Clarity, Warmth, Timbre, Communication with the main Auditorium, Echoes and Overall Acoustic Impression. This work differs from previous subjective stage acoustics studies in several significant respects. First, the sets of venues (8 for each orchestra) were assessed with the same repertoire, and over a short concert tour. This eliminated many variable elements in the assessments, and ensured that the comparisons were made by the subjects within the timespan of good acoustic memory, which is known to be short. Additionally, the chamber orchestra configuration performing without a conductor is postulated to be the ideal medium for such a study. Larger orchestras would rarely work without a conductor; hence many of the ensemble and balance problems that depend on good acoustics become less critical. The results from the two surveys indicate that Ensemble and Support are the most important subjective characteristics for a chamber orchestra, and were highly correlated with the Overall Acoustic Impression. This work is part of a larger project in which these subjective assessments will be used to compare with both traditional acoustic measurements on stage with omnidirectional source/receiver, as well as novel measurements employing a spherical microphone array.

1. Introduction

Previous studies of auditorium acoustics from the perspective of musicians have often lacked a suitable quantity of subjective data from musicians. Often studies have relied on different orchestras assessing different venues (meaning direct comparisons could not be made) and in other cases studies have relied on drawing conclusions from assessments in a very limited number of venues. In this study the Australian Chamber Orchestra has completed questionnaires about 8 venues in which they regularly play, and additionally their sister group ACO2 has completed questionnaires about a further 8 venues in

which they played. The sets of assessments were each made during a single concert tour, eliminating variables such as repertoire and conductors, and maximising acoustic memory through the short time between performances.

The internationally renowned ACO is Australia's premier chamber orchestra comprising elite musicians. On the surveyed tour they performed 16th and 17th century repertoire involving strings with woodwind and harpsichord, and including keyboard and violin solos (compositions by Lawes, Purcell, Bach and Haydn). Sister group ACO2 was established as an opportunity for Australia's most talented young professional musicians at the outset of their careers to gain experience in chamber orchestra performance. On the surveyed tour they performed repertoire ranging from the 18th to 21st centuries involving strings only, with a violin soloist in one work (Bach, Tchaikovsky, Barber and Berger).

In this work, consideration is given to level of agreement amongst the musicians in each orchestra in regards to their assessments of each venue. Good agreement amongst the whole orchestra in regard to a venue's acoustics would indicate stage average values of acoustic parameters may be valid, whereas poor agreement may suggest individual musician response must be analysed separately. Poor agreement may be due to different acoustic *experiences* at different stage locations, different acoustic *requirements* arising from the different roles of each musician, and natural variation due to tastes and preferences. Additionally, correlations between subjective attributes are examined; particularly between 'overall acoustic impression' and the other subjective scales. A high correlation between a subjective scale and 'overall acoustic impression' is indicates that this subjective scale may make an important contribution to the overall acoustic impression, and thus can be considered an important acoustic attribute for musicians.

This paper does not relate these subjective data to objective acoustic measurements (which, at the time of writing, are being progressively made in each of the auditoria). Hence, the purpose of this paper is not to explain the responses in terms of acoustic or architectural parameters, but instead is to show the range of on-stage acoustic experiences over 16 Australian auditoria reported by touring professional chamber orchestras.

2. Background

In a comparable study Sanders sent a questionnaire to chamber ensemble musicians asking for subjective assessments of venues in New Zealand [1]. Sanders examined correlations between orchestra average 'Overall Acoustic Impression' and other subjective characteristics (also orchestra average values) in 22 venues. Sanders found 'Overall Acoustic Impression' (OAI) was the most highly correlated with 'Support', followed by 'Balance', 'Ensemble', 'Reverberance', 'Visual Impression' and lastly 'Clarity'. Sanders did not discuss whether there was good agreement between respondents in regard to the subjective characteristics in each venue, and may have lost information by considering only orchestra average values. Additionally, Sanders did not send questionnaires to musicians in conjunction with any kind of playing schedule, and therefore musicians would have relied purely on their memories of the venues, which may have made it difficult for them to give detailed assessments (or resulted in responses with limited variability - i.e. all venues rates closer to average).

Dammerud surveyed one symphony orchestra's opinions of eight venues (however discarded data from two venues because of their short reverberation times), and examined the correlation between 'Overall Acoustic Impression' and other subjective characteristics [2]. Since Dammerud was studying a symphony orchestra, not a chamber orchestra, it must be assumed that the playing conditions would have been significantly different to those in this study. However, it is worth examining Dammerud's method of comparing OAI with other subjective characteristics. Dammerud examined correlations between OAI and other subjective characteristics by comparing all the (unaveraged) values of OAI with their corresponding values of each subjective characteristic. This meant the total number of samples (N) used in the regression analysis was quite high. Dammerud found 'Hearing Others' and 'Clarity' and 'Reverberance' correlated best with OAI.

A range of other studies have been completed involving subjective surveying of musicians; these studies have generally been different from this work as they have focused on symphony orchestras and as they have generally lacked a significant amount of subjective data. For example, Cederlöf used 5 different symphony orchestras to access 5 different venues [3], Van Luxemburg et al. surveyed a student

symphony orchestra about 7 venues [4], and Lautenbach & Vercammen surveyed one symphony orchestra about 3 venues and another symphony orchestra about 6 venues (no venues were assessed by both orchestras) [5].

3. Survey Methods

The questionnaire itself asked musicians to rate venues on the following subjective scales: Overall Acoustic Impression (OAI), Hearing Self (HS), Support (Sup), Ensemble (Ens), Reverberance (Rev), Clarity (Cl), Warmth (War), Timbre (Tim), Communication with the main auditorium (Com), Echoes (Ech) and lastly Visual Impression (VI). Additionally, the questionnaire asked whether there were any instruments which the player struggled to hear or could hear prominently. The questionnaire is shown in full in Figure 1. The questionnaire covers the mains aspects of auditorium acoustics which are known to be important to musicians (outlined in work by [6] and [7]). The questionnaires were completed in conjunction with relevant tours of each orchestra, so that the musicians would have played recently in the venue they were assessing. Additionally, this ensured the program played in each venue would be consistent, allowing musicians to more easily compare the acoustics from each venue directly (without any impact from a change in program played). Each musician completed a separate questionnaire for each venue on the tour, and each questionnaire completed by a single musician was linked to the other questionnaires completed by the same musician, so individual musician trends can be examined as necessary.

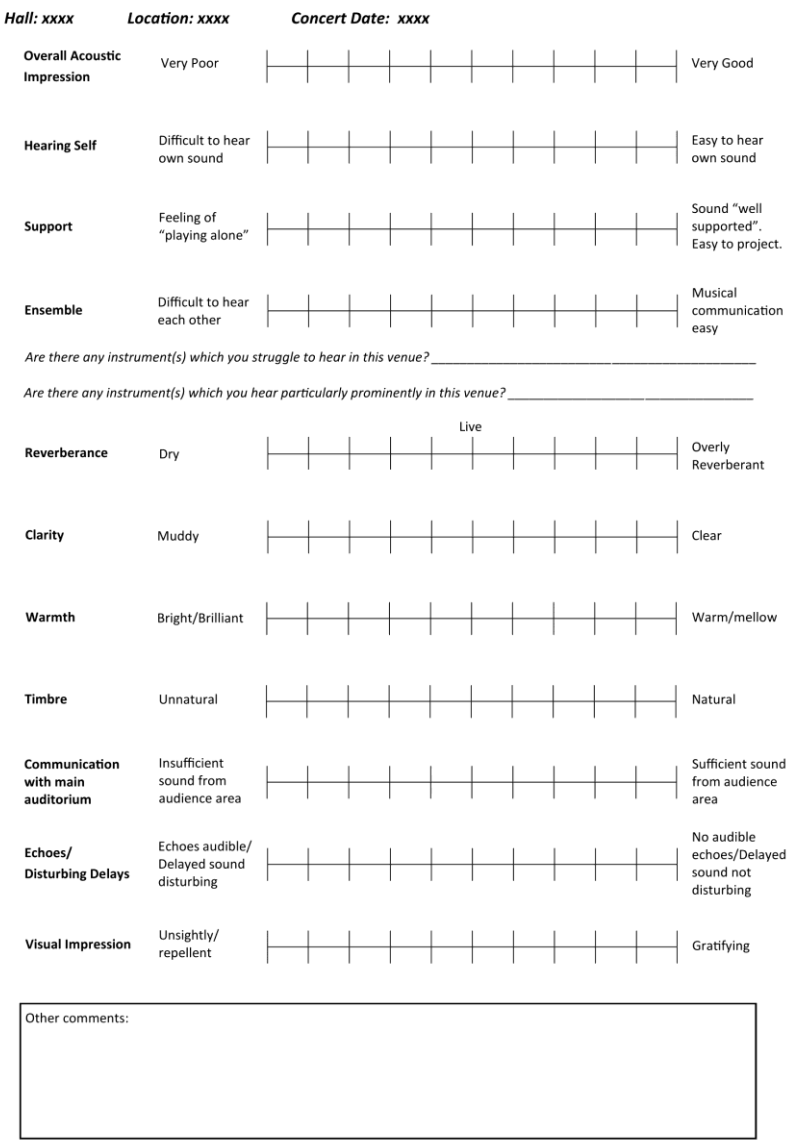


Figure 1: Questionnaire administered to musicians

4. Subjective Responses

The majority of musicians in both ACO and ACO2 completed the questionnaires in all relevant venues. ACO performed exclusively in major Australian purpose built concert halls, listed in Table 1, while ACO2 toured regional centres and performed mainly in community halls, conference centres etc. For ACO the venues visited were Perth Concert Hall, Adelaide Town Hall, Sydney City Recital Hall, Llewellyn Hall (Canberra), Hamer Hall (Melbourne), Sydney Opera House Concert Hall, Wollongong Town Hall and QPAC (Queensland Performing Arts Centre, Brisbane), as listed in Table 1. In the case of ACO2 the name of the town in which the venue is located is listed in Table 2; the actual venues were Armidale Town Hall, Bellingen Memorial Hall, St John's School Hall (Mullumbimby), Gold Coast Arts Centre, Nambour Civic Centre, Moncrieff Theatre (Bundaberg), Gladstone Entertainment Centre and the Auditorium at Redlands Performing Arts Centre (Cleveland). Note that for the Gold Coast and Gladstone venues conference rooms were used rather than auditoria designed for music. For the ACO tour 15 out of a possible 22 musicians completed the questionnaires (68% response rate) and for the ACO2 tour 15 out of a possible 17 musician completed the questionnaire (88% response rate). From ACO six violins, two violas, two cellos, two oboes, two horns, and one double bass player responded to the questionnaire From ACO2 eight violins, three violas, three cellos and one double bass player responded to the questionnaire. The statistical analyses were carried out using the computer program R. Table 1 shows the orchestra average results and corresponding standard deviations for subjective characteristics in the eight venues for the ACO dataset. Similarly, Table 2 shows the orchestra average results for subjective characteristics and corresponding standard deviations in the eight venues for the ACO2 dataset.

Table 1: Average orchestra assessments and standard deviations for subjective characteristics studied for venues assessed by ACO. These are sorted based from highest to lowest based on OAI (scale 0–10).

Venue	OAI	HS	Sup	Ens	Rev	Cl	War	Tim	Com	VI
Perth	8.8±1.0	8.1±1.8	8.9±1.9	7.7±1.0	6.1±1.0	7.5±1.7	7.2±2.0	8.3±1.2	7.6±1.7	7.5±1.6
Adelaide	8.4±1.1	7.5±2.3	7.7±1.7	7.2±1.3	7.3±1.3	6.3±2.0	6.1±2.3	8.4±1.2	8.5±0.9	8.9±0.9
Syd Recital	7.8±1.4	8.0±1.3	7.2±2.1	7.7±1.2	6.1±1.2	7.7±1.1	3.6±1.9	6.5±2.2	7.8±1.8	7.9±1.5
Llewellyn	6.3±1.9	7.3±2.1	6.0±2.3	5.1±1.5	5.7±1.5	5.9±1.7	5.6±2.0	6.5±1.3	5.8±1.8	4.9±2.0
Hamer	6.2±1.9	6.7±2.2	5.8±1.9	6.0±1.4	5.6±1.4	5.6±1.7	5.7±1.6	6.4±1.5	4.5±2.2	6.3±2.3
Syd Opera	5.9±1.5	7.1±1.6	5.0±2.2	5.4±1.4	5.5±1.4	4.8±2.1	5.7±2.3	6.2±1.3	6.6±2.3	7.5±1.1
Wollongong	5.4±1.9	6.2±2.0	5.7±1.6	4.9±2.6	5.9±2.6	5.4±2.2	5.1±2.2	5.6±1.8	6.2±2.1	3.9±2.2
QPAC	5.3±2.3	6.2±2.4	4.5±2.3	4.3±2.3	5.2±2.3	4.9±2.7	5.3±1.7	4.9±2.1	5.4±3.0	5.8±1.9

Table 2: Average orchestra assessments and standard deviations for subjective characteristics studied for venues assessed by ACO2. These are sorted based from highest to lowest based on OAI (scale 0–10).

Venue	OAI	HS	Sup	Ens	Rev	Cl	War	Tim	Com	VI
Bellingen	7.2±1.3	7.3±1.7	7.3±1.2	7.2±1.4	6.2±1.4	6.2±1.8	6.1±1.6	6.9±1.8	7.5±1.9	6.3±1.8
Cleveland	6.2±2.0	6.6±2.7	6.7±2.0	7.1±2.0	5.4±1.5	6.2±1.3	5.6±2.2	6.9±2.1	7.4±2.1	6.6±2.1
Mullumbimby	5.5±2.6	7.1±1.9	5.7±2.6	6.3±2.6	4.4±2.6	5.8±2.7	5.7±1.7	6.7±2.1	6.6±2.8	5.1±2.1
Armidale	5.4±1.3	7.6±1.3	5.3±2.2	5.5±1.8	3.6±1.7	6.6±1.4	4.7±1.7	5.8±2.1	6.5±1.6	6.3±1.9
Bundaberg	4.4±1.8	6.1±1.6	4.9±2.2	5.0±2.4	2.9±1.2	5.6±2.1	4.3±1.8	4.5±2.8	5.5±3.0	3.8±2.8
Gold Coast	2.9±1.7	6.4±2.1	3.6±2.4	4.4±1.8	2.2±1.8	6.2±2.2	4.5±2.2	4.0±2.6	6.2±2.2	4.7±2.6
Gladstone	2.4±1.8	7.0±2.0	3.3±2.0	4.4±2.6	1.0±1.0	6.3±2.8	4.3±2.9	3.7±2.4	4.8±3.2	3.0±2.4
Nambour	1.6±1.5	6.6±2.3	2.6±3.0	2.5±2.4	0.8±0.9	5.4±2.6	5.7±2.4	3.0±2.6	4.1±3.3	3.4±2.6

4.1 Subjective characteristics related to overall acoustic impression

It is of interest to gauge how well correlated 'Overall Acoustic Impression' (OAI) is with the other subjective characteristics. A high level of correlation between OAI and another subjective characteristic may indicate that this subjective characteristic highly influences ratings of OAI (i.e. it is an important subjective characteristic). To examine these trends a correlation/regression analysis has been conducted.

4.1.1 Checking Data for Assumptions of Regression Analysis

To perform correlation/regression analysis the data must meet the assumptions of parametric tests [8]. The assumptions of parametric tests are: normally distributed data, homogeneity of variance, interval data and independence [8].

The data obtained from the questionnaires can be considered a close approximate to interval data; as discussed by [9] the data extracted from 'rating scales' completed by human participants is often considered to be close enough to interval data for the purpose of regression analysis. Field et al. [9] also comment that the more categories the respondents are able to use the closer the data will be to true interval data. In this study, the participants are asked to indicate a location anywhere on a continuous line (although 11 vertical lines are provided to indicate the integers 0-10), and thus the data extracted will be a close approximation to interval data.

The normality and homogeneity of variance assumptions have been tested for each data set and in general found to be met for the datasets considered in this paper. The normality assumption is important, as for significance tests (i.e. *p* values) to be meaningful the data should be normally distributed.

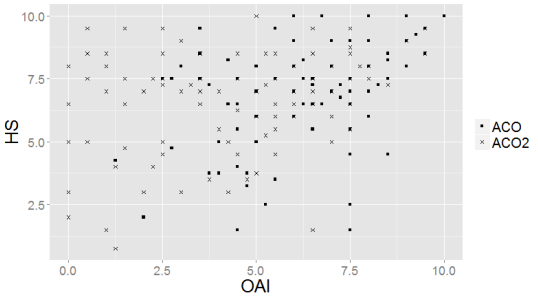
The independence assumption may be violated in these two datasets since each musician completed multiple questionnaires. This potential dependence in the data could be accounted for with a more advanced statistical analysis (such as multi-level modelling); however, an initial visual examination of the data has indicated that dependency within these two datasets is not an issue and will not be accounted for the in the statistical analyses used in this paper.

4.1.2 Regression Analysis

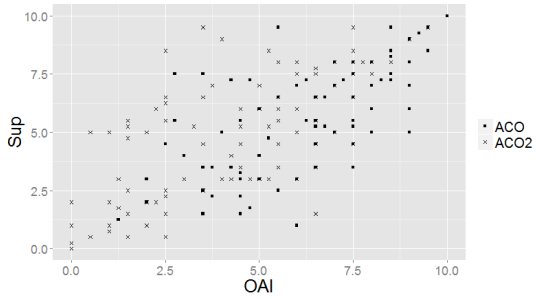
To examine potential correlations between the subjective data scales and OAI the data has been plotted against each other, shown in Figure 2. Additionally, a correlation matrix has been produced to examine relationships between OAI and the other subjective scales, as well as any relationships between all the other subjective scales. The correlation tables for ACO and ACO2 are shown in Tables 3 and 4 respectively. The correlation coefficients have been computed using all the available musician data; the number of samples (*N*) varies due to missing data, where musicians have not completed all the relevant subjective scales.

Table 3: The upper portion shows Pearson correlation coefficients, *r*, between subjective characteristics, for ACO tour. Bold numbers indicate significance at the 1% level, underlined significance at the 5% level. The lower portion shows number of samples (*N*). The column and row abbreviations correspond to the scales shown in Figure 1.

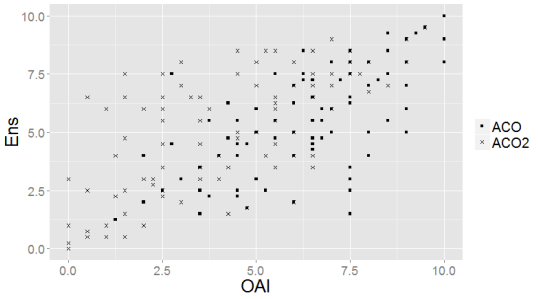
	OAI	HS	Sup	Ens	Rev	Cl	War	Tim	Com	Ech	VI
OAI	1	**0.48**	**0.73**	**0.71**	**0.50**	**0.62**	0.17	**0.68**	**0.55**	**0.31**	**0.55**
HS	116	1	**0.42**	**0.54**	0.20	**0.4**	0.08	0.27	**0.32**	**0.37**	0.18
Sup	115	115	1	**0.76**	**0.41**	**0.57**	0.18	**0.67**	**0.49**	0.24	**0.36**
Ens	114	114	114	1	**0.27**	**0.64**	0.12	**0.54**	**0.36**	**0.38**	**0.39**
Rev	115	115	115	114	1	0.15	0.12	**0.42**	**0.34**	0.18	0.26
Cl	114	114	114	113	114	1	-0.09	**0.36**	**0.35**	**0.39**	**0.37**
War	115	115	115	114	115	114	1	**0.43**	-0.03	0.04	0.06
Tim	114	114	114	113	114	113	120	1	**0.46**	0.26	**0.48**
Com	113	113	113	112	113	112	112	112	1	0.18	**0.53**
Ech	114	114	114	113	114	113	113	113	113	1	0.25
VI	114	114	114	113	114	113	112	113	112	113	1



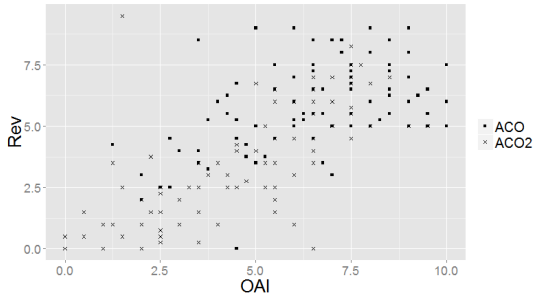
a) OAI vs HS, ACO: r = 0.48, N=116, p<0.01
ACO2: r = 0.24, N =115, p<0.05



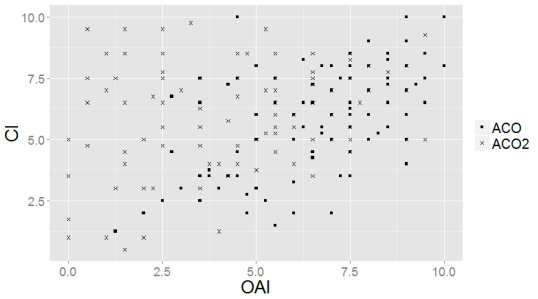
b) OAI vs Sup, ACO: r = 0.73, N=115, p<0.01
ACO2: r =0.73, N=115, p<0.01



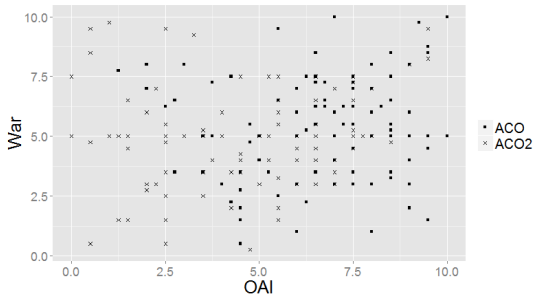
c) OAI vs Ens, ACO: r = 0.71, N=114, p<0.01
ACO2: r = 0.70, N =114, p < 0.01



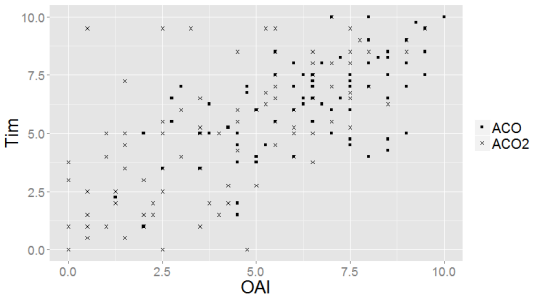
d) OAI vs Rev, ACO: r = 0.50, N=115, p< 0.01
ACO2: r = 0.75, N=112, p <0.01



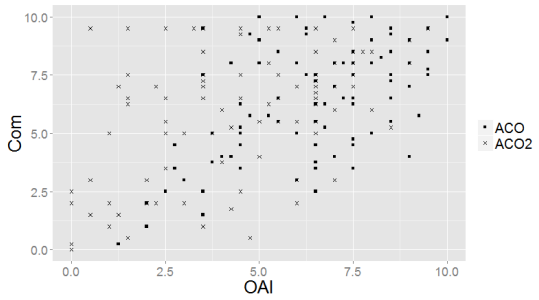
e) OAI vs Cl. ACO: r = 0.62, N= 114, p<0.01
ACO2: r = 0.23, N =111, p<0.05



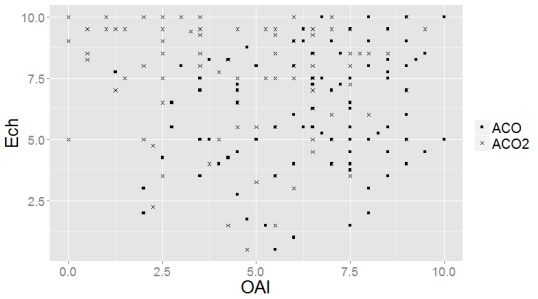
f) OAI vs War. ACO: r = 0.17, N=115,
ACO2: r = 0.22, N = 108, p<0.05



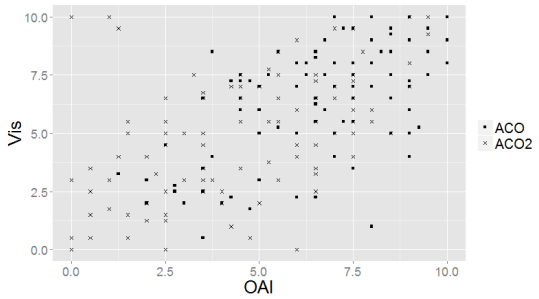
g) OAI vs Tim. ACO: r = 0.68, N =114, p<0.01
ACO2: r = 0.68, N=111, p <0.05



h) OAI vs Com. ACO: r = 0.55, N=108, p<0.01
ACO2: r = 0.47, N = 108, p < 0.01



i) OAI vs Ech. ACO: r =0.31, N=114, p<0.01
ACO2: r = -0.17, N=109



j) OAI vs Vis. ACO: r=0.55, N=114, p<0.01
ACO2: r = 0.52, N =110, p <0.01

Figure 2: Plots of OAI versus other subjective characteristics for ACO and ACO2 tour data. The parameter abbreviations correspond to the scales shown in Figure 1.

Table 4: The upper portion shows Pearson correlation coefficients, *r*, between subjective characteristics, for ACO2 tour. Bold numbers indicate significance at the 1% level, underlined significance at the 5% level. The lower portion shows number of samples (*N*). The column and row abbreviations correspond to the scales shown in Figure 1.

	OAI	HS	Sup	Ens	Rev	Cl	War	Tim	Com	Ech	VI
OAI	1	0.24	**0.73**	**0.70**	**0.75**	0.23	0.22	**0.68**	**0.47**	-0.17	**0.52**
HS	115	1	0.22	**0.34**	0.14	**0.38**	**0.33**	**0.34**	**0.36**	0.19	0.03
Sup	115	115	1	**0.64**	**0.63**	0.11	0.22	**0.52**	**0.37**	-0.15	**0.37**
Ens	114	114	114	1	**0.5**	**0.45**	0.13	**0.66**	**0.53**	0.04	**0.44**
Rev	112	112	112	112	1	0.05	0.21	**0.56**	**0.44**	**-0.27**	**0.41**
Cl	111	111	111	111	111	1	0.04	**0.34**	**0.31**	0.24	0.13
War	108	108	108	108	108	108	1	**0.47**	**0.28**	0.03	**0.22**
Tim	111	111	111	111	111	111	108	1	**0.68**	0.08	**0.52**
Com	108	108	108	108	108	108	105	108	1	0.09	**0.44**
Ech	109	109	109	109	109	109	106	109	108	1	0.09
VI	110	110	110	110	110	110	107	110	108	109	1

4.2 Differences in subjective characteristics between venues

This section considers which of the venues are judged as being significantly different in terms of the subjective acoustic characteristics, based on assessment from the whole orchestra. This is of interest because if the orchestra as a whole judges the venues as being significantly different then it is more likely that acoustic parameters will be able to indicate orchestra preferences, whereas if the orchestra found minimal difference in the acoustic conditions in different venues then the potential for acoustic parameters to distinguish between venues will be limited. Additionally, this analysis may help to indicate whether orchestra average values for OAI (and other subjective characteristics) are valid. If individual musicians assess the same venue differently then it is less likely significant differences would be found between venue assessments when considering the orchestra data as a whole. This may indicate that musician preferences based on instrument group or position on stage need to be considered.

Figure 3 shows the mean orchestra assessment (and corresponding standard deviation) for the subjective characteristic OAI for the ACO tour data. Figure 4 shows the mean orchestra assessment (and corresponding standard deviation) for the subjective characteristic OAI for the ACO2 tour data. Table 5 summarises the *p* values for differences between orchestra assessments of OAI in venues for the ACO data, and similarly Table 6 summarises the *p* values for differences between orchestra assessments of OAI in venues for the ACO2 data.

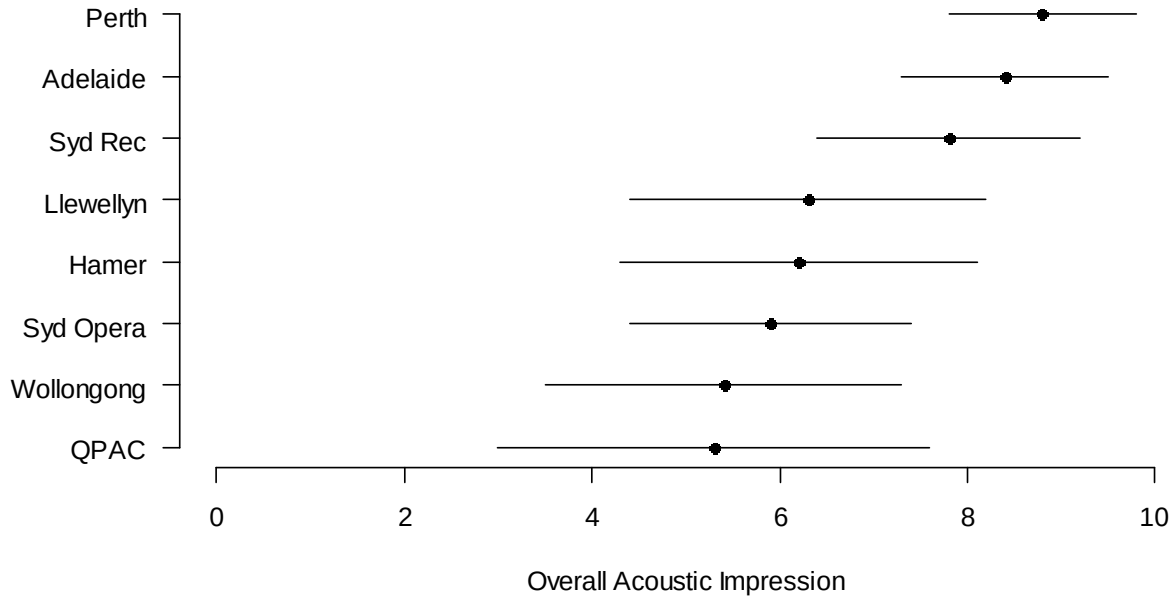


Figure 3: Mean and standard deviation for 'Overall Acoustic Impression' in each venue for ACO

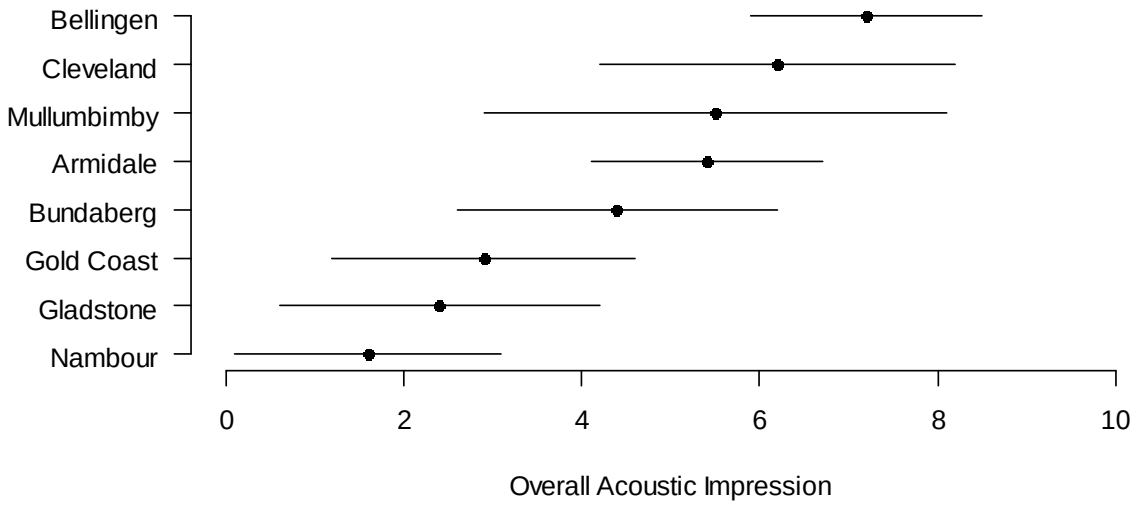


Figure 4: Mean and standard deviation for 'Overall Acoustic Impression' in each venue for ACO2

Table 5: *p* values (i.e., probability of a null hypothesis, adjusted with Holm) for difference between orchestra assessments of OAI in venues assessed by ACO. Bold numbers indicate significance at 1% level, underlined significance at 5% level.

	Perth	Adelaide	Syd Rec	Llewellyn	Hamer	Opera	Wollongong
Adelaide	1		-	-	-	-	-
Syd Rec	0.49	1	-	-	-	-	-
Llewellyn	0.022	0.017	0.458	-	-	-	-
Hamer	**0.005**	0.042	0.458	1	-	-	-
Opera	**0.000**	**0.003**	0.069	1	1	-	-
Wollongong	**0.004**	**0.002**	0.09	1	1	1	-
QPAC	0.011	**0.001**	0.094	1	1	1	1

Table 6: *p* values (adjusted with Holm) for difference between orchestra assessments of OAI in venues assessed by ACO2. Bold numbers indicate significance at 1% level, underlined significance at 5% level.

	Bellingen	Cleveland	Mullumbimby	Armidale	Bundaberg	Gold Coast	Gladstone
Cleveland	0.513	-	-	-	-	-	-
Mullumbimby	0.363	1	-	-	-	-	-
Armidale	0.026	1	1	-	-	-	-
Bundaberg	0.019	0.284	1	0.879	-	-	-
Gold Coast	**0.000**	**0.001**	0.271	0.010	0.289	-	-
Gladstone	**0.000**	0.014	0.011	**0.003**	0.019	1	-
Nambour	**0.000**	**0.001**	0.019	**0.000**	**0.004**	0.765	1

5. Discussion

Interestingly, in spite of significant differences in the venues visited by the two orchestras, there were both remarkable similarities and remarkable differences between ACO and ACO2 in the ranking of subjective attributes that were well-correlated with overall acoustic impression. Only two attributes of significance differed markedly between ACO and ACO2 in terms of both ranking and correlation coefficient. These were 'Reverberance' (ranked 7th and 1st out of 10 attributes by ACO and ACO2 respectively, with correlation coefficients r=0.50 and 0.75 respectively) and 'Clarity' (ranked 4th and 7th, r=0.62 and 0.23).

With these two attributes removed from the list, the top five remaining attributes were remarkably similar, being in order 'Support' (r=0.73/0.73 for ACO/ACO2 respectively), 'Ensemble' (0.71/0.70), 'Timbre' (0.68/0.68), 'Visual Impression' (0.55/0.52) and 'Communication with the Main Auditorium' (0.55/0.47), which were all significant at the 1% level. They were not only ranked in the same order but in most cases had almost identical correlation coefficients. The remaining three were also ranked

similarly but were in some cases significant only at the 5% level or not at all: 'Hearing Self' (0.48/0.24), 'Echoes' (0.31/-0.17) and 'Warmth' (0.17/0.22).

The importance of 'Support', 'Ensemble' and 'Timbre' to chamber orchestra musicians is apparent from the high correlation between these aspects and OAI in both datasets. The high ranking and virtually identical correlation coefficients in this study suggest that this may be generalised beyond the orchestras and venues in the current study. Sanders also found 'Support' and 'Ensemble' to be key subjective characteristics in a study of chamber ensemble musicians; Sanders did not ask musicians to rate venues in regard to 'Timbre' [1].

'Reverberance' is known to be a subjectively important characteristic for musicians playing on stage; in this study it was more correlated with OAI for ACO2 than for ACO. This may be because the 'Reverberance' was adequate in all venues in the ACO playing tour (they fell within a narrow range of 5.2–6.1), so this aspect became less subjectively important to the musicians in ACO; whereas, the 'Reverberance' was clearly inadequate in some of the regional venues on the ACO2 playing tour (as low as 0.8, but ranging to 6.2) and hence had a more significant impact of OAI ratings. This agrees with the findings from Sanders [1]. It should also be noted that the 'Reverberance' scale was set up with the optimal rating being 5; a rating of 0 indicated the venue was too dry and a rating of 10 indicated the venue was overly reverberant. Therefore, a linear relationship between OAI and Reverberance is not necessarily expected. The fact a linear trend was observed between OAI and Reverberance indicates that many of the venues were too dry (particularly on the ACO2 tour) and with increasing Reverberance the OAI ratings increased. Far fewer venues were observed to be overly reverberant, so a trend of decreasing OAI with increasing 'over reverberant' ratings was not strongly observed.

It is interesting too that there seems to be no correlation between clarity and reverberance (r=0.15/0.05), especially since these are the two attributes that differed most between the two orchestras. This indicates against the common assumption that clarity and reverberance are inversely related.

Given that all the subjective scales correlated significantly with OAI (with the exception of warmth for ACO and echoes for ACO2) the subjective scales chosen appear to be all relevant aspects of overall acoustic impression.

'Visual Impression' was included on the survey to gauge if this had any impact on the OAI. In both datasets a significant correlation was observed between 'Visual Impression' and OAI (with correlation coefficients of 0.55 and 0.52 for ACO and ACO2 respectively). This may indicate 'Visual Impression' was impacting OAI; however, it may instead indicate that those venues which had better acoustics were also more visually pleasing (i.e. high quality venues which were designed for good acoustics were also designed to be visually pleasing).

Based on ratings of OAI, the most preferred venue from the ACO tour was Perth Concert Hall. Perth was statistically significantly better than all venues except Adelaide Town Hall and Sydney Recital Hall. The least preferred venue was QPAC; however, it was only statistically significantly worse than Adelaide Town Hall and Perth Concert Hall. Based on the results in Table 1 and Table 5, Perth Concert Hall and Adelaide Town Hall were the most favoured venues, followed by Sydney Recital Hall. The other five venues can then be grouped as the less favoured venues. Notably, all ACO venues rated well on average (i.e. 5/10 or greater), which was not the case for the more regional venues in the ACO2 tour.

Based on ratings of OAI, the most preferred venue from the ACO2 tour was Bellingen. Bellingen was statistically significantly better than all the other venues in the study, except Cleveland and Mullumbimby. The least preferred venue was Nambour, and it was statistically significantly worse than all other venues in the study, except Gold Coast and Bundaberg. Between the best and worst rated venues, some but not all differences were observed as statistically significant based on OAI ratings, see Table 6. Based on the average orchestra assessments, OAI ratings were observed to show the clearest difference between venues for both ACO and ACO2.

6. Further Work

The subjective musician data presented in this paper could be analysed with more advanced statistical methods to better capture the structure of the data. Namely, a multi-level model (mixed model) analysis could be used to account for the fact each musician has completed multi questionnaires, and there could

be some underlying dependency within the data based on musician (this structure is ignored by regression analysis).

Additionally, data was collected regarding musicians' playing experience, position on stage, instrument, and whether they were playing as a section leader. It would be worthwhile considering whether splitting the musician data into these groups alters the results presented in Sections 4.1 and 4.2. Musicians were also asked to comment on which instruments they could not hear or could hear prominently in certain venues, and again this data was not analysed within the scope of this paper but will be in future work. Finally, some musicians provided written comments about the venue's acoustics, and again this data was not considered within the scope of this paper, but will be analysed in future.

Acoustic measurements in the venues assessed by ACO and ACO2 are planned. This will allow comparison between the subjective musician assessments and objective acoustic parameters. As well as traditional omnidirectional acoustic parameters (such as those specified in ISO 3382-1 [10]), acoustic parameters derived from measurements with a spatial microphone (Eigenmike) will be investigated.

7. Conclusions

This paper has provided an initial analysis and discussion of data obtained from ACO and ACO2 about sixteen venues in Australia. This study has found that 'Ensemble', 'Support' and 'Timbre' were key acoustic attributes for chamber orchestra musicians, which correlated highly with 'Overall Acoustic Impression' (OAI). The study found good agreement between individual musicians in the orchestras, particularly when rating OAI. Statistically significant differences were observed between the ratings of some, but not all, venues when examining orchestra average assessments. Further work will examine the correlation between these subjective datasets and objective acoustic measurements in venues, as well as further additional examination of the subjective data which was not analysed within the scope of this paper.

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