The importance of bass clarity in pop and rock venues

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High levels of bass sound have been shown to stimulate the part of the brain that controls such basic instincts as sexual desire and hunger. In rock and pop music, the bass frequencies from 40-125 Hz get amplified to very loud levels. Easily half of the electrical power of the PA and monitor system goes to these 1.5 octaves. A recent survey showed that the most important subjective parameter for a rock and pop music hall to score a high rating was 'bass clarity' which correlated with a coefficient of 0.74 to 'overall impression'. Informal discussions with audio engineers and bass players give the perspective that artificial reverberation is rarely, if ever, added to bass-frequencies. This supports the idea that a hall should be as dry as possible at low-frequencies. In the mid-treble frequency range, sound absorption, and thereby 'clarity', is easily obtained through the presence of the audience that absorbs 4-6 times more mid/high frequency sound energy than bass sound energy. In the low-frequency range 'clarity' is not so easily obtained. This paper discusses the challenge in depth and proposes design solutions.

1 Introduction

The acoustics literature contains very little in the way of design recommendations for room acoustics for rock music performances, and there are few, if any, scientific investigations into the subject. This contrasts with the relatively high number of concertgoers who attend rock music concerts compared to classical music concerts. A recent survey of performance venues in Denmark [1] showed that there were approximately 12,500 rhythmic music concerts held in Denmark in 2004 with about 2 million attendees. During the same time frame, there were an estimated (conservatively large) 2000 classical music concerts in Denmark [2]. This means that there were at least five to six times as many rhythmic music concerts than classical music concerts.

An earlier study investigated the recommended acoustics for concert halls that present rock and pop music [3]. Objective acoustic measurements and a questionnaire survey were made in 20 small to mid-sized Danish concert halls used primarily for pop, rock and similar rhythmic genres of music. These genres largely depend on amplification through a PA system and an on-stage monitor system to generate the desired sound levels. The results of the survey showed that the general acoustic impression of the concert halls by musicians and sound engineers was strongly correlated with the perceived clarity of the hall, including the bass frequencies. The present study is an extension of [3].

1.1 Definition of the music genres

Rhythmic music covers a broad spectrum of musical genres such as rock, pop, jazz, punk, latin, etc. with different characteristics regarding instrumentation, typical sound levels and overall spectral content. Consequently, it can not be assumed that all of these genres will demand the same from the acoustics of the hall. Therefore, this discussion is limited to the acoustics for rock and pop music, which are similar in most aspects and cover the majority of rhythmic concert performances (at least in Denmark). For brevity, the two genres will collectively be referred to as rock music in the remainder of the paper.

1.2 Characteristics of rock concerts

There are many differences between rock and classical music concerts that create the need for different acoustic design recommendations.

1.2.1 Sound levels

Rock concerts generally have a higher sound level, generated through high-power PA systems, and a smaller dynamic range than classical concerts. In addition, there is often more emphasis placed on the low frequencies, generated by the bass (usually guitar) and bass drum. Usually at least half of the electrical power in the sound system is used for the 1.5 octaves from 40-125 Hz. This may mean that acoustic design specifications for rock music halls should start with the 63 Hz octave band, where the acoustics for classical music halls are typically only specified from 125 Hz. In order to investigate these low-frequencies, a subwoofer was added to the typical omnidirectional (dodecahedral) speaker for the room acoustic measurements.

1.2.2 Monitors

The musicians in rock bands typically use a form of monitors on stage to listen to the band. These can be in the form of on-stage or in-ear monitors. On-stage monitors can create high sound levels that can be picked up by the microphones creating unwanted feedback. In-ear monitors avoid acoustic feedback and can reduce the influence of the room acoustics on the sound heard by the musicians, but also reduce contact with the audience.

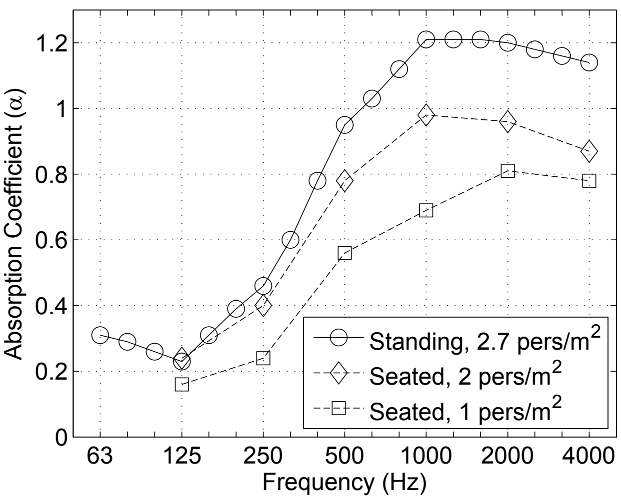


Figure 1: Absorption coefficients for an audience. Standing audience with a density of about 2.7 people/m^2 (circles, [3]) and a seated audience on wooden chairs with a density of 2 people/m^2 (diamonds) and 1 person/m^2 (squares, seated audience data from [4], adapted by [6]).

1.2.3 Expert Listeners

During a rock concert, it is the primary task of the sound engineer to create the best possible sound for the audience (in combination with, or in spite of the acoustics of the hall). For this reason, the mixing board is usually located somewhere in the audience. Therefore, the sound engineer can be considered an expert listener from the perspective of the audience. The acoustics on stage, as with classical music concerts, are best judged by the musicians themselves. In order to rate the halls from both the perspective of the audience and the stage, the questionnaire was sent to both sound engineers and musicians.

1.2.4 Audience

The audience at a rock concert is generally standing and relatively tightly packed, while the audience at a classical music concert is usually seated. Sound absorption coefficients can be found for a seated audience (e.g., [4]) and absorption areas for single standing persons (e.g., [5]), and for a standing audience (see Fig. 1, [3]). Simply multiplying the absorption area of a single standing person by the number of people in attendance will overestimate the sound absorption, because a large portion of the absorption area will be rendered ineffective by the presence of other tightly packed members of the audience. Figure 1 shows that the absorption of a standing audience is 5-6 times as high in the mid-high frequencies than in the low frequencies. This means that the high-frequency reverberation times can be brought under control by the presence of the audience, but the low-frequency reverberation must be controlled through other means. Also, a hall that is designed to have approximately equal reverberation times across frequencies when empty will have disproportionately high low-frequency reverberation when the hall is full.

Table 1: Basic details of the twenty surveyed concert halls including hall volume, T_{30} for 500 Hz to 1 kHz (subscript m) and for 63 Hz to 1 kHz (subscript b), and maximum audience capacity.

Name	Vol. [m^3]	$T_{30,m}$ [s]	$T_{30,b}$ [s]	Aud. Cap.
Amager Bio	4500	1.0	1.1	1000
Forbrændingen	3050	0.9	1.0	450
Godset	2150	0.8	0.7	700
Lille Vega	800	0.7	0.6	500
Loppen	900	0.8	0.9	350
Magasinet	2550	1.3	1.6	525
Musikhuzet	2100	0.8	0.9	700
Paletten	1400	0.8	0.9	375
Pumpehuset	3000	1.2	1.1	600
Rytmeposten	650	0.8	0.8	300
Skråen	1100	0.7	1.1	375
Slagelse	3800	1.6	1.8	700
Sønderborghus	1600	0.9	1.1	420
Stars	1450	0.6	0.6	400
Store Vega	5800	1.2	1.3	1430
Tobakken	6500	1.0	1.2	1200
Torvehallen	5400	1.6	1.4	700
Train	3300	1.0	0.9	900
Viften	3950	1.1	1.8	700
Voxhall	1600	0.6	0.7	500

2 Experimental Methods

2.1 Subjective measurements

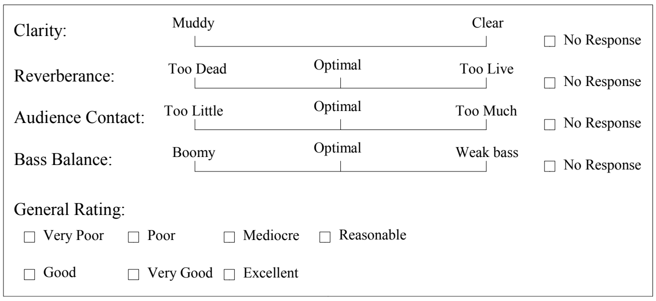
2.1.1 Choice of halls and subjects

Many rock concerts are held in halls that were not designed for that purpose and acoustically are clearly unsatisfactory, e.g., in sports halls, stadiums, and classical music halls. Therefore, these halls were excluded from consideration for this study. Instead, only halls whose primary purpose is rock and pop music concerts were considered.

Twenty of the most frequently used rock concert halls in Denmark were chosen for the study. Relevant details on the halls are given in Table 1. Objective acoustic measurements were performed in each hall and questionnaires regarding the subjective impression of the acoustics in the halls were sent to 50 touring musicians and 18 sound engineers, who were most likely to have worked in most, if not all, of the halls. Of these potential subjects, 25 musicians and 8 sound engineers returned the questionnaires.

2.1.2 Design of the subjective method

For this study, questionnaires were sent to participants to respond based on their memory of the acoustic experience in the halls. This method was chosen because the target group of respondents were those musicians and sound engineers who had great experience with working in and listening to the halls, and it was not expected that this group would be willing or able to travel to the lab or to all of the halls specifically for the purpose of



Clarity: Muddy — Clear ☐ No Response

Reverberance: Too Dead — Optimal — Too Live ☐ No Response

Audience Contact: Too Little — Optimal — Too Much ☐ No Response

Bass Balance: Boomy — Optimal — Weak bass ☐ No Response

General Rating:

☐ Very Poor ☐ Poor ☐ Mediocre ☐ Reasonable

☐ Good ☐ Very Good ☐ Excellent

Figure 2: Musicians' questionnaire form for the subjective rating of each of the concert halls (translated from Danish).

participating in the study.

A cover letter was sent with the questionnaire explaining the purpose of the study and providing instructions on how they should answer. The first page of the questionnaire consisted of general questions regarding what instrument they played, about their use of monitors and their impression of the importance of the acoustics of a hall for their performance. Then there were twenty forms to complete, one for each hall. The design of the form was based on a similar study of classical music halls by Barron [7]. The musicians' form is shown in Fig. 2. The first two scales, 'Clarity' and 'Reverberance,' are the same as on Barron's questionnaire. For the present study, Barron's ratings of 'Envelopment,' 'Intimacy,' and 'Loudness' were dropped because these are expected to be more influenced by the PA system configuration in a rock concert than the room acoustics. Instead the scales 'Audience Contact' and 'Bass Balance' were added. The sound engineers' form differed from the musicians' form on two questions. The 'Clarity' rating was split into 'Clarity treble-mid' and 'Clarity bass,' and the 'Audience Contact' rating was removed. Each group then had four attributes to rate with a continuous scale and a general rating with discrete values. The intention was that the respondents should complete as many forms as possible, but should at least fill in the general rating for all of the halls with which they were familiar.

It was expected that the three subjective ratings 'Clarity,' 'Reverberance,' and 'Bass balance' would correlate strongly with the objective measurements D_{50} ('Deutlichkeit' or 'Definition'), T_{30} or EDT (reverberation time or early decay time), and BR (bass ratio). The 'Audience Contact' rating came from the first author's own experience that the room acoustics of a hall can have a strong effect on the feeling of contact with an audience.

The respondents were free to set a mark anywhere on the continuous lines. The lines were 10.8 cm long in the original format with an 'Optimal' mark at the center point for all but the 'Clarity' ratings. The position of the mark on the line was measured and the data was assembled for statistical and correlational analysis of the data.

Table 2: Correlation coefficients for the musicians' subjective ratings (Clarity, Reverb, Audience Contact, and Bass Balance). Significant correlations ($|r| > 0.5$) are shown in bold.

	Clar	Reverb	AudCon	BassBal
Reverb	**-0.58**			
AudCon	0.02	0.00		
BassBal	**0.67**	-0.49	0.06	
GenRat	**0.75**	-0.42	0.21	**0.70**

2.2 Objective measurements

The objective measurements were performed in accordance with ISO 3382:1997 [8]. The DIRAC software package was used on a laptop computer with a dodecahedral speaker array and a subwoofer for the bass frequencies. A sweep signal was generated by the software and used to calculate the room impulse response. An AKG C34 condenser microphone in omnidirectional mode was used for measuring the impulse response.

Only the reverberation time, T_{30}, was extracted from the impulse response as the objective parameter for the purpose of this paper. The correlation with the general ratings of the halls give a starting point for the design of acoustics for rock concert halls.

2.3 Analysis of results

The subjective data were analyzed for significant differences between respondents on the five subjective parameters using a one-way unbalanced analysis of variance (ANOVA) with the respondent as the parameter. This analysis showed that there were significant differences between respondents ($p < 0.05$) on all ratings except 'Bass balance' by the sound engineers. Since the respondents had not received training on the rating scales nor examples of the end-points, it was expected that each respondent could have a different bias point. Therefore, each respondent's data was normalized so that their mean rating for each subjective parameter was zero.

Pairwise Pearson's linear correlation coefficients between the five normalized subjective parameters were calculated and the significance of the correlation was calculated using a Student's t-distribution. As found also by Barron [7], the correlations required to show statistical significance with the large number of usable data points (about 300 from the musicians and 140 from the sound engineers) were too small to be meaningful. Therefore, following Barron's example, a correlation of $r \geq 0.5$ was arbitrarily selected as the threshold to have a meaningful significance.

3 Results and Discussion

3.1 Subjective Ratings

There were significant differences seen in the analysis (ANOVA) of the responses on every rating scale with halls as the factor except for 'Audience Contact'. The

Table 3: Correlation coefficients for the sound engineers' subjective ratings (Clarity Bass, Clarity Mid/Treble, Reverb, and Bass Balance). Significant correlations ($|r| > 0.5$) are shown in bold.

	$Clar_B$	$Clar_{M/T}$	Reverb	BassBal
$Clar_{M/T}$	**0.66**			
Reverb	**-0.50**	-0.46		
BassBal	**0.51**	0.25	-0.38	
GenRat	**0.74**	**0.72**	**-0.64**	**0.50**

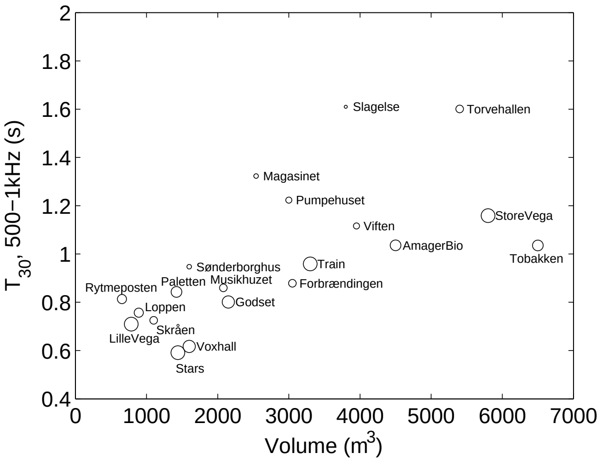


Figure 3: Mean measured T_{30} for the 500 Hz and 1 kHz octave bands vs. hall volume for the twenty halls in the study (empty halls). The size of the marker indicates the general rating of the hall with better ratings having larger markers.

ratings of 'Audience Contact' had the smallest overall variance of the ratings, indicating that the respondents may not have understood the category and simply rated all halls the same. However, even within the small variance, there were significant differences between respondents, so the ratings of 'Audience Contact' may be based more on the personality of the respondent, or on the instrument played (lead singers may feel more contact with the audience than drummers).

Correlation coefficients were calculated pairwise between the five subjective ratings of the musicians and the sound engineers (see Tables 2 and 3, respectively). The musicians' 'General Rating' was strongly correlated with 'Clarity' and 'Bass Balance', indicating a preference for crisp, not boomy halls. 'Clarity' and 'Reverberation' also have a strong inverse correlation, as has been reported in other studies.

There were also strong correlations between the sound engineers' subjective ratings (Table 3) of 'General Rating' and the two 'Clarity' ratings (Bass and Mid/Treble), showing the sound engineers' preference for crisp sound. The 'Clarity' ratings from the two frequency ranges were expected to be more correlated than they were, but show that the sound engineers could judge them separately. A look at the 'Clarity' data set showed that if there was a difference in the ratings, then 'Clarity Mid/Treble' was generally rated as more clear than 'Clarity Bass'.

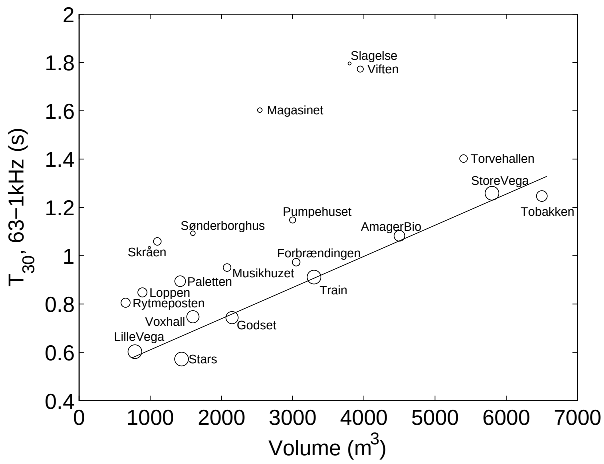


Figure 4: Mean measured T_{30} for the 63 Hz to 1 kHz octave bands vs. hall volume for the twenty halls in the study (empty halls). A larger marker indicates a better 'General Rating.' The line shows a recommended guide for the reverberation time for a given hall volume.

3.2 Correlation between T_{30}, hall volume and the general rating

The reverberation time of a hall generally increases with hall volume, and listeners' expectations of hall quality also require longer reverberation times from larger halls. For example, Train and Sønderborghus have very similar reverberation times across frequency, however Train was rated much higher than Sønderborghus. Adding the dimension of Volume can help clarify the ratings. Figure 3 shows a plot of the mean reverberation time in the 500 Hz and 1 kHz octave bands for each hall as a function of its volume. The higher rated halls are marked with a larger circle than the lower rated halls. From this, it can be seen that Train is about twice as large as Sønderborghus, so should be expected to have a longer reverberation time. Most of the halls in the plot fall in an area that increases in T_{30} with volume. Those that are significantly beyond this area are rated the lowest (Slagelse, Magasinet), however there is an overlap of highly rated and mediocre, or even poorly rated, halls. For example, Viften and Sønderborghus are close to the main cluster even though they are two of the four lowest rated halls.

Greater separation between the highly rated and mediocre halls can be achieved by including the bass frequencies. Figure 4 is the same as Figure 3 except that all frequency bands from 63 Hz to 1 kHz are included. In this plot, a line can be drawn through the best rated halls. Viften now lies well away from this line because of its disproportionately long bass reverberation time. This shows that the bass frequencies are critical to have a favorable general rating of the acoustics of a hall.

By separating the halls into groups of the best- and worst-rated halls, some trends can be seen that can be used to help design the acoustics of a rock concert hall. Figure 5 shows the estimates of the mean and standard errors of the reverberation time as a function of hall volume by frequency band. The model used was an approximate fit to the data of the best halls shown in

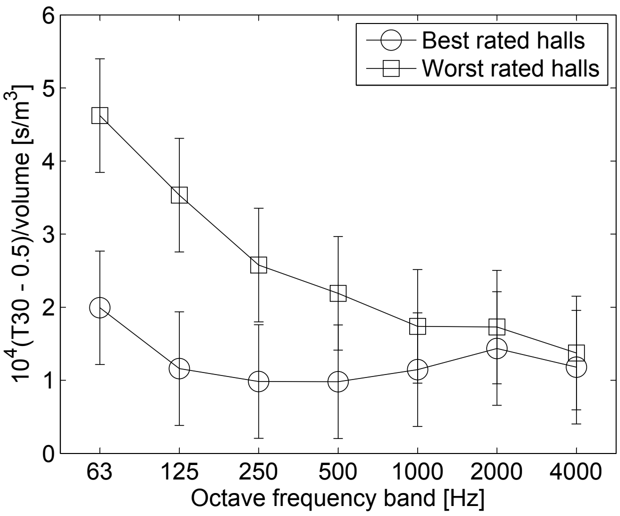


Figure 5: Linear transform of T_{30} by volume as a function of frequency band, grouped by best- and worst-rated halls. Shown are the estimates of the means of (T_{30}-0.5s)/Volume and 95% confidence intervals for the two groups.

Fig. 4:

$$(T_{30} - 0.5s)/V. \quad (1)$$

A two-way ANOVA on the normalized T_{30} with main effects of group (best/worst) and frequency showed a significant effect of group ($F(1) = 35.9$, $p \ll 0.001$) and of frequency ($F(6) = 6.4$, $p \ll 0.001$), as well as a significant interaction ($F(1, 6) = 3.05$, $p < 0.01$). The estimated mean normalized reverberation times and 95% confidence intervals are shown in Fig. 5. This shows that the normalized reverberation times are significantly lower in the low-frequencies for the best-rated halls, and that there is little difference in the high-frequencies. It is also interesting that the worst-rated halls tend to have sloping reverberation times with higher T_{30} in the bass than in the higher-frequencies. This suggests that the best halls should have flat reverberation time profiles across frequencies and that the reverberation times should be in the range of

$$1 - 2 \times 10^{-4} \times \text{Volume}[m^3] + 0.5s. \quad (2)$$

4 Conclusions

In the subjective survey, both musicians and sound engineers find the acoustics of the concert hall “very important” for their performance. More than one in three musicians responding reported choosing not to play in a hall on account of bad acoustics. Therefore, it is important to do a proper acoustic design for a rock concert or multipurpose hall.

The general acoustic impression of a rock concert hall is strongly correlated with the perceived clarity of the hall, also in the bass-frequencies. Therefore, it is critical to include the 63 Hz octave band in the acoustic design of the hall. The best-rated halls have a flat reverberation time profile across frequencies and have a reverberation time in the range given in Eq. 2. This recommendation was found for small to medium-sized halls and needs to be verified for scalability to larger halls. Of course, T_{30} is only one aspect of acoustic design. Further studies should investigate other acoustic parameters, e.g., Bass Ratio, Early Decay Time, and Definition.

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