CHALMERS

Perceived Sound Qualities for Trumpet Players in Practice Rooms

Master's Thesis in the Master's programme in Sound and Vibration

OLOF OLSSON & DANIEL SÖDERSTRÖM WAHROLÉN

Department of Civil and Environmental Engineering
Division of Applied Acoustics
Chalmers Room Acoustics Group
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2010

Master's Thesis 2010:127
ISSN 0283-8338

MASTER'S THESIS 2010:127

Perceived Sound Qualities for Trumpet Players in Practice Rooms

OLOF OLSSON & DANIEL SÖDERSTRÖM WAHROLÉN

Department of Civil and Environmental Engineering
Division of Applied Acoustics
Chalmers Room Acoustics Group
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2010

Perceived Sound Qualities for Trumpet Players in Practice Rooms

Master's Thesis 2010:127

Department of Civil and Environmental Engineering
Division of Applied Acoustics
Chalmers Room Acoustics Group
Chalmers University of Technology
SE-41296 Göteborg
Sweden

Tel. +46-(0)31 772 1000

Cover: `http://upload.wikimedia.org/wikipedia/commons/0/0e/Louis_Armstrong_restored.jpg` provided by Wikimedia Commons for non-commercial use

Reproservice / Department of Civil and Environmental Engineering
Göteborg, Sweden 2010

Perceived Sound Qualities for Trumpet Players in Practice Rooms
Master's Thesis in the Master's programme in Sound and Vibration
OLOF OLSSON & DANIEL SÖDERSTRÖM WAHROLÉN
Department of Civil and Environmental Engineering
Division of Applied Acoustics
Chalmers Room Acoustics Group
Chalmers University of Technology

Abstract

The binaurally measured sound level at the ears of trumpet players differ only slightly between different practice rooms, but the subjective perception of the sound level has a larger deviation than the scale of $L_{pA,eq}$. Legislation for maximum sound exposure levels for musicians at work is $L_{EX,8h}$ 85 dB(A) [Arb05]. Trumpet players are typically exposed to free-field value of $L_{p,eq}$ 95 dB(A) while playing in practice rooms. The risk for hearing damage, like tinnitus and hyperacusis, is also influenced by stressors. The perceived sound level is therefore important from a sound health point of view and it is necessary to review the common rehearsal methodology used at various institutions. The subjective sound level seems to be influenced by the character of the sound (warmth or Bass-Ratio) and the location and amount of absorbing surfaces in the rooms. Small practice rooms are subjectively not necessarily rated louder than larger ones as long as they have enough absorptive drapes at the walls. A subjective evaluation has showed that the room quality correlate negatively to $1 - IACC_{E3}$.

Keywords: Subjective perception, Practice rooms, Trumpet player, Sound levels

Contents

Acknowledgements

The authors wish to thank their supervisor Johan de Sousa Mestre at Artifon AB for all assistance throughout the whole project and Alf Berntsson and Johan Andersson at Artifon AB for always helping out and sharing their knowledge and experience. This thesis would not have been possible without their help.

It is an honor for the authors to thank, at Chalmers University of Technology, supervisor Professor Mendel Kleiner and Erkin Asutay for assistance of questions regarding room acoustics, and supervisor Associate Professor Daniel Västfjäll and Penny Bergman for guidance through the field of psychoacoustics. Thanks to Börje Wijk for providing high quality measurement equipment and Gunilla Skog for administration guidance.

Many thanks to Kjell Thorbjörnson at Gothenburg Music Academy for arranging the rehearsal rooms and useful office space. Thanks to the trumpet players Mats Ander and Gösta Emelius for assistance developing the questionnaire and selecting proper music pieces for the study. A special thanks the musicians who made this thesis possible, Mats Ander, Gösta Emelius, Nils Israelsson, Albin Löfgren, Hilde Muribø Berg, Charlotte Richardsen, Mia Samuelsson, Paul Spjuth and Oskar Stenmark for sharing their knowledge and participating in this study.

The authors would also like to show their gratitude to Professor Kerstin Persson Waye and Dr Kim Kähäri for useful discussions. Many thanks to people at the conference BNAM 2010 in Bergen Norway for good response. The authors are indebted to the many fellow Master Students at Applied Acoustic for their support, especially Erik Backman and Henrik Lundgren for their continuos help. The authors like to thank Ragnar Vidarsson for helping out with grammar when writing the report.

The authors owe their deepest gratitude to their families and friends, for support and understanding throughout the work. Last but not least the authors like to thank paintbox and The Tranq for the continuos inspiration.

Notations

$L_{EX,8h}$	Equivalent A-weighted sound pressure level normalized to eight hours	dB(A)
$L_{pAeq,Te}$	Measured equivalent A-weighted sound pressure level	dB
t	Time	s
p	Pressure	Pa
p_0	reference pressure of 20 μPa	Pa
p_A	A-weighted sound pressure	Pa
f	Frequency	Hz
T	Reverberation time	s
A	Total absorption	m^2S
V	Volume	m^3
G	Strength	dB
L_N	Loudness level	Phon
N	Loudness	Sone
$IACC$	Interaural cross-correlation	
$IACC_{E3}$	Early Interaural cross-correlation mean value for 500, 1000 and 2000 Hz	
$IACF$	Interaural cross-correlation fraction	
BR	Bass-Ratio	
C_{80}	Clarity	dB
D_{50}	Definition	
r	Pearson's sample correlation	
s	Sample standard deviation	
n	Number of samples	
df	Degrees of freedom	
L_p	Sound pressure level	dB
L_w	Sound power level	dB
Δ	Difference	

Subscript

x_i	index number
$IACC_A$	All
$IACC_E$	Early
$IACC_L$	Late
T_{60}	Reverberation time calculated for a 60 dB decay
T_{20}	Reverberation time interpolated for a decay from -5 to -25 dB
T_{30}	Reverberation time interpolated for a decay from -5 to -35 dB
Δ_{max}	Maximal difference

Superscript

$\bar{x}$	mean value of x

1. Introduction

Research of the acoustics in small rehearsal rooms is a rather neglected topic. This should be compared with the efforts made for performance and listening acoustics, such as in concert halls and recording studios. Studies have been made for practice rooms, but often focusing on sizes of floor area above 100 m^2 [FY87]. A more common room size for one's own practice is in the range of 5 to 30 m^2. Even fewer studies have focus on a specific instrument.

In order to improve one's musical skills, the acoustical characteristic of the practice room is of great importance, since it is in the practice room the feeling for the musical tone is trained. The preferred characteristic of the practice rooms is highly complex, and varies greatly between different instruments [RMW02] and even within instruments and genres.

For most musicians the way of playing is affected in some way by the feedback from the room. This adjustment can be both good and bad, depending on the situation. Musicians are required to perform in most kinds of acoustical environments, from churches to outdoors to small jazz club. For the best results in a concert the musician should be able to adapt to the acoustics, but in some cases of "bad acoustics" also be able to trust the "inner" systems of playing, being indifferent of the environment.

Trumpet players are often regarded as one of the loudest instrument in a symphony orchestra along with percussion. Even so, the use of ear protection is not very common for trumpet players, partly because the perception of the playing is changed by the "occlusion" of the ear canal. Ear protection also changes the balance between perceived sound from the air and the bone conduction, which is shifted with more focus to the bone conduction. This can be compared with the often unfamiliar experience of listening to your own voice recorded.

Important for all musicians are the risks of hearing damage. Both sound pressure level, SPL, and its duration play a major part [Arb05]. It is therefore important to investigate the actual SPL which the trumpet players withstand when they practice.

In order to investigate sound qualities in practice rooms, among other actions, subjective judgements from nine trumpet players were used. The musicians had a large distribution regarding age, profession, music style and gender. For the subjective judgement tests, a questionnaire was designed and it was judged as important to fully explain the words and concepts used in the questionnaire to the musicians. At the same time, it was judged as important not to bias the musicians before the tests. It was important trying to find a balance between these opposing interests.

1.1. Previous work

Room acoustic investigations of churches and concert halls have been made with respect to subjective qualities. During 2003 Leo L. Beranek published the work "Subjective Rank-Orderings and Acoustical Measurements for Fifty-Eight Concert Halls". These fifty-eight concert halls are judged subjectively based on interviews of conductors, music critics and well-traveled music enthusiasts. The objective and subjective data were compared and evaluated and conclude the importance of a specific number of measurable acoustic parameters. Most noticeable correlations with subjective judgements was found for $1 - IACC$, EDT, G_{mid} and G_{125} [Ber03].

The aspect of acoustic quality was also studied for school-band rehearsal rooms. In the beginning of 1966 Nelson G. Patrick and Charles R. Boner published the work "Acoustics of School-Band Rehearsal Rooms". The work tried to frame the special acoustical considerations that is assigned to a rehearsal space, since critical listening, intonation, musical balance, tone production, and dynamic control of tonal intensity are partly developed during practice. The study showed that the preferred acoustical properties for a rehearsal situation differ from the usual criteria used for performance situations [PB66].

1.2. Background

Artifon AB carried out a small pilot study during the spring of 2004. The purpose of the pilot study was to investigate how the size of music rehearsal rooms affects the equivalent sound levels, L_{eq}. The music rehearsal rooms were located at the Gothenburg Academy for Music and Drama, where a number of rooms with varying size were compared. The comparison of rooms showed that for a trumpet player the L_{eq} fluctuates in the range of maximum 1 to 2 dB(A). These small fluctuations of L_{eq} were probably influenced by room acoustics (including the musicians feedback from the room), but also visual aspects and the general feeling of the room.

The perceived loudness difference was not measured, but the feeling was that the total subjective impression of the rooms had a larger deviation than the scale of L_{eq}. This indicated that the issue is more complex than simply measuring parameters of room acoustics with the musician not present.

Furthermore, the Gothenburg Academy for Music and Drama has a vision of finding a suitable way to categorize the different rehearsal rooms. Categorizing the rehearsal rooms at the Gothenburg Academy for Music and Drama is a way to make it easier for the students to chose rehearsal rooms, and develop an understanding for different acoustic environments.

A part of the thesis, regarding perceived sound level, was presented at BNAM, Baltic-Nordic Acoustic Meeting in Bergen 10-12 May 2010. The contributed paper "Sound Levels for Trumpet Players in Practice Rooms" is available at `www.BNAM2010.com`.

1.3. Goal

The aim of this thesis is to find room acoustic parameters that correlate with perceived sound qualities, particularly sound level, in practice rooms for trumpet players. The goal is also to investigate the possibility to find a method that is applicable for other instruments than trumpet, and for other types of small practice rooms.

1.4. Limitations

As mentioned above, trumpet players have been chosen for this study, mainly due the loudness of the instrument and that it is relatively easy to model and also because it has a well-known directivity.

Two rooms were chosen for the study, known as C707 and C711, see Figure 1.2 and Figure 1.3. Both rooms are located at the 7th floor at the Gothenburg Academy for Music and Drama and are primarily used by brass students. The rooms are used mainly for personal practice but C707, referred to as Room 1, is also used for lecturing. C707 has the dimensions (L*W*H) 6.3 m*4.3 m*3.2 m, whereas C711, referred to as Room 2, has the dimensions 4.7 m*1.9 m*3.2 m. Room 1 had a grand piano placed by a wall with windows as illustrated in Figure 1.2 and Room 2 had a piano placed along one of the side wall close to the window as described in Figure 1.3.

Most remarkable design solutions in these rooms can be seen on one of the walls in each room and in the ceilings. One of the largest walls in each room were designed with skew sections made out of gypsum, directing the reflecting sound towards the ceiling, where further acoustic design solutions were present. Most acoustic treatment of the ceiling could be found in the larger rehearsal room, Room 1. The ceiling in Room 1 was supplied with two areas of painted absorbers and three diffusors. The diffusors, only used in Room 1 were designed as a convex shape, going in "Y" direction in Figure 1.2. In Room 1, fixed absorbers are mounted on each side of the door. Room 2 was only equipped with fixed absorbers in the ceiling, due to the limited space. The ceiling absorption in both rooms were painted, which reduces the absorptive qualities of the absorbers. A collage of the acoustic treatment can be seen in Figure 1.1, where the diffusors and absorbers in the ceiling, fixed absorbers on each side of the door and the reflecting wall design can be seen. All fixed acoustic treatment were kept, since and a majority of the rehearsal rooms in Gothenburg Academy for Music and Drama are of similar design.

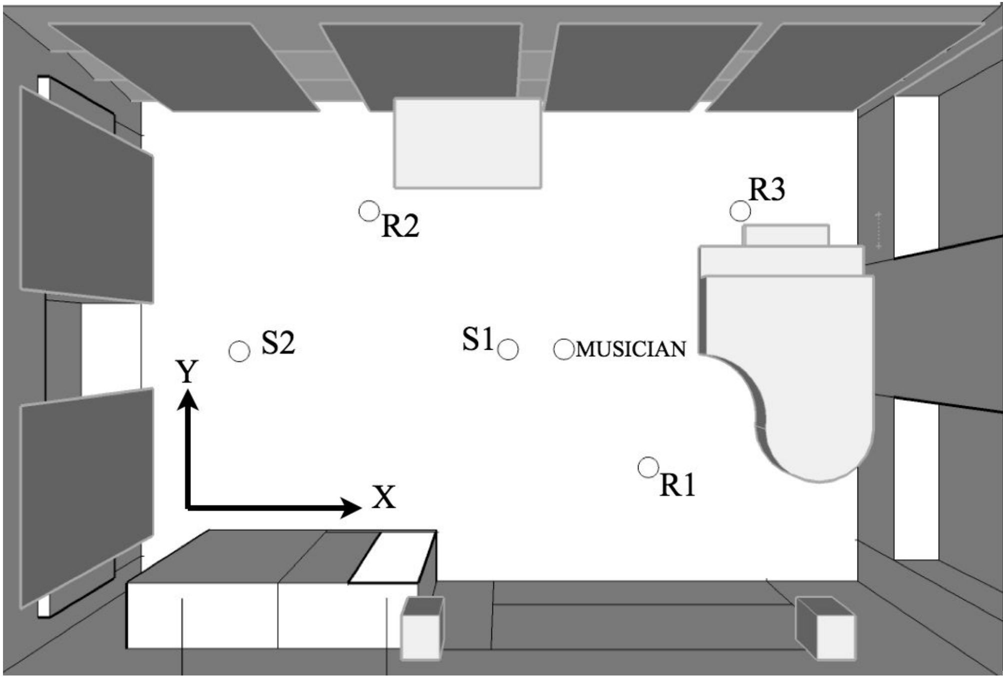
Figure 1.1.: Collage of the acoustic design solutions.

Two drape arrangements were used; drapes fully folded and drapes fully unfolded, where two adjoining walls were covered with six drapes for Room 1 and four drapes for Room 2. For both rooms the wall in front of the musician was covered together with the side wall to the right (Room 1) or to the left (Room 2). This leads to four configurations, which are presented in Table 1.1.

Table 1.1.: Notation and relations of room size and drape arrangement

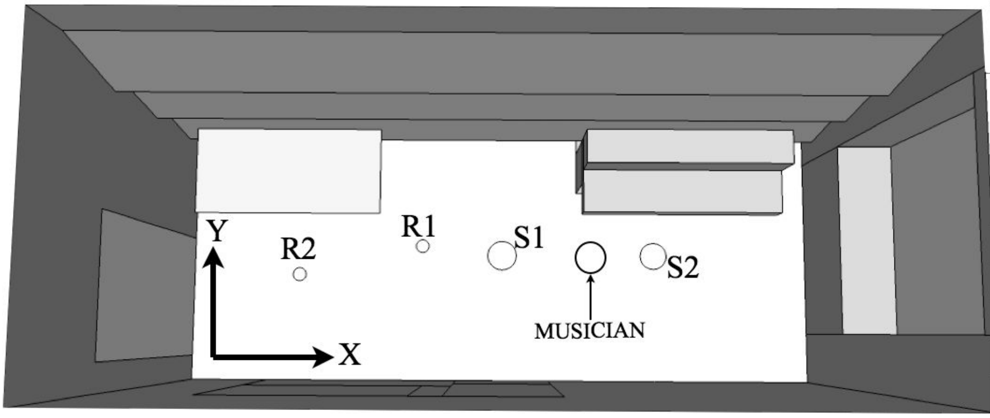
	Large room (C707)	Small room (C711)
Folded drapes (min absorption)	Room 1A	Room 2A
Unfolded drapes (max absorption)	Room 1B	Room 2B

To further limit the study a number of parameters had to be fixed; such as the position of the trumpet player and direction of the trumpet. The positions used are noted MUSICIAN and S1 (trumpet), these are presented in Figure 1.2 and Figure 1.3. The position of the musician was chosen to approximately 2/3 of the rooms' length from



[m]	X	Y
S1	3.23	2.0
S2	0.86	2.0
R1	4.46	1.0
R2	2.0	3.25
R3	5.27	3.25
DISTANCE [m]		
S1/S2	3.86	
S1/R1	1.61	
S1/R2	1.72	
S1/R3	2.38	
S2/R1	3.74	
S2/R2	1.68	
S2/R3	4.58	

Figure 1.2.: Room 1 with drapes and measurement positions marked out. The door is to the left and the windows are to the right. The marks are explained in Section 3.1.



[m]	X	Y
S1	2.35	0.95
S2	3.51	0.95
R1	1.74	1.02
R2	0.80	0.80
DISTANCE [m]		
S1/S2	1.16	
S1/R1	0.61	
S1/R2	1.56	
S2/R1	1.77	
S2/R2	2.71	

Figure 1.3.: Room 2 without drapes and measurement positions marked out. The door is to the left and the window is to the right.The marks are explained in Section 3.1.

the door, centered in width and pointing towards the door. The music stand was positioned to the side of the musician while playing. The musicians were standing during the whole test session. The different rooms were used in a random sequence during the subjective evaluation and can be seen in Table 1.2. Different effects on the results from the subjective evaluation, due to a specific room sequence, were minimized by using a random room sequence.

Table 1.2.: Randomization of the rehearsal rooms

Musician	Room sequence			
1, 5, 9	Room 1A	Room 1B	Room 2A	Room 2B
2, 6	Room 1B	Room 2A	Room 2B	Room 1A
3, 7	Room 2A	Room 2B	Room 1A	Room 1B
4, 8	Room 2B	Room 1A	Room 1B	Room 2A

2. Theory

2.1. Noise exposure recommendations

The body of law from the Swedish Work Environment Authority regarding noise, AFS 2005:16, states the limitations and public advice regarding noise exposure levels [Arb05]. The equivalent A-weighted sound pressure level normalized to eight hours is referred to as $L_{EX,8h}$. The upper limit is, according to 3§ in AFS 2005:16, 85 $L_{EX,8h}$ [dB] [Arb05]. The daily noise exposure level are calculated by Equation 2.1

$$L_{EX,8h} = L_{pAeq,Te} + 10lg\left(\frac{T_e}{T_0}\right) \tag{2.1}$$

where $L_{pAeq,Te}$ is the measured equivalent A-weighted sound pressure level given as Equation 2.2

$$L_{pAeq,Te} = 10lg\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\left[\frac{p_A(t)}{p_0}\right]^2 dt\right] \tag{2.2}$$

where $T_e = t_2 - t_1$ is the daily time of exposure expressed in hours, and $T_0 = 8$ hours, $p_0 = 20\mu Pa$ and p_A is the A-weighted sound pressure in Pa.

The standard "Determination of occupational noise exposure and estimation of noise-induced hearing impairment" shows that even though these levels are fulfilled, the risk of hearing impairment due to daily noise exposure still exists [ISO90].

2.2. Limitations in small rooms

It is important to have a sufficient density of modes when using a statistical model i.e. diffuse field theory [Lon06]. In a diffuse field there is equal probability that a sound wave comes from any direction at any given time. There is no precise modal density that states the transition between the modal model and the statistical model, but the $Schroeder\ frequency$ is used as a general breakpoint. The $Schroeder\ frequency$ indicates the frequency where the modal spacing has at least three modes within a given mode's half-power bandwidth and is defined as,

$$f_s = 2000\sqrt{\frac{T}{V}} \quad [\text{Hz}] \tag{2.3}$$

where T is the reverberation time in seconds and V is the volume of the room in cubic meters.

Sound Power Level

In rooms with static diffuse sound field and where the receiver point is in the far-field, the sound power level, L_W, of the source can be calculated from the sound pressure level, L_p if the room volume and reverberation time is known. In Equation 2.4 the expression is shown as

$$L_W = L_p + 10\log_{10}\frac{V}{V_{ref}} - 10\log_{10}\frac{T}{T_{ref}} - 14 \text{ dB} \tag{2.4}$$

where $V_{ref} = 1 \text{ m}^3$ and $T_{ref} = 1$ s.

In order to know if the receiver is sufficiently far from the source to be in the far-field, a critical distance, d_c, can be calculated with Equation 2.5, assuming Sabine's approximation. The critical distance is defined as the distance where the direct-field level is equal to the reverberant-field level.

$$d_c \approx 0.057\sqrt{\frac{V}{T_{60}}} \tag{2.5}$$

where V is the the volume and T_{60} is the reverberation time.

2.3. Acoustic parameters

Strength, G

Measurements of sound strength, G, can be measured using a calibrated omni-directional source, often a dodecahedron loudspeaker, according to [ISO09]. The strength shows the sound pressure level at a given location relative to the free-field level measured with an omni directional source at a distance of 10 m. Strength is calculated by Equation 2.6

$$G = 10lg\frac{\int_0^\infty p^2(t)dt}{\int_0^\infty p_{10}^2(t)dt)} = L_{pE} - L_{pE,10} \quad \text{[dB]} \tag{2.6}$$

in which

$$L_{pE} = 10lg\left[\frac{1}{T_0}\int_0^\infty \frac{p^2(t)dt}{p_0^2(t)dt)}\right] \quad \text{[dB]} \tag{2.7}$$

and the free-field level of an omnidirectional source at a distance of 10 m

$$L_{pE,10} = 10lg\left[\frac{1}{T_0}\int_0^\infty \frac{p^2(t)dt_{10}}{p_0^2(t)dt)}\right] \quad \text{[dB]} \tag{2.8}$$

where

$p(t)$ = sound pressure at a given position in the room

$p_{10}(t)$ = sound pressure level in free-field at a distance of 10 m

p_0 = 20 μPa

T_0 = 1 s

L_{pE} is sound pressure exposure level of $p(t)$

$L_{pE,10}$ is the the sound exposure level of $p_{10}(t)$.

The free-field reference is measured at a distance of 10 m. In situations where this is not achievable it is possible to measure at a shorter distance and calculate the 10 m free-field level according to Equation 2.9. Measurements made of shorter distances still needs to be made in far-field, where the distance should be at least four times the largest dimension of the effective radiating surface.

$$L_{pE,10} = L_{pE,d} + 20lg\left(\frac{d}{10}\right)\text{ [dB]}. \tag{2.9}$$

Loudness

During the year of 1933 a well known study by Fletcher and Munson was published. The study was carried out using a short sequence of a pure tone at a particular frequency and amplitude. These pure tones were compared to a fixed reference tone at 1000 Hz with the amplitude raised in 10 dB steps for the range of 0 to 120 dB. This investigation was repeated in 1956 by Robinson and Dadson using an anechoic chamber and loudspeakers, whereas Fletcher and Munson used headphones.

The work done by Fletcher and Munson resulted in the *Fletcher-Munson curves* presented in Figure 2.1 where the different phon lines represent the equal loudness i.e. any position at one curve is perceived equally loud. The *Fletcher-Munson curves* are sometimes referred to as the equal-loudness countours and have the unit of phons. The unit phon depends on the sound pressure level at 1000 Hz whereas the sound pressure level at other frequencies follows the equal loudness countours.

Another measure of loudness was developed by expanding the loudness level contours, based on the perception of absolute levels. This approach uses the measure of when the subject rate the sound pressure level as twice as loud. This gave rise to a measure of relative loudness which uses the unit sone. The relation between equal loudness (phon) and relative loudness (sone) is presented Equation 2.10. There is a linear relation between sone levels, that is to say, two sone is twice as loud as one sone and so on [Lon06].

$$L_N \cong 30lgN + 40 \tag{2.10}$$

where N=loudness (sone), L_N=loudness level (phon).

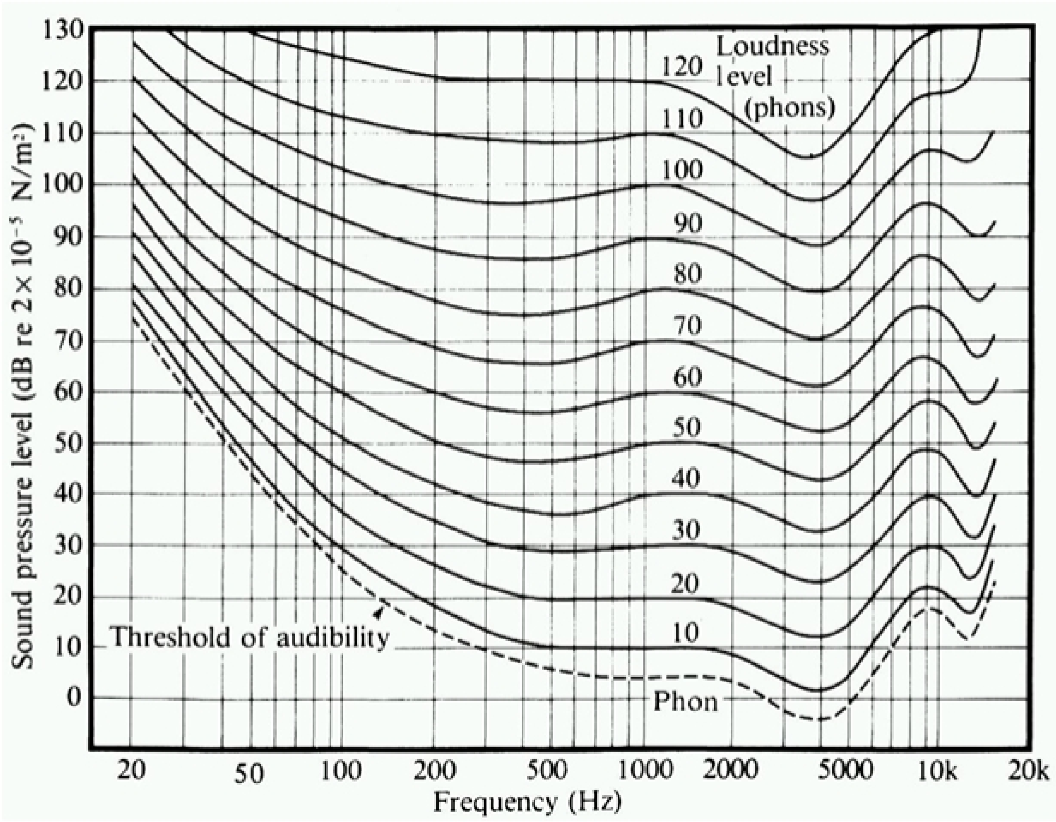


Figure 2.1.: Equal-loudness contours [Jan].

IACC

A way of measuring spatial impressions is by using the interaural cross-correlation coefficients ($IACC$), which to confirm well to the spatial impression. How to measure the $IACC$ is found in the standard SS-EN ISO 3382-1:2009, where the use of either a dummy head or a real head is specified [ISO09].

The $IACC$ is a ratio of the similarity of pressure between two ears. This is based on the interaural cross-correlation fraction, which is defined in Equation 2.11 as

$$IACF_{t_1,t_2}(\tau) = \frac{\int_{t2}^{t1} p_L(t) * p_R(t+\tau)dt}{\sqrt{\int_{t2}^{t1} p_L^2(t)dt \int_{t2}^{t1} p_R^2(t)dt}} \tag{2.11}$$

where the subscript L and R refer to the left and right ears. The time difference τ between both ears is varied over a range of -1 to +1 msec from the first reaching signal.

In order to inspect the single value of $IACC$ one has to take the maximum of the $IACF$ as shown in Equation 2.12

$$IACC_{t_1,t_2} = max|IACF_{t_1,t_2}| \quad \text{for} -1 < \tau < +1 \tag{2.12}$$

The integration is set to the period of interest, whereas the most common periods are $IACC_A$, $IACC_E$ and $IACC_L$, these are specified below

$IACC_A$ where $t_1 = 0$ and $t_2 = 1000$ msec

$IACC_E$ where $t_1 = 0$ and $t_2 = 80$ msec, which is referred to as the apparent source width (ASW)

$IACC_L$ where $t_1 = 80$ and $t_2 = 1000$ msec, which is referred to as the envelopment.

Observations of $IACC$, measured with the source on stage and head in audience seats in concert halls, show that low values are preferred, and therefore one usually list the data as $(1 - IACC)$, where higher number are better. The just noticeable difference between different $IACC$ values are assumed to be 0.075 [ISO09] [Lon06].

Warmth, BR

A common acoustical parameter is *Bass-Ratio, BR*, which is defined as a ratio of the mid frequencies and the low frequencies as written in Equation 2.13

$$BR = \frac{T_{60}(125) + T_{60}(250)}{T_{60}(500) + T_{60}(1000)}. \tag{2.13}$$

The ratio is also known as *Warmth* since high values of *BR* are perceived as warm [Lon06].

Clarity, C_{80}

Clarity is a measure of the ratio of the energy in early and late arriving sound [Lon06] [ISO09]. Highly reverberant halls could generate negative values of C_{80}, whereas dead rooms would give positive numbers [Lon06]. C_{80} is defined as

$$C_{80} = 10lg\frac{\int_0^{80} p^2(t)dt}{\int_{80}^{\infty} p^2(t)dt} \quad [\text{dB}]. \tag{2.14}$$

Reverberation time

Reverberation is the presence of sound after a sound source has stopped [Lon06]. The attenuation is generally defined to be 60 dB i.e. the reverberation time T_{60} is the time in seconds it takes for the sound pressure to decay 60 dB. The reverberation is affected by the total absorption and volume of the room, and is usually calculated using Sabines reverberation formula according to Equation 2.15

$$T_{60} = 0.161\frac{V}{A} \quad [\mathrm{s}] \tag{2.15}$$

where A is the total absorption in m^2S and V is the volume of the room in m^3. Since it is often problematic to achieve signal to noise ratios of 60 dB, measurements evaluate the decay in the range of -5 dB and -35 dB and interpolate the gradient to 60 dB. This is referred to as T_{30}. There are several ranges used to extrapolate the reverberation time e.g. T_{20} and T_{10} [ISO09].

Definition, D_{50}

Definition is an early to total sound energy ratio, and can be used to evaluate speech conditions in rooms [Lon06]. Definition is defined as in Equation 2.16.

$$D_{50} = \frac{\int_0^{0.050} p^2(t)dt}{\int_0^{\infty} p^2(t)dt} \tag{2.16}$$

2.4. Statistics

Variance

Variance can be measured in many ways, from measuring the *range* of the two extremes to calculating the deviation from the mean. Both will be used in this thesis where the *Sample variance*, s^2, is defined as

$$s^2 = \frac{\sum(x_i - \bar{x})^2}{n-1} = \frac{S_{xx}}{n-1} \tag{2.17}$$

and the corresponding *Sample standard deviation* defined as

$$s = \sqrt{s^2}. \tag{2.18}$$

Confidence interval

A confidence interval is used to gain knowledge about the distribution of a parameter, and not only its average or mean value. Without knowing the distribution of a parameter, a mean value does not say much, since it heavily relies on the number of samples used in the estimation. When using confidence intervals, a confidence level is chosen, setting the lower and upper limit. A confidence level of 95 % implies that a mean value of 95 % of all samples will give a mean value within the lower and upper limit. A higher confidence level means a greater confidence that the real mean value lies within the interval.

Since only nine trumpet player participated in this study, extra concern must be taken to what statistical model one use. A *t distribution* will be used, that has similar properties as the normal distribution but differs in some aspect [DF05], namely;

- the t distribution is based on and defined by the number of degrees of freedom, *df*
- The shape of the t distribution is similar to the normal distribution and centered around zero
- Any t distribution is more spread out than the normal distribution
- The higher the number of df, the less spread out the t distribution will be
- For $df = \infty$, the t distribution will be identical to the normal distribution.

For a t distribution of df = 8 and confidence level of 95 %, the confidence interval is

$$\bar{x} \pm (2.306)\frac{s}{\sqrt{n}} \tag{2.19}$$

where 2.306 refers to the critical value of a t distribution for df = 8 and a confidence level of 95 %. s stands for the sample standard deviation, n is the number of samples and df is defined as n-1.

Correlation

Correlation is investigated in order to find out how strongly parameters are related to each other. The strength of a relationship is measured as a correlation coefficient, which can be both positive and negative. One commonly used correlation coefficient, and the one used in this thesis, is the Pearson's sample correlation coefficient r [DF05].

To understand the concept and the value of the correlation coefficient, it is worthwhile to look into an imaginary scatter plot of two parameters with numerical data. Assuming that the numerical data, x and y, have some kind of distribution and a mean value, e.g. $\bar{x}$, the scatter plot can be divided into four sections. The first section, *I - upper right*, is where the values of the both parameters x and y are larger than its corresponding mean value. The second section, *II - upper left*, is where the value of the first parameter, x, is smaller than its mean, $\bar{x}$, and the value of the second parameter, y, is larger than its mean, $\bar{y}$. The third section, *III - lower left*, is where the values of both parameters is smaller than its mean, and finally, the forth section, *IV - lower right*, is where the value of the first parameter, x, is larger than its mean, $\bar{x}$, and the value of the second parameter, y, is smaller than its mean, $\bar{y}$.

By multiplying $(x_i - \bar{x})(y_i - \bar{y})$ one yield the product of deviation. This product is positive in section I and III, and negative in section II and IV. In order to evaluate the relationship of the two parameters it is necessary to take a look at the sum $\sum(x_i - \bar{x})(y_i - \bar{y})$. For a scatter plot with most of the data are in section I and III, the sum will be a large positive number and indicating a strong positive relationship between the two parameters. Similarly, a scatter plot with most of the data in section II and IV, will lead to a large negative sum and indicating a strong negative relation. For a scatter plot with data in a four sections, the sum will be containing both positive and negative products and therefore the sum will be small and no indication of any relationship between the parameters.

However, to make the correlation independent of units of the parameters, and fix the scale to values between -1 and +1, a modification has to be done, which leads to the equation of Pearson's sample correlation r

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2}\sqrt{\sum(y_i - \bar{y})^2}} = \frac{S_{xy}}{\sqrt{S_{xx}}\sqrt{S_{yy}}} \tag{2.20}$$

where

$$S_{xx} = \sum x_i^2 - \frac{(\sum x_i)^2}{n} \tag{2.21}$$

$$S_{yy} = \sum y_i^2 - \frac{(\sum y_i)^2}{n} \tag{2.22}$$

$$S_{xy} = \sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n}. \tag{2.23}$$

The limits of strong correlation is ± 0.8 and a moderate relation is set to ± 0.5, where as the rest is considered weak. This is however dependent on samples of data, n one has. A significance level is therefore often presented in order to affirm that there is a veritable relationship. Since correlations use pairs the degrees of freedom, df is defined as n-2. As can be seen in Equation 2.20, the value of r is independent of which of the parameter that is labeled x. It is important to have in mind is that Pearson's sample correlation is only a measure of the linear relationship between the parameters and not any other correlation. As for all statistics, it is important to remember that association does *not* imply causation.

ANOVA

ANOVA is an abbreviation for Analysis of Variance, which focus on finding variances between parameter means. The analysis consist of testing a null hypothesis, H_0, that the means of the all investigated parameters are the same. Accordingly, the alternative hypothesis, H_a, is that at least two of the means differ from each other. In order to evaluate the parameter means in a correct and understandable way, it is a good idea to start with some terminology. A *factor* is a category in which the parameters differ into different *levels*, and the measurement of the difference is called the *response*.

In our thesis, *room size* and *drape arrangement* are factors in which *Large* and *Small*, and *Drapes folded* and *Drapes unfolded* are the corresponding levels. The response is the measurements of the subjective judgements.

The analysis of variance compares the variation between the sample means with the variation within each sample, yielding a ratio

$$\text{test statistic} = \frac{\text{between-samples variation}}{\text{within-samples variation}} \tag{2.24}$$

which follows an F distribution. The F distribution is a continuous probability distribution that is based on the degrees of freedom for the numerator and the denominator, in our case the degrees of freedom for the between-sample variation and the within-sample variation.

Since a large value of the *test statistic* ratio implies that the means differ from each other, in other words that H_0 is false, and vice versa, the analysis of variance should be seen as an upper-tail test. This means that when looking at an F curve plot, it is the shaded area to the right, "upper-tail", of the F-value that determines the *P-value*. The P-value is also known as the observed significance level and describes the probability of yielding a test statistic value that at least differs from the null hypothesis H_0 as much as the observed test statistics, assuming that H_0 is still true. Accordingly, a sufficiently small P-value means that H_0 should be rejected [DF05].

It is important to remember that ANOVA assumes that variations for all sample populations are equal and that they follow a normal distribution.

3. Approach

The approach was divided into three parts in this study;

1. Acoustic parameter measurements
2. Sound levels and spectral measurements while the musicians were playing
3. Subjective judgement measurements.

3.1. Acoustic parameter measurements

In order to get an estimation of the acoustic environment in the practice rooms, acoustic parameters were measured using measurement software WinMLS and Matlab. Measured parameters are Reverberation Time (T_{30}), Bass-Ratio (BR), Clarity (C_{80}), Definition (D_{50}), Strength (G), Early Decay Time (EDT) and Interaural Cross-Correlation ($1 - IACC$). The rehearsal rooms were arranged according to Table 1.1. In addition to these acoustic parameters further work has been carried out analyzing the impulse responses measured in each room. The Support Factor ($ST1$) was not investigated, since the previous work by Johan Andersson [And08] showed no correlations to subjective impressions.

3.1.1. Equipment

- The software used for impulse response measurements had the following configuration.

  Sampling frequency 44100 Hz

  FFT length 65635 samples

  Loop-back yes

  Speed of sound 344 $\frac{m}{s}$

  Number of averages 16

  Type of MLS A

- Microphone: Audix TR40 and DPA 4060 omni directional

- Loudspeaker: a dodecahedron and a Genelec 8020A
- Dummy head
- Audio devise: EDIROL UA-25
- B & K calibrator

3.1.2. Mono parameters

The acoustic parameters were measured using two different setup configurations. The first setup was configured according to ISO 3382, using a dodecahedron loudspeaker and a microphone with omni directional characteristics. The measurement positions used for the standard measurement can be seen in Figure 1.2 and Figure 1.3, whereas the "MUSICIAN" position was excluded, microphone positions are market "R" and source positions are market "S". The measurements in Room 1A and 1B were carried out in full accordance to ISO 3382. Since Room 2 was very small, a modification was made to the ISO standard measurement, whereas positions were chosen with respect to the available space.

The second setup was made to simulate the conditions of a musician playing the trumpet and primarily measured to compare the sound strength between standard measurements and the modified in setup two. The modified setup contained a directive source representing the clock of the trumpet, and an omni directional microphone placed 60 cm behind the loudspeaker representing the head of the musician, which can be seen in Figure 3.1. Additional analysis was made to measured impulse responses gathered using the second setup where a directional source was used.

Reference measurements were made according to standard in an anechoic chamber with a source to receiver distance of 3.2 m, Figure 3.2 shows the setup used in the anechoic chamber. The distance was interpolated to 10 m since the parameter G requires the reference of 10 m in free-field. An additional reference measurement was made that corresponded to the second setup using a directive source, where the directive source represented the trumpet, and a omni directional microphone placed 60 cm behind the directive source represented the musician. This modification of setup was an attempt to more closely simulate an actual playing situation. The directivity of both a trumpet and the directive source, Genelec 8020A were compared and the differences were judged as acceptable [Gen, Bun, ORC$^+$02].

3.1.3. Spatial parameters

A dummy head was used in order to measure the spatial parameter $1 - IACC$. The measurement setup was configured to mimic the situation of a musician playing the

Figure 3.1.: Modified setup with directive source.

Figure 3.2.: Referens measurement in a anechoic chamber.

trumpet. The height of the dummy head was set to 1.75 m whereas the acoustic centre of the source was set to 1.6 m representing the height of a normal trumpet position when coupled to the mouth. Only one position in each room was considered for the spatial evaluation. The positions used are marked MUSICIAN and are displayed in Figure 1.2 and Figure 1.3. The position in the room was chosen due to the fact that the musicians were placed at that position during the subjective evaluation. Therefore they were interesting for comparison of the results gathered from the subjective evaluation. The microphones integrated in the dummy head were not used, instead small microphones were mounted using adhesive tape, the setup can be seen in Figure 3.3.

3.2. Sound levels and spectral measurements while musicians were playing

Binaural recordings were made in order to evaluate possible differences between perceived and measured sound levels. Binaural measurements were only evaluated for four out of nine musicians due to technical misfortune. The musicians had to warm-up before they were recorded to minimize variations. Figure 3.4 shows one of the musicians playing during the acoustic measurements. The recordings were made with DPA

Figure 3.3.: Spatial measurement setup.

microphones attached as close to the ear as possible. The trumpet players played two predefined musical pieces from Arban's Complete Conservatory Method for Trumpet, namely piece 13 (referred to as piece one), and 28 (referred to as piece two), which both have a duration of approximately 35 seconds. The pieces played were decided in collaboration with professional trumpet players, including several attributes like, fast, slow, strong, and weak parts. Piece one played by the musicians did not have a dynamic indication, which piece two had, (mp and mf). The rooms were arranged according to Table 1.1.

After minor editing of the binaural recordings using Logic Pro, the tracks were analyzed with software Aurora, which is a plug-in for Adobe Audition. Aurora was used to calculate absolute L_{eq} through loading a reference tone. The reference tone was recorded after every recording using a B & K calibrator, which generates a 1 kHz tone at a level of 114 dB. The edited recordings were also processed in MATLAB in order to evaluate the frequency distribution generated by the trumpet.

Figure 3.4.: One of the musicians playing while binaurally recorded, where the left picture is a close-up and the right picture shows the setup in Room 1B at Gothenburg Academy for Music and Drama.

3.3. Subjective judgement measurements

The subjective investigation was divided in two parts; answering a questionnaire and taking part in an interview. The interview was carried out in the end of each session where further discussions made it possible collect additional information and potential difficulties that the subject might have experienced [BZ06]. The questionnaire, containing ten questions, was created using a nine-point hedonic category scale [BZ06] presented in Figure 3.5. Space for additional discussion and written thoughts were made available for the questionnaire for each question. The questions considering the subjective impressions were formed with respect to measurable acoustic parameters.

3.3.1. Preparation

In order to create the questionnaire, inspiration was taken from a questionnaire used in a Master Thesis by Johan Andersson [And08]. The questions were tested and discussed together with two trumpet players, both later participating in the real subjective judgement evaluation of the rooms. This was done to see how relevant the questions were for trumpet players and, in the end, find the right and most understandable words and meanings to make the questionnaire as clearly expressed as possible. The preparing discussion with the musicians also gave them an opportunity to add relevant aspects which were included in both questionnaire and interview. The questions were chosen to take several aspects of trumpet playing in a room into account. The first page of the questionnaire contained a list of personal information, such as questions regarding genre, hearing impairment, and common rehearsal methodology used by the musicians.

Interview methodology was studied in order to carry out the interview without making leading questions [BZ06]. An interview foundation was built to keep the structure of the interview, where all musicians were asked the same questions. Even though there was a consistent structure in the interview, space was made available for further thoughts and deeper discussions when needed. As a measure of security the interviews were recorded, which made it possible to get back to the interview if further lines of thought needed to be clarified.

During the test session with the two trumpet players, the limitations listed in Section 1.4 were evaluated. The time needed for the real test were also evaluated. The time plan included, needed time for the musician to warm-up, approximately 15 minutes for judging each room and 30 minutes for the interview was decided to be appropriate.

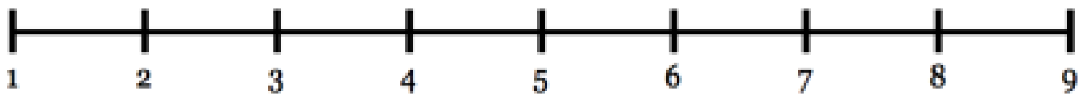


Figure 3.5.: The figure shows the nine point hedonic category scale.

Questions 1 to 10 are displayed in the list below. Take into account that the original questions were written in Swedish and translation of questions like these are maybe ambiguous. The original questionnaire in Swedish is included in Appedix A.

1. How important is the acoustic environment in practice rooms?

   Range: Not at all - Very

2. How good is the room for rehearsing?

   Range: Bad - Excellent

3. How do you perceive the sound level in this room?

   Range: Too low - Too strong

4. How strenuous is it to play in this room?

   Range: Not at all - Very

5. How do you rate your ability to play dynamical?

   Range: Small - Big

6. How well are the rapid parts perceived?

   Range: Bad - Excellent

7. How well are the slow parts perceived?

   Range: Bad - Excellent

8. How do you perceive the support from the room?

   Range: Bad - Excellent

9. How would you rate the balance between hard/soft?

   Range: Too soft - Too hard

10. Describe the room coloration with a color.

3.4. Analysis

The idea was to compare measurements for similar quantities by using the different approaches described earlier in this chapter. Comparing different approaches would give indications on areas where normal standard acoustic measurements converge or diverge with subjective measurements.

Sound levels were one attribute that was measured using several different approaches. Sound levels were judged in the questionnaire, measured while the musician was playing, and measured according to standard. Investigations were made whether the standard measurements showed similar results as the subjective. Analysis of impulse response measurements where made in order to investigate the behavior of the rooms and find a tendency in the room character that corresponded to any quality subjectively evaluated in the questionnaire.

The recorded impulse response data using MLS sequences, from the room acoustic parameter measurements was exported from WinMLS into MATLAB. The first processing was done using MATLAB, including average data of acoustic parameters mentioned in chapter 3.1. The averaged data was then imported to SPSS where Repeated Measures Analysis of Variance were done to see the influence of room size and drape arrangement on the subjective measurements. Since similar measurements were done in all rooms, between effects can be calculated, i.e. by altering the drapes, the effects of the drapes can be estimated. This approach can analogically be used to estimate the influences of room size. The method is explained in Section 2.4.

4. Results

4.1. Acoustic Parameters

Reverberation time

The curves of the reverberation time in Figure 4.1 show tendencies of modal behavior in the lower frequency range due to the limited size of the rooms (more clear in narrow band), thereby one should be well-aware of uncertainties when evaluating values below 500 Hz. Room 1A clearly has the longest reverberation time and Room 2B has clearly the shortest reverberation time. The reverberation time measured in Room 1B and Room 2A show rather similar results. Within Room 1 and Room 2, the biggest differences are found between 500 Hz and 4 kHz.

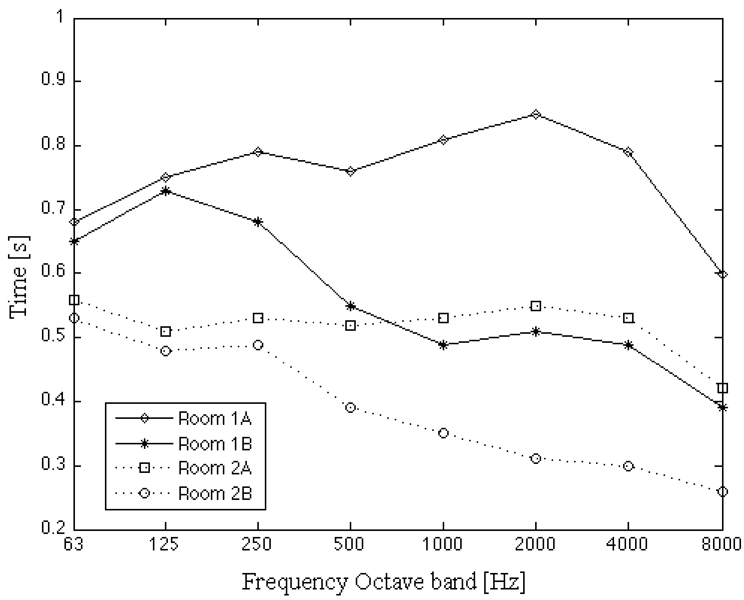


Figure 4.1.: Reverberation time for the room configurations.

The Schroeder frequency, critical distance and total absorption are calculated for each room, based on the measured reverberation time and volume. The presence of absorbing drapes lowers the Schroeder frequency and thereby increases the frequency range of diffuse field, which makes it possible to use the statistical model further down in frequency to analyze the behavior of the room. The presence of drapes also increases the critical distances (average of octave bands 500 Hz, 1 kHz and 2 kHz) that are calculated with Equation 2.5. The calculated Schroeder frequency, critical distance and total absorption can be seen in Table 4.1.

Table 4.1.: Schroeder frequency, critical distance (500 Hz - 2 kHz) and total absorption for the room configurations.

Room	Schroeder frequency [Hz]	Critical distance [m]	Tot. Absorption [m^2S]
1A	190	0.59	18
1B	156	0.73	26
2A	266	0.42	9
2B	220	0.52	13

Warmth, Bass-Ratio

Calculated BR values are shown in Table 4.4, where the two rooms with drapes unfolded show larger values than the rooms with drapes folded. The calculations are made according to Equation 2.13. It is noticeable that there seem to be two clusters, one at ~ 1.3 and the other at ~ 1 for the room distribution of BR.

Table 4.2.: Bass-Ratio for the room configurations.

Room	BR
1A	0.981
1B	1.356
2A	0.991
2B	1.311

Clarity

Calculated clarity, C_{80}, can be seen in Figure 4.2. Highest values of clarity appear in Room 2B and the lowest in Room 1A. Small differences are noticeable between Room 1B and Room 2A. The clarity is calculated according to Equation 2.14.

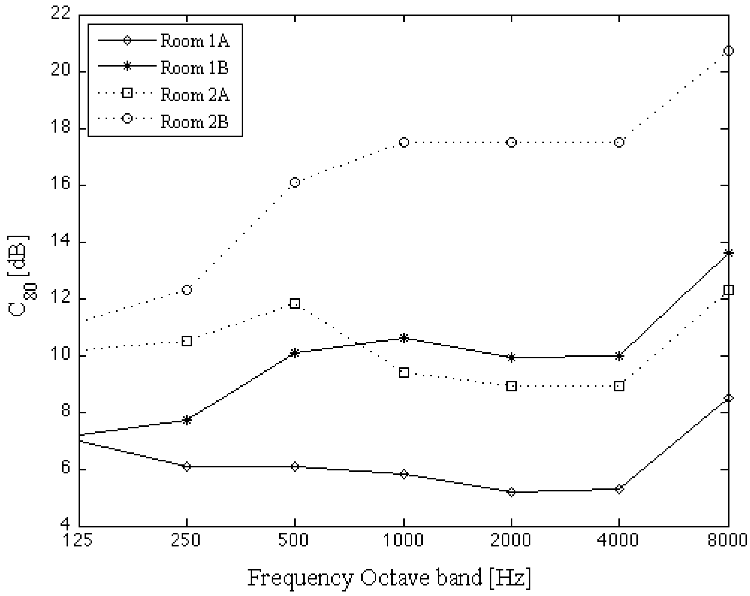


Figure 4.2.: Clarity, C_{80}, for the room configurations.

Definition

Definition D_{50} show similar behavior as previously mentioned for C_{80}. The calculation of D_{50} are according to Equation 2.16 and can be seen in Figure 4.3.

Interaural Cross-Correlation

Figure 4.4 show the $IACC_A$ and the amount of diffusion and correlation between both ears. This was measured according to Section 3.1.3. Room 2A is most diffuse, whereas Room 1B shows the lowest values of diffusion. Room 1A and Room 2B show largest similarities of the four different rooms even though the difference is substantial.

The early interaural cross-correlation is evaluated and Table 4.3 shows the averaged $1 - IACC_E$ values for the mid frequency octave bands 500 Hz, 1000 Hz, and 2000 Hz. The integration time has been varied between 80 ms and 60 ms since the relatively small size of the rooms might have some influence. The additional integration time of 60 ms was established by looking at the impulse responses in Figure 4.7 and trying to localize the break between early and late reverberant field. According to Table 4.3 a small difference appears when changing the integration time and this difference is far below the just noticeable difference level. In Room 2A, which is most diffuse, only 17 % of the early arriving sound from each ear is correlated.

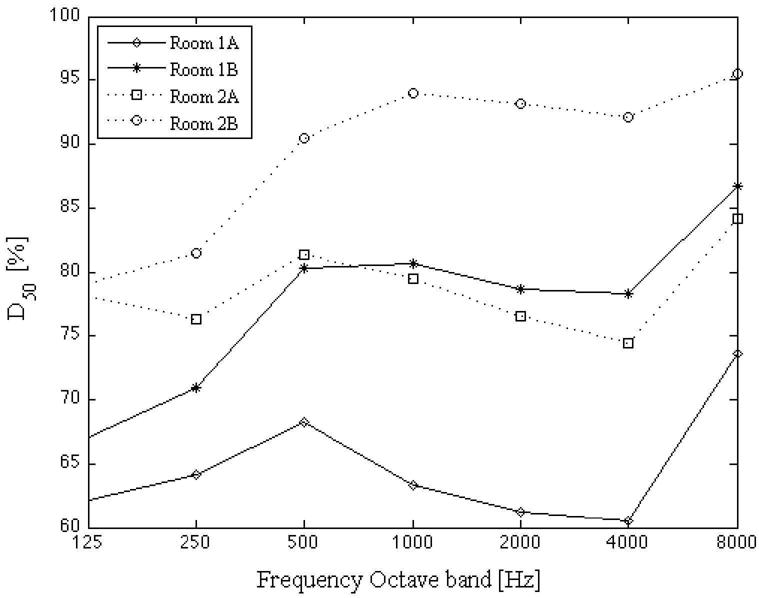


Figure 4.3.: Definition, D_{50}, for the room configurations.

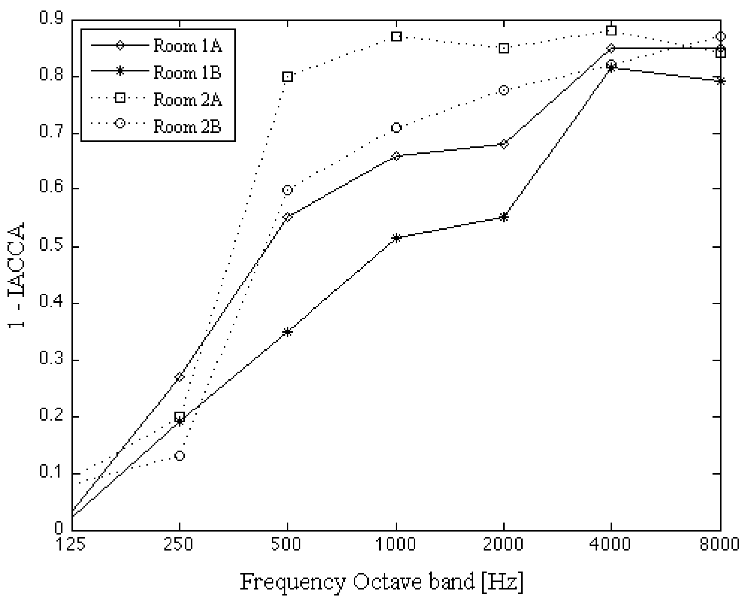


Figure 4.4.: Interaural Cross-Correlation, 1-$IACC_A$, for the room configurations.

Table 4.3.: 1-$IACC_{E3}$ with a time limit set to 80 ms and 60 ms.

Room	$1 - IACC_{E3,80ms}$	$1 - IACC_{E3,60ms}$
1A	0.54	0.52
1B	0.44	0.42
2A	0.83	0.81
2B	0.69	0.69

Strength

The measured strength according to standard is shown in Figure 4.5, the positions used are specified in Figure 1.2 and Figure 1.3. Large differences in measured strength are seen in both rooms, where each case measured with absorbing drapes show lower levels than the case without drapes. The difference between the measured strength decreases as we go higher in frequency for Room 2B and Room 1A. This behavior is due to the absorbing drapes, which act like a porous absorber where only frequencies above approximately 500 Hz are damped. The curves representing rooms without drapes show rather constant strength values above 500 Hz, whereas the rooms with drapes show a decrease at approximately 1 kHz and 2 kHz due to the absorptive range of the drapes.

The middle frequency strength (G_{mid}) is calculated by averaging the mid frequency octave bands of 500 Hz, 1000 Hz, and 2000 Hz. Table 4.4 show the calculated G_{mid} values. The biggest difference is between Room 2A and Room 1B, which is in the range of 6 dB. The smallest difference of strength is found between Room 2B and Room 1A and it is 1 dB.

Table 4.4.: G_{mid} for the room configurations.

Room	G_{mid} [dB]
1A	25.6
1B	23.2
2A	28.9
2B	26.6

Strength measured with directive source, according to Section 3.1.2 is shown in Figure 4.6. Strong interference behavior is present for all four rooms in this case. In the small room a peak is present at 250 Hz, which might be due to the wall in front of

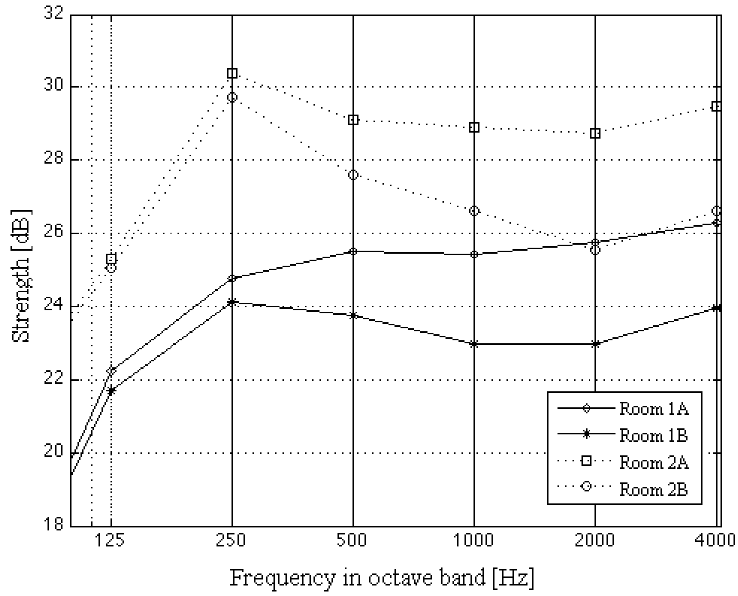


Figure 4.5.: Strength measured with omni-directional source.

the loudspeaker, since half of the wavelength fits into this distance. Both the specific value of strength and the difference between the rooms seem to increase with higher frequency.

The middle frequency strength (G_{mid}) is also calculated for the directive source by averaging the mid frequency octave bands of 500 Hz, 1000 Hz, and 2000 Hz. Table 4.5 shows the calculated G_{mid} values for the directive source. The largest difference is between Room 2A and Room 1B reaching a level difference of 4 dB. The G_{mid} values for Room 1A and Room 2B differ roughly by 1 dB. The differences between the four rooms are smaller measured with the directive source than with omni directional source. It is noticeable that the levels in the rooms with reference to the free-field are lower than 10 dB.

Impulse Response

The measured impulse responses, using the directive loudspeaker, can be seen in Figure 4.7, where the first row shows Room 1A and Room 1B and the second row shows Room 2A and Room 2B. Impulse responses measured in Room 1 show less peaks and valleys in the pressure distribution than the impulse responses measured in Room 2. The effect of the absorbing drapes is clearly visible in both rooms. In excess to the faster pressure decay, an effect of smoothening appears of peaks and valleys, where for example the

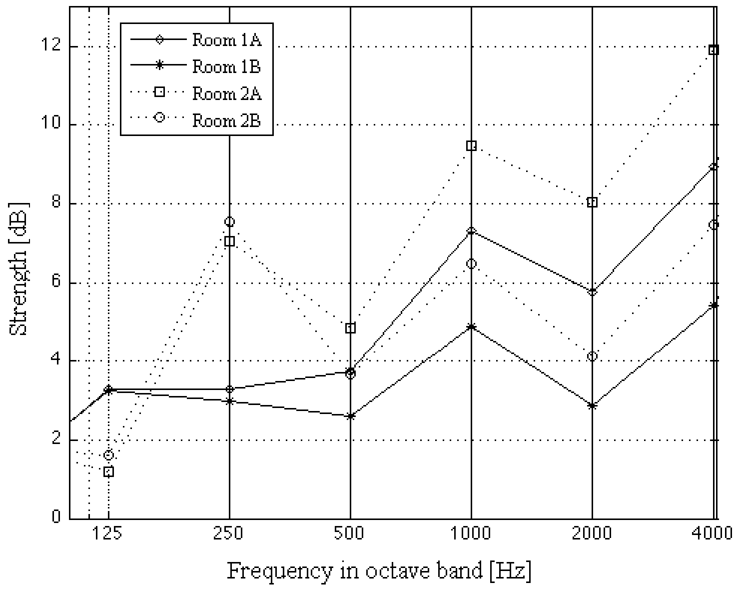


Figure 4.6.: Strength measured with a directive source (Genelec loudspeaker).

Table 4.5.: G_{mid} measured with a directive source for the room configurations.

Room	G_{mid} [dB]
1A	5.6
1B	3.5
2A	7.5
2B	4.8

strong reflections at 25 ms and 60 ms in Room 2A are reduced in Room 2B. The impulse response of Room 1B show three clear limits of direct, early ($\sim$ from 10 to 50 ms) and late (from 50 ms) arriving sound with a relatively even distribution over time. These transitions are not as distinguishable in the impulse responses of the three other rooms.

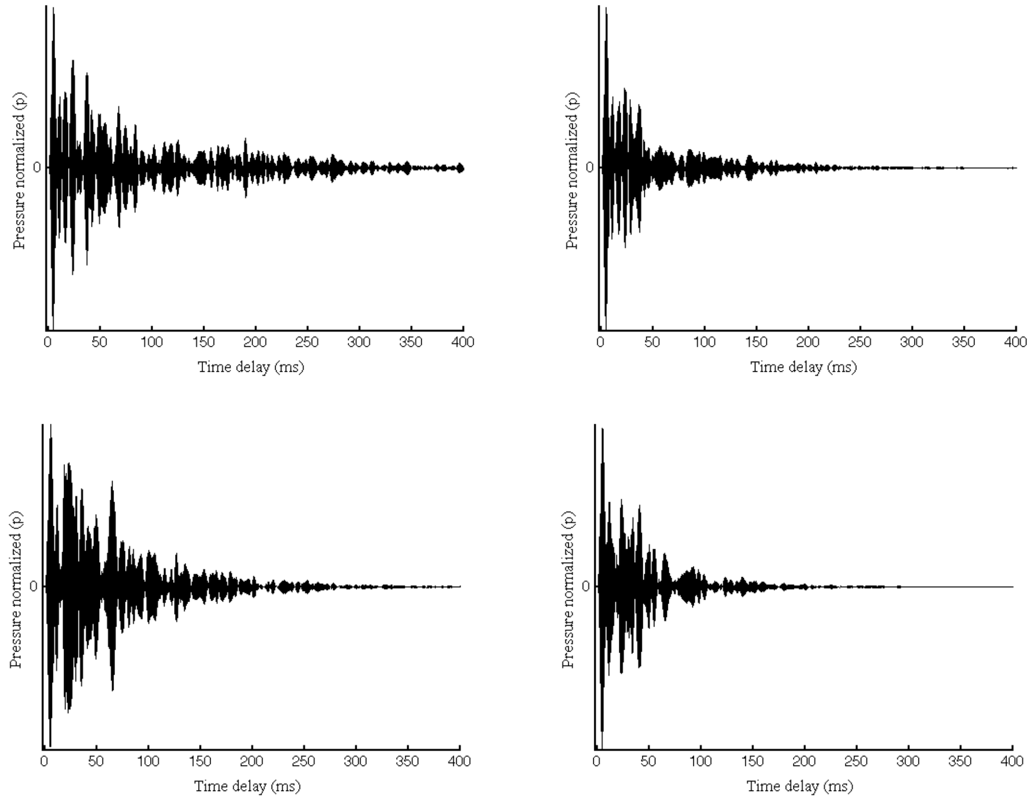


Figure 4.7.: Impulse responses of the four rooms, displayed in order from left to right; 1A, 1B, 2A and 2B.

4.2. Results of measurements while playing

In this section, the results from the measurements while playing are presented. Figure 4.8 shows the frequency content of two pieces played by one of the musicians. The visual differences are in some extent rather small, but indeed significant to the musician. The frequency content distributed by the trumpet seems to be in the range of approximately 250 Hz to 4 kHz, whereas most energy is found between 500 Hz and 2 kHz. Level differences of particular frequency regions are not only due to the specific room, since no strong pattern can be seen comparing frequency spectra of other musicians. Frequency spectra of other musicians can be seen in Appendix B

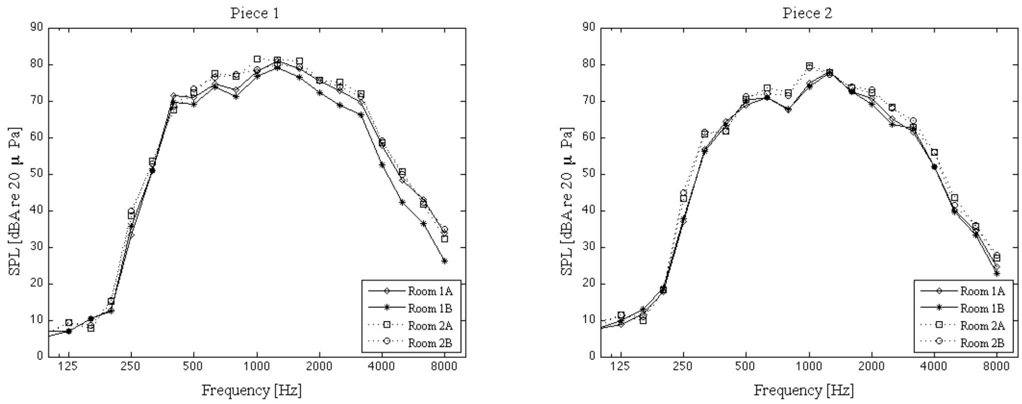


Figure 4.8.: Frequency spectra of the right ear for the two pieces played by one musician.

In Table 4.6 the equivalent sound pressure level is presented for the four trumpet players. The table is divided into each of the two pieces and the individual difference between the largest and the smallest value is shown. Also, the standard deviation is presented. To the right, two columns with the average $L_{eq}(A)$ and the calculated average L_W for each of the four rooms are presented.

Table 4.6.: Equivalent sound pressure levels and calculated sound power levels for the trumpet players.

Tr. #	1		2		3		4		Av. $L_{eq}(A)$	Av. L_W
Piece	1	2	1	2	1	2	1	2	Both	Both
Room 1A	98.5	94.6	98.4	95.8	97.8	93.4	95.8	94.9	96.2	102.4
Room 1B	95.7	93.4	98.1	94.6	95.6	92.9	95.2	94.6	95.0	103.2
Room 2A	96.7	93.5	99.7	95.8	97.5	93.8	96.8	96.1	96.2	99.5
Room 2B	95.6	93.5	99.7	95.9	96.3	93.8	96.2	95.2	95.8	100.9
Δ_{max}	2.9	1.2	1.6	1.3	2.2	0.9	1.6	1.5	1.2	3.7
STD	1.35	0.57	0.85	0.62	1.02	0.40	0.66	0.64	0.56	1.64

The L_W is calculated from the average $L_{eq}(A)$ with Equation 2.4, assuming static sound field [AK08].

As mentioned before, the first piece did not have any dynamic indicators which the second piece had. For all trumpet players, the second piece has less difference between the four rooms compared to the first piece. It is also seen in the lower value of the standard deviation, STD.

In the column second from the right, one can see that the average largest difference between the rooms is 1.2 dB, which should be compared with the average largest difference in the calculated L_W between the rooms which is 3.7 dB.

4.3. Subjective Measurement Results

For the first nine questions, a nine point hedonic category scale was used in order to rate the rooms. For the following figures, both color and shape coding is used.

1. Color - Genre

   C Classical music genre is represented by a black marker

   J Jazz and Afro music genre is represented by a white marker

2. Shape - Music level

   Am Amateur is represented by a square

   Pr Professional is represented by a circle

   St Student is represented by a triangle

4.3.1. Question 1 - How important is the acoustic environment in practice rooms?

This general question was asked before the trumpet player entered any room. It is in a way a confirmation of this thesis and its importance to this neglected topic. In Figure 4.9 and Table 4.7, the ratings and its mean and standard deviation are presented. With a mean value of 8.2 is obvious that the acoustic environment is important in practice rooms. Among the answers the following answer summarizes it quite well, *"It's at practice one shapes the tones and learns in a correct or incorrect way"*[1].

4.3.2. Question 2 - How good is the room for rehearsing?

In this question, the trumpet players were asked to judge the overall quality of each room, where nine represents *Excellent* and one represents *Bad*. As can be seen in Figure 4.10, the ratings vary much for the different musicians. In table 4.8 the mean and the standard deviation of the rating are presented. Room 1B has the highest mean value

[1] All the answers were in Swedish, and the translations should be regarded carefully since some meaning and content could be lost or changed in the translation.

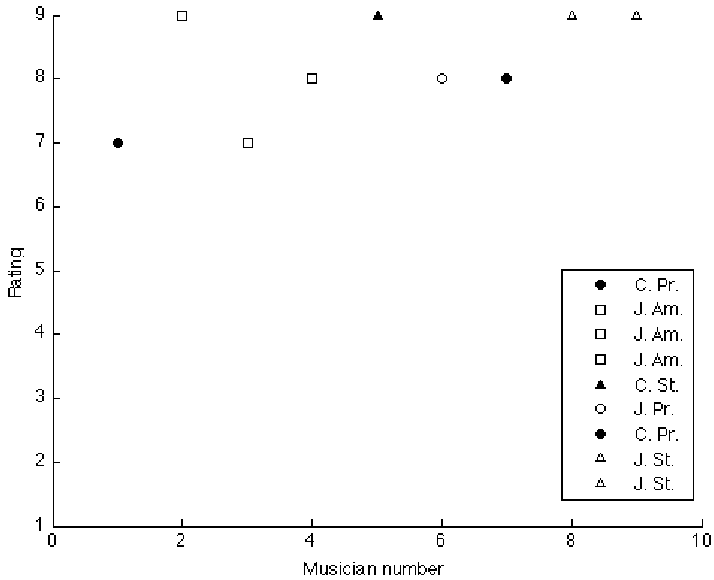


Figure 4.9.: Ratings for question 1 - How important is the acoustic environment in practice rooms?

Table 4.7.: Mean and Standard deviation for question 1 - How important is the acoustic environment in practice rooms?

	Mean	STD
General	8.22	0.83

and the smallest deviation. The rooms without drapes, Room 1A and 2A, show the highest deviations. Room 2A has the lowest mean value. In Figure 4.11 the 95 % confidence interval is presented for each room.

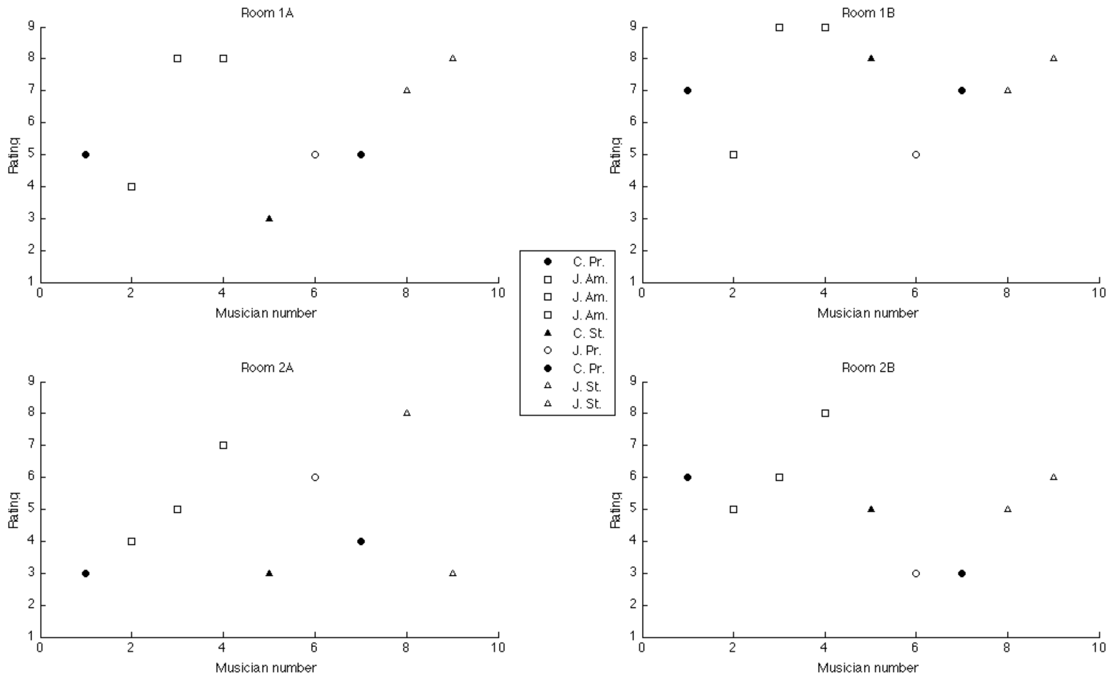


Figure 4.10.: Ratings for question 2 - How good is the room for rehearsing?

4.3.3. Question 3 - How do you perceive the sound level in this room?

In this question, nine represents *Too high* and one represents *Too low*. Compare to question 2, the variations in the ratings for question 3 are smaller, see Figure 4.12 and Table 4.9. The rooms with drapes are generally closer to the optimum (5), whereas the rooms without drapes are around 7 in their mean values. In Figure 4.13 the 95 % confidence interval is presented for each room.

4.3.4. Question 4 - How strenuous is it to play in this room?

In this question, nine represents *Much* and one represents *Not at all*. It should be noted that it can be strenuous to play in many different ways. Generally one can see that for the large room, Room 1A and 1B, the mean value is rather low, around 3, whereas the small room, Room 2A and 2B, show larger values (4.5 and 5.9), see Figure 4.14 and Table

Table 4.8.: Mean and Standard deviation for question 2 - How good is the room for rehearsing?

	Mean	STD
Room 1A	5.9	1.9
Room 1B	7.2	1.5
Room 2A	4.8	1.9
Room 2B	5.2	1.6

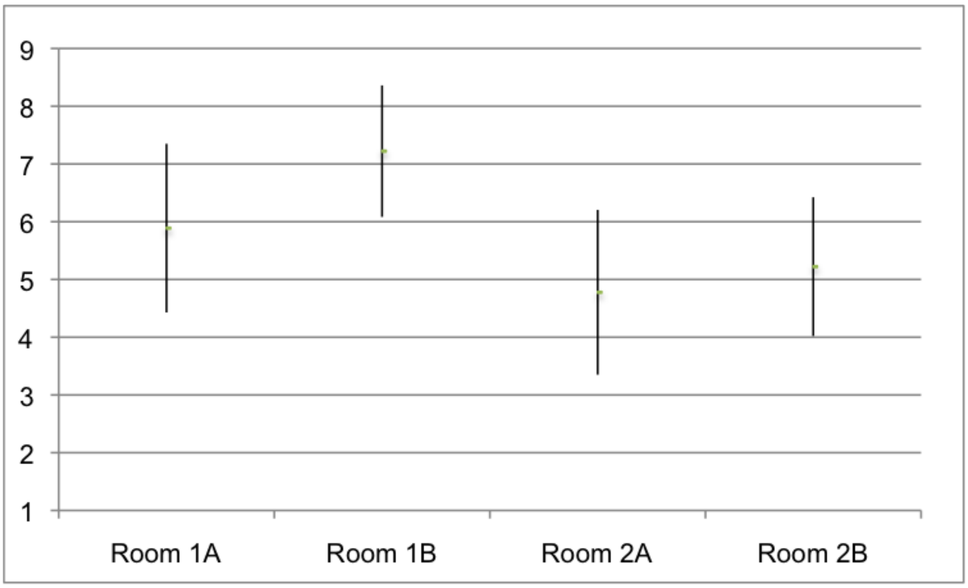


Figure 4.11.: 95 % confidence interval for question 2 - How good is the room for rehearsing?

Table 4.9.: Mean and Standard deviation for question 3 - How do you perceive the sound level in this room?

	Mean	STD
Room 1A	6.9	0.9
Room 1B	5.6	0.7
Room 2A	7.0	1.4
Room 2B	5.4	0.9

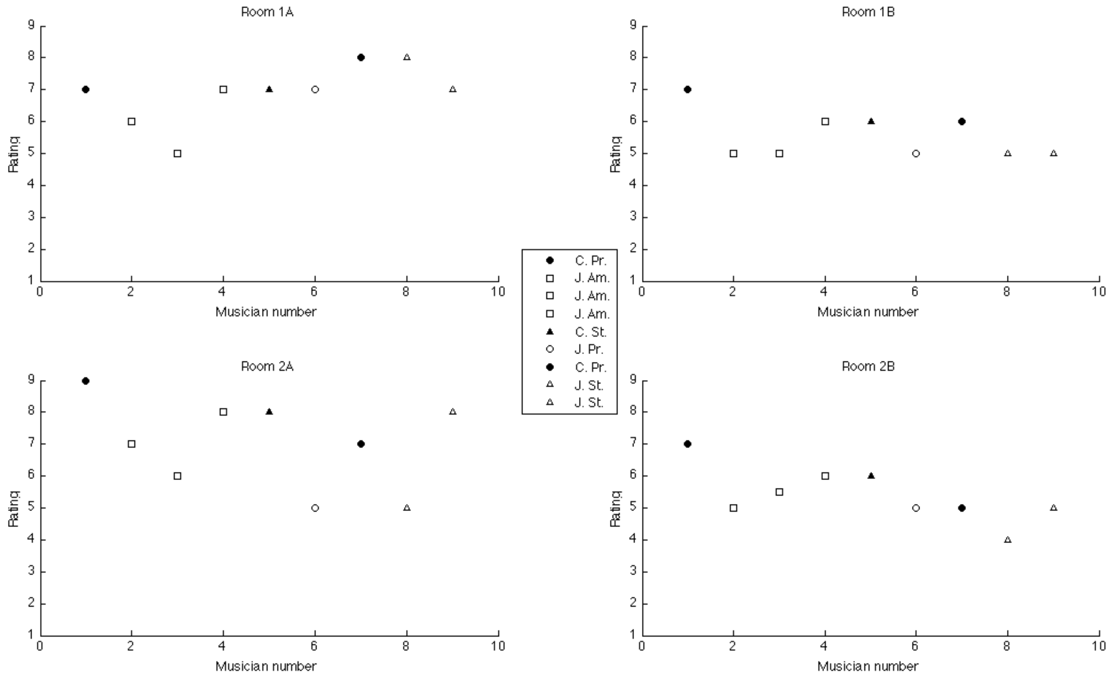


Figure 4.12.: Ratings for question 3 - How do you perceive the sound level in this room?

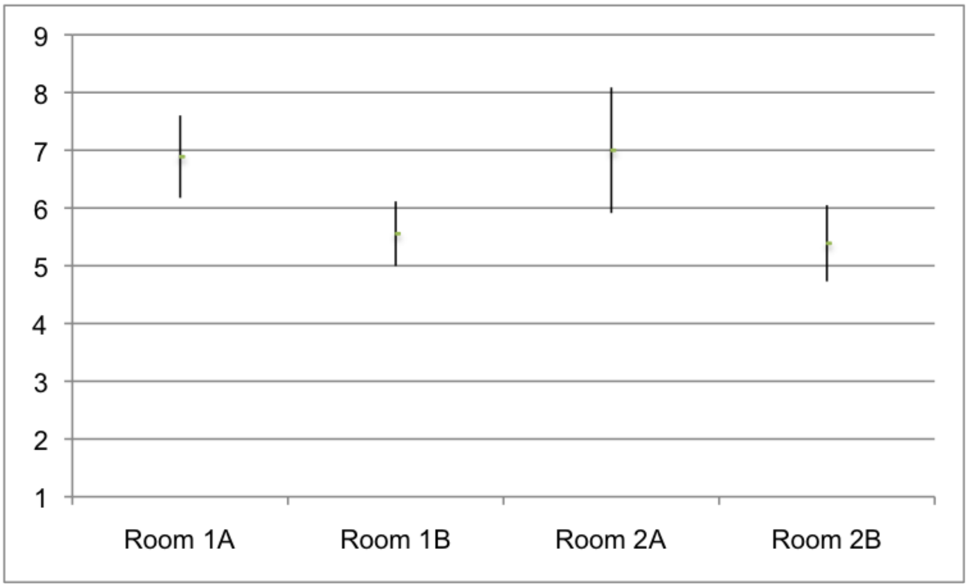


Figure 4.13.: 95 % confidence interval for question 3 - How do you perceive the sound level in this room?

4.10. One can also see that is only a couple of musicians that found it strenuous to play in Room 1A, most of the answers lay around 2. As for many other questions, Room 2A has the largest deviations, here rated from 2 to 8. In Figure 4.15 the 95 % confidence interval is presented for each room.

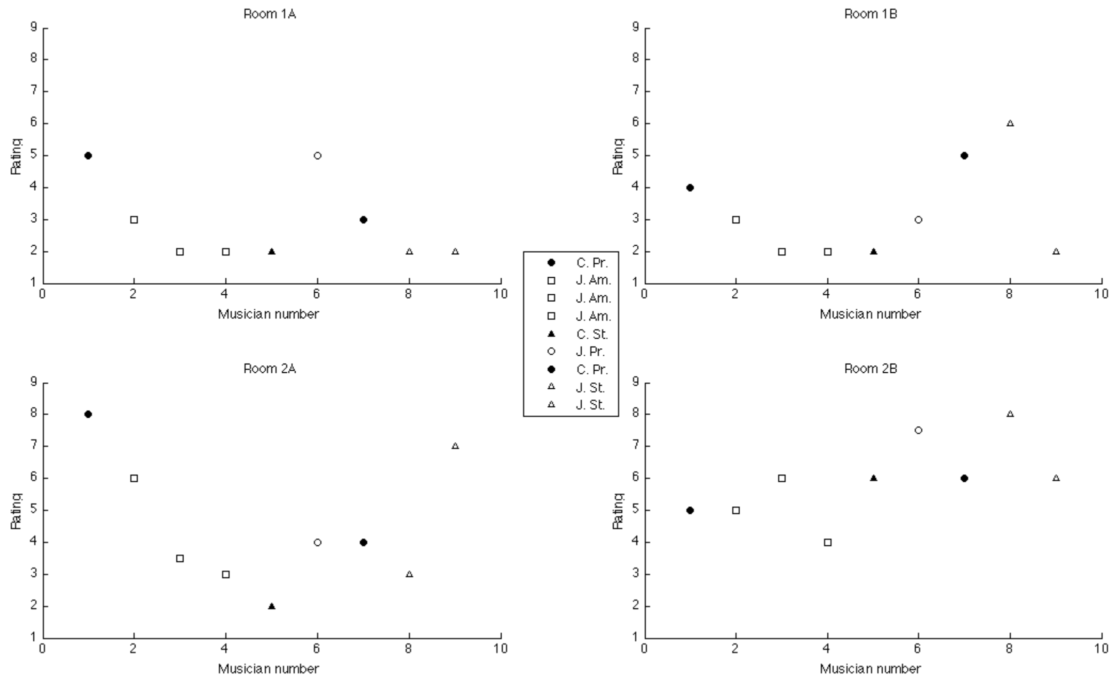


Figure 4.14.: Ratings for question 4 - How strenuous is it to play in this room?

4.3.5. Question 5 - How do you rate your ability to play dynamically?

In this question, nine represents *Large* and one represents *Small*. Large variations can be seen for all four rooms, although Room 1B has a slightly higher mean value than the others, see Figure 4.16 and Table 4.11. Room 1A and 2B have almost the same mean value and standard deviation. Room 2A is rated lowest in this particular question. In Figure 4.17 the 95 % confidence interval is presented for each room.

4.3.6. Question 6 - How well are the rapid parts perceived?

In this question, nine represents *Excellent* and one represents *Bad*. As can be seen in Figure 4.18 and Table 4.12, the mean value is higher for the rooms with drapes, Room 1B and 2B, than for the room without drapes, Room 1A and 2A. Although the variance

Table 4.10.: Mean and Standard deviation for question 4 - How strenuous is it to play in this room?

	Mean	STD
Room 1A	2.9	1.3
Room 1B	3.2	1.5
Room 2A	4.5	2.0
Room 2B	5.9	1.2

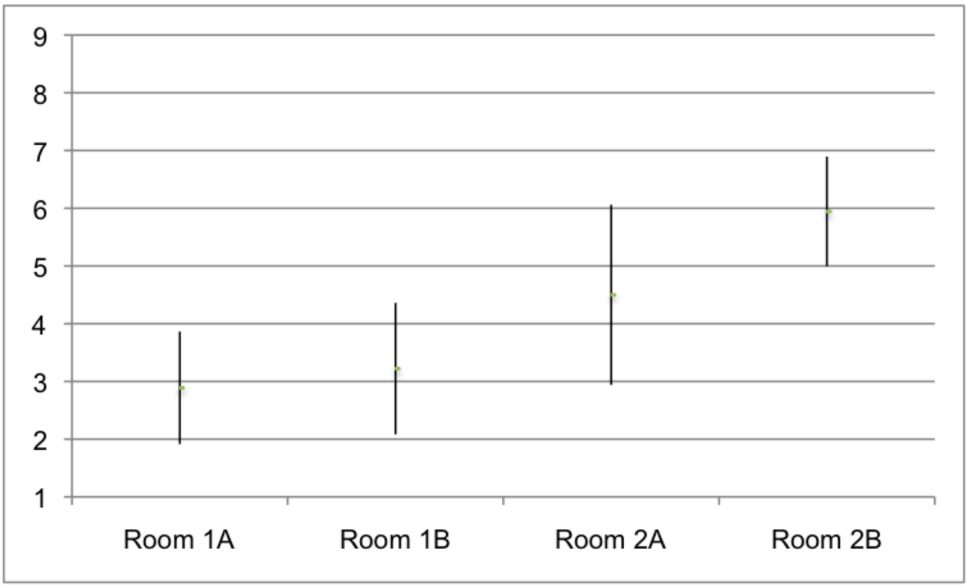


Figure 4.15.: 95 % confidence interval for question 4 - How strenuous is it to play in this room?

Table 4.11.: Mean and Standard deviation for question 5 - How do you rate your ability to play dynamically?

	Mean	STD
Room 1A	5.4	1.9
Room 1B	6.1	1.6
Room 2A	3.9	1.3
Room 2B	5.3	1.7

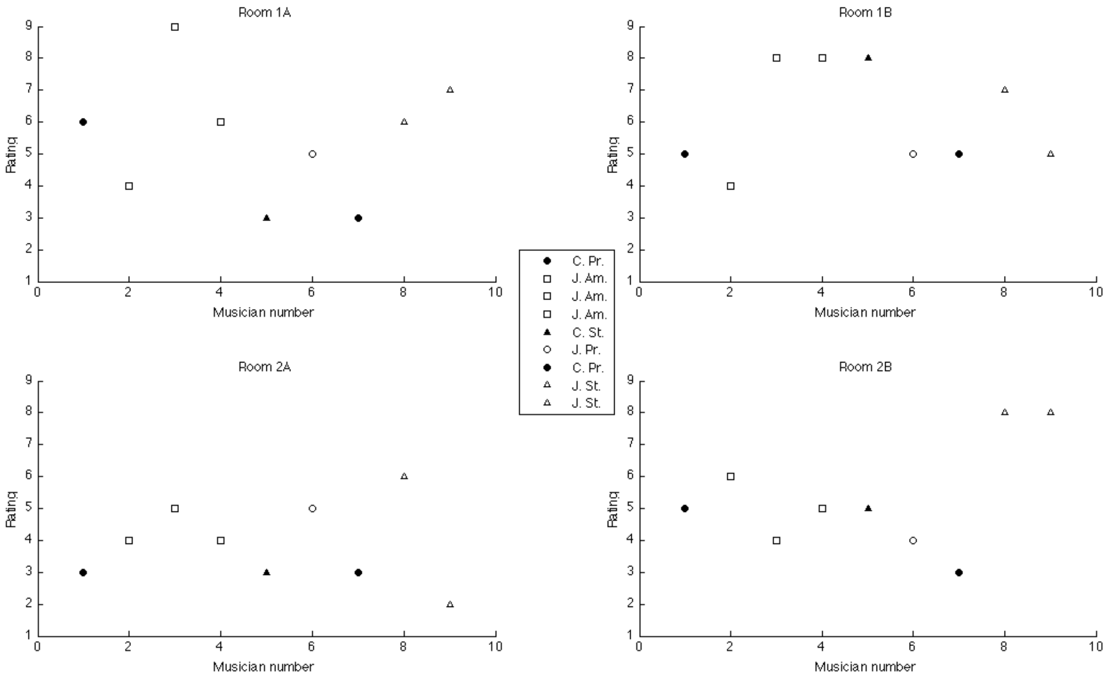


Figure 4.16.: Ratings for question 5 - How do you rate your ability to play dynamically?

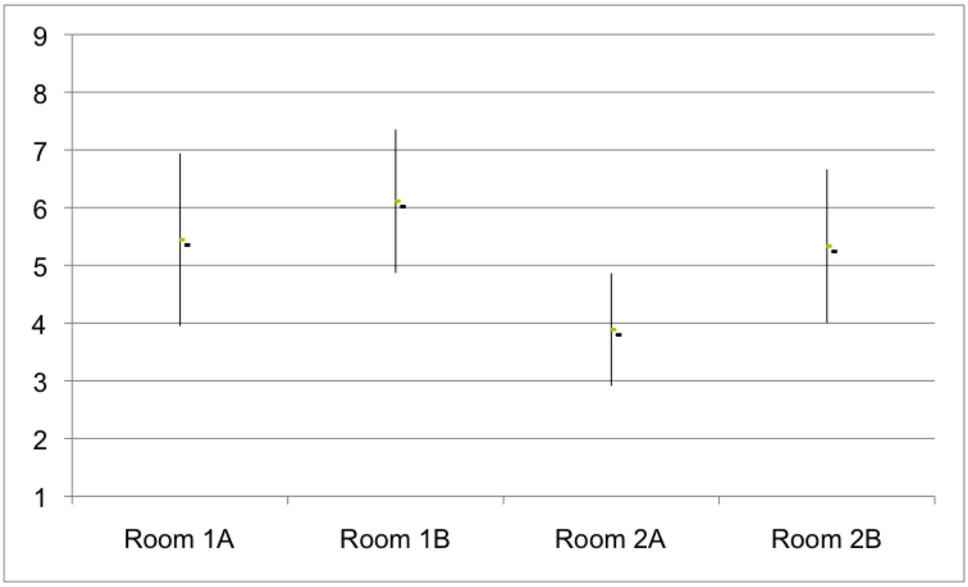


Figure 4.17.: 95 % confidence interval for question 5 - How do you rate your ability to play dynamically?

is largest in Room 2A, which is mainly due to two musicians, it can be compared with variations in Room 1B where the distribution is more even. In Figure 4.19 the 95 % confidence interval is presented for each room.

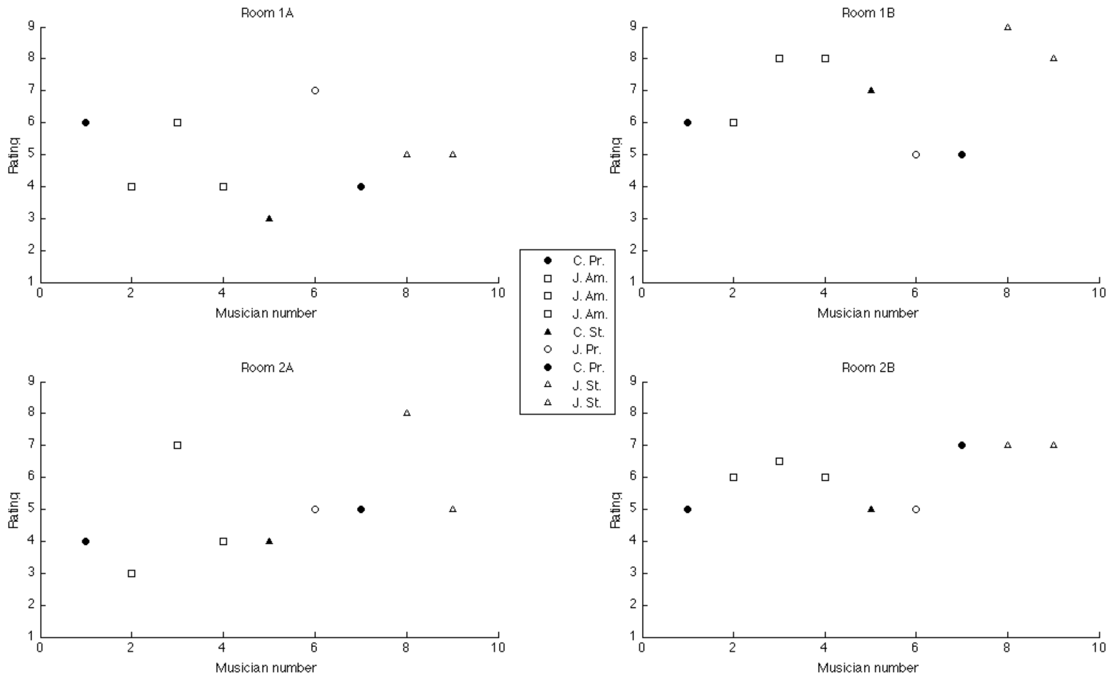


Figure 4.18.: Ratings for question 6 - How well are the rapid parts perceived?

4.3.7. Question 7 - How well are the slow parts perceived?

In this question nine represents *Excellent* and one represents *Bad*. The highest mean value can be seen for Room 1A, see Figure 4.20 and Table 4.13. Room 1B shows rather big deviations but is rated in general above Room 2A. Room 2B is rated the worst, with a mean value of 4.2. In Figure 4.21 the 95 % confidence interval is presented for each room.

4.3.8. Question 8 - How do you perceive the support from the room?

In this question nine represents *Excellent* and one represents *Bad*. The highest values can be seen in the large room, Room 1A and 1B. Largest deviation can be seen in Room 2A, which has a range from 2 to 9. The small room with drapes, Room 2B, seems to give least support to the trumpet player, with a mean value of 3.2, exactly half of the

Table 4.12.: Mean and Standard deviation for question 6 - How well are the rapid parts perceived?

	Mean	STD
Room 1A	4.9	1.3
Room 1B	6.9	1.5
Room 2A	5.0	1.6
Room 2B	6.1	0.9

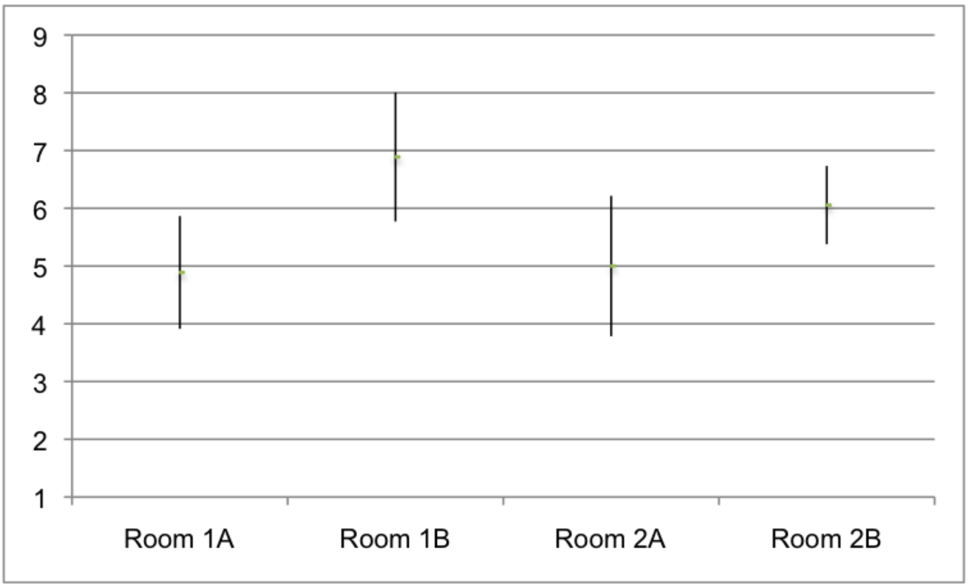


Figure 4.19.: 95 % confidence interval for question 6 - How well are the rapid parts perceived?

Table 4.13.: Mean and Standard deviation for question 7 - How well are the slow parts perceived?

	Mean	STD
Room 1A	7.3	1.2
Room 1B	6.7	1.6
Room 2A	6.0	1.2
Room 2B	4.2	1.6

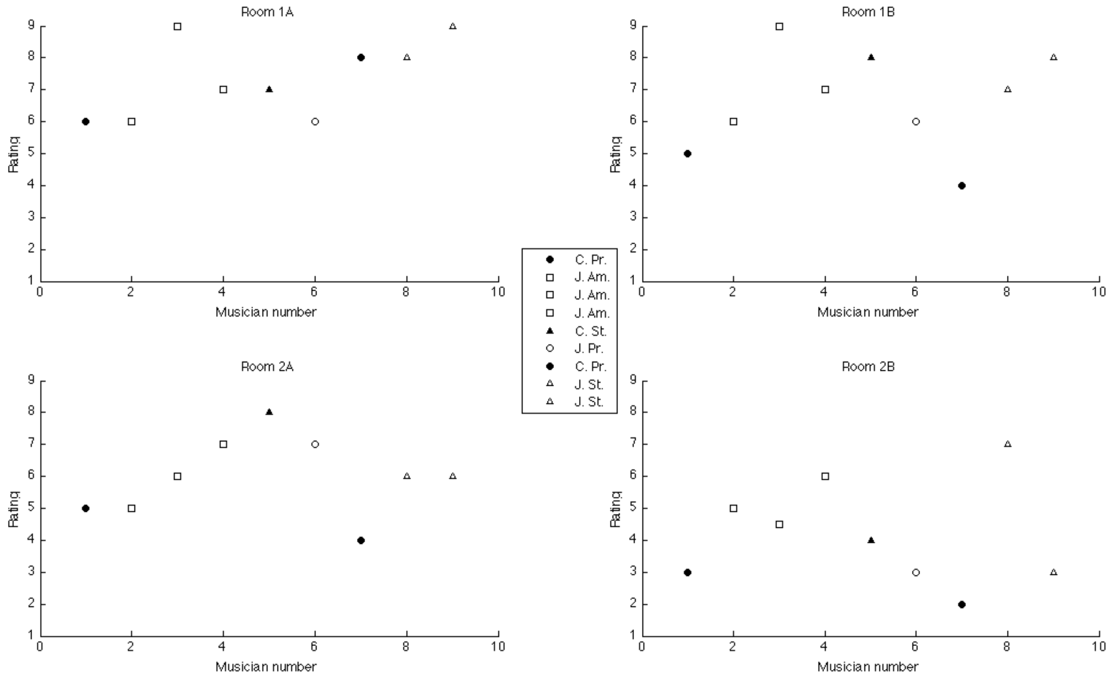


Figure 4.20.: Ratings for question 7 - How well are the slow parts perceived?

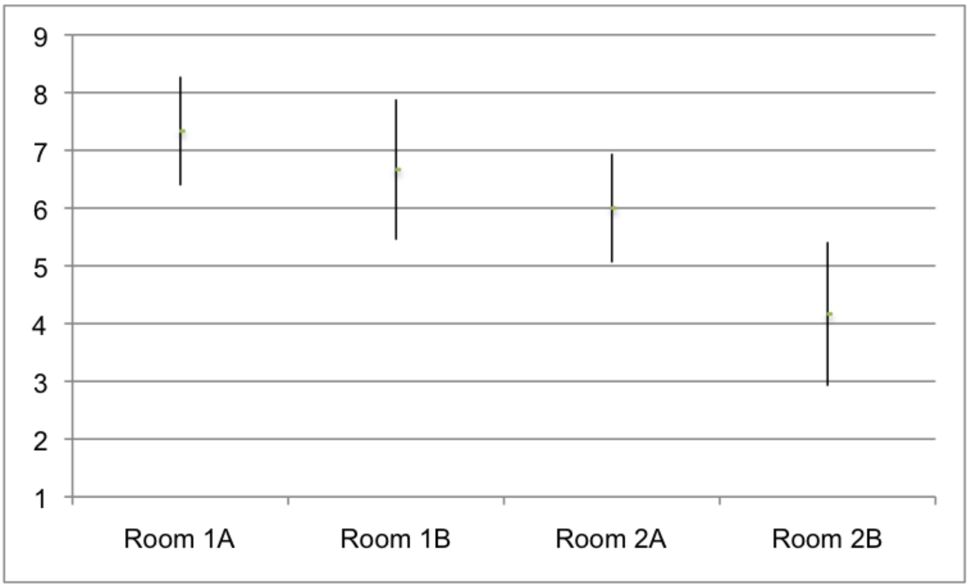


Figure 4.21.: 95 % confidence interval for question 7 - How well are the slow parts perceived?

mean value of Room 1A (6.4). In Figure 4.23 the 95 % confidence interval is presented for each room.

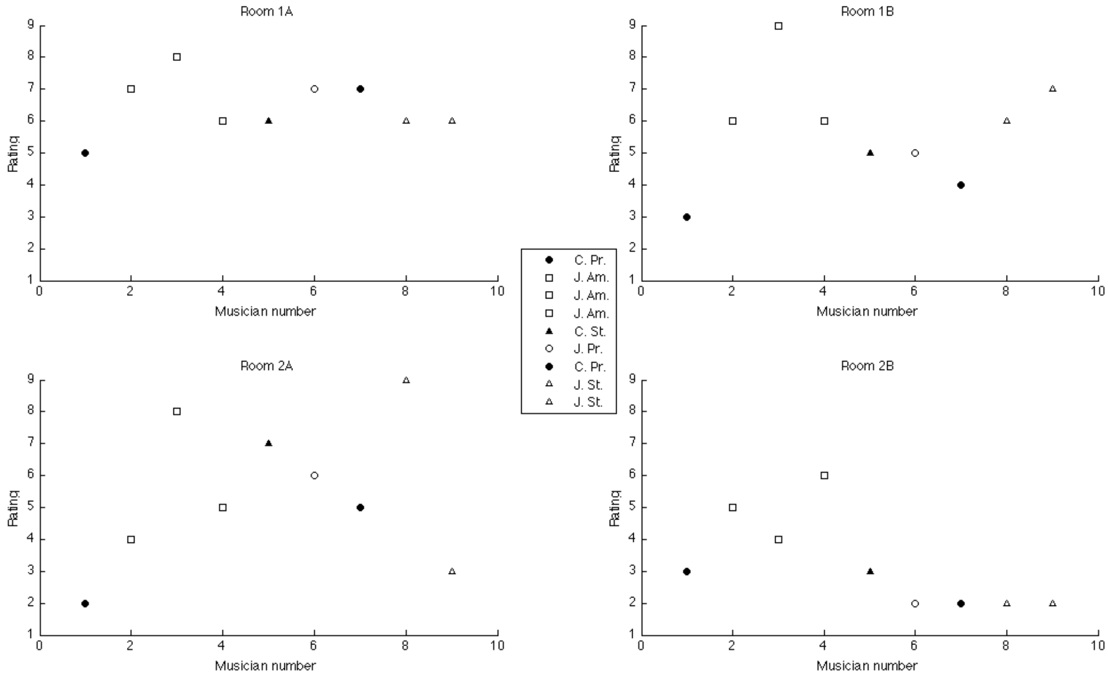


Figure 4.22.: Ratings for question 8 - How do you perceive the support from the room?

4.3.9. Question 9 - How would you rate the balance between hard/soft?

In this question nine represents *Too hard* and one represents *Too soft*. The optimum value is here 5, which also happens to be Room 1B's mean value. Room 2B is very close with 4.8, so the rooms with drapes seem to be perfectly balanced when it comes to hard and soft. The rooms without drapes, Room 1A and 2A, are both rated too hard, with a mean value around 6.5. Again, the variations are large especially for Room 2A, but also Room 1A and 2B show great variations. However, one can see some differences in the characteristics in Figure 4.24. In Room 1A, it is mostly musician number 5 and 8 that differ from the others. In Room 2B for example, the distribution is more even where almost every available number is represented. In Figure 4.25 the 95 % confidence interval is presented for each room.

Table 4.14.: Mean and Standard deviation for question 8 - How do you perceive the support from the room?

	Mean	STD
Room 1A	6.4	0.9
Room 1B	5.7	1.7
Room 2A	5.4	2.3
Room 2B	3.2	1.5

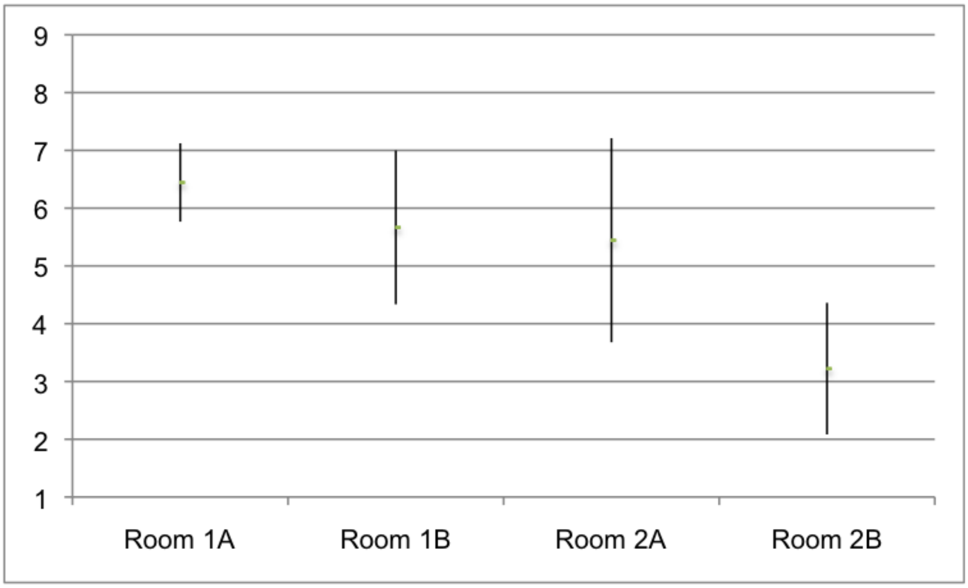


Figure 4.23.: 95 % confidence interval for question 8 - How do you perceive the support from the room?

Table 4.15.: Mean and Standard deviation for question 9 - How would you rate the balance between hard/soft?

	Mean	STD
Room 1A	6.3	2.0
Room 1B	5.0	1.0
Room 2A	6.6	2.5
Room 2B	4.8	1.7

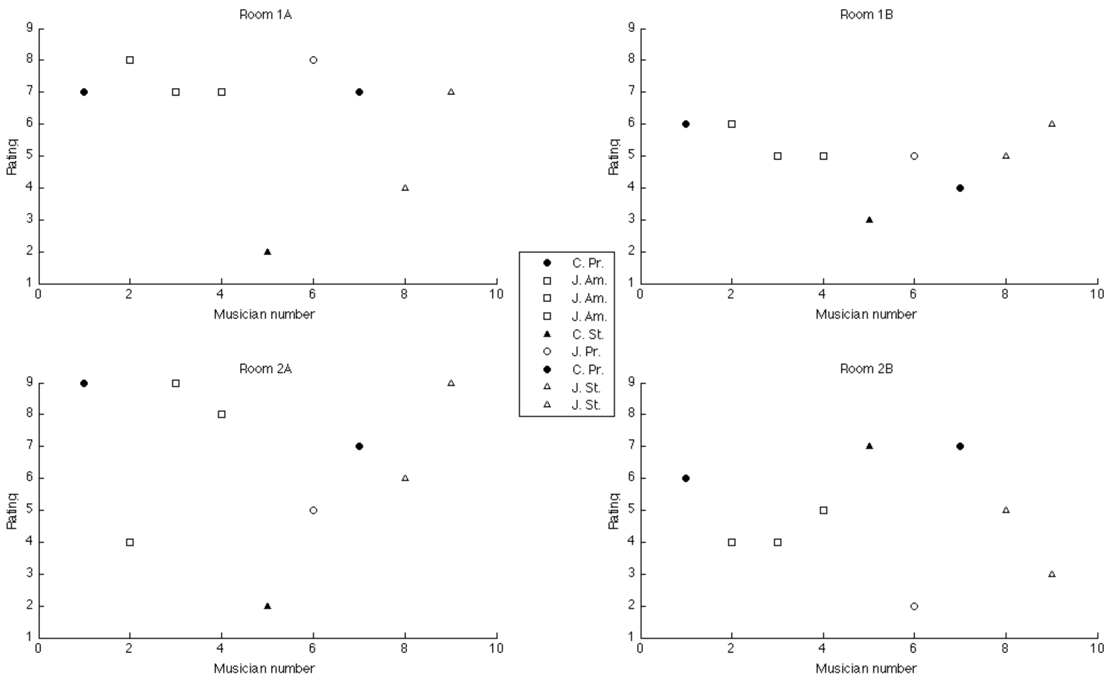


Figure 4.24.: Ratings for question 9 - How would you rate the balance between hard/soft?

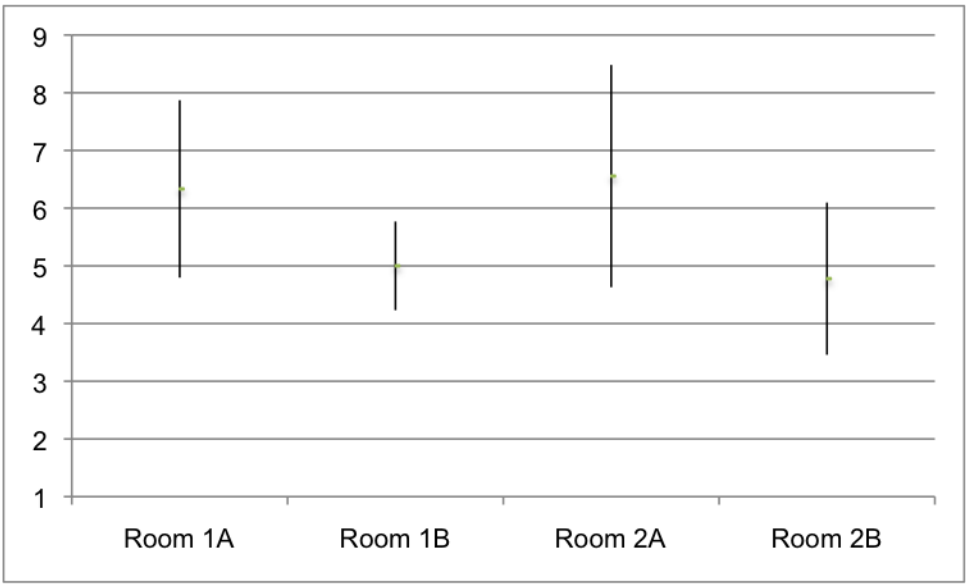


Figure 4.25.: 95 % confidence interval for question 9 - How would you rate the balance between hard/soft?

4.3.10. Question 10 - Describe the room coloration with a color.

This question differs from the others, not only is it not rated on a nine point hedonic category scale but also focusing on associations and not on the actual perception of the sound characteristic. The answers were written down but are here presented in a color plot in Figure 4.26. Our idea was that there might be some connection between color association among musicians, especially in classical music, and their perception of sound qualities. Unfortunately most of the musicians had hard time to even chose a color. Some trumpet players thought of a typically landscape that they felt in the room and chose a domination color in that imaginary picture, such as blue when the room felt like a warm summer day, same had an association path through temperature, e.g. warm tone is red and cold means blue. The distribution of answers in Figure 4.26 indicates that this question should be revised for further work.

4.3.11. Interveiw

During the last section of the subjective evaluation an interview was carried out. Figure 4.27 show the result of all musicians quality ranking of the rooms. Room 1B is clearly more favourable than the others, and Room 2A seems to divide the trumpet players into two groups, those who like it and those who do not. Room 2A and Room 2B are chosen as the least liked rooms (4th place, white bar) to practice in by all participants.

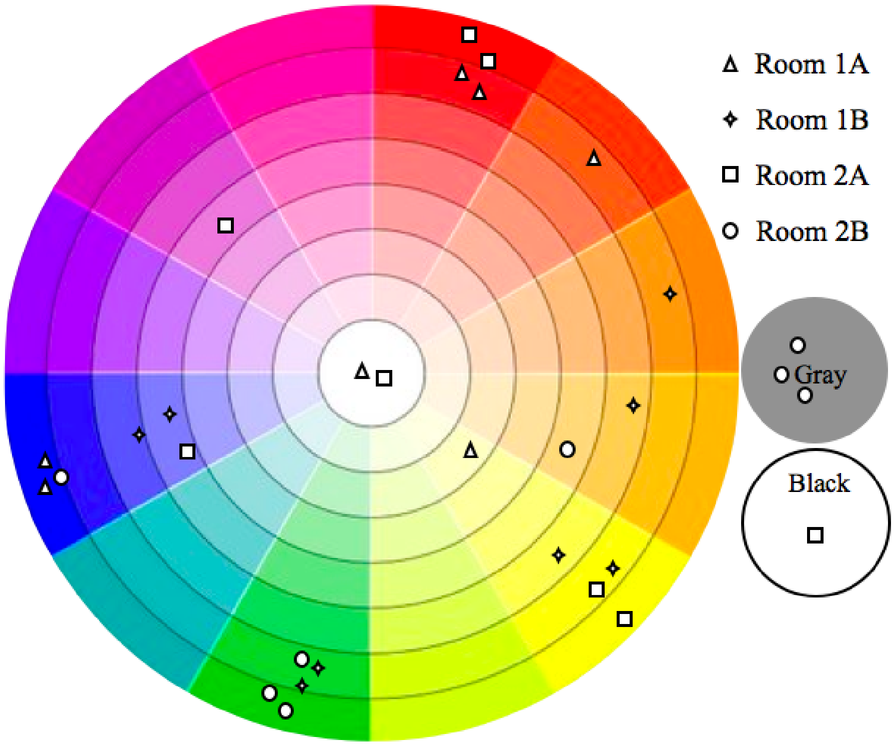


Figure 4.26.: Question 10 - Describe the room coloration with a color.

Room 1A is regarded as neither the best nor the worst room but somewhere in between. The general feeling during the evaluation of all rooms was that the small room were surpassingly good.

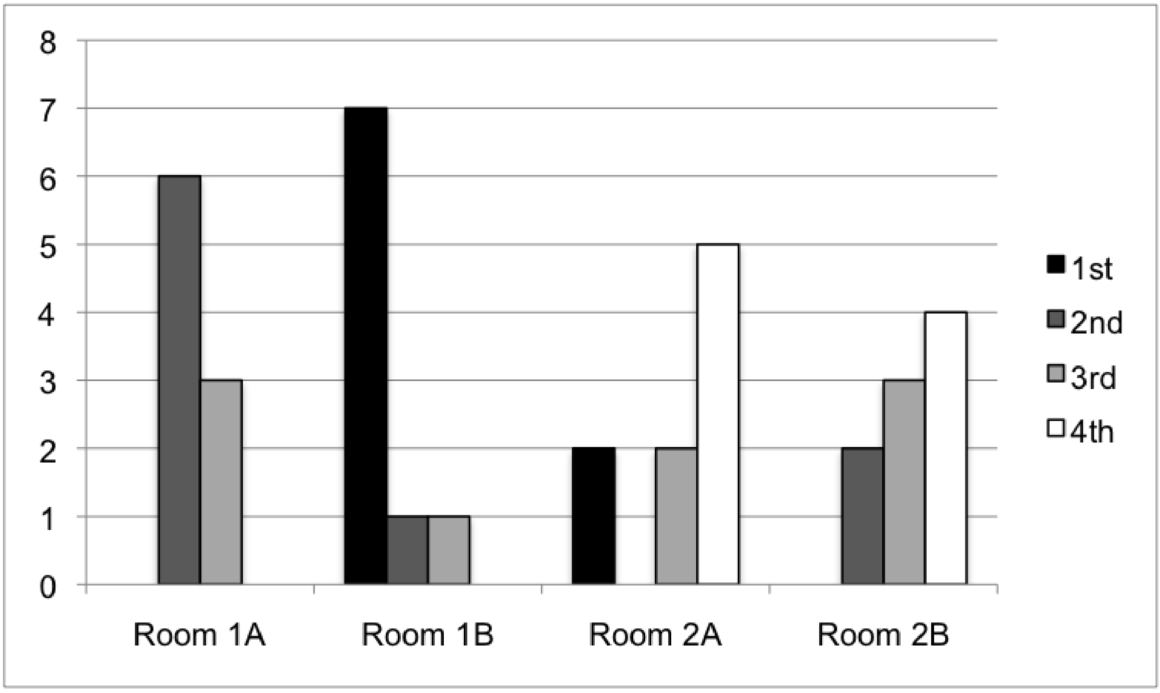


Figure 4.27.: Quality ranking of the rooms from interview, y-axis represents number of votes.

Information that was extracted from the interviews and the list of personal information on the first page of the questionnaire, can be seen in Table 4.16. Apparently not all trumpet players use hearing protection even though it is needed. As many as eight out of nine musicians adjust their way of playing to some extent, whereupon four musicians adjust many aspects in their way of playing. The hearing impairments mentioned by the musicians were things such as sensitivity, frequency reduction in a fixed frequency range, and tinnitus. A selection of translated quotes from the questionnaire is presented in the list below.

Room 1A "Too much sound and response". "one can hear the room answering which is good, but too noisy". "It gets easily a bit too strong even though i try to hold back".

Room 1B "Good damping - still a correct rendering and a good reverberation". "Rather large, so there's not too much sound. One hear good what one plays". "I can play rather strong without having pain in my ears. The drapes helps a lot".

Room 2A "Becomes easily too strong, have to hold back and loose a lot of dynamic". "Good, Not a muffled sound. Got a good feeling. Negatively is the sound level". "It feels like it damps a rush, which makes it pleasant for trumpet".

Room 2B "Gives nothing for free. Have to work harder with the sound, much more tiresome, becomes less fun". "Too studio-like. Very dry and dead". "Okey to play strong and weak. Doesn't hurt my ears even though i'm playing loud".

Table 4.16.: Information extracted from interviews.

Do you wear hearing protection?	Seldom	Sometimes	Always
Number of musicians	5	4	0
Do you adjust your way of playing?	Not at all	Some	Much
Number of musicians	1	4	4
Do you suffer from any hearing impairment?	Not at all	One ear	Both ears
Number of musicians	6	1	2

When evaluating noise induced hearing impairment or just the risk of hearing impairment, the equivalent time of exposure serves a great importance. Information of the rehearsal methodology was discussed during the interview and a question regarding the normal rehearsal time was put in the personal information section of the questionnaire. The answers from the musicians regarding normal rehearsal hours is shown in Table 4.17.

Table 4.17.: Average rehearsal time according to the participating musicians.

Musician 1	Student	3 - 4 hours a day
Musician 2	Amateur	2 hours two times a week
Musician 3	Amateur	1 hour a day
Musician 4	Amateur	2 hours two times a week
Musician 5	Student	3 hours a day
Musician 6	Professional	15 minutes a day
Musician 7	Professional	5 hours a day
Musician 8	Student	4 hours a day
Musician 9	Student	2 hours a day

5. Analysis

5.1. Sound levels

Sound levels were measured using several different approaches, a comparison is presented in Table 5.1. One should not compare the actual values of the perceived sound level, since they refer to the ratings according to the nine point hedonic category scale and not to decibel levels. By comparing subjective results and the measured strength it can be concluded that measurements do not follow the perception of sound level. Only slight differences can be seen for perceived sound levels in Room 1B and Room 2B, whereas the difference measured according to standard is 3.4 dB. Strength measured with the directive source show smaller differences between the rooms than strength measured with an omni directional source. Measurements made on the musicians while playing show remarkably small differences between the rooms, where the largest difference is 1.2 dB. The last column shows the total absorption, where the levels fairly agrees to the standard strength measurements.

Table 5.1.: Level comparison between different approaches.

Room	Perceived sound level rated 1-9	Measurements on musician $L_{pA,eq}$[dB]	G_{mid} [dB] ISO 3382	G_{mid} [dB] directive source	Total absorption 10 log (A) [dB]
1A	6.9	96.2	25.6	5.6	12.3
1B	5.6	95.0	23.2	3.5	14.2
2A	7.0	96.2	28.9	7.5	9.3
2B	5.4	95.8	26.6	4.8	11.2
Δ max	1.6	1.2	5.7	4	4.9

5.2. Within-subject effects

In order to find out if there is any difference in the subjective judgement of the rooms, a within-subject effects-test were done according to Section 2.4. By doing this, differences due to room size and drape configuration can be seen. This can be seen as making the same measurements again, the subjective judgements, changing one factor at a time to see what influence e.g. the room size has on the perceived sound level.

Table 5.2.: Within-subject effects for all questions with the two factors *Room Size* and *Drapes*.

		Room Size	Drapes
Q2	F	14.863	2.660
	P-value	0.005	0.142
Q3	F	0.006	43.891
	P-value	0.938	0.000
Q4	F	40.358	2.031
	P-value	0.000	0.192
Q5	F	5.444	5.641
	P-value	0.048	0.045
Q6	F	1.470	12.872
	P-value	0.260	0.007
Q7	F	19.236	13.636
	P-value	0.002	0.006
Q8	F	20.232	8.526
	P-value	0.002	0.019
Q9	F	0.000	5.091
	P-value	1.000	0.054

In Table 5.2 the within-subject effects are presented. The the factors used are *Room Size* and *Drapes*, which both had two levels, *Large/Small* and *Without/With* respectively.

For question 2 it is clear that the size of the room effects the impression of how good the room is to rehearse in. Also the drapes influence, though in a smaller extent.

Answers for question 3 show no effects of the room size on the perceived sound level but, the drapes influence the perception greatly.

Room size seems to have a big impact on how strenuous it is perceived to play in a practice room. The drapes, on the other hand, shows a rather weak effect.

The within-subject effects for the ability to play dynamical show a rather strong effect for both factors.

Both parameters show an effect on how well the fast parts are perceived but the drapes seem to have a large effect.

The within-subject effect of how well the slow parts are perceived states that both factors show great effects, with a slightly higher F value for room size.

For question 8 both factors have big influence as can be seen in Table 5.2.

Question 9 deals with how hard a room is perceived and the within-subject effects presented in Table 5.2 show that room size has no effect at all, but the drapes seem to have a great impact.

5.3. Correlations

5.3.1. Correlations between questions within rooms

By looking into correlation between questions one can see how the test persons rate questions in relation to each other. This is done within the rooms, which enable comparison between the rooms.

In this section, r corresponds to Pearson's sample correlation coefficient and P-value to the significance (2-tailed). In Tables 5.3-5.6, * means that the correlation is significant at the 0.05 level (2-tailed) and ** that the correlation is significant at the 0.01 level (2-tailed). As mentioned in Section 2.4, Pearson's sample correlation coefficient only consider linear correlation between two parameters. It might therefore exist other strong correlations than those that are presented in the tables below.

Room 1A

In Table 5.3 one can see the correlations between the questions in Room 1A. Strong correlation can be seen between question 2 and question 5 meaning that the trumpet players rated how good the room is for rehearsing in the same way as the ability to play dynamically. Further, question 4 and 7 correlate negatively. These were the effort needed to play in the room and the quality of playing slow parts.

Room 1B

In Table 5.4 one can see the correlations between the questions in Room 1B. Again a correlation between question 2 and 5 can be seen. A negative correlation between question 3 and 8 means that the perceived sound level correlates negatively to the support of the room. A correlation can also be seen between the quality of playing fast and playing slow. The second last row show the strong correlation of the quality of playing slow and the support of the room.

Table 5.3.: Correlations for Room 1A.

		Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Q2	r	1	- .150	- .420	.827**	.305	.662	.108	.274
	P-value	-	.701	.260	.006	.425	.052	.783	.475
Q3	r	- .150	1	.094	- .524	- .224	- .073	- .543	- .314
	P-value	.701	-	.809	.148	.562	.851	.131	.410
Q4	r	- .420	.094	1	- .180	.612	- .697*	- .174	.460
	P-value	.260	.809	-	.643	.080	.037	.655	.213
Q5	r	.827**	- .524	- .180	1	.580	.508	.162	.279
	P-value	.006	.148	.643	-	.102	.163	.677	.468
Q6	r	.305	- .224	.612	.580	1	- .054	.161	.509
	P-value	.425	.562	.080	.102	-	.891	.678	.162
Q7	r	.662	- .073	- .697*	.508	- .054	1	.309	- .153
	P-value	.052	.851	.037	.163	.891	-	.419	.694
Q8	r	.108	- .543	- .174	.162	.161	.309	1	.331
	P-value	.783	.131	.655	.677	.678	.419	-	.385
Q9	r	.274	- .314	.460	.279	.509	- .153	.331	1
	P-value	.475	.410	.213	.468	.162	.694	.385	-

Table 5.4.: Correlations for Room 1B.

		Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Q2	r	1	.219	-.367	.772*	.652	.569	.422	-.253
	P-value	-	.571	.331	.015	.057	.110	.258	.511
Q3	r	.219	1	.103	.047	-.289	-.472	-.728*	-.172
	P-value	.571	-	.792	.904	.450	.200	.026	.658
Q4	r	-.367	.103	1	-.273	-.103	-.605	-.455	.000
	P-value	.331	.792	-	.478	.792	.084	.219	1.000
Q5	r	.772*	.047	-.273	1	.645	.652	.417	-.541
	P-value	.015	.904	.478	-	.061	.057	.264	.132
Q6	r	.652	-.289	-.103	.645	1	.744*	.629	.086
	P-value	.057	.450	.792	.061	-	.022	.069	.826
Q7	r	.569	-.472	-.605	.652	.744*	1	.822**	-.079
	P-value	.110	.200	.084	.057	.022	-	.007	.840
Q8	r	.422	-.728*	-.455	.417	.629	.822**	1	.144
	P-value	.258	.026	.219	.264	.069	.007	-	.711
Q9	r	-.253	-.172	.000	-.541	.086	-.079	.144	1
	P-value	.511	.658	1.000	.132	.826	.840	.711	-

Room 2A

In Table 5.5 one can see the correlations between the questions in Room 2A. A negative correlation can be seen between question 2 and 3. As for the two previous rooms, a correlation between question 2 and 5. A strong negative correlation between the rated perceived sound level and the ability of playing dynamically can be seen in the third row. A negative correlation can also be seen between the rated perceived sound level and the quality of playing fast and the support of the room. A strong negative correlation between question 4 and 8 indicates that perceived sound level is negatively correlated to the support of the room. For the last two entries, a correlation between the support of the room and the ability to play dynamically and the quality of playing fast can be seen.

Table 5.5.: Correlations for Room 2A.

		Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Q2	r	1	-.667*	-.531	.837**	.554	.220	.612	.030
	P-value	-	.050	.142	.005	.122	.570	.080	.939
Q3	r	-.667*	1	.457	-.836**	-.671*	-.072	-.731*	.212
	P-value	.050	-	.216	.005	.048	.854	.025	.585
Q4	r	-.531	.457	1	-.485	-.350	-.553	-.844**	.467
	P-value	.142	.216	-	.186	.355	.123	.004	.205
Q5	r	.837**	-.836**	-.485	1	.623	.161	.748*	-.135
	P-value	.005	.005	.186	-	.073	.679	.021	.728
Q6	r	.554	-.671*	-.350	.623	1	.000	.723*	.284
	P-value	.122	.048	.355	.073	-	1.000	.028	.459
Q7	r	.220	-.072	-.553	.161	.000	1	.400	-.407
	P-value	.570	.854	.123	.679	1.000	-	.286	.277
Q8	r	.612	-.731*	-.844**	.748*	.723*	.400	1	-.331
	P-value	.080	.025	.004	.021	.028	.286	-	.385
Q9	r	.030	.212	.467	-.135	.284	-.407	-.331	1
	P-value	.939	.585	.205	.728	.459	.277	.385	-

Room 2B

In Table 5.6 one can see the correlations between the questions in Room 2B. No strong correlations occur. A correlation between question 2 and 8, indicates a relationship between the impression of how good the room is for rehearsing and the support of the room. A negative correlation can be seen between question 3 and 4, and between question 4 and 8.

Table 5.6.: Correlations for Room 2B.

		Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Q2	r	1	.440	-.640	.339	.035	.502	.678*	.021
	P-value	-	.236	.064	.373	.928	.169	.045	.958
Q3	r	.440	1	-.684*	-.393	-.652	-.300	.366	.363
	P-value	.236	-	.042	.296	.057	.433	.333	.337
Q4	r	-.640	-.684*	1	.214	.175	.036	-.777*	-.272
	P-value	.064	.042	-	.580	.652	.926	.014	.479
Q5	r	.339	-.393	.214	1	.355	.490	-.130	-.266
	P-value	.373	.296	.580	-	.349	.181	.739	.488
Q6	r	.035	-.652	.175	.355	1	.190	-.154	-.032
	P-value	.928	.057	.652	.349	-	.625	.692	.935
Q7	r	.502	-.300	.036	.490	.190	1	.477	-.052
	P-value	.169	.433	.926	.181	.625	-	.194	.893
Q8	r	.678*	.366	-.777*	-.130	-.154	.477	1	.022
	P-value	.045	.333	.014	.739	.692	.194	-	.955
Q9	r	.021	.363	-.272	-.266	-.032	-.052	.022	1
	P-value	.958	.337	.479	.488	.935	.893	.955	-

5.3.2. Correlations between questions and acoustic parameters

A major part of this thesis is to see if there is a possibility to find any correlation between acoustic parameters and how the musicians perceive different aspects in a small rehearsal room.

In Table 5.7 the correlations between questions and acoustic parameters are presented. The most interesting results are marked with a star (*), which means that the correlation is significant at the 0.05 level (2-tailed). Since Pearson's Correlation Coefficient only consider linear correlation, it is possible that there is another type of correlation that might fit better, for instance a quadratic curve. The following subsections will discuss each question shown in Table 5.7 separately.

Table 5.7.: Correlations between questions and acoustic parameters.

		T_{30}	EDT	C_{80}	BR	$1-IACC_{E3,80ms}$	$1-IACC_{E3,60ms}$	D_{50}	G_{mid}
Q2	r	.192	.170	-.280	.541	-.947	-.952*	-.228	-.969*
	P-value	.808	.830	.720	.459	.053	.048	.772	.031
Q3	r	.706	.739	-.732	-.983*	.393	.349	-.734	.555
	P-value	.294	.261	.268	.017	.607	.651	.266	.445
Q4	r	-.838	-.840	.919	.304	.655	.695	.885	.528
	P-value	.162	.160	.081	.696	.345	.305	.115	.472
Q5	r	.067	.022	.007	.666	-.936	-.916	-.026	-.960*
	P-value	.933	.978	.993	.334	.064	.084	.974	.040
Q6	r	-.562	-.580	.458	.962*	-.559	-.536	.528	-.719
	P-value	.438	.420	.542	.038	.441	.464	.472	.281
Q7	r	.889	.898	-.974*	-.467	-.509	-.553	-.939	-.363
	P-value	.111	.102	.026	.533	.491	.447	.061	.637
Q8	r	.886	.902	-.988*	-.564	-.381	-.430	-.945	-.233
	P-value	.114	.098	.012	.436	.619	.570	.055	.767
Q9	r	.681	.717	-.724	-.974*	.411	.366	-.716	.567
	P-value	.319	.283	.276	.0266	.589	.634	.284	.433

Question 2 - How good is the room for rehearsing?

For the second question (Q2), concerning the overall rating of the room, a negative correlation can be seen to $1 - IACC_{E3}$. In the table, only one of the $1 - IACC_{E3}$ is marked, but as can be seen, both are quite near the "mark-level" of 0.05. In other words, a low value of $1 - IACC_{E3}$ is preferable in small rehearsal rooms. In Figure 5.1 the correlation can be seen. The values of $1 - IACC_{E3}$ are quite spread out and it is clear that there is a good correspondence between low $1 - IACC_{E3}$ and high rating of the overall quality of a rehearsal room. One would assume that G_{mid} should correlate with question 3, which concerns the perceived sound level. This is not the case, as G_{mid} and the third question (Q3) show a weak correlation according to Table 5.7. Instead, the musicians seems to rate the quality of how good the room is for rehearsing in a manner that correlates to the value of G_{mid}. Figure 5.1 show mean values of the subjective ratings of question 2 compared with the measured G_{mid} in the different rooms.

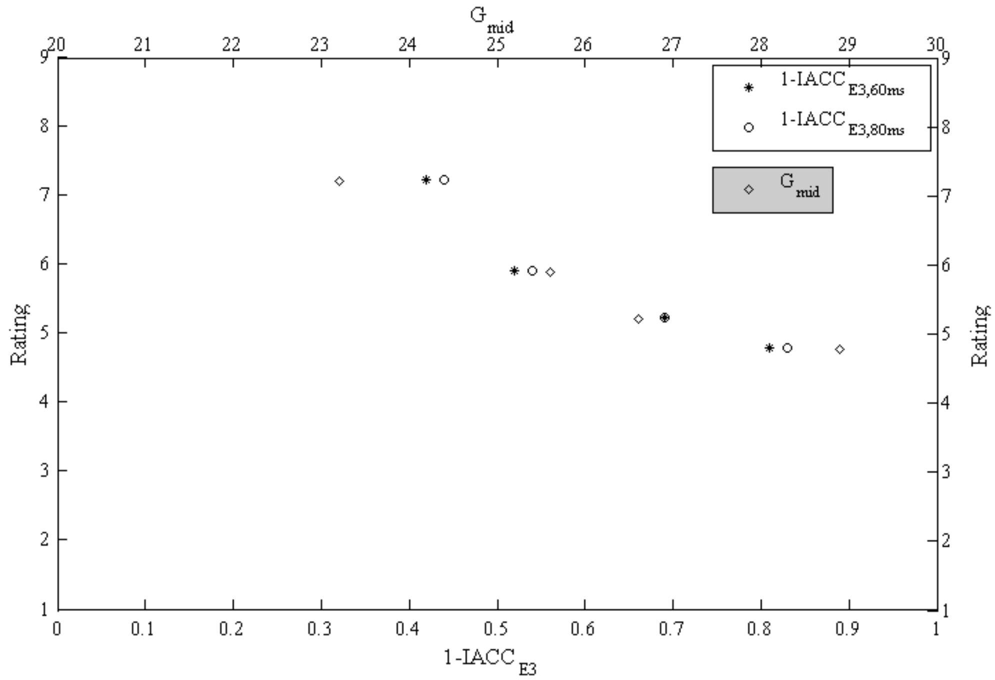


Figure 5.1.: Average ratings for Q2 compared with $1 - IACC_{E3}$ and G_{mid}.

Question 3 - How do you perceive the sound level in this room?

Bass-Ratio, denoted BR in Table 5.7, correlates negatively well with question 3. A high BR gives a low rated perceived sound level, good perception for fast parts and a room, which is subjectively perceived as soft. This can also be seen in Figure 5.2. The values for BR are not distributed over a broad range which might give erroneous conclusions when looking for correlation. On the other hand, for question 3, having "two distinct positions", one at $\sim(1, 7)$ and one at $\sim(1.3, 5.5)$ leads to the conclusion that there is some kind of consistency of the relation between BR and question 3.

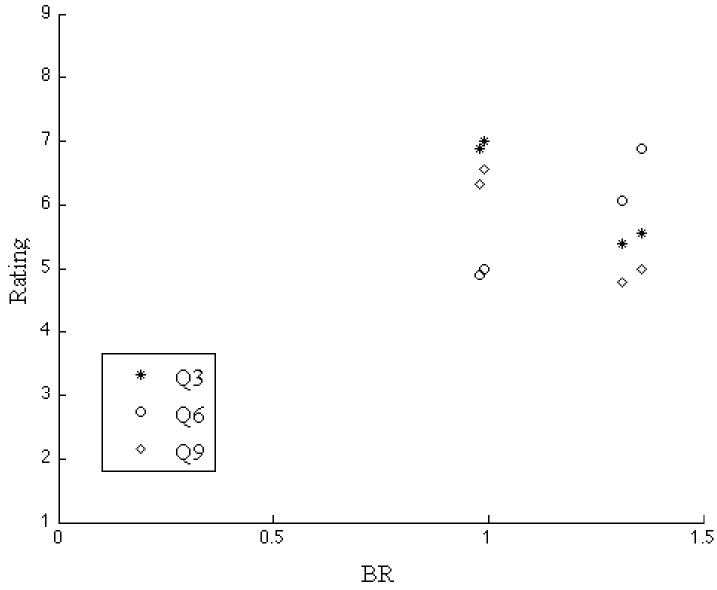


Figure 5.2.: Average ratings for Q3, Q6 and Q9 compared with Bass-Ratio.

Question 4 - How strenuous is it to play in this room?

For this question in Table 5.7 no parameter show a clear correlation. The acoustic parameter that generate highest correlation to the strenuosity is C_{80} that display a correlation of 0.919. This indicates that higher values of C_{80} make it strenuous to play in the room.

Question 5 - How do you rate your ability to play dynamical?

The ability to play dynamically seems to correlate fairly well to the acoustic parameter $IACC_{E3}$. All the other acoustic parameters except G_{mid} show nominal correlation to this acoustic room quality when evaluating Table 5.7. The acoustic parameter G_{mid} correlate to the subjective ability to play dynamically. The acoustic parameters G_{mid} and $IACC_{E3}$ follow each other, which also can be seen by the correlation between questions within rooms in Table (5.3, 5.4, 5.5). Figure 5.3 shows the comparison of the musicians subjective impressions of question 5 and measured G_{mid} levels. Lower values of G_{mid}

give rise to a higher ability of play dynamical, which also is mentioned during the interview and discussed in Section 4.3.11.

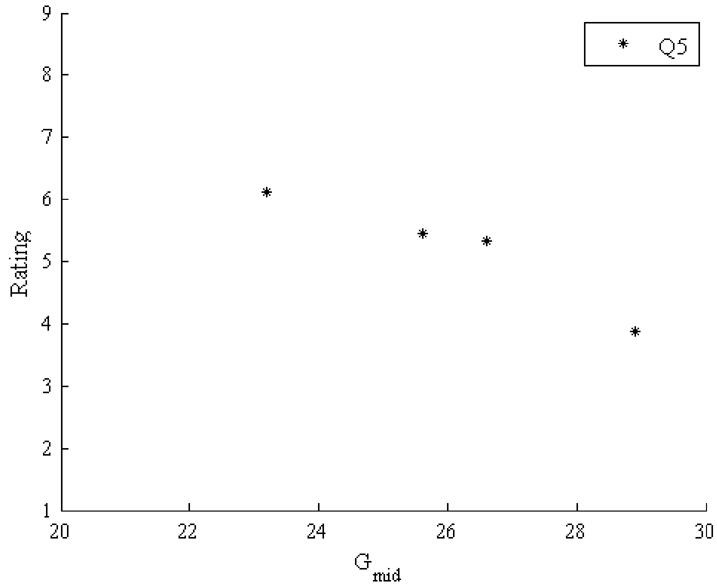


Figure 5.3.: Average ratings for Q5 compared with G_{mid}.

Question 6 - How well are the rapid parts perceived?

How well the rapid parts are perceived correlates to BR with a level of 0.962, which also can be seen in Figure 5.2. As showed in question 3 the BR values of the rooms are distributed in two clusters. One would need a wider distribution of BR to fully conclude this level of correlation. Even though the distribution of BR could be wider, this shows that the perceived sound quality when playing rapid parts increase with higher BR values in small rehearsal rooms.

Question 7 - How well are the slow parts perceived?

The perceived sound quality when playing slow parts show a strong negative correlation to the acoustic parameter C_{80}. The correlation factor, r, of -0.974 between C_{80} and question 7 can be seen in Table 5.7. Figure 5.4 shows that the perceived sound quality, when playing slow parts, rises for lower C_{80} values.

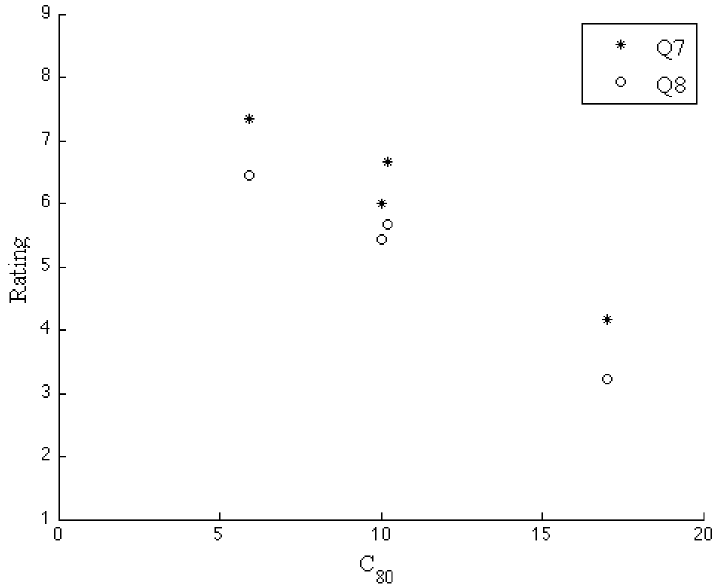


Figure 5.4.: Average ratings for Q7 and Q8 compared with C_{80}.

Question 8 - How do you perceive the support from the room?

As for question 7, question 8 seems to negatively correlate to the acoustic parameter C_{80}. The subjective judgement of the support in the room is showed together with question 7 in Figure 5.4. This would then indicate that both the subjective quality of the support from the room and how well the slow parts are perceived while playing increase for lower values of C_{80}.

Question 9 - How would you rate the balance between hard/soft?

The balance between hard and soft correlate negatively to the perceived warmth, which is the acoustic parameter BR. A correlation factor of -0.974 can be seen in Table 5.7 and the subjective rating according to BR value is visualized in Figure 5.2 together with question 3 and 6. Same reasoning as in previous evaluations regarding the distribution of BR should be considered even for this correlation.

6. Discussion

The study was made to investigate how widely used acoustic parameters correlate with subjective judgements of small rehearsal rooms. In an early stage of the project, the work was divided into three major parts.

The first question was how to choose and perform the acoustic measurements in small rehearsal rooms, since there are no specific measurable parameters suitable for small rooms. Parameters based on reverberation time require a number of measurement positions in a diffuse field, which in small rooms are hard to accomplish. This is further complicated by instruments having different directivity and frequency ranges. The acoustic parameters normally used nowadays are developed with respect to an audience to stage perspective. The audience is usually located within a certain distance to the performer, whereas the musician is very close to the source. The differences in these situations might require further investigation of the impulse responses to find the different characteristics of rehearsal rooms.

The second question deals with how to gather the subjective judgements in an appropriate way, which is both time efficient and gives useful information about the subject of this thesis. It was judged as important to use an adjustable questionnaire that frames the conditions that are of interest to a specific problem. The approach of developing a questionnaire through discussion and inquiry with musicians makes the approach dynamic and makes it fairly easy to apply to other situation, such as other instruments or room situations.

The third question regards the issue of how to correlate and analyze the data from both the acoustic measurements and the subjective judgements. As mentioned in Section 2.4, correlation analyses were only made regarding linear relationship. The linear relationship was regarded as sufficient, since only four data points were gather for each question. To make a more complex analyses with other types of curves were judged as unreliable with so few data points.

The preferred values in a concert hall will probably not correlate well with subjectively preferences of a musician in a rehearsal situation, as mentioned by Nelson G. Patrick and Charles R. Boner in 1966 [PB66]. It would therefore be of great use to be able to utilize the information collected during a subjective evaluation like this. There are several aspects that indicate that the perceived room characteristics need to be in relation with the actual room. For the early part of the interaural cross-correlation usually referred to as the apparent source width, ASW, the difference is quite large. The preferred values of ASW for symphony halls are usually quite high, whereas in much smaller rooms, such as a rehearsal room, our results show that a small ASW is preferred, where ASW is more suitable to the actual room. Figure 5.1 shows the correlation that support this reasoning.

There seems to be a connection between perceived sound level and BR, which can be seen in Figure 5.2. Higher values of BR results in a slightly lower measured, and clearly lower perceived, sound level. The latter can be due to that the instrument feels softer and warmer in its tone and less hard since BR also correlates negatively with perceived hardness of the room, see question 9.

C_{80} is a parameter made for big halls, such as churches and concert halls. It is noticeable that strong correlation occurs also for small rehearsal rooms with respect to question 7 and 8. The rooms with lower measured C_{80} seem to be better in the aspects of playing slow and the quality of room support.

Sound level has been evaluated by; standard acoustic measurement, modified standard, binaural measurements on the musicians while playing and subjective judgements through a questionnaire. These approaches of investigating sound level do not end up with the same results. Apparently, more absorption area does not always lead to an expected reduction of $L_{pA,eq}$ for the musician. From the binaural measurements on the musicians while playing, there are only small changes of measured $L_{pA,eq}$, the average difference between all four rooms is 1.2 dB. The small differences at the ears indicates that the trumpet players adjust their way of playing in the different rooms, which was also mentioned by the musicians during the interview. The two musical pieces differed in one aspect, namely that second piece had dynamic indicators. From the result one can see that the difference was smaller for the second piece than for the first piece. It seems like the trumpet players stabilize the output level more if they get a dynamic indication.

Swedish legislation for maximum sound exposure levels for musicians at work is $L_{p,eq}$ 85 dB(A) measured during 8 hours a day, five days a week [Arb05]. The study shows that trumpet players are typically exposed to about $L_{p,eq}$ 95 dB(A) (free field corrected value) in practice rooms. This means that the effective musical rehearsal time should be kept to less than 1 hour a day, 5 days a week. Apparently this is not the case, since students and professionals rehearse in the range of 3 to 5 hours a day, which can be seen in Table 4.17. These sound levels put the musicians hearing in jeopardy, and it is important to inform the musicians about the risk that they expose themselves to. It is also important to start a discussion regarding the rehearsal methodology used in music academies, operas, and symphonic orchestras. For example, a singer usually takes care of the voice by means of different training tunes, and breathing techniques, but seldom do anything for the hearing that also needs training. It might be of great inspiration to observe athletes, since they have in many ways a special composition of training. The preventive health training is in several aspects more evolved among athletes.

One way to increase the trustworthiness of these results would be to increase the number of musicians and use a wider range of rooms. For example the measured BR resulted in two cluster of values, but if the results would have given access to a wider distribution, the correlation could have been more certain. For the within-subjects effect, room size is mentioned as one factor together with drape arrangement. However, in the room size factor the rooms did not just have different volume but were also slightly differently furnished and of different geometrical shape, which might have colored the characteristic of the room. Also, an evaluation of more drape arrangements would be of great interest, including variable low frequency absorption in order to further investigate the influence of BR.

7. Conclusion

This study indicates that the size of a rehearsal room does not necessary affect the sound level perceived by a trumpet player, where on contrary the amount of absorption clearly show influence on the perceived sound level.

From the correlations between the subjective judgements and the acoustic parameters it is clear that $1 - IACC_{E3}$ correlates well with how good the rooms is for rehearsing. Further, BR seems to correlate well with perceived sound level, how well rapid parts are perceived and how hard a room feels.

From a level comparison one can conclude that despite the differences in measured strength, G_{mid}, between the rooms, the measurement done on the musician while playing show a remarkably low variation. Further, despite the low variations of the measurements on musician while playing, they still rate their perception of the sound level as there is large differences between the sound level in the rooms.

Since ISO 3382, [ISO09], requirer a certain distance to walls and other obstacles, measurements of acoustic parameters in small rehearsal rooms are unfeasible and hard to analyze and compare with other measurements. However, using humans as measurement tools work in all room sizes.

In the question of perceived sound level, all tested room situations were rated slightly higher than the middle value from Bad to Excellent in average by the musicians. Despite this, Room 2B was often remarked as "too dry" or "dead". In this question one can also see a big influence of the drape, whether they were folded or unfolded but no direct effect of the room size. This is also reflected in results for question 4, where the musicians rate it more strenuous to play at lower levels in both Room 2A and 2B. This is probably due to that the trumpet players cannot play freely and are forced to hold back or compensate the tone. In Room 2B, they also rate it worst with regard to the room support and quality of playing slow parts.

Room 1A and 1B get the highest values of the overall quality according to the subjective results. This should be compared with Room 1B, which is ranked 1^{st} by 7 musicians. Room 1A got most 2^{nd} places (6 votes) but no first place. The most surprising results are yielded for Room 2A, which is both rated best (2 votes) and worst (5 votes) by the musicians. Room 2B did not get any 1^{st} place but two 2^{nd} place votes. Room size clearly influence the perception of how good a room is for rehearsing, but the small room seems to be considered okay since their mean-values are around the middle value.

These results together suggest that for future planning, larger room sizes with more drapes could represent an improved situation. Small rooms can be seen as acceptable complements to the larger rooms and should not necessarily be rejected due to issues regarding sound levels, but possibly due to their generally lower perceived quality. Further investigations need to be made in order to clarify what makes the rooms with drapes more preferred, and how to arrange them in the best way to allow musicians to practice without risking hearing impairments.

References

[AK08] Patrik Andersson and Wolfgang Kropp. Introduction to Sound and Vibration: Lecture 9, 2008.

[And08] Johan Andersson. Investigation of Stage Acoustics for a Symphony Orchestra. Master's thesis, Chalmers University of Technology, 2008.

[Arb05] Arbetsmiljöverket. Buller AFS 2005:16, 2005.

[Ber03] Leo L. Beranek. Subjective Rank-Orderings and Acoustical Measurements for Fifty-Eight Concert Halls. *Acta Acustica united with Acustica*, 89, 2003.

[Bun] Physikalisch-Technische Bundesanstalt. Directivity of the Trumpet (without player). `http://www.ptb.de/en/org/1/17/173/trompete.htm`

[BZ06] Søren Bech and Nick Zacharov. *Perceptual Audio Evaluation*. John Wiley & Sons Ltd, 2006.

[DF05] Jay Devore and Nicholas Farnum. *Applied Statistics for Engineers and Scientists*. Thomson Brooks/Cole, 2005.

[FY87] T. Fujita and K. Yamaguchi. A study on the Acoustical Characteristics of a Piano Practice Room. *Acustica*, 63:211–221, 1987.

[Gen] Genelec. Acoustical Simulations. `http://www.genelec-install.com/technical-data/acoustical-simulations/`

[ISO90] Iso 1999:1990. In *Acoustics - Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment*, pages 335–353. International Organization for Standardization, First edition, 1990.

[ISO09] Ss-en iso 3382-1:2009. In *Byggakustik - Mätning av rumsakustiska parametrar - Del 1: Samlingslokaler*. SIS, Swedish Standard Institute, 2009.

[Jan] Roger Jang. Fletcher-Munson curves. `http://neural.cs.nthu.edu.tw/jang/books/audiosignalprocessing/image/Fletcher-Munson.gif`

[Lon06] Marshall Long. *ARCHITECTURAL ACOUSTICS*. Elsevier Academic Press, 2006.

[ORC+02] Felipe Otondo, Jens Holger Rindel, René Causse, Nicolas Misdariis, and Patricio de la Cuadra. Directivity of Musical Instruments in a Real Performance Situation. Technical report, Ørsted-DTU; IRCAM, 2002.

[PB66] Nelson G. Patrick and Charles R. Boner. Acoustics of School-Band Rehersal Rooms. *The Journal of the Acoustical Society of America*, 1966.

[RMW02] Thomas D Rossing, F Richard Moore, and Paul A Wheeler. *The Science of Sound*. Pearson Education, Inc., 3rd edition, 2002.

A. Questionnaire

In the following pages the questionnaire used for the subjective evaluation, described in Section 3.3, is shown. Note that the questionnaire is attached in its original form, and it is written in Swedish.

ENKÄT

DANIEL SÖDERSTRÖM & OLOF OLSSON

1. Personlig information

Prov nr:________ Musiker nr:________ Datum:________

Genre:________________________

Lider du av någon hörselproblematik?________________

Om ja, vad? Ange även om det gäller vänster/höger eller båda öronen________

____

Anställning:________________________

Hur länge har du musicerat?________________

Hur länge har trumpet varit ditt huvudinstrument?________

Vart repeterar du vanligtvis?________________

____

Hur ofta och länge repeterar du?________________

____

____

2. Kryssfrågor

Kryssfrågorna som följer är graderade från 1 till 9. Markera ett värde som motsvarar din upplevelse/uppfattning. För varje fråga finns även möjlighet att kommentera med egna ord.

2.1. Hur viktig är ljudmiljön i övningsrum?

Inte alls | Varken eller | Mycket viktig

1 2 3 4 5 6 7 8 9

Beskriv med egna ord:

2.2. Hur bra är rummet för övning?

Dåligt | Medel | Excellent

1 2 3 4 5 6 7 8 9

Beskriv med egna ord:

2.3. Hur upplever du ljudnivån i rummet?

För lågt Lagom För högt

1 2 3 4 5 6 7 8 9

Beskriv med egna ord:

2.4. Hur ansträngande var det att spela i detta rum?

Inte alls Något Mycket

1 2 3 4 5 6 7 8 9

Beskriv på vilket sätt det är ansträngande:

2.5. Hur upplever du din möjlighet att spela dynamiskt i detta rum?

Små OK Stora

1 2 3 4 5 6 7 8 9

Beskriv med egna ord:

2.6. Hur bra upplevs de snabba partierna?

Dåligt Medel Excellent

1 2 3 4 5 6 7 8 9

Beskriv med egna ord:

2.7. Hur bra upplevs de långsamma partierna?

Dåligt Medel Excellent

1 2 3 4 5 6 7 8 9

Beskriv med egna ord:

2.8. Hur upplever du rummets support/gensvar?

Dåligt Medel Excellent

1 2 3 4 5 6 7 8 9

Beskriv med egna ord:

2.9. Hur hårt skulle du bedöma detta rum?

För mjukt Lagom För hårt

1 2 3 4 5 6 7 8 9

Beskriv med egna ord:

2.10. Försök beskriva rummets klang med en färg:

3. Intervju

3.1. Lyssnar du mycket på musik? I Mp3 spelare eller att du går på konsert.

3.2. Erfarenhet. Hur stor kännedom har du om olika övningsmiljöer?

3.3. Generella intryck. Hur ser du på andra faktorer så som ljud, ljus, luft och temperatur?

3.4. Jämförelse av rummen. Vad upplever du var de största skillnaderna? Föredrar du något rum? Rangordna rummen?

3.5. Intervju reflektion. En genomgång av kryssfrågorna samt det personliga, så vi lättare förstår vad trumpetaren menar.

3.6. Anpassar du ditt sätt att spela i de olika rummen? Ändrar du stycke? Styrka? osv.

3.7. Vad har övningsrummet för funktion. Vilka kvalitéer är viktiga i övningsrum.

3.8. Idealt övningsrum. Hur skulle du beskriva ett idealt övningsrum.

B. Frequency spectras

The following graphs show additional frequency spekta from recordings while the musicians were playing, as discussed in Section 4.2.

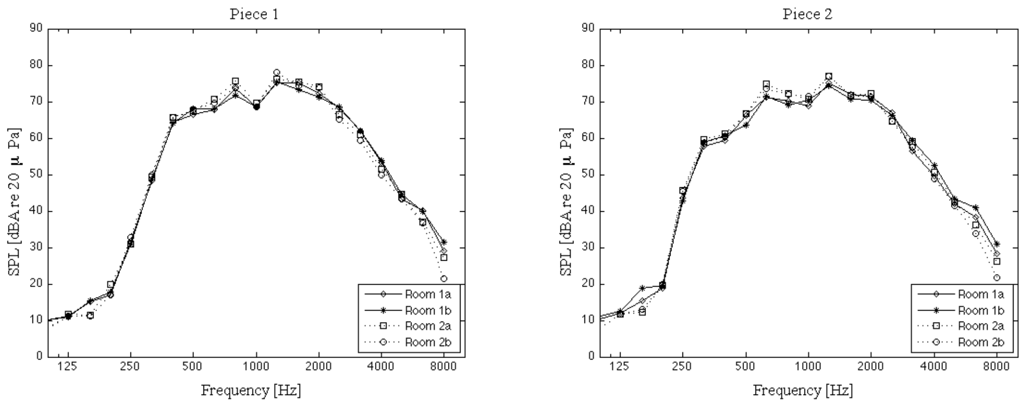


Figure B.1.: Frequency spectra of the right ear for the two pieces played by one musician.

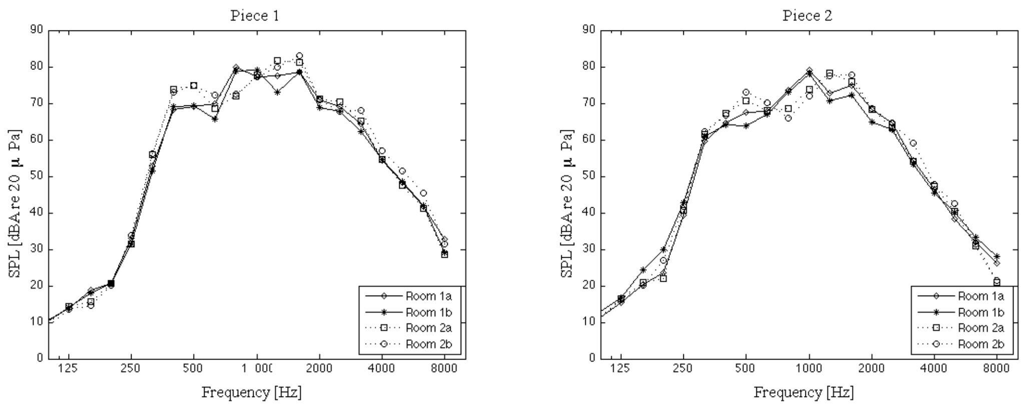


Figure B.2.: Frequency spectra of the right ear for the two pieces played by one musician.

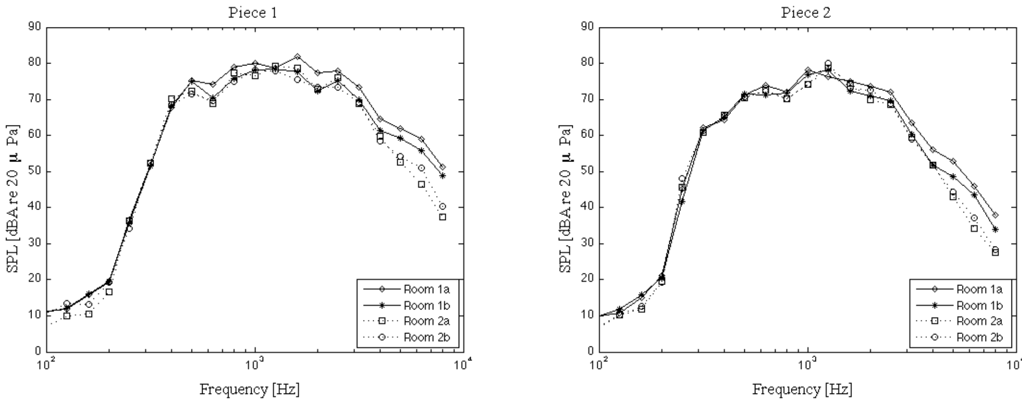


Figure B.3.: Frequency spectra of the right ear for the two pieces played by one musician.