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Are Musicians Affected by Room Acoustics in Rehearsal Rooms?

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Problem Description

Music rehearsal rooms often vary in size and designs depending on the purpose of the room. A proper template on how to achieve good acoustics in rooms that are to be used for anything from individual practicing to larger ensembles are missing to some extent. One of the key factors is the conditions for sound levels. The sound levels can easily become extensively loud in a rehearsal room compared to larger performance halls. Similar studies have shown indications that musicians adjust their source levels based on the acoustic environment, meaning that the sound pressure levels are more constant between different rooms than what room acoustical measurements would suggests. In this study the extent to which a musician adapts his/her source level to the room acoustics will be investigated. This is studied experimentally by letting musicians both sing and play guitar while repeating the same song in different rehearsal rooms. The recordings are made by placing microphones at the nose tip and at the ears of the musician and also at the sound hole of the guitar. By comparing the sound pressure levels produced in each room for the individual musician it is possible to conclude to what extent a musician adjust his source level to the room acoustics.

Abstract

This study has investigated to what extent musicians adjust their source levels to different music rehearsal rooms. In the experiment, six amateur musicians were to perform the same song i four different rehearsal rooms, by first singing, then by playing guitar and last by combining singing with guitar playing. All sound sources were recorded and analyzed. The results shows that the average musician adjusts his source levels to the rehearsal room and that most of the adjustments are made in the guitar playing. Looking at the individual musician there are some that do not show any signs as to being affected by the rooms, and there are some that shows clear signs of being affected by the rehearsal room. The result also shows that the musicians are affected differently by different acoustic parameters, whereas the strength shows the least correlation and reverberation time shows the most correlation to the adjustment made by the average musician.

Sammendrag

Denne masteren har studert i hvilken grad musikere tilpasser sin kildestyrke i forhold til ulike akustiske forhold. Seks amatør musikere har fremført samme sang tre ganger i fire forskjellige musikkøvingsrom. Først bare ved sang, så ved bare gitar og tilslutt ved å kombinere sang og gitar. Sangopptakene er blitt gjort ved nesetippen, mens gitaropptakene er gjort ved lydhullet til gitaren. Resultatene viser at gjennomsnittsmusikeren tilpasser sin kildestyrke i forhold til de ulike øvingsrommene og mesteparten av endringene blir gjort på gitaren. Når en studerer de individuelle musikerne ser en at det er noen som ikke viser tegn til noe påvirkning, mens andre blir tydelig påvirket. Resultatene viser også at de ulike musikerne blir påvirket ulikt av ulike akustiske parametere, der romstyrken har minst påvirkning på gjennomsnittsmusikeren, mens etterklangstiden har størst påvirkning.

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Chapter 1

Introduction

Music rehearsal rooms literally sets the tone for rehearsing musicians. Their acoustical parameters are important since they highly affect how musicians can perform and improve their skills in their surrounding environment. Working as a monitor the rehearsal room gives constant feedback to the musicians performing, which makes it easier for them to hear their own faults and again making it easier for them to adapt.

A rehearsal room should ideally have changeable acoustic parameters since they are often used for different instruments. Looking at e.g. wind and string instruments one can clearly see the different preference in room characteristics. Wind instruments typically have short decay time since the energy stored in vibrating air is very little[Mey93]. This makes them more dependent on the reverb they get from the room. String instruments typically have longer decay time because of vibrating strings and thus they don't need the same support from the room. Another example is percussion instruments, which prefers completely absorptive room and not to say good insulation to surrounding rooms. All in all the preferred acoustic in rehearsal rooms is very complex and it also varies between different instruments.

Research into defining what is good rehearsal room have been made ([PB66],[LM55], [AES94], [Weng], [Mc90], [Ge91],[EC55]). The problem with these are that instead of giving fixed specifications they work more as guidelines giving approximations to certain parameters. They also recommend room sizes that are in most cases impossible to achieve. This leads to smaller rehearsal rooms and poor acoustics since research into defining what is a good small rehearsal room is more neglected.

All the ignorance on the topic leads to the fact that music rehearsal rooms are often not built properly. Musicians have to settle for rooms with poor and varying qualities, which forces them to make adjustments when changing between rooms.

The focus on this thesis will be on how variation in certain acoustical parameters affects musician's unconscious adjustment to source levels. To investigate this 6 amateur musicians were asked to play guitar and sing in 4 rooms with different acoustical characteristics. By amateurs, one means that they are all competent guitar players and singers. The hypothesis is that musicians will in some way make adjustments to their source levels based on the characteristics of each room. None of the musicians were informed of the real purpose of the study, which was essential to get reliable results. They were only told to play as similar as possible in each room.

1.1 Previous Work

There has been a lot of research on how humans adjust their performance to acoustic environments. Lombard found that speakers involuntary increase their vocal effort in the presences of background noise [Lomb]. Kob [Mal08] and Brunskog [Bru08] found that room acoustics highly affects teachers voice production. Kob found that with poor acoustical support and high background noise, their effort to convey speech increases causing great reduction in voice performance. He also found that the variability in the teacher's fundamental frequency depends on the acoustical conditions. Brunskog found that teachers voice power correlates with the size and the strength of the room.

It is also a common phenomena that professional *musicians* consciously and unconsciously adapt to their acoustical environments ([Bre11], [Ue05], [Ue10], [Wos], [Ten89],[OD10]). In [Ue05] and [Ue10] Ueno looks at professional musicians awareness of concert halls and how they adjust their performance to suit the acoustics of concert halls. She found that musicians both consciously and unconsciously change their style of playing, based on two types of feedback systems; one which she calls an automatic response system which all humans have and use unconsciously and the second system she calls the acquired feedback system, which is based on each performers specific skill formed by his/her experience. The latter feedback system is typically not found among amateur musician due to lack of experience and that is mainly why only amateurs have been used in this thesis.

Ueno's main focus is on on how the musicians change their way of playing in terms of tempo, note length, vibrato and dynamics. She does not use musical pieces that include different dynamic levels, which most likely relates to the adjustments to the acoustical environment. She does also find that the relative sound levels produced by the musicians are affected by the room conditions, which will be investigated further in this thesis.

One of the main differences in this study as opposed to most of the previous studies is that real rehearsal rooms will be used. In [Ue05],[Ue10], [Bre11] and [Wos] they create synthesized rooms using an anechoic room, which makes it possible to simulate different acoustic environments. While different variables are easy to change in simulated sound fields the sound quality might be less realistic due to real time processing of the loudspeaker signals.

1.2 Goal

In this thesis the main focus will be on what Ueno calls the automatic feedback response system and to see whether or not amateur musicians unconsciously adjust their source levels when performing in different acoustical environments.

The project is divided into six sections. Section 2 presents some basic understanding into what is a good rehearsal room together with different suggestions from previous authors. It also presents the theory on some important acoustical parameters used in this study. Section 3 explains the setup for measuring the acoustical parameters of each of the 4 rooms together with the setup used for recording the musicians in each room. Section 3 will also present the different equipment and software that has been used and what post processing that has been done. Section 4 presents the results after being processed in MATLAB and chapter 5 gives a discussion of the results. Chapter 6 gives the final conclusion.

Chapter 2

Theory

This section will give an introduction to what previous authors suggests as good rehearsal rooms. It will also present some theory behind the used acoustical parameters and some basic statistical theory.

2.1 What is a Good Rehearsal Room?

A good rehearsal room depends on many important factors. Cubic volume, room shape, acoustical treatments to walls and ceiling, sound isolation, different acoustical parameters all contributes to the acoustics to what can be regarded as good a rehearsal room. Ignoring some of these factors when building a rehearsal room can easily result in some unwanted acoustical phenomena's.

2.1.1 Volume and Shape

The volume of a rehearsal room highly affects the experienced acoustics. Higher ceilings and adequate floor space helps dissipate the loudness and provides delayed primary sound reflections which again creates envelopment[Weng]. In small rehearsal rooms the primary reflections are typically received before 30ms after the direct sound, resulting in poor envelopment, but also makes the room sound very loud and unresponsive. This may again cause hearing damage to the people who are subjected to it day after day. Early reflection does also contribute less to spaciousness [Gries], meaning that smaller rooms will have poor room impression.

The shape of a rehearsal room can also have great effects on the acoustics. Rectangular and cube shaped rooms will typically amplify lower frequencies due do standing waves [Lon06]. Curved ceilings and walls can create acoustic hot spots which reduces feedback to musicians in the other areas[Weng].

The ideal size of a rehearsal room depends on the style of music being performed and also the number of musicians. There are many guidelines to solutions for different musical groups. Some of them can be seen in Table 2.1- 2.2 below.

Table 2.1: Guidelines to achieve proper large rehearsal rooms

Author	**Room**	**N** [p]	**H** [m]	**V** [m^3]	**V/N** [m^3/p]	**S/N** [m^2/p]	**RT** [s]
[Weng]	Choral	60-80	4.9-6.1	815-1020	13		
[Weng]	Band	60-70	5.5-6.7	1274-1557	22		
[PB66]	Band	80-135		1020-1360	11		0.30-0.55
[EC55]	Band			1020		1.85	1.2
[Mc90]	Instr.ens		6.1		11		
[Ge91]	Small.ens		6.1-6.7		14		
[Ge91]	Large.ens		6.7-7.6		14		

Table 2.2: Guidelines to achieve proper small rehearsal rooms

Author	**Room**	**V** [m^3]	**RT** [s]
[AES94]	Individual room	30-200	0.2-0.6
[LM55]	Small practice room	10-20	0.4-0.5
[No10]	Band room	50-100	0.3-0.4

N is the room capacity, H is the ceiling height, V is the room volume, V/N is volume pr musician, S/N is floor space per musician and RT is the reverberation time.

2.1.2 Absorption

Rooms with no or little absorption can become extensively loud. It can also lead to overly reverberant rooms, or rooms with flutter echo. Flutter echo can be avoided by using absorption material on opposing walls at the musicians ear height, either by standing or sitting [Weng]. Ineffective sound absorption can lead to poor frequency balance in the room. For example, thin absorbers or carpets typically dampen the higher frequencies and the harmonic overtones. This results in a room that sounds boomy, where the bass masks the mid and high range, which again changes the timbre and articulation of many instruments [Weng].

To create an effective critical listening environment, sound absorption must be used in together with properly placed diffusion[Weng]. The number of absorption units per instruments (A/N) is a good way to see whether or not a room has sufficient absorption. Patrick and Boner found in [PB66] 6 large rehearsal halls where the most recommended hall had A/N = $0.94m^2$, whereas the average of 5 of the 6 rooms were 1.7 m^2 (the extremely big room is excluded). Gade also looked at different performance and smaller rehearsal halls, in [Ga12], and he found that a good approximation to A/N is $8m^2$, which differs a lot from [PB66]. In terms of practice room capacity, Gade's approximation gives more reasonable results in this study. His approximations/recommendation is equivalent to the room acoustical capacity below,

$$N = \frac{V}{50T} \tag{2.1}$$

Where N is the number of musicians, V is the volume in m^3 and T is the reverberation time in seconds. Using Patrick and Boners suggestions ($1.7m^2$) in the smallest room ($30m^3$) gives a capacity of 8 musicians, which is almost more than what the room can fit. Gade's suggestion gives a maximum of 2 musicians, which is reasonable.

2.1.3 Isolation

It is important with isolation between a music rehearsal room and its surroundings. Noise from rehearsal rooms may disrupt nearby classrooms or common areas and vice versa. Floor, walls, ceiling, doors, ventilation systems, windows, etc. are all compromised by airborne sound or sound vibrations leaking through holes or travelling through the room structure. Keeping this in mind is essential when building a rehearsal room. In [PB66] and [LM55] they found that minimum isolation between practice rooms and teaching studios should be 55dB and 60 dB between practice rooms private offices. The Norwegian standard NS8175[ISO3] suggests 60dB between rehearsal rooms.

2.2 Acoustical Parameters

This section gives a short introduction to some acoustic theory used in this thesis.

2.2.1 Sound Pressure Level, SPL

Assuming a point source with spherical spreading the sound pressure level can be expressed as [Lon06]

$$L_p = L_w + 10\log\left[\frac{Q}{4\pi r^2} + \frac{4}{A}\right] \quad [dB] \tag{2.2}$$

where
L_w = sound power level (dB re 10^{-12}W)
L_p = sound pressure level (dB re 2 x 10^{-5}Pa)
r = measurement distance
Q = source directivity
A = total absorption area

Equation 2.2 contains contributions from both the the direct field and the reverberant field. At a critical distance r_c the direct field equals the reverberant field.

$$r_c = \sqrt{\frac{QA}{16\pi}} \tag{2.3}$$

Beyond this distance the reverberant field dominates. When measuring the SPL produced by the musicians the microphones will be placed near the source, meaning that the contributions from the reverberant field can be neglected. This gives

$$L_p = L_w + 10\log\frac{Q}{4\pi r^2} \quad [dB] \tag{2.4}$$

2.2.2 Strength, G

Strength also known as room gain, G, is the SPL at a given location written relative to the free field level of an omni-directional source at 10 m [Lon06]. Calibrated strength measurements are done using an anechoic chamber in accordance to the ISO standard 3382 part 2 [ISO2]. Strength is expressed by the equation below

$$G = 10lg\frac{\int_0^\infty p^2(t)\mathrm{d}t}{\int_0^\infty p_{10}^2(t)\mathrm{d}t} = L_{pE} - L_{pE,10} \quad [\mathrm{dB}] \tag{2.5}$$

in which

$$L_{pE} = \left[\frac{1}{T_0}\int_0^\infty \frac{p_{10}^2(t)\mathrm{d}t}{p_0^2}\right] \quad [\mathrm{dB}] \tag{2.6}$$

and

$$L_{pE,10} = 10lg\left[\frac{1}{T_0}\int_0^\infty \frac{p_{10}^2(t)\mathrm{d}t_{10}}{p_0^2}\right] \quad [\mathrm{dB}] \tag{2.7}$$

where

$p(t)$	is the instantaneous sound pressure of the impulse response measured at the measurement point,
$p_{10}(t)$	is the instantaneous sound pressure of the impulse response measured at a distance of 10m in a free field,
p_0	is 20 μPa
T_0	= 1s
L_{pE}	is the sound pressure exposure level of $p(t)$
$L_{pE,10}$	is the sound pressure exposure level of $p_{10}(t)$

In the equations above, t=0 at the start of the direct sound and t=∞ is the time greater or equal to the point at which the decay curve has decreased by 30 dB.

In a situation where a large anechoic room is not available when measuring $L_{pE,10}$, the sound pressure level at a distance d($\geq$3m) from the source $L_{pE,d}$ may be measured and $L_{pE,10}$ can be calculated from the equation below.

$$L_{pE,10} = L_{pE,d} + 20lg(\frac{d}{10}) \quad [\mathrm{dB}] \tag{2.8}$$

Michael Barron's formula for strength is as follows [Lon06],

$$G = 10lg(100/r^2 31200T/V) \quad [\text{dB}] \tag{2.9}$$

2.2.3 Reverberation Time, T_{60}

The Reverberation time, T_{60} is defined as the time it takes for the sound level to drop 60 dB after the source emission has stopped [Lon06]. It can be calculated using Sabine's well-known equation

$$T_{60} = 0.161\frac{V}{A}, \quad [\text{s}] \tag{2.10}$$

Where V is the volume of the room in cubic meters and A is the total area of absorption in the room.

Sometimes the signal to noise ratio can be less than 60 dB. If so, T is evaluated on a smaller dynamic range for so to be extrapolated to a decay time of 60dB [ISO2]. Normally this means looking at the time at which the decay curve first reaches 5dB and 35dB, which is referred to as T_{30}. Several other extrapolation ranges can also be used e.g. T_{20}.

2.2.4 Early Decay Time, EDT

The Early decay time, EDT, is similar to reverberation time, but it only measures the time of the first 10 dB decay. This time is then multiplied by a factor 6, which makes EDT more comparable to the reverberation time. EDT is related to how humans perceive reverberance. It is also strongly influenced by early reflections meaning that it depends more on the measuring position than the reverberation time [KUTT].

2.2.5 Clarity, C_{80}

Clarity refers to how clear the sound quality is, which again relates to how well one can hear the separation of individual notes and articulations. It is defined as the early-to-late arriving sound energy ratio [ISO1]. The early sound energy arrives within 80 ms of the direct sound and the late sound energy arrives after 80 ms.

$$C_{80} = 10lg\frac{\int_0^{80} p^2(t)\mathrm{d}t}{\int_{80}^{\infty} p^2(t)\mathrm{d}t} \quad [\mathrm{dB}] \tag{2.11}$$

C_{80} is the early-to-late index and p(t) is the instantaneous pressure of the impulse response measured at the measurement point.

2.2.6 Definition, D_{50}

Definition (D_{50}) is the defined as the ratio between the early and the total received sound energy. The early sound energy is calculated from the first 50 ms of the direct sound. D_{50} can be written as

$$D_{50} = \frac{\int_0^{0,050} p^2(t)\mathrm{d}t}{\int_0^{\infty} p^2(t)\mathrm{d}t} \quad [\%] \tag{2.12}$$

To get a single number value for the previous parameters T_{60}, G, EDT, C_{80} and D_{50}, ISO 3382-1 suggest to use the arithmetical average of the 500 Hz and 1000 Hz octave bands.

2.3 Statistics

This section gives a short introduction to some of the statistical theory that has been used in this thesis.

2.3.1 Variance and Standard Deviation

Variance and standard deviation are measures of variability. Looking at a certain distribution, the variance and the standard deviation measures how spread out the distribution is. Variance is the average of the squared differences from the mean where the sample variance s^2 is defined as [Prob07]

$$s^2 = \frac{\sum(x_i - \overline{x})^2}{n-1} \tag{2.13}$$

The sample standard deviation is defined as the square root of the sample variance

$$s = \sqrt{s^2} \tag{2.14}$$

2.3.2 Correlation

A correlation analysis attempts to measure the strength between two variables, describing it by a single number called the correlation coefficient. Pearson's sample correlation coefficient r gives the linear dependence between two variables. The sample correlation coefficient r is defined as [Prob07]

$$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}} \tag{2.15}$$

Pearson's coefficient can have values between -1 and +1. With r=-1 the data lies on a straight line with a negative slope, meaning that if one variable increases the other decrease. r=1 gives the opposite results. If r=0 there are no linear relationship between the two variables. r values close to zero means poor correlation, while r values close to +1 or -1 means strong positive or negative correlations respectively. In this study Pearson r-squared as been used. r-squared or R^2 is the proportion of variation in Y that can be accounted for by knowing X and vice versa [Prob07].

2.3.3 ANOVA

ANOVA(Analysis of variance) is way of testing parameters means. It is based on testing a null hypothesis, which says that means of all parameters are the same. ANOVA compares the variation of group means to the variation within each group, in terms of the F ratio:

$$F = \frac{found\ variation\ between\ groups}{found\ variation\ within\ group} \tag{2.16}$$

A large value of F implies that the means are different from each other and thus the null hypothesis is false and can be rejected. The significance of F is given by the p-value. The number of degrees of freedom (df) for the numerator is one less than the number of groups. The number of df for the denominator (the error or the variation within groups) is the total number of samples within all groups minus the total number of groups.

The null hypothesis in this thesis is as follows: "The acoustical characteristics of the rooms has no significant affection on the produced sound pressure levels from the musicians. On the contrary, they are completely unaffected by the acoustics of the room and the measured differences are only random natural variations".

Chapter 3

Measurements

This section gives a description of all the rooms that have been used. It will also describe the procedure for measuring the acoustic parameters in each room together with the setup used for recording and measuring sound pressure levels while the musicians were playing. There will also be a description of the equipment and the software that has been used together with all the post processing.

3.1 The Measurement Rooms

It is important that the rooms used for study have different acoustical parameters. This will show how musicians adapt to different acoustical environments and will hopefully give a better understanding of the results.

6 rooms were measured according to the ISO standard 3382, and the four rooms, which differed most in characteristics, were used. Three of four rooms are used as music rehearsal rooms and one is used as a storage room. The storage room is an old common shower room and was included in the study because of its different acoustical characteristics, which again will give a broader spectrum of results. The rooms are known as "Drum room", 2442, 2440 and "Storage room" and they are all located at NTNU Dragvoll and used primarily by music students. Images of the rooms can be seen in the Appendix A.

Room 1

The Drum room will be referred to as Room 1 and is illustrated in Figure 3.1. This room is used mainly for drum and band rehearsing and it is therefore very well dampened. The south wall is made of brick and the three remaining walls are made out of gypsum. Except from a wooden door and a glass door the walls are almost entirely covered with absorbent panels. The roof is sloping and made of wooden panel where the south wall is the tallest. The floor is tiled with two carpets on top of it. Inside the room there are two drum sets and three guitar amplifiers. See Table 3.1 for room parameters.

Table 3.1: Room 1 parameters

Room 1	
Volume:	7m x 4m x (2,5 -3,2)m = 79,8 m^3
Background noise:	26.1 dB
T_{60}:	0,26 sec
EDT:	0,21 sec
Strength(cal):	4.16 dB
C_{80}:	23,1 dB
D_{50}:	96,99 %
Absorption area:	49.4m^2
Capacity, N (Gade):	6
V/N:	13.3m^3

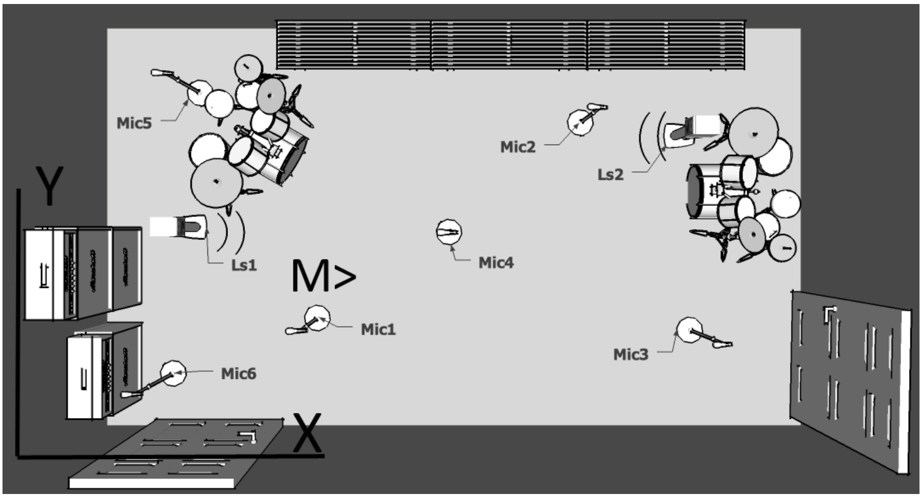

Figure 3.1: Room 1 as made in Google Sketchup

Room 2

Room 2442 will be referred to as Room 2. This room is the smallest of the four rooms (see Figure 3.2). It is also the room with best insulation and is therefore used for louder instruments such as trumpets, trombones etc. 3 out of 4 walls are gypsum walls whereas the 4th wall is partly concrete and partly brick (north wall). The latter wall is almost entirely covered with acoustic absorbents. The floor is linoleum and the roof is concrete. Inside the room there is one upright piano and a wooden desk.

Table 3.2: Room 2 parameters

Room 2	
Volume (LxWxH):	3,7m x 2,6m x 3,2m = 30,78 m^3
Background noise:	29.8 dB
T_{60}:	0.32 sec
EDT:	0.34 sec
Strength:	7.81 dB
Clarity, C_{80}:	16.6 dB
Definition, D_{50}:	90.8 %
Absorption area:	15.5m^2
Capacity, N (Gade):	2
V/N:	15.4m^3

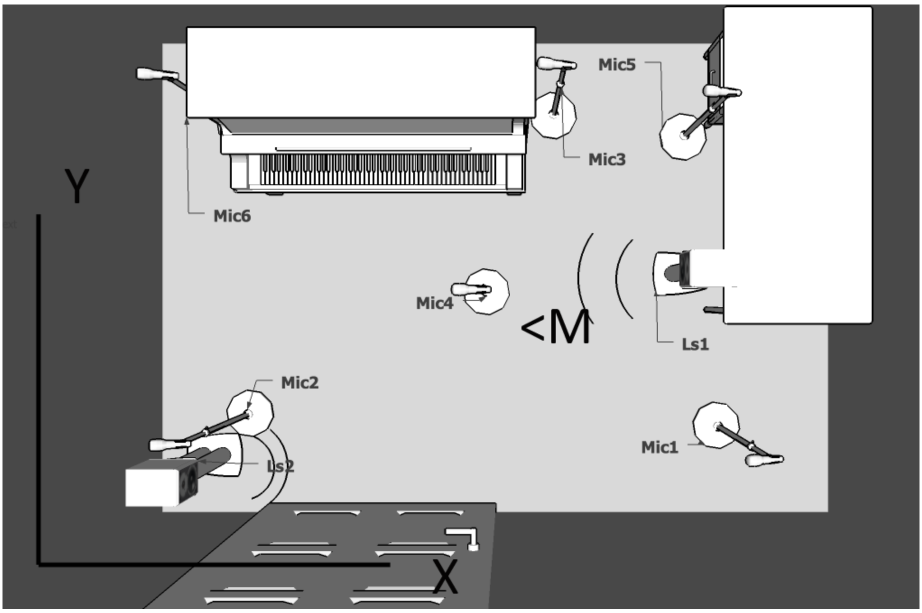

Figure 3.2: Room 2 as made in Google Sketchup

Room 3

Room 2440 will be referred to as Room 3 and is illustrated in Figure 3.3. Room 3 is primarily used for private rehearsal and teaching lessons for pianists. The east wall is a gypsum wall almost entirely covered with windows. The rest of the walls except from a wooden door and a blackboard (north wall) are gypsum walls. The roof is covered with gypsum panels with absorptive panels hanging down. The floor is linoleum. Inside the room there is one grand piano and one upright piano.

Table 3.3: Room 3 parameters

Room 3	
Volume(LxWxH):	5.9m x 4.5m x 3,1m - (1.2m x 1.0m x 3.1m) = 78,58 m^3
Background noise	32.2 dB
T_{60}:	0.75 sec
EDT:	0.71 sec
Strength:	7.44 dB
C_{80}:	6.5 dB
D_{50}:	65.45 %
Absorption area:	16.9m^2
Capacity, N (Gade):	2
V/N:	39.29m^3

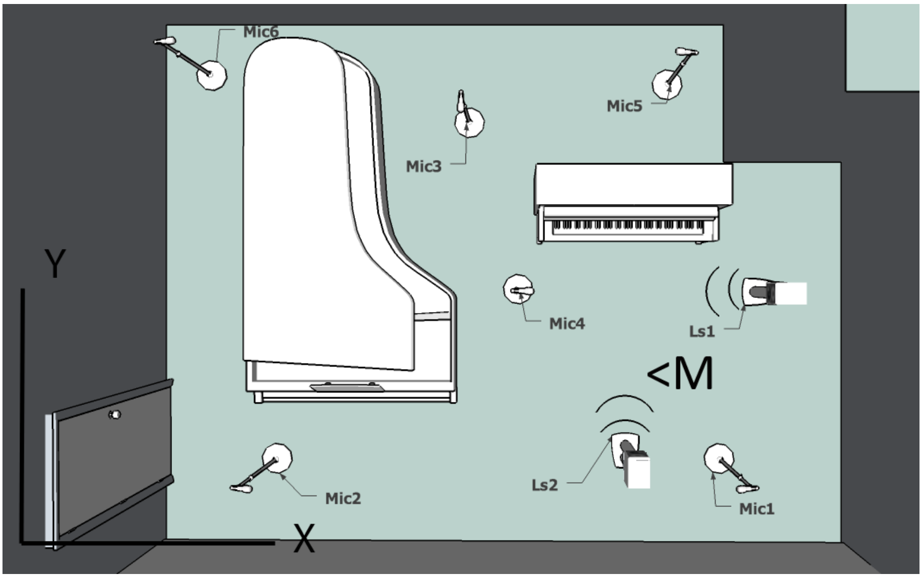

Figure 3.3: Room 3 as made in Google Sketchup

Room 4

The storage room will be referred to as Room 4. See Figure 3.4 for illustration. It is only used for storing gear and instruments. As mention this room were once used as a common shower, which means that all walls are tiled from the floor to half the room height and from there to the roof the walls are made of brick. As for Room 1 the roof here is also sloping and covered with gypsum panels with the south wall as the tallest. Inside the room there are a couple of guitar bags and some drum equipment.

Table 3.4: Room 4 parameters

Room 4	
Volume(LxWxH):	4m x 3,9m x (3,4-4,1)m = 58,5 m^3
Background noise	44.0 dB
T_{60}:	1.18 sec
EDT:	1.07 sec
Strength	10.03 dB
C_{80}:	3.0 dB
D_{50}:	49.2 %
Absorption area:	7.9m^2
Capacity, N (Gade):	1
V/N:	58.5m^3

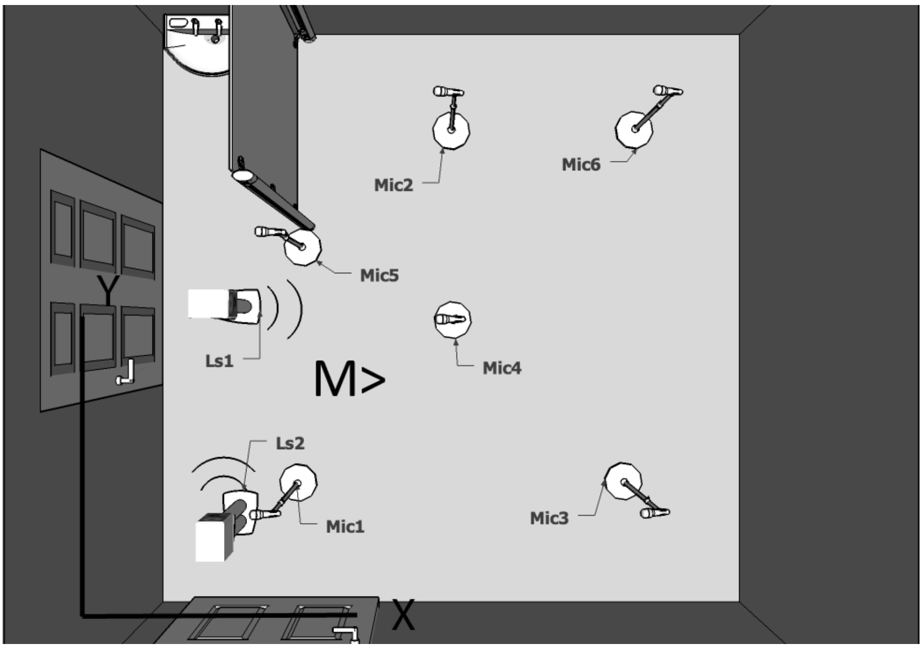

Figure 3.4: Room 4 as made in Google Sketchup

3.2 Parameter Measurements

The ISO standard 3382 part 2[ISO2] is used for measuring room acoustical parameters. The standard gives fixed specifications for certain acoustical parameters. In this study these parameters are reverberation time, EDT, clarity, definition and strength.

ISO 3382 introduces three different methods with different accuracy requirements and gives the minimum number of measurement positions to achieve a proper room coverage for each method (See Table 3.5 from [ISO2] below). For this study the Engineering method has been used and this method requires at least six source-microphone combinations whereas there must be minimum two source-positions and minimum two microphone positions total. In this study two source-positions are used with three microphone-positions per source-position.

The measurements in Room 1 and Room 3 are done according to [ISO2], but because of the small size of Room 2 and Room 4 a small a modification to the standard had to be made with respect to the space available.

Table 3.5: Minimum numbers of positions and measurements

	Survey	**Engineering**[a]	**Precision**
Source-microphone combinations	2	6	12
Source-positions[b]	≥1	≥2	≥2
Microphone-positions[c]	≥2	≥2	≥3
No.decays in each position (interrupted noise method)	1	2	3

[a] When the result is used for a correction term to other engineering-level measurements, only one source-position and three microphone-positions are required

[b] For the interrupted noise method uncorrelated sources may be used simultaneously

[c] For the interrupted noise method and when the result is used for a correction term a rotating microphone boom may be used instead of multiple microphone-positions

3.2.1 Speaker Position

In all four rooms the speaker will be placed at two different positions in the xy-plane and the acoustic centre of the speaker is always at the same position in the z-plane (1,1m). The first speaker position (LS1 in Figure 3.1- 3.4) will always be centred in width ($y/2$). Since the speaker directivity is symmetrical around it's centre line this placement helps give a better coverage of the room since a measurement on one side of the center line would approximately have the same values as the mirrored measurement on the other side.

The second speaker position (LS2 in Figure 3.1- 3.4) is chosen based on the shape of each room. In Room 1 and Room 2 the speaker will be placed at the opposite wall from the first position facing the opposite direction, but moved in the x-direction (Figure 3.1 and Figure 3.2). In Room 2 the speaker will be placed in the corner according to [ISO2], which says that in a small room at least one source-position should be in a corner. In Room 3 and Room 4 the speaker is turned 90 degrees and moved in both x and y direction from the first position to get variation in the excitation pattern (Figure 3.3 and Figure 3.4). As for Room 2 the speaker in Room 4 will also be placed in the corner because of the small room size. Exact speaker positions can be found in Tables C.1- C.4

3.2.2 Microphone Position

There will be 3 different microphone position for each speaker position. The first 3 positions correspond to the first loud speaker position (LS1) and last 3 corresponds to the second loud speaker position (LS2). The six microphone positions are spread throughout the room to get a best possible coverage of each room. The diaphragm is always pointing upwards and placed at 1,2 m in the z-plane.

The spacing between microphone positions should preferably be at least half a wavelength apart, i.e at least 2 meters apart ([ISO2]) and this was uphold in all rooms except for Room 2 and Room 4. Exact microphone positions can be found in Table C.1- C.4

3.2.3 Equipment

The equipment and the measurement settings will be exactly the same for all rooms. The measurements in this study are made using WINMLS 4 on a laptop together with an external sound card, D-audio USB Audio Reference Preamplifier. The sound card uses a software mixer where the input gain is set to 30 dB and the output gain is set to -15dB. The microphone used is a free-field microphone from Bruel & Kjær (type 4165). To measure the impulse responses a sine-sweep signal from a range 20-20000Hz is used, with duration of 5 seconds in each room. The loudspeaker used is a Genelec (Model 1029A). It is measured to be omni-directional up to approximately 300Hz (See Figure B.1 in Appendix. To measure background noise a Norsonic N-116 is used together with a microphone preamplifier (N-1201) and a B&K microphone (type 4190). The background noise is calibrated using a B& K calibrator.

3.2.4 Post-Processing

When all measurements are done the data from WINMLS is imported into MATLAB for analyzing and plotting. The strength measurements are calibrated in an anechoic room according to [ISO2] using WINMLS.

3.3 Recording Setup

This section explains the setup used for recording the musicians. The settings are the same for all musicians.

3.3.1 Musician Position

The musicians will be placed in each room were it feels most naturally to perform and the position in each room is exactly the same for all musicians. They will all be sitting during the recordings. The *M* and the arrow in Figure 3.1 - 3.4 gives the placement and the direction of the performance. For exact positions see Table C.1- C.4.

3.3.2 Microphone Positions

Two microphones will be placed at the ears to measure the sound pressure levels at the ears. One microphone will be placed at the nose tip to measure the direct sound from the voice. By placing the microphone close to the mouth the reverberant field effects can be neglected 2.2.1. The fourth microphone will be placed at the tip of the sound hole on the guitar with the intention of just to measure the direct sound. See Figure 3.5 and 3.6.

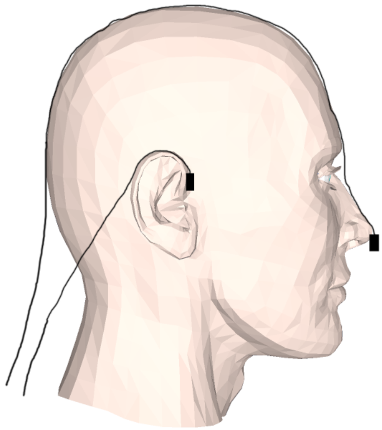

Figure 3.5: Microphone placement on head

Figure 3.6: Microphone placement on guitar

3.3.3 Performance and Recording

To get reliable results none of the musician will be informed about the real purpose of the study. They are only told that they are to sing and play the song as similar as possible in each room. All musicians are to play guitar and sing a verse and a chorus from the song Idyll by the band Postgirobygget. The song uses 5 simple chords and they were asked to perform it 3 times; first only by singing, second only by playing guitar and third by combining singing with guitar playing. To get different dynamic levels in their performance they are asked to play and sing the verse in piano and the chorus in forte. The guitar is tuned down half a note to best fit the male voices (2 tenors and one bass). There are also one female musician (alto), which will use a capo on the 7th fret on the guitar.

Before each recording the musicians are asked to get to know the acoustic of the room by playing some simple chords and singing some random words. Then they shall start either by singing, playing guitar or combining the two. This is set up in a random order. The room sequence for each musician is also chosen in random order since it is expected that all musicians will play louder and louder as they get more comfortable with the situation. The room sequence for each musician can be seen in Table 3.6 below. The time spent between each room is no more than 5-10 minutes, making it easier to play as similar as possible.

Table 3.6: Room Sequence for each musician

Musicians	**Room Sequence**			
OM	Room 4	Room 3	Room 2	Room 1
VE	Room 3	Room 2	Room 1	Room 4
MA	Room 1	Room 2	Room 3	Room 4
BR	Room 2	Room 3	Room 4	Room 1
MW	Room 1	Room 4	Room 2	Room 3
PC	Room 4	Room 1	Room 3	Room 2

3.3.4 Equipment

The equipment and the measurement settings will be exactly the same for all rooms. None of the measured sound levels are calibrated since the only interest is to see how the sound pressure levels varies between the rooms. To measure the different sound levels a firewire audio interface (Fireface 800) together with 4 condenser microphones (AKGC577WR, 2 x SennheiserMKE2PC, Sony ECM50PS) are used. The sound card uses analogue gain switches on the 4 microphone inputs and to avoid small changes in input gain between each measurement a B & K calibrator together with a 1/2inch microphone (BSWA MP216) are used to set gain correctly before all measurements. The input gain on each channel is set to avoid problems with clipping and also in terms of proper balance between the channels. (1&2:-19.2dB, 3:-17.2dB, 4:-29dB). The guitar used is a Martin guitar (type 000-18ge). All recordings are made into a Macbook Pro using Logic Pro.

3.3.5 Post-Processing

When all recordings are done the soundtracks is exported as wav files from Logic pro and from there they are imported into MATLAB for further analyzing. All SPL measurements is A-weighted and normalized such that the average of each sound source is 0dBA. By doing so each musicians source level is eliminated. The source levels are irrelevant for this study because the differences between individuals are not the focus. The focus lies on how each room affects each musician.

Chapter 4

Results

This chapter will present and comment the results from the measured acoustical parameters together with the results from the recordings of each musician's performance.

4.1 Acoustic Parameters

Reverberation Time

Figure 4.1 shows that there are significant variations in reverberation time between the rooms. Only Room 1 and 2 shows clear similarities in RT. Between Room 1 and Room 4 the difference is almost 1 second in the 500 Hz and 1000 Hz octave bands. Room 1, 2 and 3 all seem to be affected by modal behaviour in the lower frequencies, which adds some uncertainties to the results in this range.

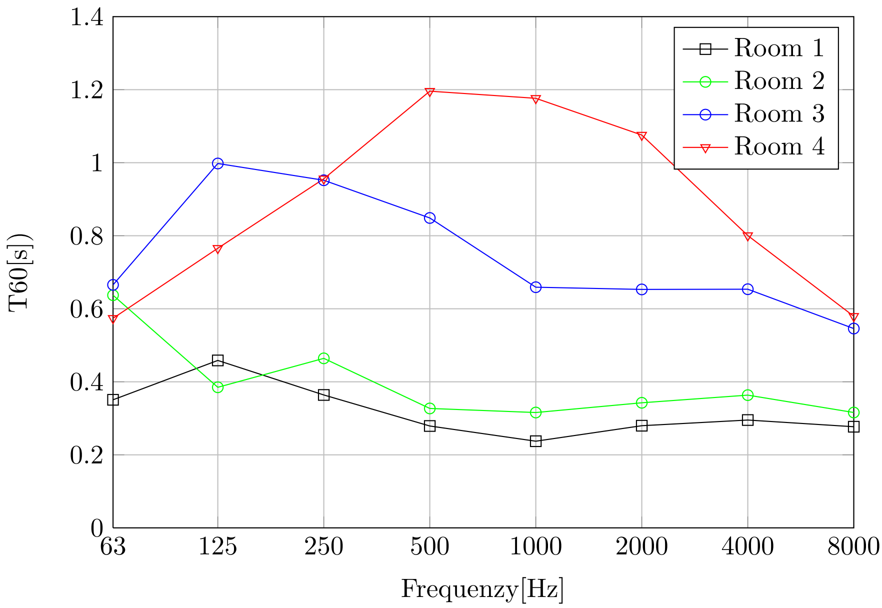

Figure 4.1: Reverberation time measurements for the different rooms

Early Decay Time

The Early decay time shows similar behaviour as to the reverberation time. From Figure 4.2 it can be seen that the EDT is generally lower then the reverberation time, with an exception in Room 2, where the 500Hz and 1000Hz octave bands have slightly higher values (0.02 seconds).

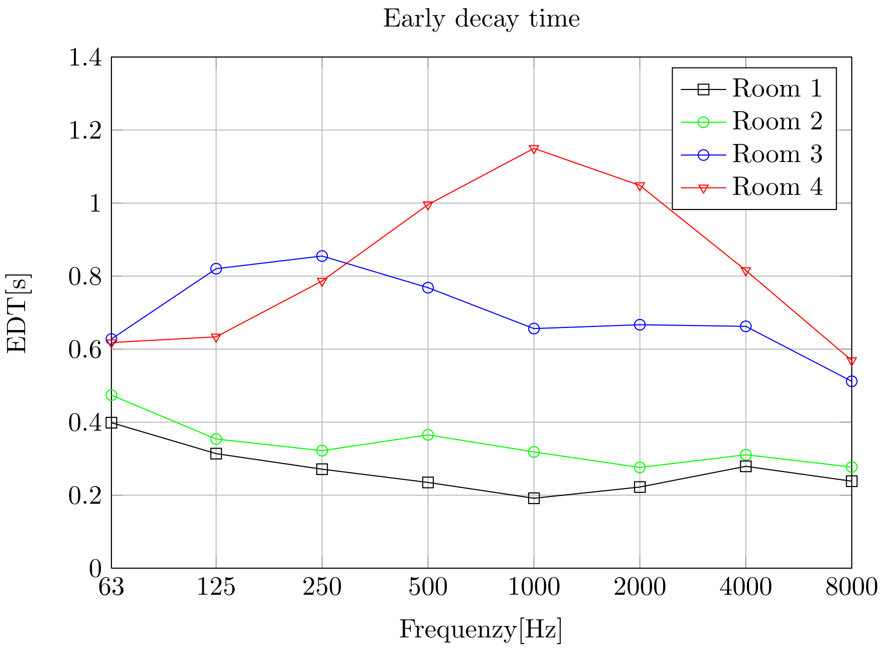

Figure 4.2: Early decay time measurements for the different rooms

Clarity

Figure 4.3 shows the clarity values for all rooms. Notice the high values of clarity in Room 1 and Room 2, whereas the highest value is observed in Room 1 in the 1000 Hz octave band. The biggest difference between the rooms is found in the 1000 Hz octave band for Room 1 and Room 4. It is measured to be 21.7dB. Similarities in clarity can be seen between Room 1 and Room 2, and Room 3 and Room 4.

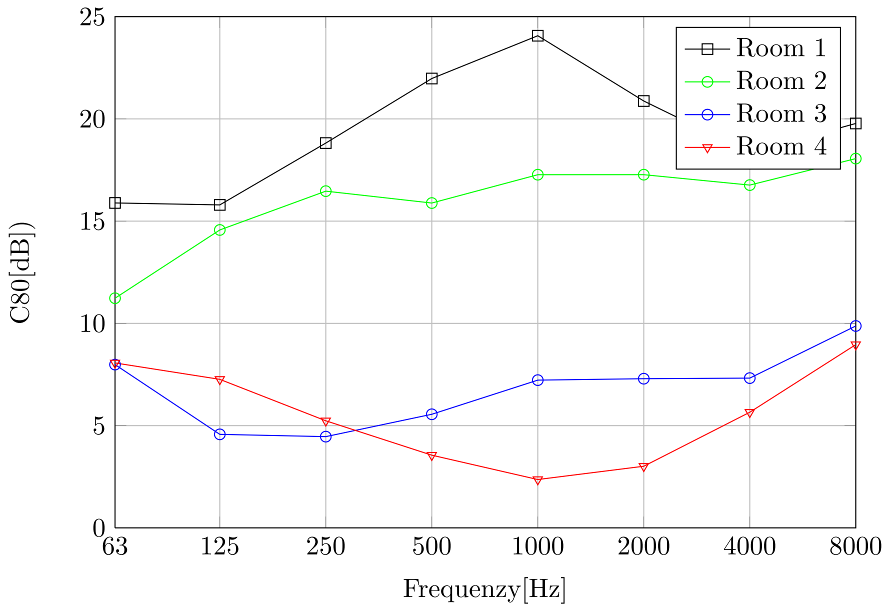

Figure 4.3: Clarity measurements for the different rooms

Definition

Definition plots for the different rooms can be seen in Figure 4.4 below. For all rooms the definition plots for are comparable to the clarity plots in Figure 4.3. They have the same significant differences between Room 1 and Room 4 and also the same similarities between Room 1 and Room 2, and Room 3 and Room 4.

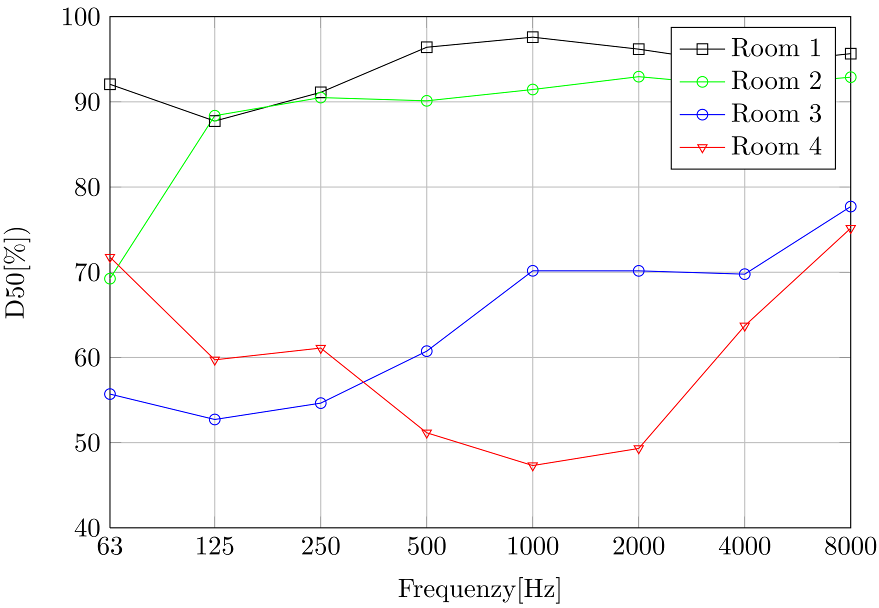

Figure 4.4: Definition measurements for the different rooms

Strength

Figure 4.5 shows the strength measurements in the different rooms. According to Barron's equation for strength (2.9) these values are much to low. The figure below shows the strength as WINMLS plots it based on the impulse responses. The values are questionable, but the relationship of the strength between the rooms seems to be same, which is the most important in this study. The measurements has been calibrated according to [ISO2] using an anechoic room together with equation 2.8. The biggest difference in strength is found between Room 1 and 4 within the 500Hz and 1000Hz octave bands (5.87dB).

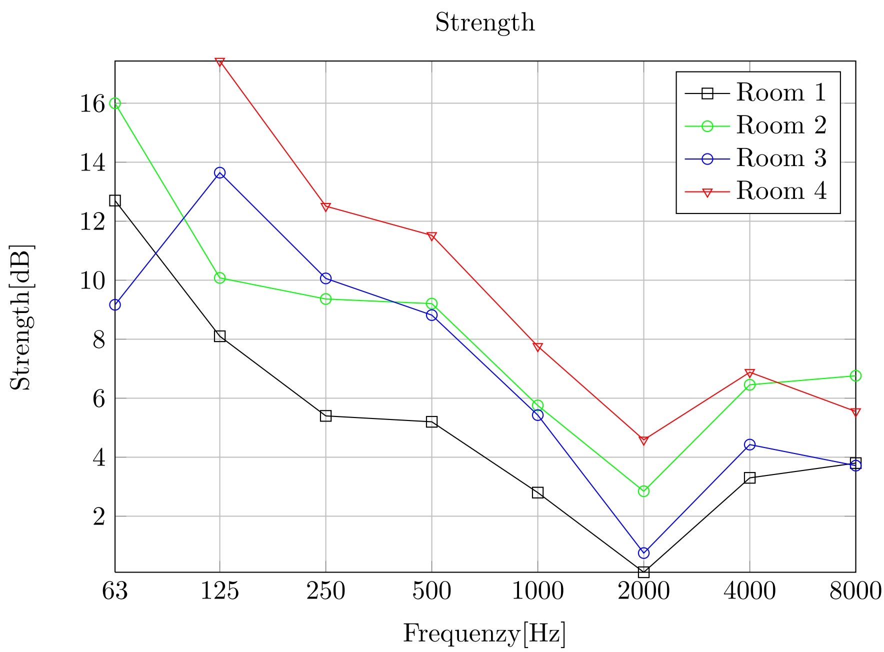

Figure 4.5: Strength(cal), measurements in the different rooms

Impulse Response

The impulse responses of the four rooms can be seen in Figure 4.6 below. Impulse responses for Room 1 and Room 2 is shown in the first row and the impulse responses for Room 3 and Room 4 is shown in the second row. By just looking at the figure one can see that there are some differences in room characteristics as shown in the previous subsections. The impulse response of Room 1 has small magnitudes in the pressure distribution with a short reverberation time. Notice that the early and late reflections are small in amplitude, most likely caused by the many acoustic absorbers in the room. Room 2 shows signs of more early reflections compared to the other rooms, which is typical for a small sized room. The EDT is also longer than the reverberation time in Room 2, indicating that sound decays slower in the first 10 dB drop and faster for the last 50 dB drop.

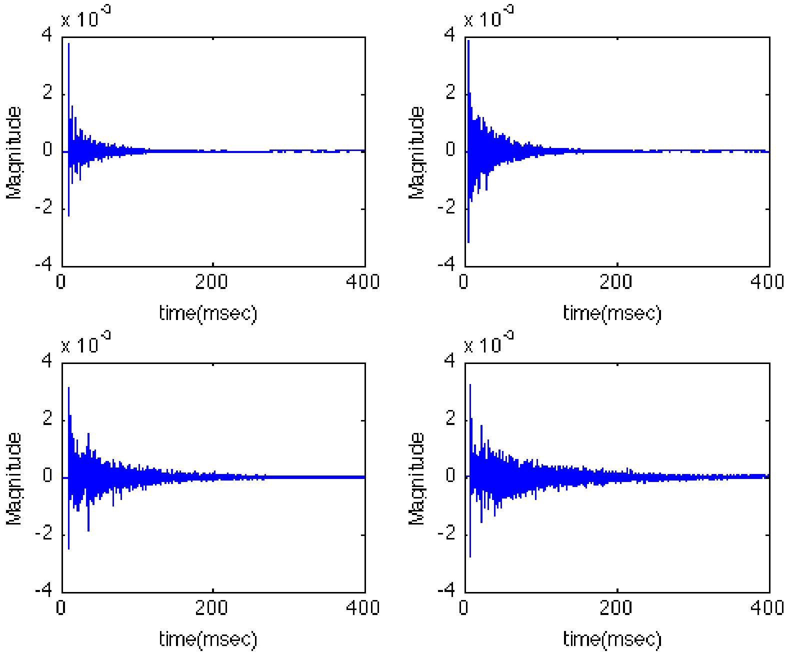

Figure 4.6: Impulse responses of the four rooms

4.2 Performance Results

This section presents the results for the musician's performances. As mentioned in chapter 3 there are total of 4 sound sources. Two of the sources measures the solo performances and will be referred to as Lp_{nose}(solo) and Lp_{guitar}(solo), and the two remaining sources measures the performances when combining guitar playing and singing and they will be referred to as Lp_{nose}(comb) and Lp_{guitar}(comb). All normalized SPL's can be found in appendix E

4.2.1 Audio Signal

Figure 4.7 shows plots of the average audio signal recorded on the nose tip and the sound hole of the guitar as played in Room 1 and Room 4 by OM. The first row shows the signal plot for Room 1 (G=4.16dB) and the second row shows the signal plot for Room 4 (G=10.03dB). Clear differences in magnitude can be seen between the two rooms where the mean magnitude of the signal in Room 1 is measured to be almost twice (1.85) the magnitude of the signal in Room 4. Differences in dynamics can be seen in the plot for Room 1, where it starts in piano and builds up to forte before it ends in piano. In Room 4 the dynamics is less noticeable. Such dynamic levels differences could not be found among the other musician's recordings.

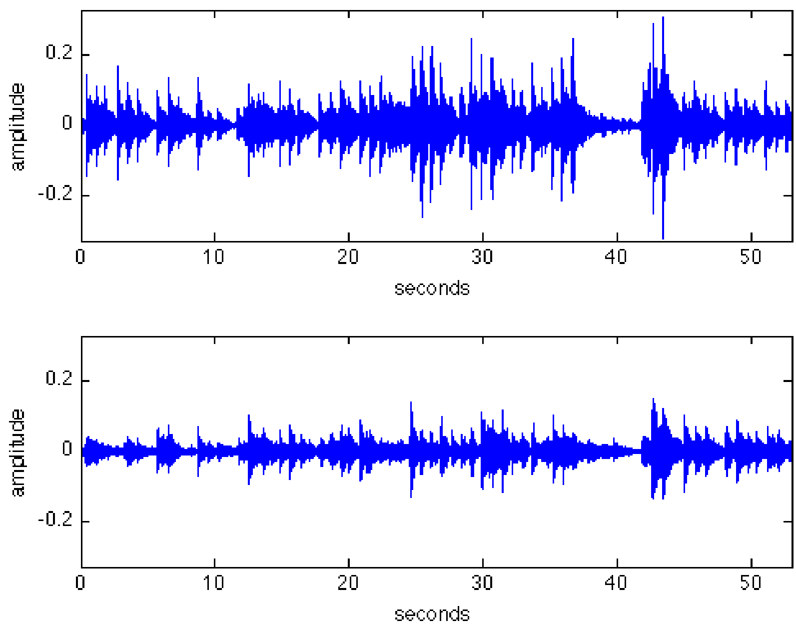

Figure 4.7: Plot of an audio signal as played by OM in Room 1 and Room 4 respectively

4.2.2 Average Source Levels versus Room Sequence

Figure 4.8 shows the average source levels of all four sources of the three performances for each musician together with their room sequence. The room sequences were presented in section 3.3.3 in Table 3.6, but can also be seen in the upper corner of Figure 4.8. Musicians OM, PC and MW increase their produced SPL's from the first to the last room in their sequence, respectively by 6.58 dBA, 3.46dBA and 0.94dBA. With MA the opposite is found with a decrease in SPL by -5.16dBA from the first to the last room. VE and BR and does not show significant signs of increase in source levels based on their room sequences. Average changes made within the sequences can be seen in Figure 4.9 and Table 4.1. It shows that there is an average increase of 0.33dBA from one room to another. This result is however somewhat dependent on the rooms and will be discussed further in section 5.2.

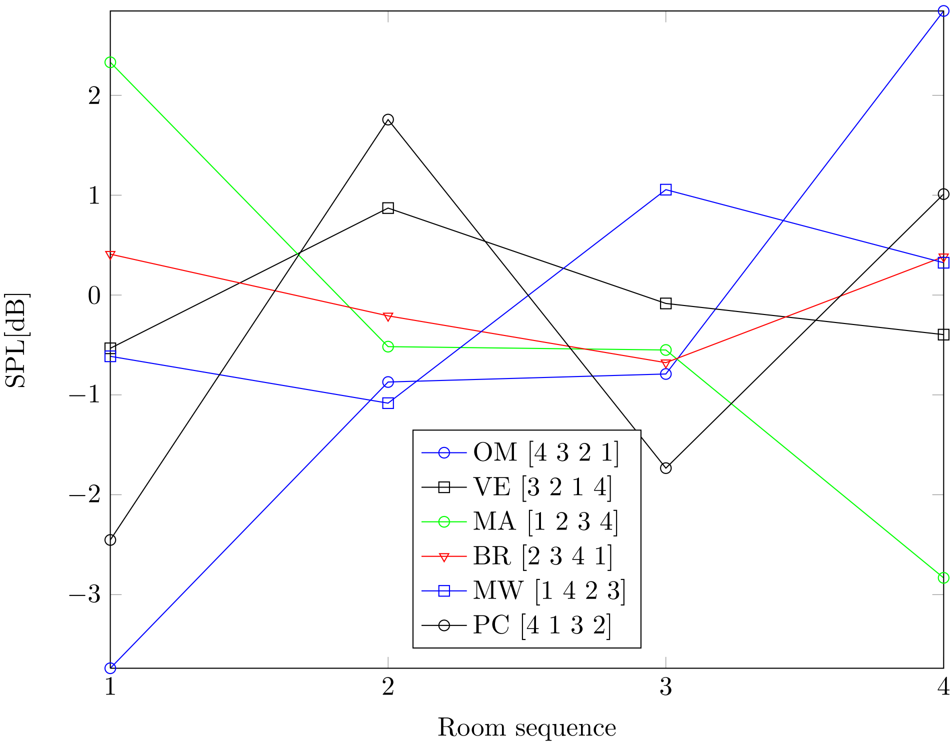

Figure 4.8: Average levels for Lp_{guitar} and Lp_{nose} for all musicians vs Room sequence

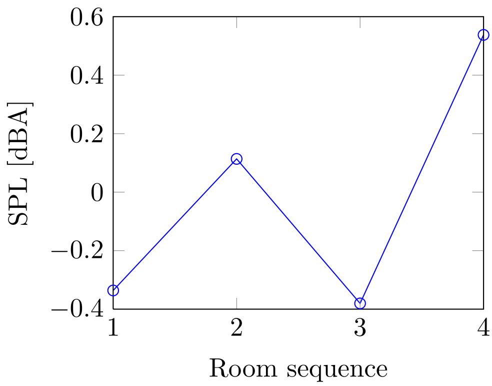

Figure 4.9: All musicians levels for Lp_{guitar} and Lp_{nose} averaged versus room sequence

Table 4.1: Average changes made to source levels for the rooms sequences

Sequence	**1-2**	**2-3**	**3-4**	**avg**
ΔSPL [dBA]	0.45	-0.49	0.92	0.33

4.2.3 Average Source Levels versus Rooms

Figure 4.10 and Table 4.2 shows each musicians average source levels of all four sources of the three performances in each room. From Room 1 to Room 4 the strength parameter gradually increase except from between Room 2 and 3 where there is a slight decrease. OM, MA and PC all seems to play softer as the strength in the room increases except from between Room 2 and 3 where the musicians sound pressure level decrease along with the strength. OM and MA's changes in source level are so small that they can be neglected (respectively 0.08dBA and 0.03dBA), but PC has a decrease in SPL of 2.74dBA. All differences between the source levels in the rooms can be seen in Table 4.3. Notice that all musicians plays softer in Room 3 compared to Room 2. This will be discussed further in chapter 5.

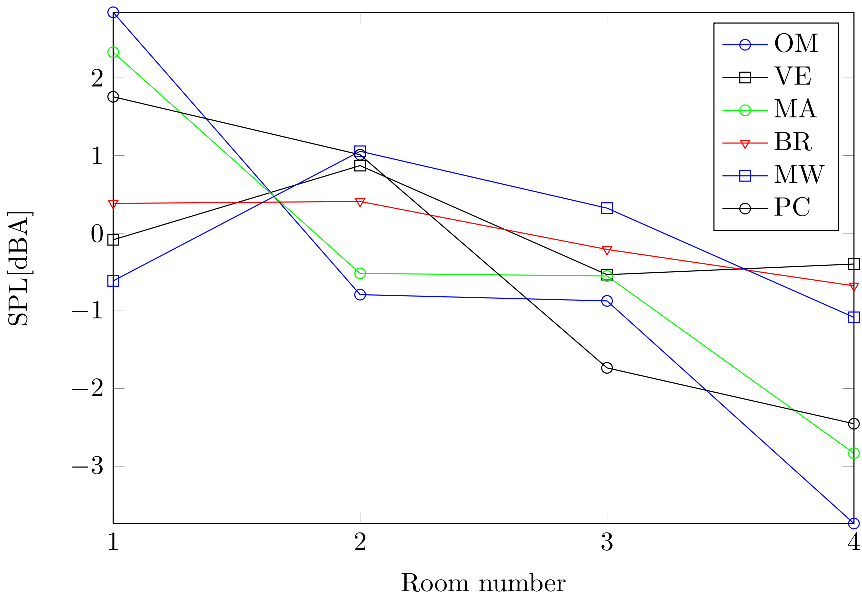

Figure 4.10: Average levels for Lp_{guitar} and Lp_{nose} versus room number

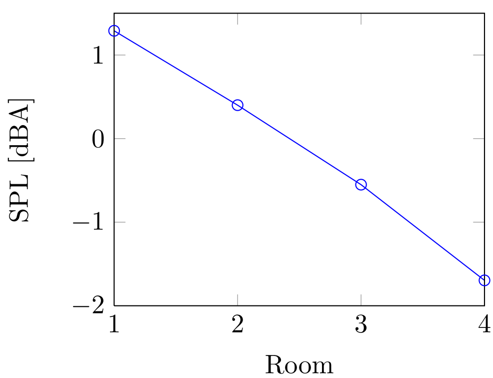

Figure 4.11: Average levels for all musicians for Lp_{guitar} and Lp_{nose} versus room

Table 4.2: Average of Lp_{nose} and Lp_{guitar} for each musician in each room

	Room 1	**Room 2**	**Room 3**	**Room 4**
G [dB]	4.16	7.81	7.44	10.03
OM [dBA]	2.84	-0.79	-0.87	-3.74
VE [dBA]	-0.08	0.87	-0.53	-0.39
MA [dBA]	2.33	-0.52	-0.55	-2.83
BR [dBA]	0.38	0.41	-0.21	-0.68
MW [dBA]	-0.61	1.05	0.32	-1.08
PC [dBA]	1.76	1.01	-1.73	-2.45
Av.Lp[dBA]	1.29	0.40	-0.55	-1.69

Table 4.3: Differences between the rooms

Room	**1-2**	**1-3**	**1-4**	**2-3**	**2-4**	**3-4**
Δ**G** [dB]	3.65	3.28	5.87	-0.37	2.22	2.59
ΔT_{60} [s]	0.06	0.49	0.92	0.43	0.86	0.43
Δ**EDT** [s]	0.13	0.50	0.86	0.37	0.73	0.36
ΔC_{80} [dB]	-6.40	-16.60	-20.10	-10.20	-13.70	-3.50
ΔD_{50} [%]	-6.19	-31.54	-47.79	-25.35	-41.60	-16.25
Δ**B.N.** [dB]	3.70	6.10	17.90	2.40	14.20	11.80
Δ**V** [m^3]	-49.0	-1.22	-21.3	47.8	27.72	-20.1
Δ**OM** [dBA]	-3.63	-3.72	-6.58	-0.08	-2.94	-2.86
Δ**VE** [dBA]	0.95	-0.44	-0.31	-1.40	-1.26	0.13
Δ**MA** [dBA]	-2.84	-2.88	-5.16	-0.03	-2.31	-2.28
Δ**BR** [dBA]	0.02	-0.59	-1.06	-0.61	-1.08	-0.46
Δ**MW** [dBA]	1.66	0.93	-0.46	-0.73	-2.13	-1.40
Δ**PC** [dBA]	-0.74	-3.49	-4.20	-2.74	-3.46	-0.71
Δ**Average** [dBA]	-0.36	-1.34	-2.32	-0.84	-1.86	-1.14

4.2.4 ANOVA test

A one-way ANOVA test comparing each of the four sources between the four rooms for all musicians can be seen in Table 4.4 below. The table shows that there are strong significant differences in produced SPL's for each source between all rooms.

Table 4.4: One-way ANOVA comparing the means of the individual source 4 rooms used

(a) ANOVA table for Lp_{nose}(solo)

Source	**SS**	**df**	**MS**	**F**	**Prob>F**
Columns	52.705	3	17.5682	5.65	**0.0057**
Error	62.17	20	3.1085		
Total	114.875	23			

(b) ANOVA table for Lp_{guitar}(solo)

Source	**SS**	**df**	**MS**	**F**	**Prob>F**
Columns	30.7256	3	10.2419	7.8	**0.0012**
Error	26.2526	20	1.3126		
Total	56.9782	23			

(c) ANOVA table for Lp_{nose}(comb)

Source	**SS**	**df**	**MS**	**F**	**Prob>F**
Columns	29.1784	3	9.72613	5.01	**0.0095**
Error	38.8443	20	1.94222		
Total	68.0227	23			

(d) ANOVA table for Lp_{guitar}(comb)

Source	**SS**	**df**	**MS**	**F**	**Prob>F**
Columns	16.2347	3	5.41155	6.93	**0.0022**
Error	15.6273	20	0.78137		
Total	31.862	23			

Sources are the different factors that contribute to the total variance, SS is the sum of squares, df is the degree of freedom, MS is the mean square.

A two-way ANOVA comparing the means of each musician's sources (rows) and the four rooms (columns) was performed (see Table 4.5). The two-way ANOVA test includes all sources for all musicians, such that the amount of sources has increased from 24 to 96 making the two-way ANOVA more reliable then the one-way ANOVA. The rows and columns for the two-way ANOVA test is seen in Table E.2 in Appendix E. As for the one-way ANOVA, the two-way ANOVA shows strong significance on how the rehearsal rooms have an affection on each source (ignoring which musicians produced what SPL). It also shows that the interaction effect is highly significant. There is not any significance effect between the persons, which is as expected since all source levels are normalized.

Table 4.5: Two-way ANOVA comparing the means of each musicians 4 sources and the 4 rooms used

Source	**SS**	**df**	**MS**	**F**	**Prob>F**
Columns	120.618	3	40.2061	69.04	**0**
Rows	6.588	5	1.3176	2.26	0.0572
Interaction	104.577	15	6.9718	11.97	**0**
Error	41.931	72	0.5824		
Total	273.714	95			

A one-way ANOVA test was also performed to see the significance effect between guitar and vocal source levels, and also the significance effect between the solo performances and the combined performances. The results in Table 4.6- 4.7 shows that there are no significant differences between nose and guitar levels, and between solo and combined levels.

Table 4.6: Lp_{nose} versus Lp_{guitar}

Source	**SS**	**df**	**MS**	**F**	**Prob>F**
Columns	1.273	1	1.27276	0.44	0.5092
Error	272.441	94	2.89831		
Total	273.714	95			

Table 4.7: Lp.(solo) versus Lp.(comb)

Source	**SS**	**df**	**MS**	**F**	**Prob>F**
Columns	0.635	1	0.63542	0.22	0.6411
Error	273.079	94	2.90509		
Total	273.714	95			

4.2.5 Regression Analysis

Since there are no significant differences between nose and guitar measurements, and between solo and combined performances the measured signals will be regarded as somewhat independent signals (not completely independent since Lp_{nose}(comb) and Lp_{guitar}(comb) are measured from the same performance) and a regression analysis has been performed to get a insight into what acoustical parameter has the greatest affection on the source levels. Figure 4.12 shows the R^2-values, which gives the correlations between all measured sources SPL's (6 musicians x 4 sources x 4 rooms) and the acoustical parameters measured in the different rooms. It shows that the strength parameter on average has a slightly lower influence on the source levels compared to the other parameters. All correlations have strong significant values. Regression analysis for each source versus all parameters can be seen in Appendix D.

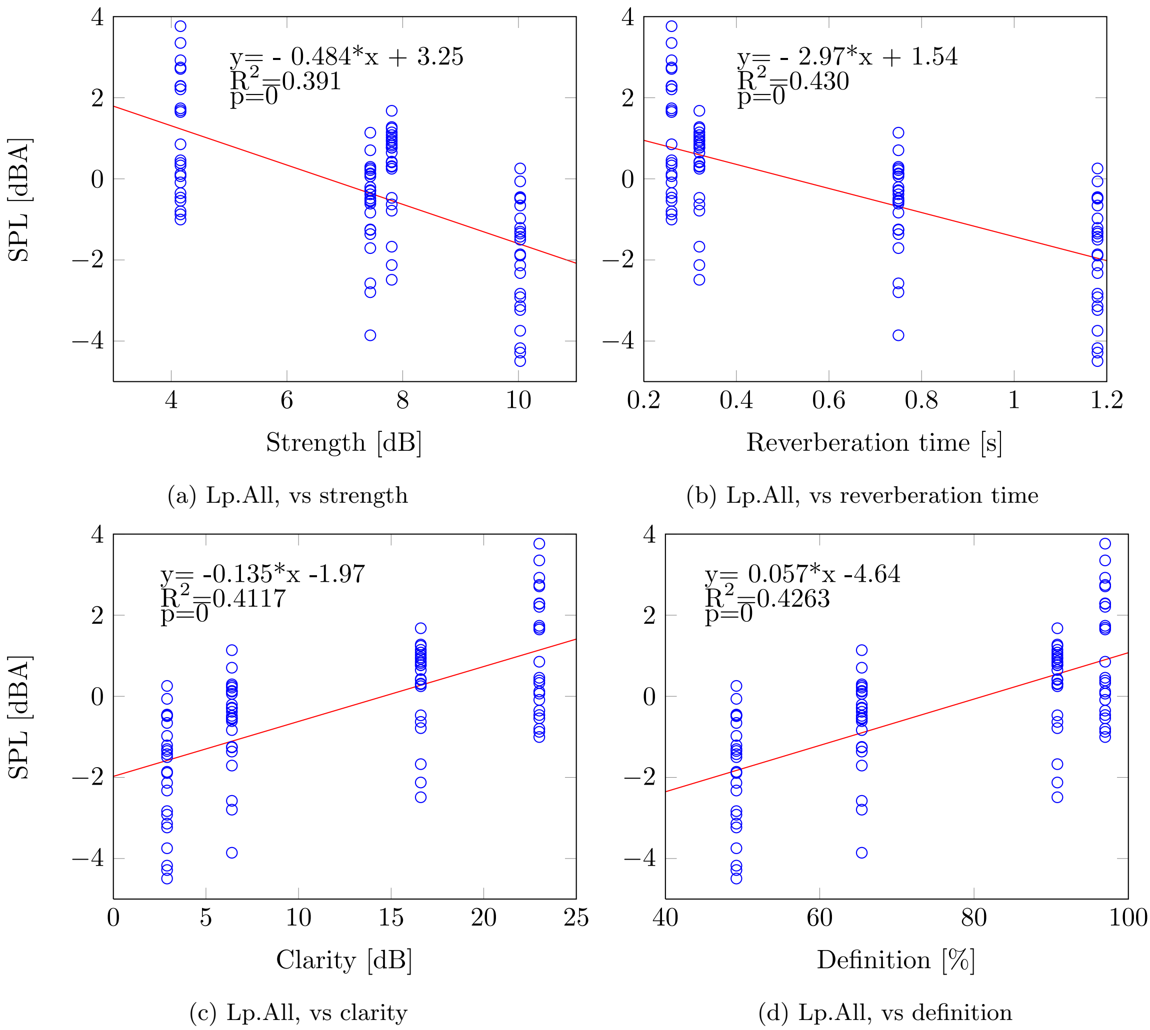

Figure 4.12: Regression plots for all 4 sources versus acoustical parameters

Table 4.8 shows the correlation between each musicians source levels and the acoustical parameters. The table indicates that, regardless of the acoustical parameter, most of the adjustments are made at the guitar. OM, MA and PC all makes significant changes to all acoustical parameters. VE and MW do not make any significant adjustments and BR has one significant adjustments.

Table 4.8: Correlations between musicians source level and the acoustical parameter together wit room size

		Lp_{nose}(solo)		Lp_{guitar}(solo)		Lp_{nose}(both)		Lp_{guitar}(both)	
Mus	**Par**	R^2	**p**	R^2	**p**	R^2	**p**	R^2	**p**
OM	G	0.983	**0.008**	0.757	0.129	0.979	**0.010**	0.993	**0.003**
VE	G	0.177	0.578	0.091	0.696	0.0001	0.991	0.576	0.240
MA	G	0.960	**0.019**	0.971	**0.014**	0.962	**0.018**	0.902	**0.050**
BR	G	0.139	0.626	0.424	0.348	0.044	0.789	0.320	0.433
MW	G	0.049	0.778	0.143	0.621	0.007	0.912	0.059	0.755
PC	G	0.481	0.305	0.701	0.162	0.571	0.244	0.586	0.233
All	G	0.423	**0.002**	0.361	**0.002**	0.357	**0.002**	0.374	**0.001**
OM	T_{60}	0.549	0.258	0.925	**0.038**	0.515	0.281	0.654	0.191
VE	T_{60}	0.618	0.213	0.472	0.312	0.257	0.492	0.073	0.729
MA	T_{60}	0.504	0.289	0.603	0.223	0.765	0.125	0.908	**0.046**
BR	T_{60}	0.574	0.241	0.934	**0.033**	0.337	0.418	0.656	0.189
MW	T_{60}	0.160	0.599	0.032	0.818	0.093	0.694	0.516	0.281
PC	T_{60}	0.821	0.093	0.886	0.058	0.837	0.084	0.993	**0.003**
All	T_{60}	0.404	**0.001**	0.529	**0.000**	0.411	**0.001**	0.496	**0.000**
OM	C_{80}	0.626	0.208	0.995	**0.002**	0.628	0.207	0.698	0.164
VE	C_{80}	0.284	0.466	0.552	0.256	0.043	0.790	0.110	0.668
MA	C_{80}	0.680	0.175	0.617	0.214	0.888	0.057	0.907	**0.047**
BR	C_{80}	0.626	0.208	0.702	0.161	0.449	0.329	0.325	0.429
MW	C_{80}	0.007	0.915	0.009	0.903	0.001	0.968	0.216	0.534
PC	C_{80}	0.927	**0.037**	0.997	**0.001**	0.966	**0.017**	0.837	0.084
All	C_{80}	0.420	**0.001**	0.514	**0.000**	0.400	**0.001**	0.419	**0.001**
OM	D_{50}	0.556	0.253	0.974	**0.013**	0.536	0.267	0.653	0.191
VE	D_{50}	0.498	0.294	0.551	0.257	0.173	0.583	0.068	0.739
MA	D_{50}	0.550	0.258	0.588	0.233	0.807	0.101	0.913	**0.044**
BR	D_{50}	0.646	0.196	0.878	0.062	0.422	0.350	0.527	0.273
MW	D_{50}	0.076	0.722	0.010	0.896	0.035	0.810	0.417	0.353
PC	D_{50}	0.901	**0.050**	0.954	**0.022**	0.920	**0.040**	0.963	**0.018**
All	D_{50}	0.411	**0.001**	0.539	**0.000**	0.412	**0.001**	0.473	**0.000**
All	Vol.	0.021	0.501	0.007	0.688	0.003	0.807	0.000	0.944

4.2.6 Relationship between SPL's at the right ear and the Average Source Level

In Figure 4.13 the SPL at the right ear for all musicians has been averaged in each room together with the average source level for all musicians. The SPL's follows each other almost exactly. The figure also shows the average SPL at VE and BR's right ear for each room. These are the two musicians with most experience compared to the others. They seem to have almost the exact same level at their ears and with an exception of Room 2 the levels are almost constant in each room. This will be discussed further in chapter 5 section 5.2.5

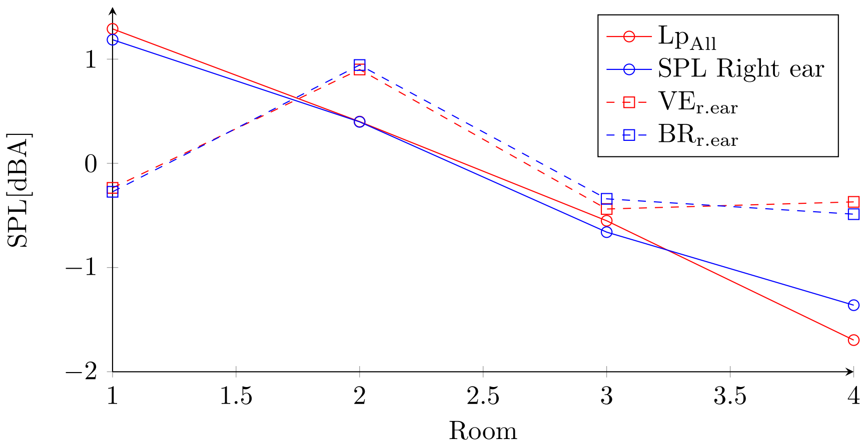

Figure 4.13: Relationship between strength and SPL's at the right ear for the average musician and for the two individual musicians VE and BR

Table 4.9: Measured SPL's at the right ear for the average musician for all rooms

	Room 1	**Room 2**	**Room 3**	**Room 4**	Δmax
Lp.all[dB]	1.29	0.40	-0.55	-1.69	2.99
$Lp_{r.ear}$**[dBA]**	1.19	0.39	-0.66	-1.36	2.55

Chapter 5

Discussion

The purpose of this study is to see if musicians make adjustments to their source levels based on some widely used acoustical parameters in four different rooms. Three of the rooms are used as music rehearsal room and one is used as a storage room. The results are divided into two parts, where the first part presents the measured acoustical parameters in all rooms and the second part presents the results from the performances. In this chapter these results will be discussed and the focus will be mainly on the performance measurements.

5.1 The Rehearsal Rooms

The measured parameters show clear differences between the rooms. When comparing the acoustics of the rehearsal rooms used in this study (excluding Room 4) to what has been previously suggested as acceptable small rehearsal rooms (Table 2.2), it is seen that they can all somewhat be regarded as usable for music rehearsing as long as the capacity limits are uphold and not take into account what instruments that are to be used. The reverberation time in Room 3 (0.75s) should probably be a bit shorter, but either way the selected rooms still gives a good representation of three standard music rehearsal rooms. Room 4 was as mentioned only included because of its different acoustic characteristics.

5.2 Performance Result

All musicians had rehearsed the song prior to the performance and they all knew the melody and chords to the song. It was however noticed during the performances that most of the musicians could not deal with the dynamic levels instructions for the song. It seemed like they had enough on keeping the beat of the song and thus the dynamic levels in most of the performances are absent.

5.2.1 Source Levels versus Room Sequence

As previously mentioned it is expected that the musicians are to increase their sound pressure levels just based on the fact that they get more and more comfortable in playing the song with each performance. Figure 4.8 shows how each musician are affected by this. When analyzing the results it is important to pay attention to the acoustical parameters of the rooms they are performing in since this most likely influence the results. The musicians that have a significant increase in source levels from the first room to the last room are OM, PC and MW respectively by 6.43dBA, 3.43dBA and 0.94dBA. They do however all start in rooms with significant lower strength compared the rooms they finish in. (see Table 3.6 for room sequences). These results are therefore as expected without regarding the room sequences. MA shows opposite tendencies compared to the 3 previous musicians with a clear decrease in source level from the first to the last room. It is quite interesting to see that MA's source plot are almost a mirror image of OM's source plot (Figure 4.8) knowing that their room sequence are exactly the opposite.

All considered, the room sequence will somewhat affect the measured results. The average increase in source level from room to room is 0.33dBA. For the average measurements to be unaffected by the room sequence there should have been 16 musicians playing such that the room sequences had been fully randomized (4 rooms have 16 possible sequences), but problems with getting enough musicians made this impossible.

5.2.2 Source Levels versus Rooms

With the room sequence playing a small role on the averaged measured source level one can start looking at how the different rooms affects the musicians. By just looking at Figure 4.10 it can be seen that the average source levels seems to decrease from Room 1 to Room 4. Doing an averaging over all musicians shows a clear tendency that the average musician plays softer from Room 1 to Room

4 (Figure 4.9). Looking at the differences in source levels between all rooms (Table 4.3) there a some changes to be noticed. All of the musicians play softer in Room 4 compared to Room 1 and Room 2 with an average decrease of respectively, 2.63dBA and 2.16dBA. This decrease is supported by the differences in acoustical parameters between the rooms. There is also a small decrease for all musicians between Room 3 and 2 (0.89dBA), but by looking at the differences in acoustical parameters this is not expected. This will be discussed later. The greatest differences in acoustical parameters are found between Room 1 and 4, and Room 2 and 4, which supports the differences in source levels between these rooms. Between Room 1 and 4 the most prominent differences are ΔT_{60} of 0.92 seconds, ΔG of 5.87dB and a background noise difference of 17.90dB. The high background noise in Room 4 might cause the Lombard effect[Lomb] to occur for some musicians in that room even though the measurements does not indicate this.

5.2.3 ANOVA Test

To see the real significance of the findings in the previous section some statistical analysis needs to be done. Starting by looking at the ANOVA test presented in section 4.4 and 4.5 the affection of the rooms on the 4 sources of the 3 attempts is tested. The one-way ANOVA test shows that the rooms have a significant effect on the source levels for both of the solo performances and the combined performance. The two-way ANOVA test found the same as the one-way ANOVA test, but with an even stronger significance since. It is also found with a strong significance that the rooms affect each musician's source levels differently. To be more precisely it proves that the source level for one musician in one room does not increase/decrease (compared to the three other rooms) equally as it would have for another musician in the same room,

These ANOVA tests confirm what was expected from just looking at the figures of the source levels and the null hypothesis presented in section 2.3.3 is *rejected*.

5.2.4 Source Levels versus Acoustical parameters

It has been shown that room interchanging causes musicians to make adjustments to their source levels. The question now is to see if there are any significant correlations between the acoustical parameters in each room and the differences in source levels or if musician's adjustment are just based on coincidences.

By looking at the regression analysis in section 4.2.5 there seems to be a slightly less affection made by the strength parameter on the average musician compared to the other 3 parameters. With a smaller correlation coefficient and also just by looking at how the different source levels are distributed around the linear line in Figure 4.12a it seems to indicate that the strength parameter correlates least to the differences in source levels. All correlations have p-values that are equal zero meaning that they are all fully significant. Since the different acoustical parameters also affect each other none of them can be regarded as independent variables and thus these coefficients cant be completely trusted. When calculating the correlation coefficient R^2 in the regression analysis there is already an assumption that the differences in source levels are either caused by the acoustical parameter that is tested for or other coincidences, which also somewhat relates to the other acoustical parameters. Looking at all coefficients as a whole is more realistic, but also more complex.

The source levels in Room 2 and 3 are the reason why strength correlates less to the average musicians source levels. There is a slight drop in strength from Room 2 to Room 3 (0.37dB), but still *all* musicians play softer in Room 3 compared to Room 2. The most significant drop is found with PC, which has a drop in 2.76dBA. While the differences in strength is fairly small between the two rooms, the reverberation time and the size of Room 3 is respectively 0.43 seconds longer and $48m^3$ larger than Room 2. The longer reverberation time gives more feedback to the musician, which might cause the softer performance. Looking at Brunskog's findings in [Bru08], he could not find any correlation between voice power and reverberation time, but he did find that the voice power correlated with the size and the strength of the room. This correlation did however show that voice power increased with room size, which is the opposite as seen between Room 2 and 3. In fact the results in this study does not show any significant correlations between source levels and room size (see Table 4.8). Even though Brunskog could not find any correlation between voice power and reverberation time it is of belief that the common drop in source level for all musicians between Room 2 and 3 is caused by the significant increase in reverberation time. The regression plot also indicates this with the R^2 value between source level and reverberation time as the highest (0.43). It should be mentioned that Brunskog used experienced speakers who are used to being on a stage talking, while in this study amateur musicians who seldom or never had performed in front people were used.

Table 4.8 shows how the individual musicians are affected by the acoustical parameters. First of all the table shows that most adjustment are made when playing guitar (This can also be seen in the regression plots for all sources for the average musician in Appendix D). Out of 22 significant adjustments made by the individual musician, 14 of them are made at the guitar. Secondly it shows that for the individual musician most adjustments are caused by the strength parameter. OM and MA shows significant correlations between strength and source level at 7 out 8 sources, while none of the other musicians have any correlations. PC seems to make significant adjustments mostly based on clarity and definition, while BR makes one significant adjustment based on reverberation time. VE and MW do not make any significant adjustments to their source levels. In this context it should be mentioned that VE and BR are the musicians with most experience (in terms of singing and playing guitar) compared to the other 4 musicians.

5.2.5 Future Work

Another thing to notice is that Table 4.8 shows that of the three musicians that are not/less (VE,MW and BR) affected by different rooms, two of them are the ones which has most experience compared to the rest. VE, which has the most experience of them all is not affected by any of the acoustical parameters and BR, who also has more experience compared to the rest, makes only one significant adjustment (out of 16 sources) to the source levels.

Figure 4.13 in section 4.2.6 show that the measured SPL at the right ear for both of them is quite constant in all rooms except in Room 2 where both has an increased SPL. All musicians were told to play as similar as possible and VE and BR have almost done this completely, with an exception of Room 2, where they both play louder compared to the rest. There are not any clear reasons why both musicians do this since the differences in acoustical parameters between the rooms should suggest otherwise. This could be the start of a future work, to see if there are any significant correlations between experience and how the musicians are influenced by room acoustics. In a study like this the number of musicians and rehearsal rooms should be increased to get more reliable results.

Chapter 6

Conclusion

This study has investigated how variations in certain acoustical environments affects musicians in terms of produced sound pressure level. As opposed to many previous studies where professional musicians were to perform in synthesized sound fields, all measurements in this study (except from in Room 4) have been made in real rehearsal rooms and all musicians were amateurs. The less experience they had with different rehearsal rooms the better. All six musicians have performed under the exact same conditions and an objective evaluation of the acoustic analysis has been made to see how the room acoustics affects the musicians and their produced sound pressure levels.

Based on the analysis of variance (ANOVA) it can be concluded that the average musician source levels are clearly affected by the different rehearsal rooms. In more details the results show that for the average musician all of the three performance attempts (solo song, solo guitar, and combined performance) are influenced by the rooms and this with a over 99% certainty. This corresponds well to previous studies. It is also observed from the two-way ANOVA test that the rehearsal rooms affect the musicians differently. The adjustment that one musician makes to the source level in one room compared to the three other rooms is not the same adjustment that any of the other musicians make.

With R^2 values between 0.36-0.54 and p-values less than 0.002 the regression analysis shows that there are strong significant correlations between source levels from the average musician and the acoustical parameters. It shows that the strength parameter has the least influence on the average musicians, whereas the reverberation time seems to affect the average musician the most. There could not be found any significant correlations between room size and source levels. These two previous findings does not correspond with Brunskog's findings in [Bru08]

Observing what happens to the individual musician one can see that they react differently to room acoustics. Out of six musicians, three show that room acoustics has an influence on source levels, while the remaining three show less or no signs of such affection. Of the musicians that show signs of affection towards the acoustical parameters most of the adjustments to the source levels are made in the guitar playing.

Future work should include more musicians and also more rehearsal rooms to get more reliable results. An investigation into how musician's *experience* correlates with the adjustments to room acoustics should also be made. There are findings in this study, which indicates this.

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Appendix A

Images of measurement rooms

Figure A.1: Room 1

Figure A.2: Room 2

Figure A.3: Room 3

Figure A.4: Room 4

Appendix B

Loudspeaker directivity

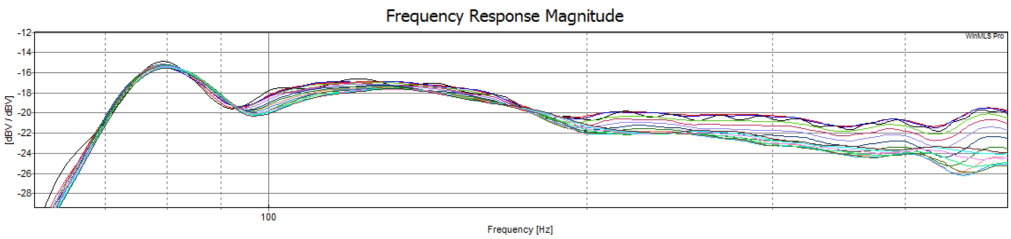


Figure B.1: Directivity of loudspeaker

Appendix C

Measurement and recording positions

Table C.1: Source and receiver positions in *Room 1*

	$X[m]$	$Y[m]$
$Ls1$	1.34	2.03
$Mic1$	3.0	1.06
$Mic2$	6.04	1.08
$Mic3$	3.98	2.94
$Ls2$	5.53	2.87
$Mic4$	3.5	2.07
$Mic5$	4.33	1.10
$Mic6$	1.50	1.14
$Musician$	2.20	1.70

Table C.2: Source and receiver positions in *Room 2*

	$X[m]$	$Y[m]$
$Ls1$	2.92	1.30
$Mic1$	2.70	0.60
$Mic2$	0.70	0.90
$Mic3$	1.87	1.76
$Ls2$	0.73	0.44
$Mic4$	1.85	1.30
$Mic5$	0.76	2.00
$Mic6$	0.75	2.10
$Musician$	2.00	1.00

Table C.3: Source and receiver positions in *Room 3*

	$X[m]$	$Y[m]$
$Ls1$	5.01	2.05
$Mic1$	4.50	1.0
$Mic2$	1.02	1.15
$Mic3$	2.33	3.52
$Ls2$	3.40	1.0
$Mic4$	2.95	2.26
$Mic5$	3.70	3.50
$Mic6$	1.02	3.53
$Musician$	4.40	2.20

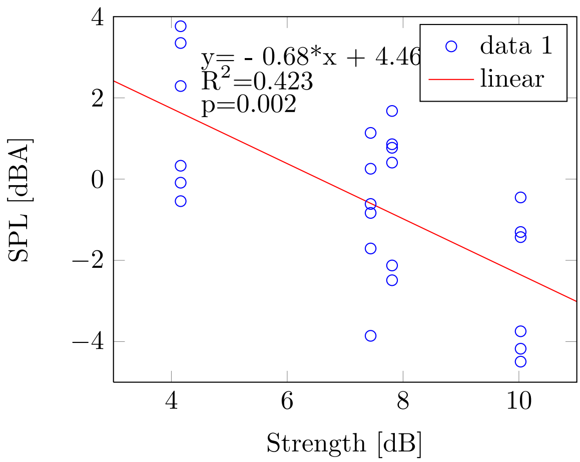
Table C.4: Source and receiver positions in *Room 4*

	$X[m]$	$Y[m]$
$Ls1$	1.00	1.97
$Mic1$	1.20	1.00
$Mic2$	2.03	2.94
$Mic3$	3.00	1.00
$Ls2$	1.00	0.74
$Mic4$	2.00	1.97
$Mic5$	1.30	2.94
$Mic6$	2.94	2.84
$Musician$	1.50	1.50

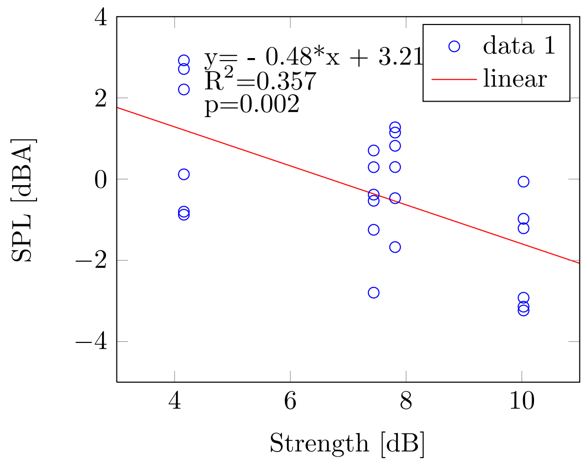
Appendix D

Regression analysis

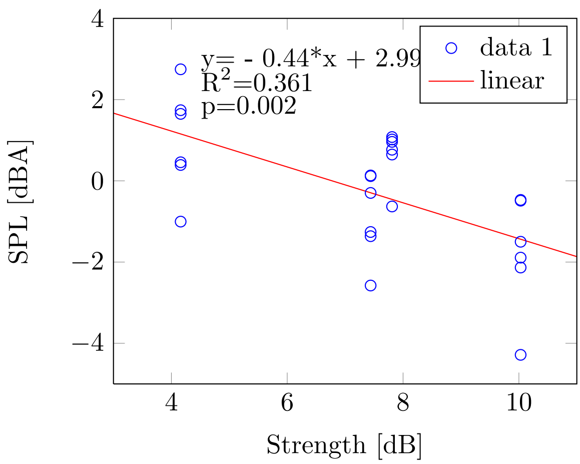
The regression analysis for all sources and all acoustical parameters can be seen below:



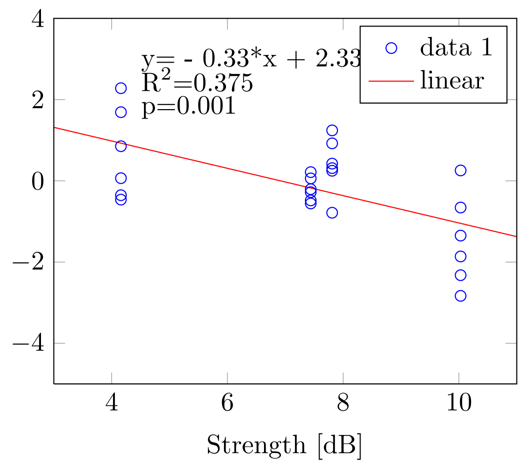
(a) Lp_{nose}, solo song



(b) Lp_{nose}, song w/guit

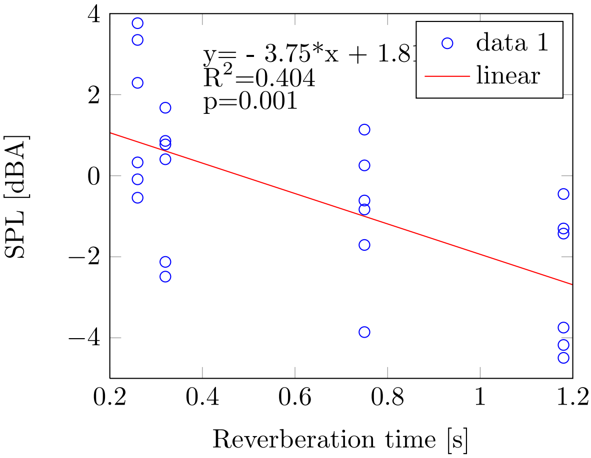


(c) Lp_{guitar}, solo guitar

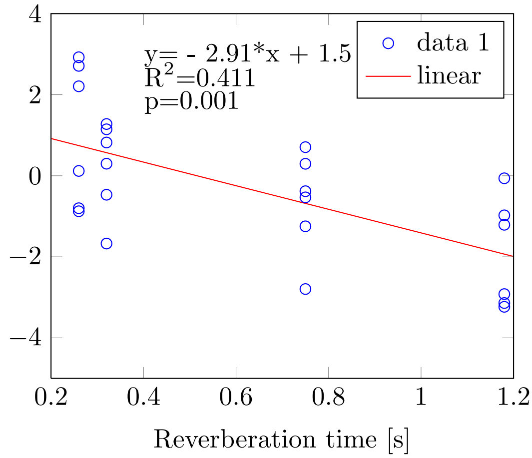


(d) Lp_{guitar}, song w/guit

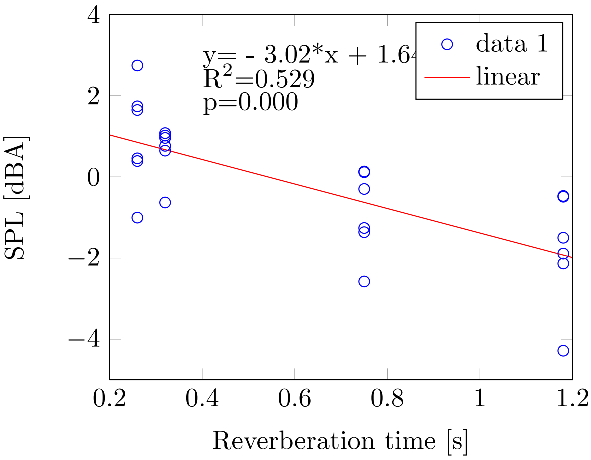
Figure D.1: Average levels for Lp_{guitar} and Lp_{nose} vs Strength



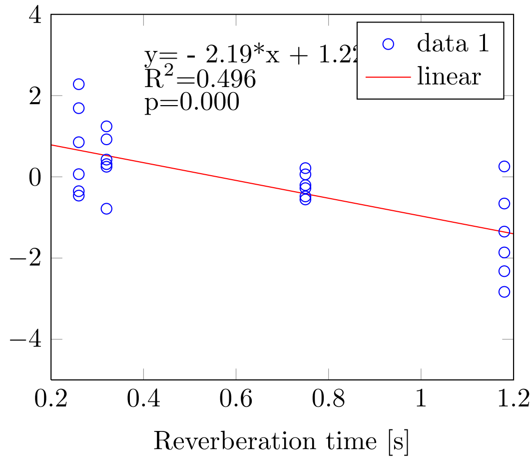
(a) Lp_{nose}, solo song



(b) Lp_{nose}, song w/guit



(c) Lp_{guitar}, solo guitar



(d) Lp_{guitar}, song w/guit

Figure D.2: Average levels for Lp_{guitar} and Lp_{nose} vs Strength

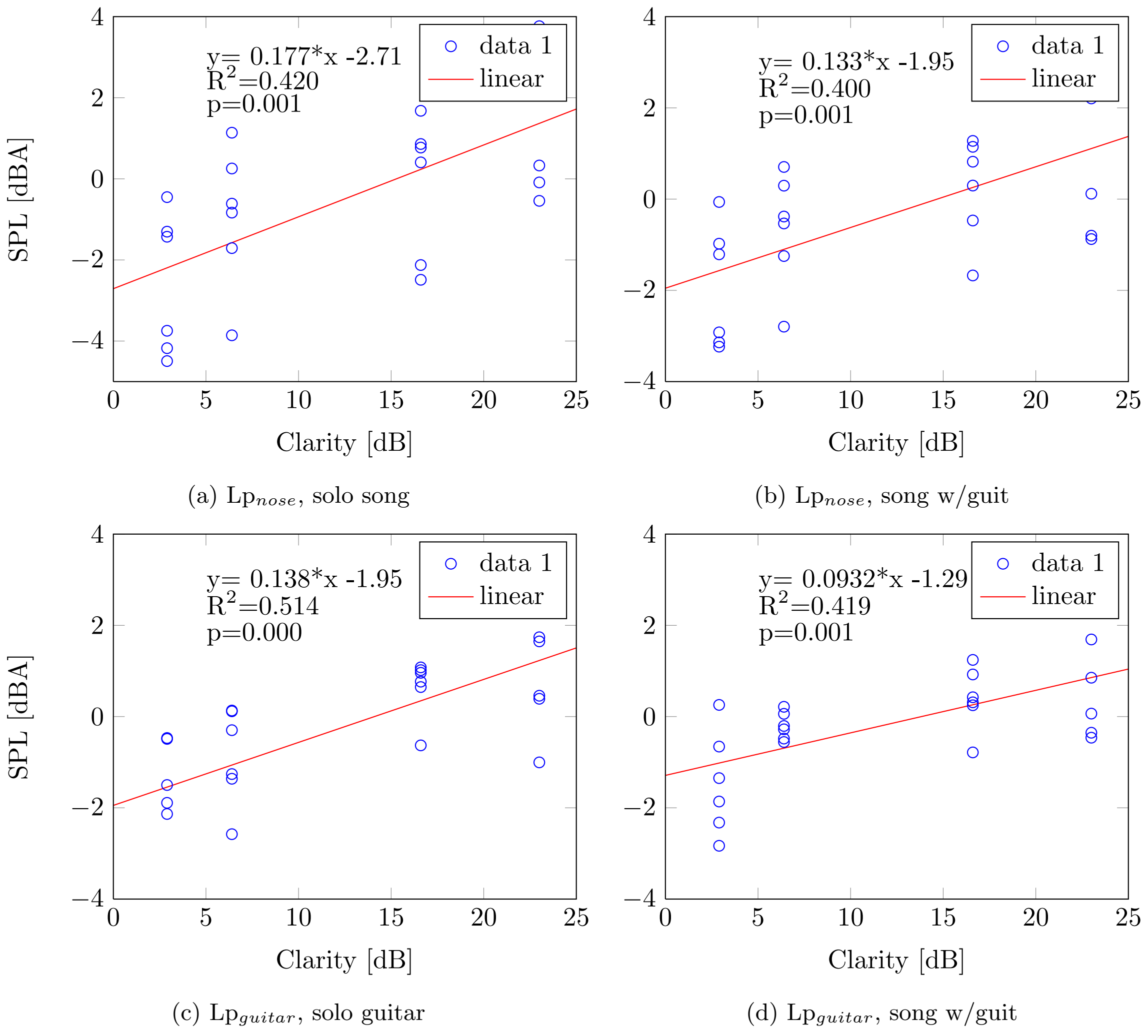
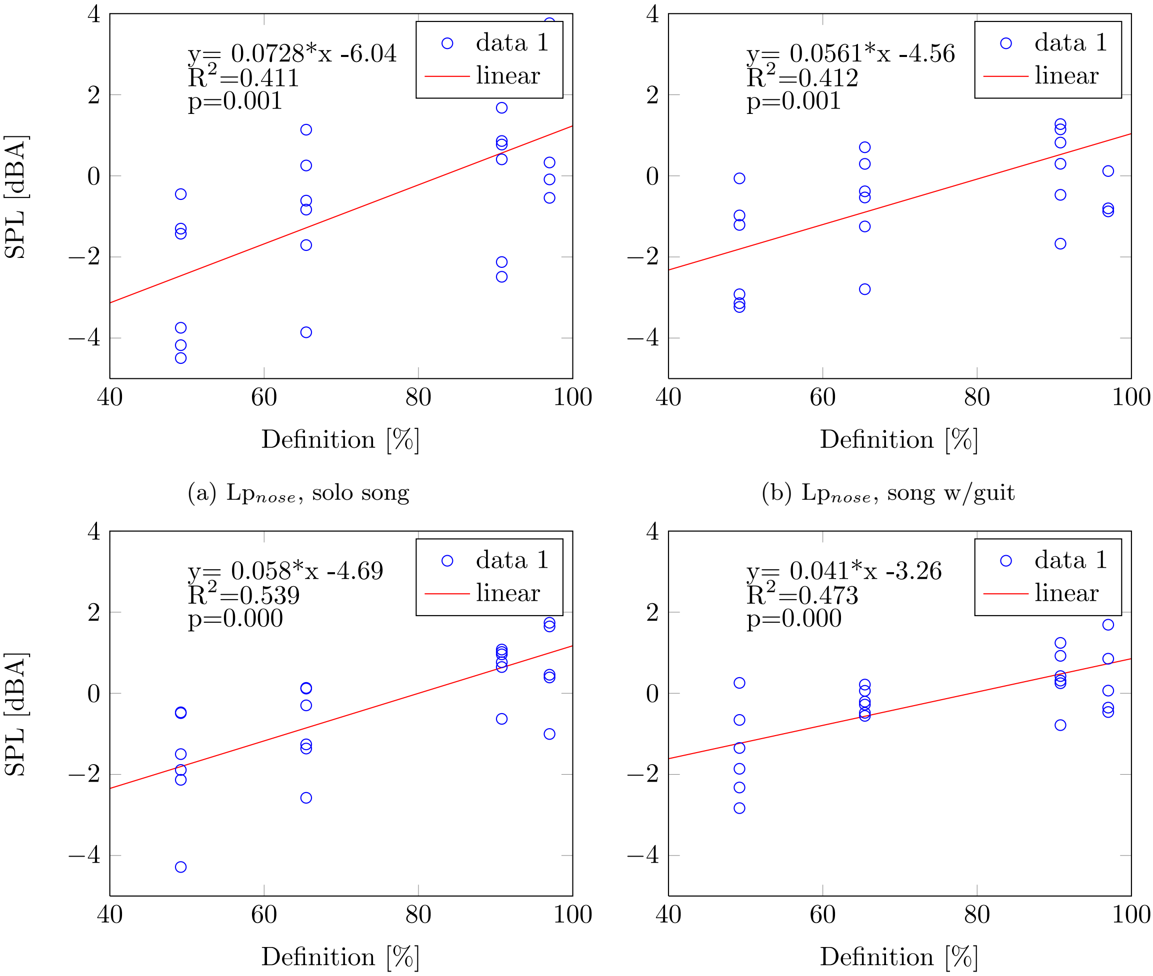


Figure D.3: Average levels for Lp_{guitar} and Lp_{nose} vs Clarity



(a) Lp_{nose}, solo song (b) Lp_{nose}, song w/guit

(c) Lp_{guitar}, solo guitar (d) Lp_{guitar}, song w/guit

Figure D.4: Average levels for Lp_{guitar} and Lp_{nose} vs Definition

Appendix E

Measurement data

Table E.1: All measured SPLs at the ears for each musician in each room

Musician	Parameters	Room 1	Room 2	Room 3	Room 4
	G [dB]	**4.16**	**7.81**	**7.44**	**10.03**
	T_{60}[s]	**0.26**	**0.32**	**0.75**	**1.18**
$\mathbf{OM}_{singing}$	$Lp_{r.ear}$	3.0527	-1.8001	-0.021717	-4.8851
$\mathbf{OM}_{guitar}$	$Lp_{r.ear}$	2.0886	0.80212	-3.2173	-1.5313
$\mathbf{OM}_{combined}$	$Lp_{r.ear}$	2.3687	-1.8888	0.54183	-3.0585
$\mathbf{VE}_{singing}$	$Lp_{r.ear}$	-0.16301	0.98529	-0.82214	-0.20163
$\mathbf{VE}_{guitar}$	$Lp_{r.ear}$	-0.25808	0.53410	-0.31618	-0.012840
$\mathbf{VE}_{combined}$	$Lp_{r.ear}$	-0.29719	0.87338	-0.14287	-0.57619
$\mathbf{MA}_{singing}$	$Lp_{r.ear}$	3.3484	-2.6383	-1.8678	-1.9187
$\mathbf{MA}_{guitar}$	$Lp_{r.ear}$	2.2134	-2.7937	-0.26185	-0.61365
$\mathbf{MA}_{combined}$	$Lp_{r.ear}$	2.1607	-0.45800	-1.2419	-1.5233
$\mathbf{BR}_{singing}$	$Lp_{r.ear}$	-0.12872	1.3798	-0.76243	-0.88186
$\mathbf{BR}_{guitar}$	$Lp_{r.ear}$	1.0907	0.25843	-1.1633	-0.51492
$\mathbf{BR}_{combined}$	$Lp_{r.ear}$	-0.55490	0.64944	0.023869	-0.20846
$\mathbf{MW}_{singing}$	$Lp_{r.ear}$	-0.31326	0.40242	0.48657	-0.68570
$\mathbf{MW}_{guitar}$	$Lp_{r.ear}$	-1.7586	1.0625	-0.26003	0.46850
$\mathbf{MW}_{combined}$	$Lp_{r.ear}$	-0.74549	0.82417	0.085867	-0.32083
$\mathbf{PC}_{singing}$	$Lp_{r.ear}$	1.9552	2.7407	-5.0648	-6.1946
$\mathbf{PC}_{guitar}$	$Lp_{r.ear}$	1.7900	-0.37854	-2.6545	0.13136
$\mathbf{PC}_{combined}$	$Lp_{r.ear}$	1.5140	1.3529	-2.1428	-2.1689

Table E.2: All measured normalized SPLs for all musicians in each room

Musician	Parameters	Room 1	Room 2	Room 3	Room 4
	G [dB]	**4.16**	**7.81**	**7.44**	**10.03**
	T_{60}[s]	**0.26**	**0.32**	**0.75**	**1.18**
$\mathbf{OM}_{singing}$	Lp_{nose}	3.3509	-2.1258	-0.61191	-4.4938
$\mathbf{OM}_{guitar}$	Lp_{guitar}	2.7459	0.76589	-2.5775	-4.2845
$\mathbf{OM}_{combined}$	Lp_{nose}	2.9235	-1.6732	-0.53349	-3.2341
$\mathbf{OM}_{combined}$	Lp_{guitar}	2.2809	-0.78537	-0.20585	-2.8321
$\mathbf{VE}_{singing}$	Lp_{nose}	-0.088266	0.85885	0.25526	-1.3023
$\mathbf{VE}_{guitar}$	Lp_{guitar}	0.39044	1.0182	-1.2599	-0.48890
$\mathbf{VE}_{combined}$	Lp_{nose}	-0.80150	1.2760	0.29466	-1.2103
$\mathbf{VE}_{combined}$	Lp_{guitar}	-0.46245	0.42398	-0.27906	0.25590
$\mathbf{MA}_{singing}$	Lp_{nose}	3.7642	-2.4894	-1.7081	-4.1759
$\mathbf{MA}_{guitar}$	Lp_{guitar}	1.7391	-0.63116	0.13271	-2.1344
$\mathbf{MA}_{combined}$	Lp_{nose}	2.7110	-0.46869	-1.2481	-3.1402
$\mathbf{MA}_{combined}$	Lp_{guitar}	1.6904	0.24844	-0.55703	-2.3234
$\mathbf{BR}_{singing}$	Lp_{nose}	0.32924	0.77124	-0.83272	-0.45086
$\mathbf{BR}_{guitar}$	Lp_{guitar}	0.45726	0.95975	-0.29784	-1.5000
$\mathbf{BR}_{combined}$	Lp_{nose}	0.11838	0.29719	-0.38164	-0.062708
$\mathbf{BR}_{combined}$	Lp_{guitar}	0.065347	0.31280	0.21440	-0.65728
$\mathbf{MW}_{singing}$	Lp_{nose}	-0.54275	0.40657	1.1379	-1.4279
$\mathbf{MW}_{guitar}$	Lp_{guitar}	-1.0040	1.0784	0.11589	-0.46965
$\mathbf{MW}_{combined}$	Lp_{nose}	-0.87616	0.82019	0.70501	-0.97684
$\mathbf{MW}_{combined}$	Lp_{guitar}	-0.35380	1.2424	0.060495	-1.3489
$\mathbf{PC}_{singing}$	Lp_{nose}	2.2917	1.6781	-3.8582	-3.7466
$\mathbf{PC}_{guitar}$	Lp_{guitar}	1.6483	0.64723	-1.3628	-1.8908
$\mathbf{PC}_{combined}$	Lp_{nose}	2.2071	1.1459	-2.7956	-2.9205
$\mathbf{PC}_{combined}$	Lp_{guitar}	0.85230	0.92317	-0.48203	-1.8617

Appendix F

MATLAB source code

The MATLAB code that was used in this study will be given by request. Please contact me if so needed

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