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Methods to evaluate room acoustical preferences regarding practice rooms

A study focusing on drummers and percussionists

Master's thesis in Sound and Vibration

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Department of Civil and Environmental Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

This thesis targets the uncertainty among European standards of how to evaluate the room acoustic quality of drum practice rooms. The interaction between percussionists and practice environments is thoroughly investigated in order to understand player preferences and gain more knowledge of what they are based on. Furthermore, different evaluation methods are applied to a number of drum practice rooms to identify a suitable approach for future studies for determining room acoustical requirements. The results indicate that the acoustic environment can influence the strength, tempo and consistency of a percussionist's playing style. The results also suggest that different acoustical requirements have to be considered for a performance environment and a practice environment. The two important aspects found for a practice situation are a clear and accurate feedback of the room as well as the possibility to learn how to adapt to different acoustic environments. With regard to the investigated room quality evaluation methods potential is seen in applying a listening test. Since the feedback of a room has been shown to be of importance also when evaluating the quality of a practice room a listening test with interactive elements could be further investigated.

Keywords: room acoustics, drummers and percussionists, practice rooms acoustics, reverberation time, tacit knowing, subjective perception

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1 Introduction

There is a variety of studies indicating that the act of practising a musical instrument comes with several benefits. Studies suggest instrumental music education has a positive effect on the auditory discrimination, fine motor skills, vocabulary and non-verbal reasoning among children (Forgeard et al., 2008; Costa-Giomi, 2005; Parbery-Clark et al., 2009; Kraus and Chandrasekaran, 2010). Acknowledging the positive effects of practising a musical instrument it becomes apparent that a great deal of attention has to be devoted to the design of practice rooms in order to make them as appreciated as possible. Besides this it is of even greater importance to create practice rooms that protect musicians from noise-induced hearing loss (NIHL). It seems reasonable to assume that this hearing impairment is especially common among musicians practising instruments causing high sound pressure level. Based on (Phillips and Mace, 2008) where the average sound pressure level measured during average practice sessions have been presented the musicians most likely to suffer from a NIHL should be musicians playing brass or percussion instruments (piano excluded). This is in accordance with (Halevi-Katz et al., 2015) where the highest hearing thresholds among rock, pop, and jazz musicians have been found among drummers[1].

Considering the importance of practice rooms that do not impair musicians in any way accurately formulated requirements are needed in order to help architects and engineers to design these sensitive environments. However, a review of three different European standards leads to the observation that the applied approaches and specified requirements among the standards differ between different countries. This suggests an uncertainty of how to evaluate music practice rooms. This uncertainty is targeted with this report.

The aim of this thesis is to develop a suitable method to identify room acoustical preferences among musicians concerning practice rooms. This is done by first thoroughly investigating the interaction of a practice room and a musician. Based on the findings three different evaluation methods are applied and reviewed concerning their appropriateness with regard to the aim specified above. In order to keep this study precis the entire investigation is focusing on drummers and percussionists, being a group of instrumentalists likely to suffer from a NIHL due to their practice. The intention, however, is to develop a method also applicable to other instrument groups.

[1] In this study no brass instrumentalist took part.

1.1 Research Question

The following research questions are targeted with this report:

- How does an acoustic environment influence the playing style of a percussionist?
- What do percussionists and drummers base their judgments on when evaluating the acoustic environment of a practice room?
- What are important room acoustical aspects of appropriate drum practice rooms?
- What are the advantages and disadvantages of the three considered evaluation methods in this report?

2 Background

It is well-known that the acoustical characteristics of a room determine the sound of musical instruments played inside the considered room. However, studies indicate that besides this the acoustic environment can also influences the playing style of a musician. In (von Békésy, 1968) a study carried out with a well-known pianist is presented where it was observed that the pianist was compensating a long reverberation time of a room by playing overall softer. In a room with a short reverberation time the pianist compensated by playing harder. The results of the study also suggest that the total dynamic range of the performed music piece was decreased in scenarios with too long and too short reverberation times. Hence, one could conclude that the acoustic environment had a negative influence on the musician in this case. In (Bolzinger et al., 1994) another study investigating the influence of room acoustics on piano performance is presented. The study was carried out with seven professional pianists in a modulable concert hall where the MIDI-output signal of a grand piano was analyzed. Also in this study the reverberation time was influencing the playing style in the same manner as observed in (von Békésy, 1968).

Regarding the influences of room acoustical characteristics on the playing style of drummers and percussionists there is a lack of scientific literature. However, it seems probable that also drum players are exposed to this influence. This is indicated by the experiences made by a professional drummer who took part in (Greeves, 2016). In the study it was investigated how the sound of a drum set played in seven different rooms changes. In order to only expose the influence of the room on the recordings the drummer had the task to perform the considered song with as little variation as possible between recordings. In (Greeves, 2016) he talks about his realization of how strong the influence of the room on his playing style was.

Acknowledging the considerations above that the acoustic environment of a room can influence the playing style of a musician and that this influence can be negative it becomes apparent how important it is to thoroughly think through the design of a music practice room. Like for any other room the aim hereby should be to create an environment appropriate for its usage. The appropriateness with regard to the function of a room can be specified as Hörsamkeit, a term defined in the German standard DIN 18041 (Beuth Verlag, 2016). The term Hörsamkeit is defined as the "appropriateness of a room for certain sound performances, especially verbal communication and musical performance at places designated for certain usages". According to the DIN 18041 the Hörsamkeit of a room mainly depends on its geometrical design, the choice and distribution of sound absorbing and sound reflecting surfaces as well as on the background noise level and the reverberation time.

In order to achieve a good Hörsamkeit the DIN 18041 focuses on the background noise level[1] and the reverberation time. Regarding the latter it is differentiated between the following kinds of room usages: music, speech, lessons and communication and gymnastics. Furthermore, the standard specifies that the requirements for music lessons and music practice rooms are strongly user-dependent and are somewhere between the requirements for music and speech. Moreover, it is emphasized in the standard that "loud" rooms used for practising, for example drums, need high room dampening. For "loud" rooms the standard specifies that the reverberation time should not exceed the requirements defined for gymnastics. It is interesting to point out that until the revised version from 2016 of the DIN 18041 no further differentiation was done between "loud" and "quiet" practice rooms. Furthermore, rooms used for music practice were treated in the same way as rooms used for speech. This approach was similar to the approach suggested in the Austrian standard ÖNORM B 8115-3:2005. The latter is strongly based on the old version of the DIN 18041 from 2004 (Eggenschwiler, 2013). However, the Austrian standard does differ from the outdated German standard by acknowledging music practice as a separate usage (Häusler, 2006). A different approach compared to the ones presented above is introduced in the Norwegian standard NS 8178, (Standard Norge, 2014). In contrast to the DIN 18041 and the ÖNORM B 8115-3 the Norwegian standard specifies requirements depending on the kind and number of instruments intended to be played in a room. Based on publications the standard states that the desirable sound pressure level in a room when playing all present instruments at *forte*, $L_\mathrm{p}(f)$, should be between 85 dB and 90 dB. Following this requirement a room gain and reverberation time are specified in dependency of the room volume. The calculation is done with the help of given sound power level at *forte* for a number of common instruments, with focus on orchestral instruments, making it possible to evaluate a variety of music scenarios. It is interesting to note that no $L_\mathrm{p}(f)$ is specified for drum set.

The presented selection of European standards exposes some uncertainty with regard to the evaluation of music practice rooms. Since the DIN 18041, ÖNORM B 8115-3 and NS 8178 differ in their approaches the question arises which approach is most suitable. It is important to point out that the specified requirements should consider a possible negative influence of the room on the playing style of a drummer. Hence, it is crucial to first investigate the latter and gain more understanding about a possible adaption in playing style with regard to an acoustic environment. This is examined in the first phase investigation of this report. Based on the findings of the first phase different methods for a quantification of the quality of practice rooms used for drum play are evaluated and compared with each other in the second phase investigations of this report.

[1] The specifications given in the standard concerning the background noise level being a rather non-room-acoustical parameter depending mostly on sound insulation and HVAC design are not further considered here.

3

Theory

This chapter contains the definitions of the room acoustic parameters measured in this study. The three parameters reverberation time, early decay time and strength will be referred to throughout this report and will be defined as stated in the standard ISO 3382-1 (Swedish Standards Institute, 2009). The chapter also contains a description of the method presented in the Norwegian standard NS 8178 (Standard Norge, 2014) to determine appropriate room volume and reverberation time for a room intended for a certain type of music.

3.1 Room acoustical parameters - ISO 3382-1

3.1.1 Reverberation time

A widely used room acoustic parameter is the reverberation time T. It is defined as the time in seconds it takes for the sound energy density to decrease by 60 dB when the source exciting the room has stopped. The reverberation time can also be determined from a smaller reduction than 60 dB by fitting a straight line to the decay curve and extrapolating to the time corresponding to a reduction of 60 dB. If a smaller reduction is used the reverberation time should be labeled there after. If a reduction of 60 dB is used the reverberation time is labeled T_{60}. In ISO 3382-1 it is recommended that when using a smaller reduction, for instance 30 dB, the straight line fitted should be fitted between -5 dB and -35 dB from the maximum value of the decay curve. (Swedish Standards Institute, 2009).

3.1.2 Early decay time

Another room acoustic parameter implementing the decline of the decay curve is the early decay time, abbreviated EDT. It is determined in a similar manner as T_{60}, but instead of studying a drop of 60 dB EDT is defined as the time it takes for the decay curve to drop 10 dB from the maximum value. The obtained time should then be multiplied by 6, which corresponds to extrapolating a straight line between 0 dB and -10 dB to a reduction of 60 dB. It has been shown that the EDT is more important than T when studying the perceived reverberance of a room. (Swedish Standards Institute, 2009)

3.1.3 Strength

By comparing the sound pressure level from a source in free field with the sound pressure level caused by the same source placed inside a room the room acoustic parameter strength G can be obtained. This parameter describes the amplification that a room will provide. ISO 3382-1 defines G as

$$G = 10 \log \frac{\int_0^\infty p^2(t)dt}{\int_0^\infty p_{10}^2(t)dt} = L_{pE} - L_{pE,10} \tag{3.1}$$

where p is the sound pressure at a measurement position inside a room and p_{10} is the sound pressure measured at a distance of 10 m in free field. L_{pE} and $L_{pE,10}$ are the corresponding sound pressure levels. The lower limit of the integral, $t = 0$, corresponds to the time when the direct sound from the source reaches the microphone. The upper limit stated as ∞ in Equation (3.1) stands for a time equal or larger than the time corresponding to a reduction of 30 dB of the decay curve. (Swedish Standards Institute, 2009)

3.2 Calculation method - NS8178

The Norwegian standard NS 8178 provides a method for calculating an appropriate range of room volume and reverberation time for a practice room specified for a certain usage. NS 8178 argues that a range is needed since a small room with long reverberation time gives an unpleasant sound environment that could harm the hearing of the musician. A big room with short reverberation time does not provide sufficient amplification, hence making the instrument sound to weak. It is stated that in both of these cases the musician will probably compensate for the inappropriate acoustical condition.

The method aims at achieving a sound pressure level between 85 dB and 90 dB for music passages with the dynamic description *forte*. This sound pressure range $L_p(f)$ then gives a range for the acoustic parameter G (see Section 3.1.3) as

$$G = L_p(f) - 59 - 10 \log \sum_i n_i k_i \tag{3.2}$$

where n_i is the is the number of a certain type of music instrument i and k_i is the sound power factor of that music instrument. Hence, knowing the number of musicians and which musical instruments the room is intended for is necessary. The sound power factor k is is determined as

$$k = 10^{(L_W(f) - 90)/10} \tag{3.3}$$

where $L_W(f)$ is the sound power level of a music instrument at the dynamic description *forte*. The sound power level of different musical instruments has been studied in (Meyer, 2009). Meyer suggests that $L_W(f)$ is determined by setting four equally large dynamic steps between *pianissimo* (*pp*) and *fortissimo* (*ff*) and the calculating $L_W(f)$ as

$$L_W(f) = L_W(ff) - \frac{D}{4} \tag{3.4}$$

where the dynamic step D is given by

$$D = L_W(ff) - L_W(pp) \tag{3.5}$$

Furthermore NS 8178 provides a table over sound power factors for a number of common musical instruments. Implementing the sound power factor in Equation (3.2) gives a range for G that can be used together with Figure 3.1 to determine an appropriate room volume and reverberation time for a room.

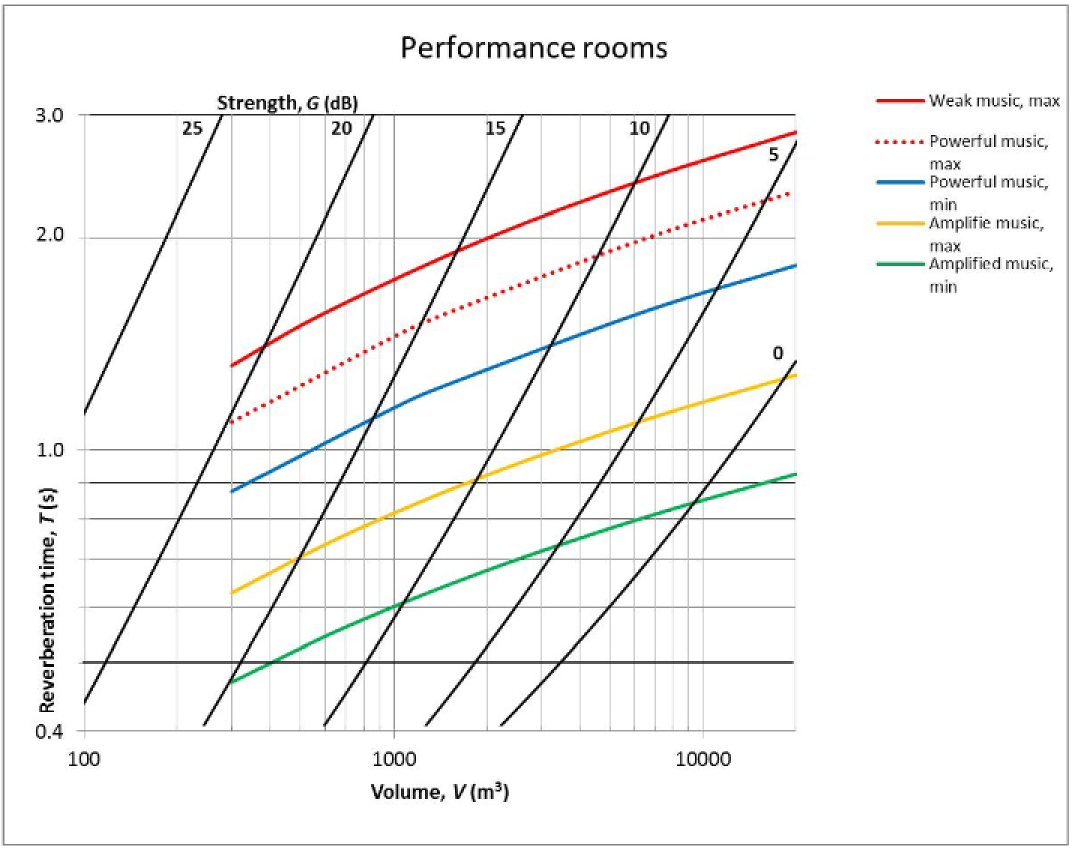


Figure 3.1: Plot of appropriate ranges of reverberation time in relation to room volume for weak music, powerful music and amplified music. The thicker black lines show the strength G in steps of 5 dB (Rindel, 2014)

As seen in Figure 3.1 NS 8178 divides the intended usage into three different categories, weak music, powerful music and amplified music. Each of these categories is assigned an appropriate range for the reverberation time in relation to the room volume. Placing the range of G between the lines for the maximum and minimum reverberation time for the intended usage then gives an appropriate range for reverberation time and room volume for the room.

4
Method

4.1 Phase 1 - Room influence on playing style

4.1.1 Aim and preliminary considerations

The aim in this part of the investigation was to get a better understanding of a possible adjustment of a drummer's playing style with regard to the acoustic environment of a room. This was considered important because such an adaptation to the room might impair the playing performance, the training progress as well as the playing experience of a musician in a practice situation. Since studies focusing on a variety of instruments indicated that musicians adjust their playing style depending on the response of the room it seems probable that the same accounts for percussionists. In studies it was shown that a room with a shorter reverberation time can lead to a harder playing and singing style, while a room with longer reverberation time may lead to a softer playing and singing style (von Békésy, 1968; Ternström, 1989; Bolzinger et al., 1994; Kawai et al., 2013; Kalkandjiev and Weinzierl, 2013; Garí et al., 2016). Furthermore, studies could show that an adaptation also occurs in the chosen playing tempo where a slower tempo is chosen in reverberant spaces (Garí et al., 2015, 2016).

Another aspect that was closer investigated in this phase of the report was the awareness level of a possible adaptation process in playing style with regard to the acoustic environment of the room. Even though musicians expressed that they had adapted to the acoustics of a room (Ueno and Tachibana, 2005; Greeves, 2016) it is uncertain if their perception was in accordance with their actual behaviour or if adaptations in playing style had happened on a subconscious base as observed in (Kalkandjiev and Weinzierl, 2013).

4.1.2 Assumptions

In this phase two mentionable assumptions were made. Firstly, it was assumed that an adaptation in playing style of a drummer will not occur only for one instrument of a common drum set (snare drum, cymbals, tom-toms and base drum) but instead will occur for all of them. Based on this the test setup of the first phase was simplified by only focusing on one instrument of a drum set: the snare drum. The snare drum was chosen of all instrument because an accelerometer could easily be attached to the drum shell. This was considered to be in contrast to other instruments of the drumset for example cymbals. The second assumption that was made is that the adaptive behaviour of a drummer who is used to playing a drum set would be the same or at least very similar to the one of a classically trained percussionist. By assuming this percussionists, usually having a repertoire of music pieces they are very accustomed to, could be included in the first phase investigations. This was considered to be in contrast to drummers with a different focus of rather accompanying other musicians. The ability of having the skill to perform a piece of music for a number of times without bigger variations was an important factor in the first phase investigations. This was because possible variations within the music pieces due to different acoustic environments might be concealed by too big variations between performances within the same environment.

4.1.3 Measurement Concept

Based on other studies (Bolzinger et al., 1994; Kawai et al., 2013; Kalkandjiev and Weinzierl, 2013; Garí et al., 2015, 2016) with similar research topics the measurements consisted of playing tests in combination with a questionnaire and an interview. In the following the measurement concept is further presented and explained in detail. To ease the understanding an illustration of the test structure is shown in Figure 4.1.

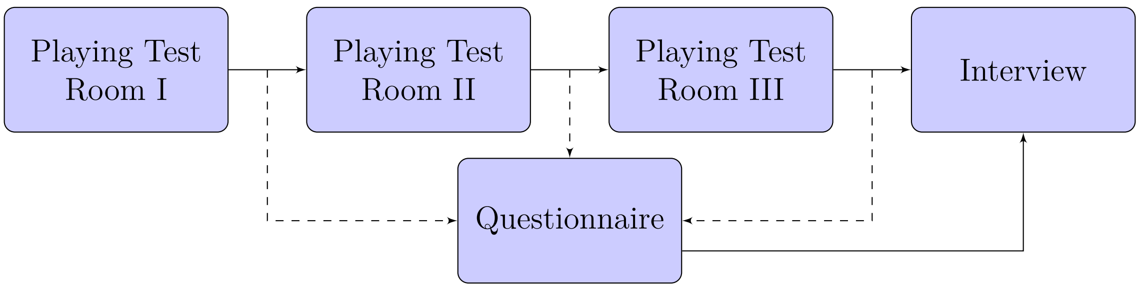


Figure 4.1: Illustration of test structure in the first phase investigation

Playing test

In order to find answers to the central questions of this investigation the test participants were taking part in a playing test where they were asked to perform a piece of music three times on the same instrument but in three different rooms, strongly varying in the acoustic environment. Similar approaches have been applied in other studies focusing on other instruments (von Békésy, 1968; Bolzinger et al., 1994; Kawai et al., 2013; Kalkandjiev and Weinzierl, 2013; Garí et al., 2015; Ternström, 1989; Garí et al., 2016). Comparable to the study presented in (von Békésy, 1968), where the vibrations of a piano body where measured in order to expose a change in playing style when changing the acoustic environment, an accelerometer was attached to the shell of a snare drum. When playing the snare drum the excitation of the drum head will cause the shell to vibrate, hence, the measured acceleration will mirror a change in dynamics and tempo of the played music piece. Since only relative changes in acceleration are studied the position of the accelerometer was chosen without further analysis, see Figure 4.2. The test procedure was verified in a pilot study.

Figure 4.2: Picture of the test snare drum with attached accelerometer

The participants were asked to repeatably perform a self-chosen piece of music three times in each test room. Before every recording the percussionists were given some time to warm up and get accustomed to the test room.

Interview and questionnaire

The playing tests were accompanied by an interview at the end of the playing tests, see Figure 4.1. The aim hereby was to find out how the test rooms where perceived by the musicians. Furthermore the interviews were used to identifying room preferences and to gain more knowledge about the underlying process of the musicians' evaluation of the acoustic environment in the test rooms. Moreover, the intention of the interviews was also to expose how aware the musicians were of a possible adaptation process in their playing style and if the musicians' perception was in accordance with their behaviour. In order to not bias the playing style of the participants the amount of information given to them before and during the test was kept to a minimum. The information presented to them is shown in Appendix C. Therefor, the interviews were carried out after the participants had played in all rooms. However, this proceeding might make it more difficult for the participants to remember certain room aspects. Because of this the participants were asked to answer a short questionnaire after having played in each room easing remembering the rooms at the end of the test. This is in accordance with the procedure in similar studies (Bolzinger et al., 1994; Berntson and Andersson, 2007; Kawai et al., 2013; Kalkandjiev and Weinzierl, 2013) facing the same issue. However, in contrast to the mentioned studies the results of the questionnaires were not directly evaluated but rather discussed in the interviews together with the test persons. The questionnaire is shown in Appendix C.

The interviews were of a semi-structured nature, containing both open- and closed-ended questions. This format was chosen to be more flexible and to not overlook certain important matters of the topic (P. Gill, 2008). The framework and a set of example questions of the interview are shown below.

Table 4.1: Overview of interview questions sorted by topic

Topics	Examples of Questions
Aspects determining quality of a room	Was there something you liked in the test room X? Was there something you disliked in the test room X? In the test room X, you stated that you were not satisfied/satisfied (referring to the answers in the questionnaire). Why was that? In the test room X, you stated that you had to not concentrate/concentrate a lot during the performance (referring to the answers in the questionnaire). Why was that?
Room ranking	Considering only the acoustics of the test rooms, in which room would you prefer to practise? In which room would you least want to practise in? Would you change your ranking if one was considering a concert situation instead of a practice situation?
Awareness of adaption in playing style	Based on your skill level was it an easy or a rather complicated music piece that you performed? Did you experience that you changed your playing style in the different test rooms?

Additional information about the tests

The test was carried out with four classically trained percussionists having a professional background. In order gain more understanding of a possible adaptation process with regard to the acoustic environment two extreme test rooms were chosen: An anechoic chamber and a reverberation chamber. Additionally, a class room was included in the investigations as a "neutral" room. The class room was included to make it easier for the participants to relate the experiences made in the extreme rooms to a more normal "neutral" situation. All rooms are located at the division of applied acoustics at Chalmers (Gothenburg). A detailed description of the rooms as well as the used measurement equipment is given in Appendix A. The snare drum used in the measurements was a Tama Swingstar 14” x 5” with a Remo Ambassador coated drum head.

It was considered important for this investigation to carry out the measurements with percussionists being very accustomed to their instruments. This is based on statements done in (von Békésy, 1968) where it was observed that the adaptation of a professional pianist to the acoustics of a room was not as pronounced when playing a more difficult and less familiar piece of music. According to (von Békésy, 1968) this is due to a shift of the musicians’ focus from the "acoustical problems of the room" towards the performance of the music piece. Despite only considering professional percussionists they could choose a music piece they were very accustomed to. This approach of only considering musicians on a high playing level is in accordance with other studies investigating similar research topics (Ternström, 1989; von Békésy, 1968; Bolzinger et al., 1994; Kawai et al., 2013; Kalkandjiev and Weinzierl, 2013; Garí et al., 2015, 2016).

4.1.4 Data processing - Extracted features

In the following all features that were extracted from the measured accelerometer signal are explicated.

In order to expose a possible change in **playing strength** between different rooms the power of the voltage signal from the accelerometer was determined. Additionally, similar to (Garí et al., 2016), an evaluation of rms-values was carried out in order to be able create a visualization of the playing strength. This was done by applying a rms-envelope operation to the accelerometer signal. The enveloped version of the signal was obtain with MATLAB's built in envelope function using a window length of 50000 samples. The three recordings in each room of every participant were then transferred into a data patch where the lower border of the patch corresponds to the momentarily lowest acceleration signal at a considered time of all three recording, see example in Figure 4.3. The upper border of the patch corresponds to the highest momentarily acceleration values in all signals.

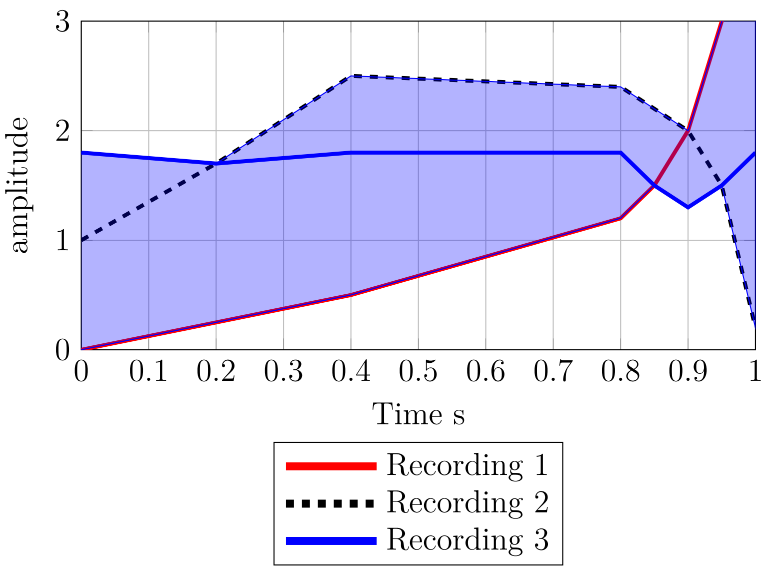


Figure 4.3: Plot illustrating the determination of a the data patches (blue coloured area) used for evaluating the measurements

The influence of the acoustical environment on the **playing tempo** was also investigated. The playing tempo was determined by evaluating the average music piece length of all three recordings in each room. This was possible since the participants were not given a chance to use a metronome during the performance.

The **consistensy in playing style** was studied, both regarding dynamics and tempo. By investigating the differences in music piece length for all three recordings in the same room, information are obtained regarding the consistency in tempo. The consistency in dynamics was investigated by studying the area of the data patches, see Figure 4.3. A larger area corresponds to less consistency in dynamics. The limitation of this method is that the variation in tempo can not be too large between the recordings in a given room, since a large shift in time can create an increment in the area of the data patch. However, this effect can be detected by visually studying the data patches.

4.2 Phase 2 - Investigation of different evaluation methods

4.2.1 Aim and preliminary considerations

In the second phase investigation three different methods of judging the quality of a room were applied to a number of drum rooms. The aim was to gain more understanding of the different evaluation methods with regard to their advantages and shortcomings as well as evaluating the suitability of each method concerning their application in future studies.

The first evaluation method considered in the second phase was an "objective evaluation" method based on measurable acoustic parameters and requirements specified in the German standard DIN 18041 and the Norwegian standard NS 8178. The second evaluation method could be seen as a "direct subjective evaluation" method where drummers were asked to judge the quality of different drum rooms after having played in them. The third method considered could be labeled as an "indirect subjective evaluation" method where drummers were asked to judge the quality of different drum rooms in a listening test. The three different methods are described in detail in Section 4.2.3 and Section 4.2.4.

Each method was applied to a number of drum rooms in order to expose possible agreements and disagreements between the methods. When comparing the methods it is important to note that the results are given in two different forms. In the objective evaluation method the results are given as an agreement or disagreement with the standard, while the results from the direct and indirect subjective evaluation methods are given as a room ranking. It is important to point out that, based on the findings from the first phase investigation and the results of studies like (Olsson and Söderström, 2010) and (Ueno and Tachibana, 2005), in the playing and listening tests it is expected that the room ranking would strongly depend on the considered drummer. Due to this expectation the tests were not set up to come up with an absolute ranking of the acoustic quality of the tested rooms. This study only examined the relative difference between the three investigated methods.

4.2.2 Assumptions and limitations

When investigating the advantages and disadvantages of the considered methods it is important to be aware of their limitations and the assumptions they make.

The acoustical parameters T, EDT and G defined in ISO 3382-1 all rely to some extend on a diffuse field. In small rooms the assumption that the sound field is diffuse might be problematic, especially for low frequencies. As a rule of thumb the sound field may be approximated as diffuse above the Schroeder frequency f_s given by

$$f_s = 2000\sqrt{\frac{T}{V}} \tag{4.1}$$

where T is the reverberation time and V is the volume of the room. Below the Schroeder frequency the modal density might not be high enough to assume the statistical conditions of a diffuse sound field (Kuttruff, 2009).

In the playing test it is assumed that the participants' judgment of the rooms is solely based on the acoustics of the room and not on other aspects as ventilation, lighting, temperature etc. The participants' judgments might also differ depending on their interpretation of the task. The participants were instructed to judge the acoustic quality of the rooms in terms of a practice situation. However, how they decided to evaluate the rooms and what they based their judgments on was up to the participants.

In the listening test the auralizations of the rooms were based on binaural recordings at a single position. This means that only the sound field at the considered positions of the measurement torso's microphones were captured. Those sound fields may or may not have been adequate representations of the sound fields in the entire rooms. Moreover, the measurement torso was not positioned at the same position in the rooms as the participants when they carried out the playing tests. However, it was assumed that the binaural recordings would provide sufficient spatial and timbral information for the participants' judgments. Lastly, in the listening tests, an eventual influence of the headphones on the participants' judgments was not further investigated.

4.2.3 Objective evaluation method

Room acoustical parameters were used as a starting point in the second phase. By determining certain room acoustical parameters comprehensible descriptions of the investigated rooms were obtained. Based on the DIN 18041 and the NS 8178 the considered parameters were reverberation time T and strength G. Furthermore, the EDT was also determined since it has been shown that the EDT is important when studying the perceived reverberance of a room (Swedish Standards Institute, 2009). See Chapter 3 for definitions of the mentioned parameters.

The parameters T and EDT were determined through the integrated impulse response method stated in ISO 3382-1. In this method the decay curves are obtained by backwards integrating each octave band of the squared impulse response. In this study the impulse responses were obtained from inverse transformations of the frequency response functions of the rooms. To obtain the frequency response functions an omni-directional source emitting pink noise was used. A pink noise signal was chosen to improve the signal-to-noise ratio for the lower frequency bands. The spatially averaging was done by considering two loudspeaker positions and four to eight microphone positions per loudspeaker position. The single number values shown in Table 5.7 are average values of the octave bands with center frequency 500 Hz and 1000 Hz of the spatial averaged T and EDT curves. These single number values for T and the volumes of the rooms were used when evaluating the rooms with the standards DIN 18041 and NS 8178.

To determine the parameter G the sound pressure level from the source was measured in the anechoic chamber at the division of applied acoustics at Chalmers. A distance of 8 m was achievable between source and receiver. The sound pressure level at 10 m was estimated by correcting for the distance with a factor of $20 \log \frac{8}{10}$. This is a slight simplification of ISO 3382-1, where it is suggested to measure the source with a spatial resolution of 12.5° to average the directivity of the source, when a distance of 10 m between source and receiver is not attainable. However, since the achievable distance was fairly close to 10 m this simplification is not believed to introduce any larger errors. The measured sound pressure levels in the anechoic chamber and in the investigated drum rooms were obtained from the auto-spectrums of the microphone signals. The single number values of G stated in Table 5.7 are average values of the octave bands with center frequency 500 Hz and 1000 Hz of the spatial averaged G curves.

4.2.4 Direct and indirect subjective evaluation method

Similar to the measurement concept of the first phase investigation, see Section 4.1.3, data was obtain in playing tests as well as in interviews after the playing tests. Additionally, a listening test was implemented. In the following the measurement concept is presented and explained in detail. To ease the understanding an illustration of the test structure is shown in Figure 4.4.

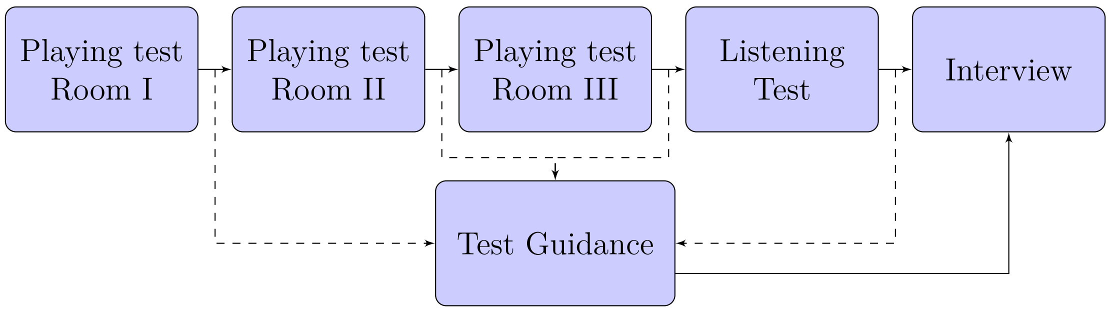


Figure 4.4: Illustration of test structure in the second phase investigation

Playing test

The participants that took part in the second phase investigation were asked to play drums in three different drum rooms using the same drum set in all of the rooms. After having played in the rooms the participants were asked to rank the rooms in order of preferred acoustic environment for a practice situation. The most preferred room should be ranked as number one and the least preferred as number three. The playing test procedure was similar to the procedure presented in the first phase of this report. However, in contrast to the playing tests of first phase the drummers could now freely experience the rooms without being bound to a pre-selected piece of music. Furthermore, no recordings were made during the playing tests. Moreover, instead of a questionnaire a test guidance was used to ease memorizing certain aspects of the rooms when ranking them and also helping the participants to remember the rooms in the interview. The test guidance consisted of a test description and blank spaces for taking notes for each room. The test guidance is presented in Appendix D.

Listening Test

In order to obtain the indirect subjective evaluations listening tests were carried out after the participants had finished the playing tests (see Figure 4.4). As in the playing test the participants were presented a number of rooms and given the task to rank them according to their acoustic quality when considering a practice situation. In contrast to the playing test the participant's perspective was now shifted from a musician's to listener's perspective (see Figure 6.1) since the judgment was only based on the acoustic features presented in the sound files. The aim of this proceeding was to find out if the room evaluation process of a drummer is based on the experienced feedback received during playing or just on features of the perceived sound. In other words, is the listener perspective sufficient enough to come to the same room ranking as in the playing test? To assure that the participants purely based their evaluation of the rooms on the presented sound files and not on the memory from the playing tests, the participants were not told that they were judging the same rooms with different methods. To further mask the fact that the participants were judging the same rooms in both tests additional sound files of recordings in other rooms were added to the listening tests.

The listening test consisted of binaural recordings of two drum grooves, one jazz oriented (see Figure 4.5) and one rock oriented (see Figure 4.6). The drum grooves were performed by one of the authors. Different drum grooves were chosen to investigate if the chosen style of music would influence the room ranking. The same drum sets were used in the recordings and in the playing tests. The drum sets were also positioned at the same places in the test rooms during the recordings and playing tests. The binaural recordings were made with a G.R.A.S. 45BB KEMAR Head and Torso positioned in front of the drum sets at a distance of 1.3 m between the microphones and the front head of the base drum. Headphones were used to play back the sound files in the listening test.

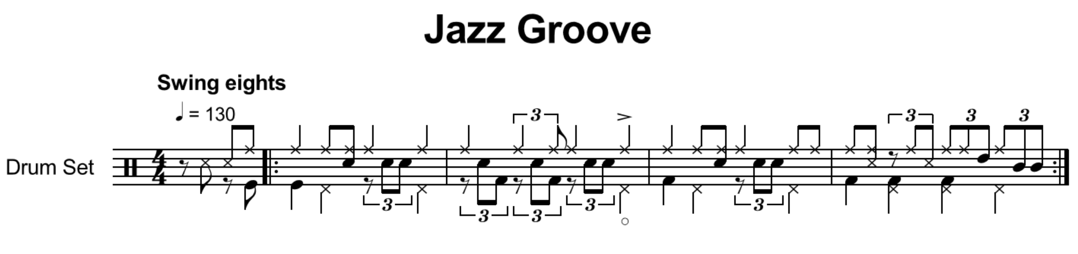


Figure 4.5: The jazz groove implemented in the listening tests

Figure 4.6: The rock groove implemented in the listening tests

During the listening tests the participants had the task to rank four sets of three different recordings with regard to a practice situation (A, B, C, in Figure 4.7). In each test set the rooms (at the same school, see Section 4.2.4) were presented either with a rock groove or a jazz groove[1], see also Appendix G. The participants were able to change freely between the recordings in each set and were also able to stop the playback at any time. The first two sets consisted of the rooms that the participants had experienced in the playing tests and the two last sets consisted of recordings from the rooms at the other test location, see Appendix E. The graphical user interface (GUI) controlling the playback can bee seen in Figure 4.7.

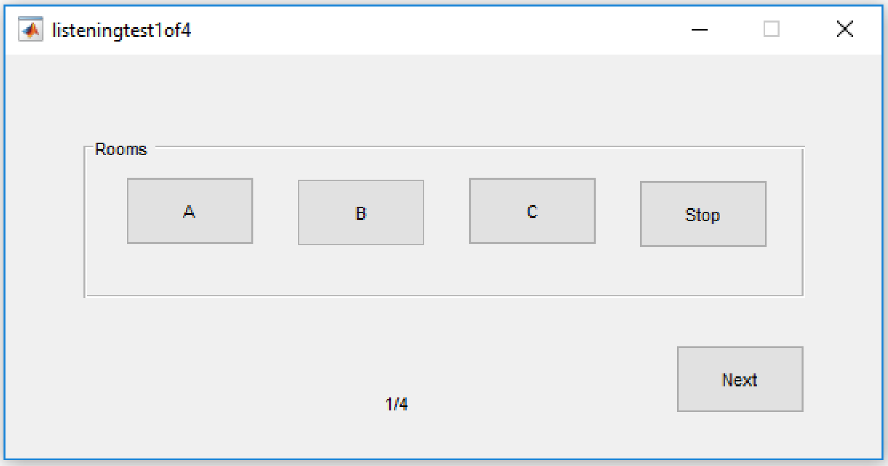


Figure 4.7: Picture of the GUI used in the listening test

Interview

Since the aim of the second phase was to gain more understanding about different evaluation methods it was not only the actual results of the different methods that were of interest, the participants' experiences of the test itself was also of interest. Therefore the tests were completed with an interview partly focusing on the participants thoughts about the test setup itself. Similar to the phase one investigation the

[1]Room B36 was only presented with the jazz groove due to issues with the recordings.

interviews were of a semi-structured nature, containing both open- and closed-ended questions. The framework and a set of example questions of the interview are shown in Table 4.2.

Table 4.2: Overview of interview questions sorted by topic

Topics	Examples of Questions
Test setup	How did you experience the evaluation process in the playing test? Was it difficult?
	Compared to the playing test was the evaluation of the rooms during the listening tests different?
	Based on what did you evaluate the rooms?
	Would you say that you got a good room impression by listening to the test rooms in the listening test?
Room ranking	Was there something that you liked a lot in room X?
	Was there something that you disliked a lot in room X?
	What was it that made you rank room X as best in the playing test? (referring to test guidance)
	What was it that made you rank room Y as the worst in the playing test? (referring to test guidance)
General practice room considerations	Based on your experiences of practice rooms what would you say are common issues with them?

Additional information about the tests

The measurements and tests in the second phase investigation were carried out at two different music schools, The Academy of Music and Drama (Högskolan för scen och musik - HSM) in Gothenburg and Skurups folkhögskola. At HSM two drummers participated in the study and at Skurups folkhögskola four drummers participated in the study. Two different drum sets were used in the tests, one set for each of the two schools. The drum sets were both four piece jazz sets with maple shells made by the drum manufacturer Gretsch. A detailed list of the equipment used in phase 2 can be found in Appendix B.

5

Results

5.1 Phase 1 - Room influence on playing style

5.1.1 Measurements

In Table 5.1 it is evaluated how the **playing strength** changed for each test participant when playing in the anechoic chamber and the reverberation chamber, respectively. The shown values represent the average power of the measured accelerometer signals. As shown, for three of four participants the average power in the signals were larger when playing in the anechoic chamber than in the reverberation chamber. Table 5.2 shows the average music piece length in each room for each participant. The table shows that the percussionists played their chosen piece of music at a slower tempo in the reverberation chamber. Table 5.3 exposes the **consistency in tempo** of each participant when playing in each of the rooms. The table contains the maximal time difference in music piece length between all three recordings in the anechoic chamber and the reverberation chamber, respectively. In Table 5.4 the **consistency in dynamics** in each room for each of the four participant is evaluated. This is done by determining the area of the data patches in Figure 5.1, Figure 5.2. In order to ease understanding the areas are related to each other and expressed in percentage. Figure 5.1 and Figure 5.2 shows the obtained **data patches** determined according to the procedure described in Section 4.1.4 for each participant.

Table 5.1: Playing strength - Evaluation of the average power of the accelerometer signals (given in millivolts squared per number of samples n)

Participant:	A	B	C	D
anechoic chamber	1.97 $\frac{\mathrm{mV}^2}{\mathrm{n}}$	1.39 $\frac{\mathrm{mV}^2}{\mathrm{n}}$	1.27 $\frac{\mathrm{mV}^2}{\mathrm{n}}$	2.39 $\frac{\mathrm{mV}^2}{\mathrm{n}}$
reverberation chamber	1.03 $\frac{\mathrm{mV}^2}{\mathrm{n}}$	1.26 $\frac{\mathrm{mV}^2}{\mathrm{n}}$	0.75 $\frac{\mathrm{mV}^2}{\mathrm{n}}$	2.43 $\frac{\mathrm{mV}^2}{\mathrm{n}}$

Table 5.2: Playing tempo - Evaluation of average music piece length per a room

Participant:	A	B	C	D
anechoic chamber	83.7 s	93.5 s	51.8 s	61.5 s
reverberation chamber	83.9 s	95.1 s	52.3 s	65.9 s

Table 5.3: Consistency in tempo - Evaluation of variations in music piece length within each room

Participant:	A	B	C	D
anechoic chamber	0.5 s	0.1 s	0.7 s	1.7 s
reverberation chamber	1.4 s	3.2 s	1.0 s	3.1 s

Table 5.4: Consistency in dynamics - Area evaluation of data patches

Participant:	A	B	C	D
anechoic chamber	100 %	100 %	100 %	100 %
reverberation chamber	185 %	516 %	146 %	99 %

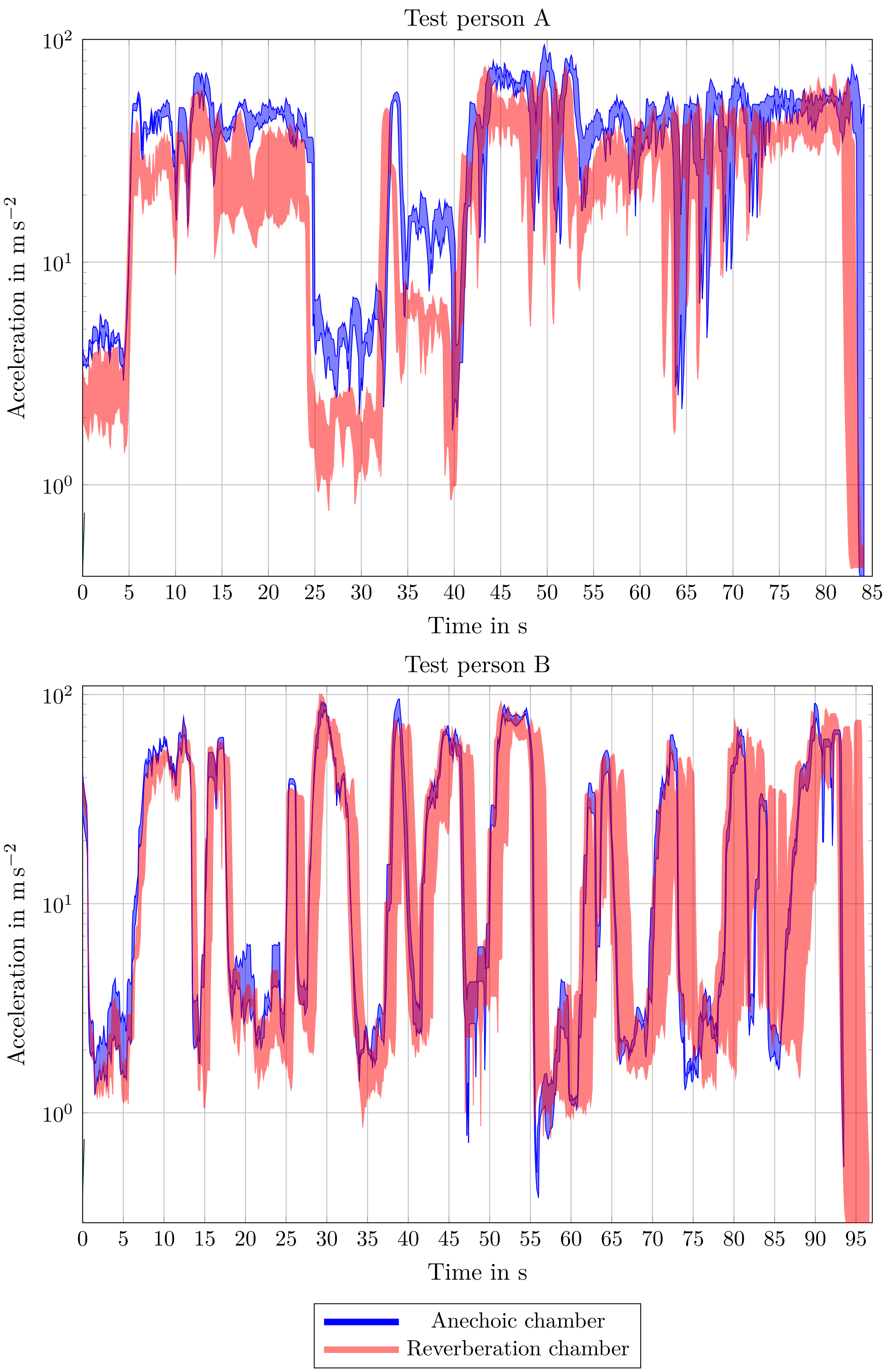


Figure 5.1: Accelerometer signals of the performances of test person A and B

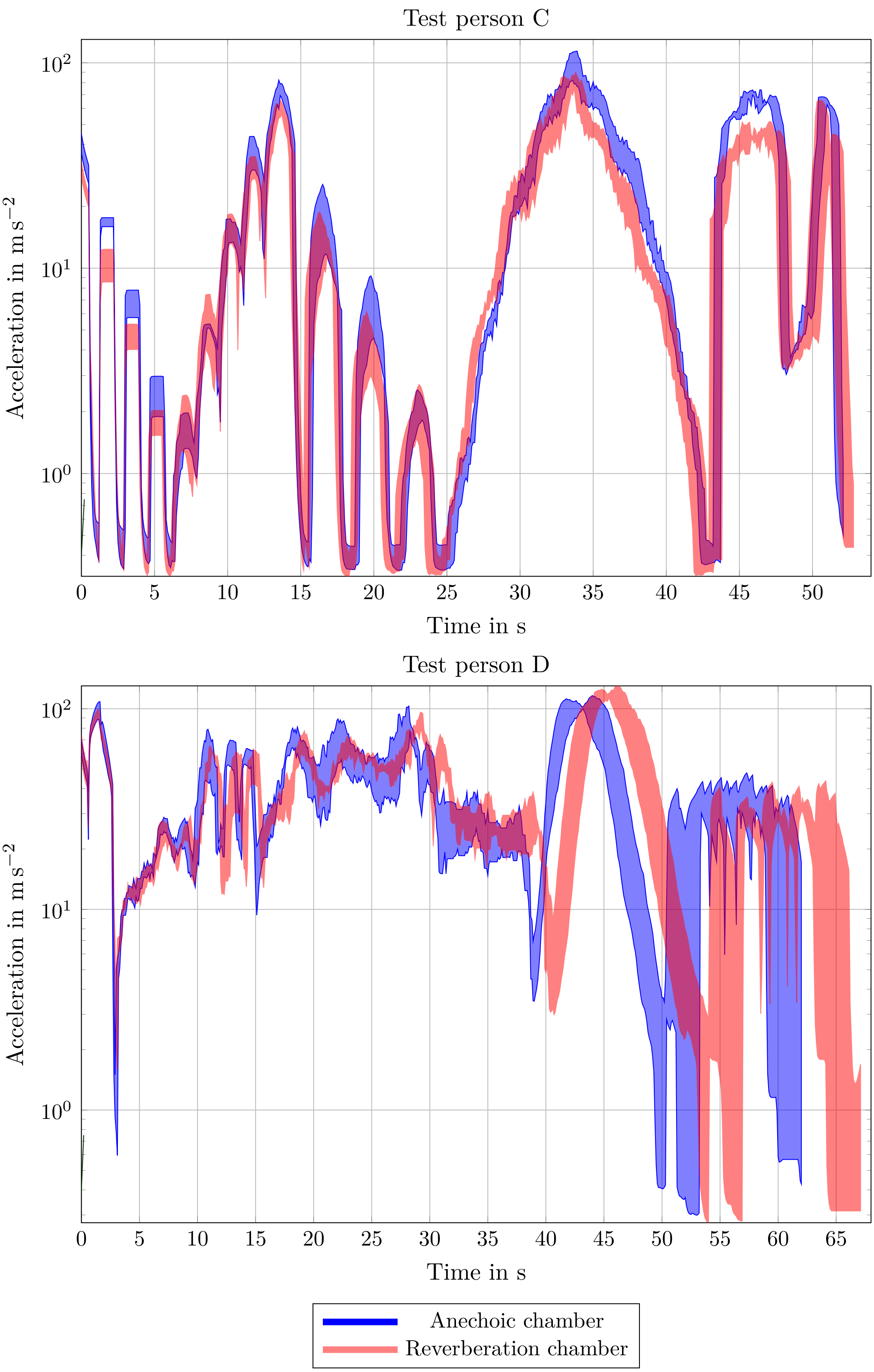


Figure 5.2: Accelerometer signals of the performances of test person C and D

5.1.2 Interview and Questionnaire

The results of the interviews were categorized and are presented by a selection of comments made by the participants during the interviews. The comments have been translated from Swedish to English. Furthermore, the obtained room rankings are presented in the category (c) Dependency of a room evaluation to a music scenario in Table 5.5 and Table 5.6.

(a) Importance of a clear and accurate acoustical feedback in a practice situation

- *It was nice to play in the anechoic chamber, not because it sounded best but because I could hear the instrument better.*
- *[In the anechoic chamber] the sound was crystal-clear [..] I was forced to focus a lot because I could hear everything, the smallest mistake I did, but it is those rooms one wants to have because one wants to hear [what one does]. One analyses the entire time so it is very good to hear exactly [what one is playing].*
- *One notices that it is most sensitive to play in the anechoic chamber, one hears everything in there. I would definitely choose this room as a practice room*
- *But it is a bit difficult to practise with hearing protection, since one also reacts to what one gets back [from the room]*
- *In a way it is nice to play in the room [reverberation chamber] but difficult to listen in. It is difficult to play what one wants to play.*
- *It [the reverberation chamber] had been a really bad practice room because one would not hear what one does. One could play rather bad but still it [the room] would be pretty "forgiving".*
- *It was difficult to go directly from loud to soft [in the reverberation chamber], I did not even hear the first [soft] beats. [..] You did not hear any differences [in the playing], it did not make any sense to play there.*

(b) Awareness of potential change in playing style

Two of the participants stated that they tried to not change their playing style throughout the entire test:

- *I tried to play the same in all rooms. I did not want that the acoustics influenced me.*
- *Actually, one should adjust ones playing style to the room but I tried to play the same in all rooms. [..] If you had asked me to play the music piece so that it matches the acoustics [of the room] then I would have changed my playing style to some extend.*

Concerning the **dynamics** of the music pieces one participant was certain and two were unsure and one was unaware of an adaptive process with regard to the room.

- *One had to keep down the dynamics in the last room [reverberation room].*
- *I think I changed [my playing style] mostly with regard to the dynamics but not the playing speed.*

All of the participants were either unsure or unaware of a possible change in **playing speed**.

- *Maybe I played a bit slower [in the reverberation room].*
- *Maybe I also took down the tempo a bit in the last room [reverberation room].*
- *I think I changed [my playing style] mostly with regard to the dynamics but not the playing speed.*
- *I think I managed to keep the same playing speed in all the rooms but I am not entirely sure.*

(c) Dependency of a room evaluation to a music scenario

- *I would prefer to have the anechoic chamber as a practice room*
- *The room [reverberation chamber] has a certain quality. It is possible to realize interesting music pieces there.*
- *[The anechoic chamber] would not have been a good concert room but good for exercise and self-analysis*
- *I liked that [the reverberation chamber] has a "forgiving" acoustic making me more relaxed. Maybe I even played some parts better due to this. It becomes another sound [in the reverberation chamber] which can be applicable in certain contexts.*

Table 5.5: Overview of the room rankings by the test persons (TP) considering a practice situation

Ranking	TP 1	TP 2	TP 3	TP 4
Place 1	Anechoic	Anechoic	Anechoic	Classroom/Anechoic[a]
Place 2	Classroom	Classroom	Classroom	Rev.-room
Place 3	Rev.-room	Rev.-room	Rev.-room	-

[a]The participant expressed that a room between the classroom and the anechoic chamber would have been most appropriate for a practice situation.

Table 5.6: Overview of the room rankings by the test persons (TP) considering a performance situation

Ranking	TP 1	TP 2	TP 3	TP 4
Place 1	Rev.-room	Classroom	-[a]	Classroom/Rev.-room[b]
Place 2	Anechoic	Anechoic/Rev.-room[c]	-	Anechoic
Place 3	Classroom	-	-	

[a]The participant was very unsure about how to rank the considered rooms with regard to a performance situation. This was because according to the test person a ranking is strongly depended on the considered music piece.

[b]The participant expressed that a room "between" the classroom and the rev.-room would have been most appropriate for a performance situation.

[c]The participant could not decide on which room was more suitable with regard to performance situation.

(d) Memory-Effect of practice situations

- *I would preferably like to have the anechoic chamber as practice room for snare drum just not every day. But some days of a week.*
- *One time [..] I practised in the basement of my mother with a lot of [room] dampening and when I came into this really good concert hall everything [the sound] just exploded into my face.*

5.2 Phase 2 - Investigation of different evaluation methods

5.2.1 Objective evaluation method

One of the considered evaluation methods in this phase of the investigation was based on acoustic parameters determined in measurements. The determined parameters, together with more information about the test rooms, are presented in Table 5.7. The obtained results are judged according to the requirements of the German standard DIN 18041 and the Norwegian standard NS 8178. Table 5.8 gives an overview of which rooms match or mismatch the specified requirements. Furthermore, interview statements linked to the results in Table 5.8 are also presented below.

Table 5.7: Overview of investigated rooms

Room	Volume	G	EDT	T_{m}	Dimensions in m	Location
B32	31 m^3	23 dB	0.19 s	0.24 s	4.2 x 3.2 x 2.3	Skurup
B36	69 m^3	17 dB	0.24 s	0.25 s	4.9 x 5.9 x 2.4	Skurup
B17	95 m^3	20 dB	0.26 s	0.36 s	4.9 x 6,1 x 3.2	Skurup
C212	31 m^3	25 dB	0.28 s	0.35 s	2.3 x 4.6 x 2.9	Gothenburg
C204	65 m^3	19 dB	0.21 s	0.28 s	4,1 x 6.1 x 2.6	Gothenburg
A501	$\approx$ 432 m^3	14 dB	0.42 s	0.49 s	8.2 x 10.7 x 5.1	Gothenburg

Table 5.8: Evaluation of the considered rooms with regard to a match (✓) or mismatch (✗) of requirements defined in different international standards

	B32	B36	B17	C212	C204	A501
DIN 18041	✓	✓	✓	✗	✓	✓
SN 8178	✗[a]	✗	✗	✗[a]	✗	✗

[a]The SN 8178 states a required minimum volume of 40 m^3 for practice rooms intended for powerful music.

(a) Thoughts on C212

- *C212 is too loud and too small.*

- *In C212 the balance between the frequencies was just wrong. I really had to pay attention to the base drum because it was all over the place [..] and when I played with higher volume then the high frequencies started to be pretty harsh.*

5.2.2 Direct subjective evaluation method

The participants taking part in the tests were asked to rank the test rooms after having played in all of them. The obtained room rankings for each location and each participant are presented in Table 5.9. Furthermore, a selection of statements made during the interviews related to the direct subjective evaluation method were categorized and are listed below. The comments have been translated from Swedish to English.

Table 5.9: Overview of the room rankings by the test persons (TP) at the test location in Gothenburg (TP 1 and TP2) and in Skurup (TP 3 - TP 6)

Room ranking	TP 1	TP 2	TP 3	TP 4	TP 5	TP 6
Place 1	C204	C204	B36	B32	B32	B17
Place 2	A501	A501	B17	B17	B17	B36
Place 3	C212	C212	B32	B36	B36	B32

(a) Importance of a clear and accurate acoustical feedback in a practice situation

- *It is maybe not so much about how good the drum sounds but it is more about the clarity of the sound and the balance between different drums.*
- *I would prefer dryer sounds when practicing, then it is easier to hear the attack and the space between notes.*
- *Even though the drum sounds best here [A501] it is a little difficult to practice here. The sound disappears a bit and you don't get much feedback.*
- *In a practice situation it is very important to have control and be able to work on details. C204 was the room that provided the clearest sound.*
- *When you practice you want to improve your sound as easy as possible and then you want to practice in a room where you hear the drums as clearly as possible. In general I prefer a smaller room where the drum sounds close. Then you hear exactly what you are doing.*
- *C212 is too loud and too small, soundwise it gets to messy. In my opinion it is a too small room for drums, it gets loud and unclear.*

5.2.3 Indirect subjective evaluation method

The participants were presented the same rooms in the direct as in the indirect evaluation method. Hence, the quality of the latter can be determined by comparing if the participants ranked the rooms analog in both evaluation methods. In Figure 5.3 (left) it is shown how many listening test sets were ranked accordingly to the rankings obtained in the direct subjective evaluation method. In Figure 5.3 (right) it is shown how many rooms were given the same ranking with both methods.

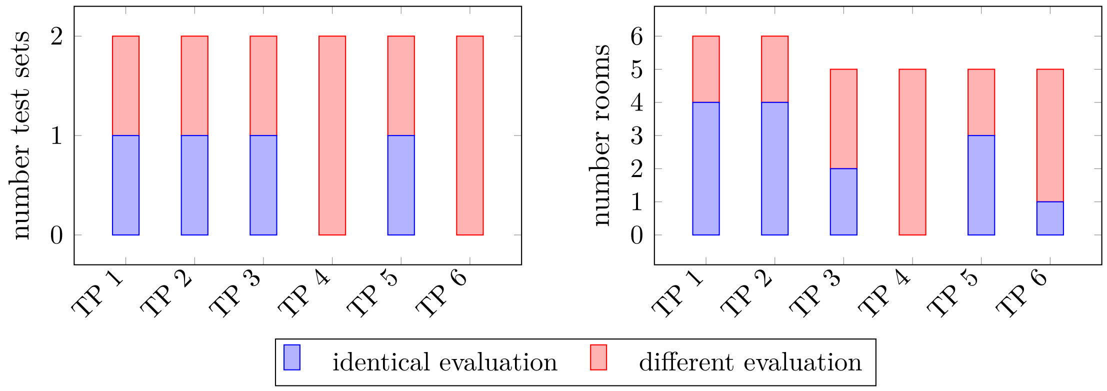


Figure 5.3: Comparison of direct and indirect subjective evaluation results. Right: number of test sets ranked identical to the direct subjective evaluation, left: number of test rooms ranked identical to the direct subjective evaluation

As before important statements done during the interviews were categorized and are presented as well. The comments have been translated from Swedish to English.

(a) Appropriateness of the listening test

- *I think that the [evaluation in the] real life test was pretty easy. The listening test was more difficult because you don't have the same physical experience.*
- *It was more difficult to just listen instead of being in the room.*
- *I did not notice a large difference between the rooms [in the listening test].*
- *In the listening test it was easy to hear the difference since you directly could change between the rooms. It was more difficult when you played in the rooms. You might adapt your playing and it is not certain that you play the same.*
- *It was difficult to come up with a ranking when there were three rooms, it was easier when it was only two. One room often stood out while the two other were fairly similar.*

(b) Quality of the binaural recordings

- *The first sound examples were easier to judge [the rooms at HSM].*
- *A [C204] sounded clearest. In C [C212] you heard that it was a small room.*
- *Many of the sound examples where very similar, especially the first ones [the rooms in Skurup]*
- *In the sound example B [C212] there was a lot of sound, it would probably be tiring to practice there.*
- *Quite a few of the sound files were pretty similar, but you still got some spatial perception from the sound files. The first sound files [Skurup] were especially difficult to tell apart.*
- *You got some spatial impression of the rooms in the listening test.*
- *I think I would have had the same order of the rooms [in the listening and the playing test] because you still get a certain kind of feeling for the rooms [when listening to them]. In a way you can still imagine how it would physically feel like.*

6
Discussion

6.1 Phase 1 - Room influence on playing style

Influence of the acoustic environment on a percussionist

The results of the first phase show that the participants adjusted their playing style with regard to the acoustic environment they were playing in. However, there is no high awareness among the musicians concerning this, see Section 5.1.2(b). The adjustments made can be observed in different aspects of the musicians' playing style. As before in other studies (von Békésy, 1968; Ternström, 1989; Bolzinger et al., 1994; Kawai et al., 2013; Garí et al., 2016) focusing on other instruments it could be observed that also in the first phase investigation every participant except participant D chose to perform their chosen piece of music less powerful in the reverberation chamber than in the anechoic chamber. This can be seen in Table 5.1, Figure 5.1 and Figure 5.2. Based on this observation one could conclude that the percussionists have a certain imagination of how loud a, for example, forte should be and hit the drum accordingly hard or soft, depending on the acoustic environment they are playing in. However, the ability to adjust the dynamics to the feedback from the room seems to be impaired when using hearing protection. This is suggested by the accelerometer signal of the performances of test person B and D who did wear hearing protection throughout the test, see Figure 5.1 and Figure 5.2.

The results also suggest that the choice of playing tempo is influenced by the acoustic environment of a room. This finding is in accordance with other studies (Kalkandjiev and Weinzierl, 2013; Garí et al., 2015, 2016). In Table 5.2 it can be seen that all participants chose a slower playing tempo in the reverberation chamber than in the anechoic chamber. A possible explanation for this can be based on the effect of the reverberation time on the duration of each played note. Since all notes played in the reverberation chamber will linger much longer in the room than in the anechoic chamber they might interfere with each other. In order to prevent this the musicians might have chosen a slower playing tempo. This argumentation is supported by what was mentioned in the interviews, where one of the participants stated that *It was difficult to go directly from loud to soft [in the reverberation chamber], I did not even hear the first [soft] beats*.

Based on (Ueno and Tachibana, 2005) it seems probable that the observed adaptive playing behaviour is a skill musicians have to acquire. According to the mentioned study investigating orchestra musicians' perception of concert halls this skill is developed by musicians when gradually realizing how reaction and action relate to each other when playing an instrument in any acoustic environment. In (Ueno and Tachibana, 2005) this process is introduced as the process of "tacit knowing" where so called particulars are integrated to a comprehensive entity. Based on this theory the study concludes that all the characteristics of a concert hall (particulars) have to be sensed in order to generate a desired musical image during a performance (comprehensive entity). The process of playing an instrument in a concert hall when considering the statements above is illustrated in Figure 6.1. Furthermore, the described process is related to the experiences of a pure listener in Figure 6.1. It seems probable that the considerations in (Ueno and Tachibana, 2005) regarding orchestra musicians in concert halls also account for percussionists in practice rooms.

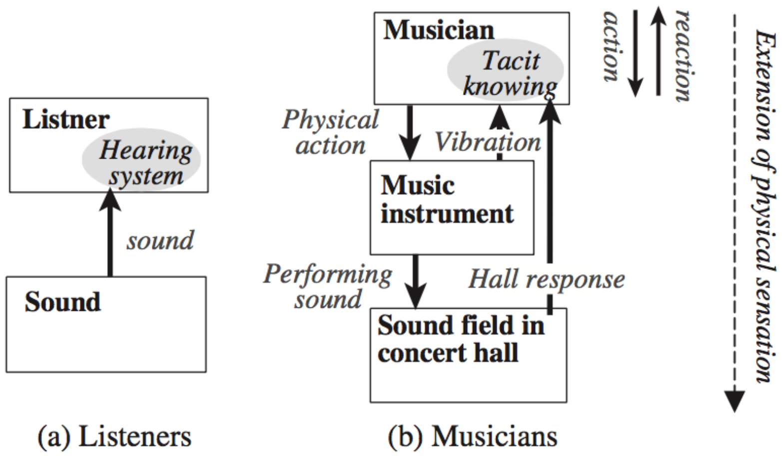


Figure 6.1: Illustration of the music making process for orchestra musicians compared to a listener situation (Ueno and Tachibana, 2005)

Important aspects for appropriate drum practice rooms

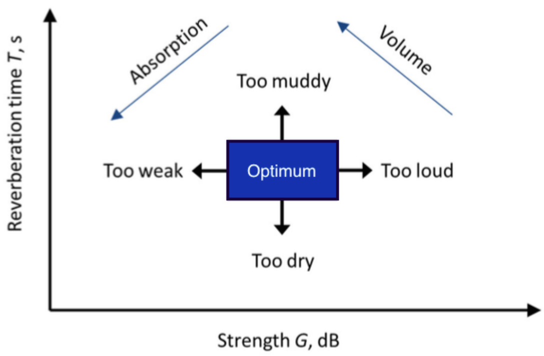
In this phase of the investigation two important aspects for appropriate drum practice rooms are indicated:

- A clear and accurate feedback of the room
- A possibility to practise in different acoustic environments in order to avoid memory effects

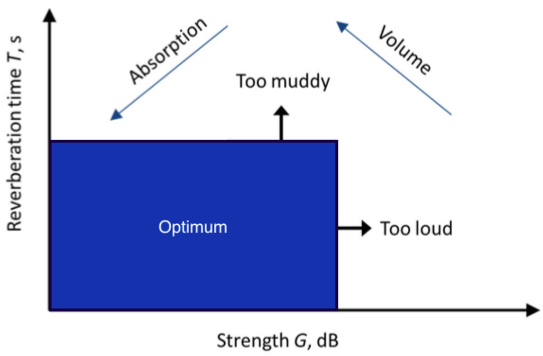
When considering the quality of any performance space like a concert hall the aim is to create an environment that sounds well. Based on this criteria an optimum range can be defined with regard to the reverberation time and the strength G as done in (Rindel, 2014) presented in Figure 6.2(a). The statements made in the interviews, however, clearly indicate that in a practice situation it is of minor importance how well the music sounds. Instead, all of the participants emphasized how important a clear and accurate acoustical room feedback is, see Section 5.1.2 (a). This is also indicated in the measurement data, obtained with the accelerometer, where it can be seen that the very reverberating environment in the reverberation chamber had a negative influence on the consistency in the musicians' playing styles. This accounts for all participants when considering the playing tempo (see Table 5.3) and for three of four participants when considering the consistency in dynamics (see Table 5.4). It seems reasonable that in an environment in which the musicians can not accurately hear what they are playing the variations between different performances increase. Hence, the reverberation time of a drum practice room should be as short as possible.

However, there is reason to believe that only practising in extremely dry environments can lead to issues when performing in non-extreme environments. This is somewhat indicate by the statements of two participants during the interviews Section 5.1.2(d). The statements suggest that musicians memorize the response of a practice room when having played there for a longer time. When exchanging the practice environment for a performance environment the playing strength is then still based on the response of the practice environment. This suggest that it might be of interest to also design some practice rooms with longer reverberation time in order to make it possible for the musicians to learn to adapt to different environments and avoid a memory effect.

It is, furthermore, interesting to point out that the requirements stated above for practice rooms expose a different focus than for performance spaces. Regarding a performance situation it seems reasonable to focus on a well-sounding environment where the requirements can be illustrated in accordance with (Rindel, 2014), see Figure 6.2(a). In a practice situation where a clear and accurate feedback could be more important the illustration can be aligned to the findings of this investigation, see Figure 6.2(b). On one hand the lower border concerning the reverberation time of the optimum range might be removed. This is because the lower the reverberation time of a given room is the clearer the room feedback will be. On the other hand, none of the participants complained about a too weak sound in the anechoic chamber. Since there is no room which gives less gain than an anechoic chamber also the lower border concerning the parameter strength might be removed. The considerations in Figure 6.2(b) together with the assumption that a clear separation between a practice and a performance space regarding requirements has to be done are also supported by the observation that the participants only favoured the anechoic chamber when considering a practice situation. When the participants instead were asked to consider a performance situation other rooms were judged as best, see Section 5.1.2(c) and Table 5.5 and Table 5.6.



(a) Performance environment



(b) Practice environment

Figure 6.2: Optimum range described by reverberation time and strength for performance environment (a)(Rindel, 2014) and a practice environment (b)

6.2 Phase 2 - Investigation of different evaluation methods

6.2.1 Room acoustical parameters

The measurement results of T_m and G stated in Table 5.7 seem reasonable since they coincide well with the values specified in Figure A.1 in NS 8178 similar to Figure 3.1. When determining G with the help of the Figure A.1 from NS 8178 based on the test room volumes and the measured values of T_m the obtained values for G correlate well with the measured values of G. There are only small deviations of about ± 1 dB between the calculated and the measured values for G for all of the test rooms, in other words about ± 1 JND (just noticeable difference) for G (Swedish Standards Institute, 2009). Furthermore, the measured single number values for the EDT stated in Table 5.7 do not deviate much from the determined T_m. Due to this the EDT will not be further discussed.

Even though all measured parameters seem adequate the general appropriateness of implementing statistical room acoustic parameters in small rooms can be questioned. As stated in Section 4.2.2 it can be problematic to assume a diffuse field in small rooms, especially for low frequencies. All of the measured rooms except for the room A501 (which is a fairly large room) have a Schroeder frequency (Equation (4.1)) above the lower considered octave bands. Hence, in most of the considered practice rooms a diffuse field at low frequencies is not guaranteed. This observation exposes a shortcoming when using acoustic parameters requiring a diffuse sound field to describe the quality of small practice rooms. It is therefore interesting to point out that the DIN 18041 and NS 8178 specify recommendations for the reverberation time in lower frequency bands.

6.2.2 Comparison of objective and direct subjective evaluation

It has been stated earlier in this report that the approaches and requirements specified in the DIN 18041 differ from the ones stated in the NS 8178. How big the differences between both standards are become apparent when considering that only one of the six investigated rooms are judged the same by both standards, see Table 5.8. However, the results obtained during the direct subjective evaluation correspond more with the judgments according to the German standard. This is because on one hand the subjective evaluation exposed that most of the rooms are appropriate regarding a practice situation which is in accordance to the German standard and in contrast to the results of the Norwegian standard. On the other hand the two participants that judged C212 agreed on that they strongly disliked this room when considering a practice situation, see Section 5.2.1 and Table 5.9. This is in accordance with the German standard that judges this room as being unsuitable, see Table 5.8. Moreover, the NS 8178 specifies a recommended minimum volume of $40\,m^3$ for practice rooms intended for powerful unamplified music with 1-2 performers. It is interesting to point out that the room B32 with a volume of $31\,m^3$ was the most favoured test room by two of four participants judging it.

The results from this phase indicate that the minimum limit for T_m (or G) given in NS 8178 might be to high. It is also possible that as illustrated before in Figure 6.2(b) and in accordance to the German standard a minimum requirement might not be necessary at all for drum practice rooms. Since the investigated rooms had reverberation times below the upper limit defined in the NS 8178 further investigations are needed to evaluate the appropriateness of this requirement for drum practice rooms. From these results it seems that the recommended range of reverberation time in relation to room volume given by NS 8178 might be better suited for a performance situation, see Figure 6.2(a), but might not fit so well to a practice room situation for drums.

6.2.3 Further thoughts on the direct subjective evaluation

As expected, the room rankings in the playing test differ from person to person, especially when the rooms are fairly similar and all well-functioning, as in Skurup, see Table 5.7 and Table 5.9. In HSM, on the other hand, the rooms differ more from each other and here the participants rank the rooms in the same order. This indicates that the playing test can function as a method to find upper or lower limits for appropriate values of certain room acoustic parameters. For instance, if Figure 6.2(b) is to be supplemented with values for the acoustic parameters a playing test could be implemented in order to identify the upper limits. The playing test does not seem to be an equally useful tool when it comes to judging similar rooms, in this case the personal taste of the participating musicians might differ so much that a clear result is not obtainable.

Even though the order of the room ranking obtained in this study differ both depending on method and on the test participant, the interview indicate that the drummers agree on the importance of a clear and accurate acoustical feedback in a practice situation Section 5.2.2(a). It is interesting to point out that both percussionists and drummers seem to appreciate a clear and accurate acoustical feedback in a practice environment.

To sum it up, the direct subjective evaluation of the playing tests seems to provide a method that could be implemented, regardless of instrument, to set up recommendations for practice rooms with regard to different room properties. However, this type of measurement is rather inconvenient since a large number of, preferably, professional musicians and a large number of practice rooms with different properties are needed. This large group of musicians then need to visit this large number of rooms to evaluate them. This set up is possible but a more convenient method is desirable.

6.2.4 Comparison of indirect and direct subjective evaluation

Compared to the direct subjective evaluation the results from the interviews in Section 5.2.3(a) and (b) indicate that judging the acoustic quality of the rooms in the indirect subjective evaluation was more difficult. As seen in Figure 5.3 there were quite large differences in the ranking of the rooms depending on the evaluation method. None of the participants ranked the rooms in the same order with the two different methods. There are several possible reason for this:

1. the recordings did not mirror the real rooms sufficiently enough
2. the chosen drum grooves were inappropriate for investigating the the quality of a drum practice room
3. the listener's perspective is not sufficient enough to evaluate a room's appropriateness for a practice situation

Concerning the first point mentioned above one could argue that since the room ranking is different depending on which method is used the recordings did not mirror the real rooms sufficiently enough. However, this argument rises the question if the insufficient recordings are due to how the drum sets were chosen to be recorded or if reason number 2 and 3 above are more important. Since the participants agreed on that there were spatial information in recordings (see Section 5.2.3(b)) this might indicate that reason number 2 and 3 are more important. Furthermore, the participants were also able to assign correct properties to the rooms from the listening test with statements like: *In C [C212] you heard that it was a small room* or stating that: *A [C204] sounded clearest*, which this participant also stated in the direct evaluation method. This further indicates that the choice of recording technique might not have been the main problem. Moreover, the interview results in Section 5.2.3(b) indicate that the rooms located in Skurup were more difficult to tell apart than the rooms at HSM. This mirrors that the rooms at Skurup were more similar both in terms of volume and acoustic parameters than the rooms at HSM.

Regarding the second point mentioned above there is reason to believe that other music samples would have been more appropriate for investigating the quality of a drum practice room. This conclusion is mainly based on observations done during the playing test. During those tests the drummers not only played certain drum grooves but also investigated the room's feedback on single instruments of the drum set one at a time. Many of the participants also investigated how the rooms responded when playing with different dynamics, going from very soft to very loud playing. The grooves in the listening test (see in Figure 4.5 and Figure 4.6) did neither clearly expose the feedback on single parts of the drum set one at a time nor expose extremes of very loud and very soft playing.

Previously, it has been argued that the feedback of the room plays an important part in a musicians playing style Section 6.1. Therefore it is possible that a shift from a musician's perspective to a listener's perspective is problematic when the same room acoustical aspects are to be investigated. When carrying out the listening test the musicians' perspective was shifted from a musician's view towards a listener's view, see Figure 6.1. From a listener's perspective sound files are just an input to the hearing system and not a feedback as in a musician's perspective. Even though the musicians were able to extract some information from the acoustics of the recorded rooms the musicians did not get the full picture since they did not generate the sounds themselves. The participants were not exactly aware how much force the drummer in the recordings needed to create the played sound. Many of the participants found it more difficult to evaluate the rooms in the listening test than in the playing test, this might be due to the missing feedback. Two of the participants even stated that during the interviews Section 5.2.3(a).

Even though the listening test, as it was carried out in this study, did not lead to the same room ranking as the playing test there seems to be potential in implementing a listening test to investigate the quality of drum rooms. However, instead of just presenting a drum groove the recordings should also include single hits on each of the instruments of the drum set and sound examples presenting larger dynamic variations. However, to fully replace a direct evaluation method with an indirect evaluation method a more interactive listening test might be needed. If the participants had been able to decide for themselves what to listen to they might have been provided with more useful information about the acoustical feedback of the considered drum room. In this way the playing and listening test would have been more similar to each other. The interactive listening test could have been implemented with a digital drum set able to play back anechoic recordings of a drum set convoluted with the impulse response of a considered room. However, this method is fairly complex and leads to a more demanding test setup.

7 Conclusion

In the first phase of this report it was investigated how the acoustic environment influences the playing style of a percussionist. The results suggest that a percussionist adapts in playing tempo and playing strength with regard to the acoustic environment. Furthermore, if the room feedback is unclear and inaccurate due to a long reverberation time the instrumentalist becomes more inconsistent in the chosen tempo and playing strength compared to when playing in a dry acoustic environment. The impact on the percussionist's consistency in playing style is a rather interesting finding since this effect is rarely mentioned in other studies. To fully understand the nature of this topic more research is needed.

Two important room acoustical aspects of appropriate drum practice rooms have been found in this study. Firstly, it is indicated that a clear and accurate acoustical feedback is of great importance. This kind of feedback can be obtained by creating an environment with a reverberation time as short as possible. However, the results indicate that more reverberant practice rooms are of importance, too. This is the second aspect found to be crucial. By offering a mix of practice rooms the musicians might be able to learn how to adjust to different acoustic environments instead of memorizing a single practice environment ("memory effect"). In the considered context it is also important to point out that the results suggest that a clear separation has to be done between the requirements specified for a practice and a performance situation. This statement is based on the finding that the participants chose to rank the same room differently depending on the considered scenario. Based on the statements made by the participants there is reason to assume that for a practice situation a clear and accurate feedback is more important than how well the music sounds in contrary to a performance situation. This seems to be important for the quality evaluation of a practice room.

Based on the findings of this report it can be stated that an objective evaluation method can be applied for determining room acoustical preferences regarding practice rooms. However, there are two main shortcomings: On one hand there is reason to believe that the acoustic parameters relying on a diffuse sound field can not be used in small practice rooms. This is because at lower frequencies a diffuse field might not be guaranteed. On the other hand the information obtained with this method ia very limited since the specified requirements are either fulfilled or not fulfilled. A detailed subjective description of room acoustical preferences can be obtained by using the direct subjective evaluation method. This method, however, comes with considerable effort in terms of test implementation.

A similar approach with less effort is presented with the indirect subjective evaluation method. This method involving listening tests makes it possible to obtain more detailed information about room acoustical preferences of drummers and percussionists including a large number of practice rooms. However, in a listening test the perspective is shifted from a musician's to a listener's perspective. There are indications that the missing feedback from the listener's point of view makes it difficult for the musician to judge the quality of a room. Further research has to be done in order to find out how interactive elements can be integrated into the listening test. With the help of those interactive elements the indirect subjective evaluation method can become a suitable method for determining room acoustical preferences regarding practice rooms for drummers, percussionists and maybe even other instrumentalists.

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A

Phase 1 - Measurement equipment and room documentation

In this section the measurement equipment used in phase 1 is presented. Furthermore, a detailed room documentation of the considered rooms is presented. All rooms are located at the Division of Applied Acoustics Chalmers (Gothenburg).

Table A.1: Measurement equipment used in phase 1

Description	Name	Serial number Inventory number
Calibration Exciter	Brüel&Kjær Type 4294	SN 2862951
DeltaTron Accelerometer	Brüel&Kjær Type 4517	SN 64371
Measurement software	Matlab R2016b	-
CompactDAQ USB chassis	NI cDAQ-9178	SN 14DAD04
Sound and Vibration Input Module	NI 9234	IN AN6

Table A.2: Overview over investigated rooms in phase 1

Room	Volume	G	EDT	T_{m}	Dimensions in m	Location
Anechoic Chamber	800m^3	-	-	-	10.0 x 10.0 x 8.0	Chalmers
Classroom	141m^3	18dB	0 40s	0 49s	5.0 x 7.8 x 3.6	Chalmers
Reverberation Chamber	95m^3	27dB	1 57s	1 87s	5.5 x 4.8 x 3.6	Chalmers

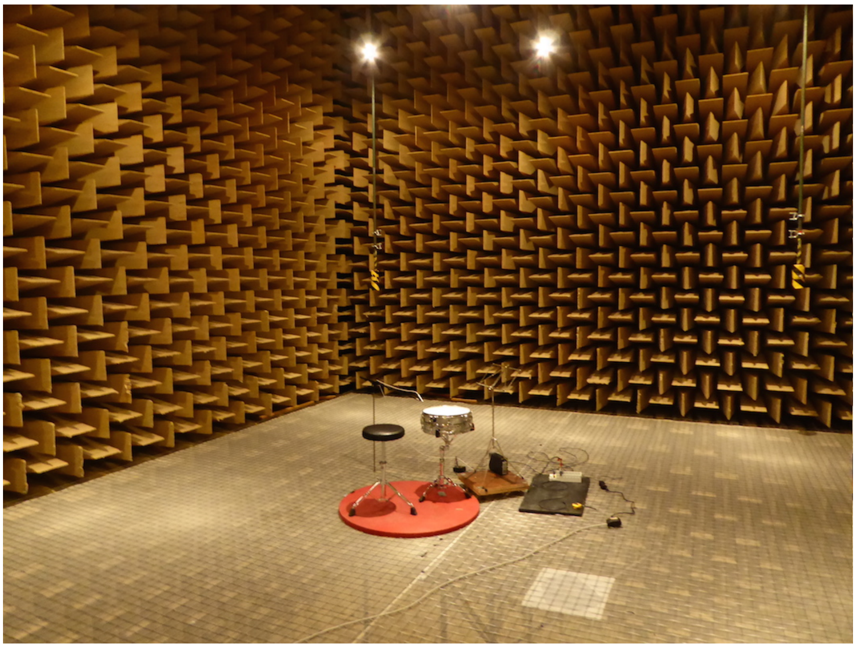

Figure A.1: Picture of anechoic chamber

Figure A.2: Picture of classroom

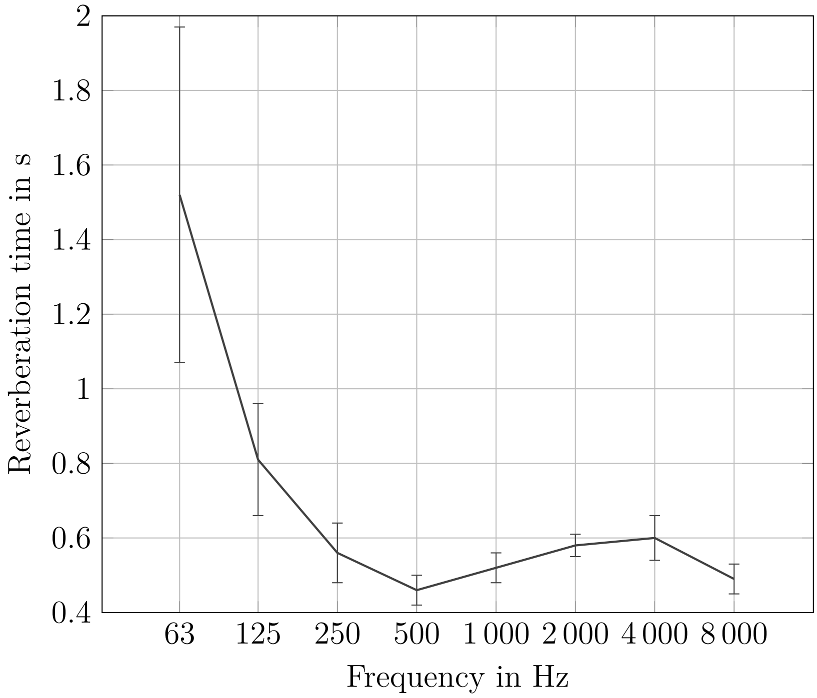

Figure A.3: Reverberation time of classroom

Figure A.4: Picture of reverberation chamber

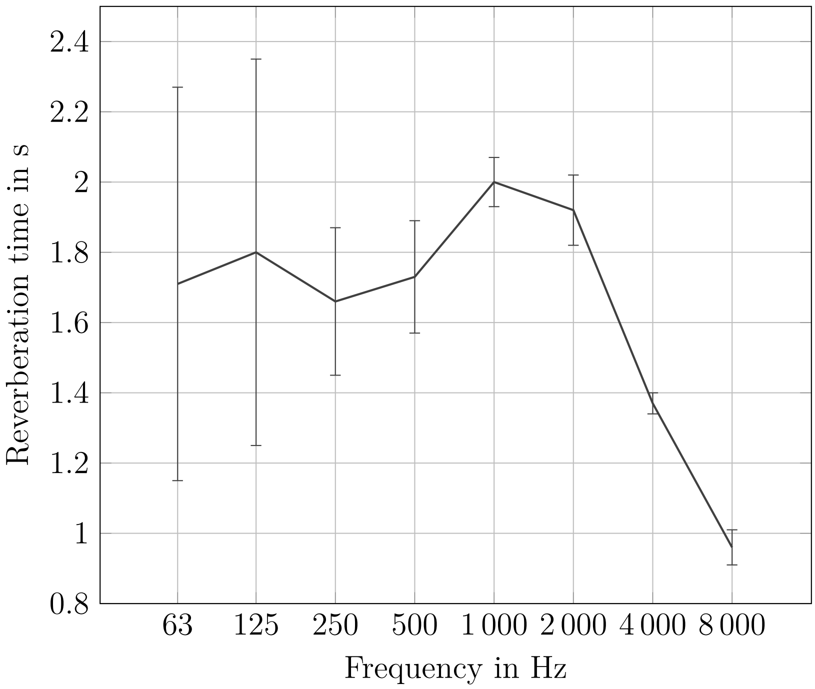

Figure A.5: Reverberation time of reverberation chamber

B

Phase 2 - Measurement equipment and room documentation

In this section the measurement equipment used in phase 2 is presented. Furthermore, an detailed room documentation of the considered rooms is presented. All rooms are located either at the Academy of Music and Drama (Gothenburg) or at Skurups folkhögskola.

Table B.1: Measurement equipment used in phase 2

Description	Name	Serial number Inventory number
Acoustical Calibrator	Brüel&Kjær Type 4231	SN 2136623
Noise Generator	Brüel&Kjær Type 1405	SN 530287
Amplifier	Crown XLS 1002 Drivecore	IN 8501215482
Loudspeaker	Dodecahedron	-
Condenser Microphone Cartridge	Brüel&Kjær Type 4133	SN 455828
Condenser Microphone Cartridge	Brüel&Kjær Type 4133	SN 455828
Microphone pre-amplifier	Brüel&Kjær	SN 1448005
Microphone pre-amplifier	Brüel&Kjær	IN Pr5
Microphone power supply	Brüel&Kjær Type 2804	SN 285276
Sound and Vibration Input Module	NI 9234	IN AN6
KEMAR Head and Torso	G.R.A.S. 45BB	SN 250201
CCP Supply	G.R.A.S. Type 12AL	SN 279718
CCP Supply	G.R.A.S. Type 12AL	SN 279640
Measurement software	Matlab R2016b	-
CompactDAQ USB chassis	NI cDAQ-9178	SN 14DAD04
Listening test headphones	Sennheiser HD650	He5

Table B.2: Overview over investigated rooms in phase 2

Room	Volume	G	EDT	T_{m}	Dimensions in m	Location
B32	$31\,\mathrm{m}^3$	23 dB	0.19 s	0.24 s	4.2 x 3.2 x 2.3	Skurup
B36	$69\,\mathrm{m}^3$	17 dB	0.24 s	0.25 s	4.9 x 5.9 x 2.4	Skurup
B17	$95\,\mathrm{m}^3$	20 dB	0.26 s	0.36 s	4.9 x 6,1 x 3.2	Skurup
C212	$31\,\mathrm{m}^3$	25 dB	0.28 s	0.35 s	2.3 x 4.6 x 2.9	Gothenburg
C204	$65\,\mathrm{m}^3$	19 dB	0.21 s	0.28 s	4,1 x 6.1 x 2.6	Gothenburg
A501	$\approx 432\,\mathrm{m}^3$	14 dB	0.42 s	0.49 s	8.2 x 10.7 x 5.1	Gothenburg

Figure B.1: Picture of room B36 - ensemble jazz

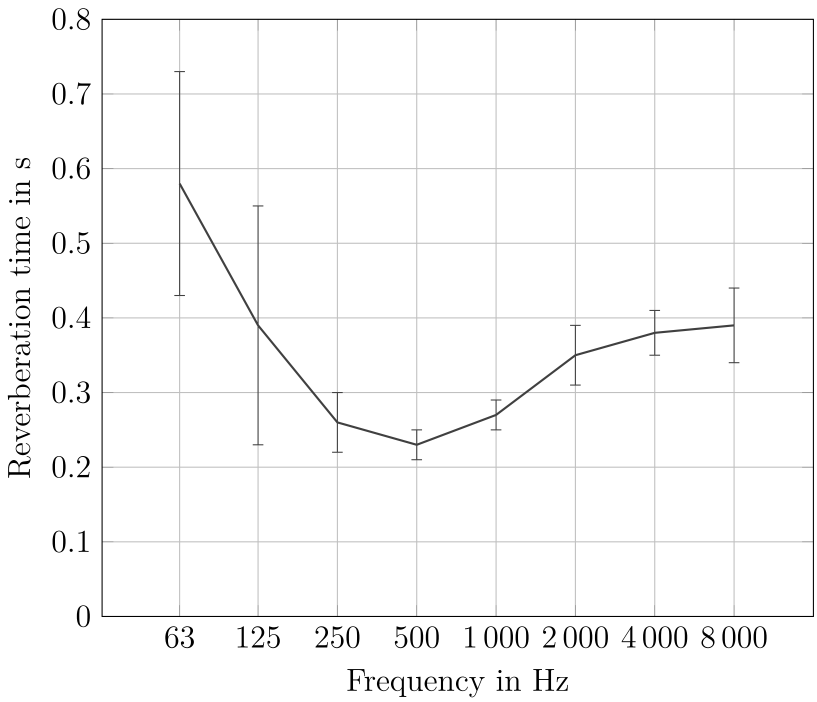

Figure B.2: Reverberation time of room B36 - ensemble jazz

Figure B.3: Picture of room B17 - ensemble jazz

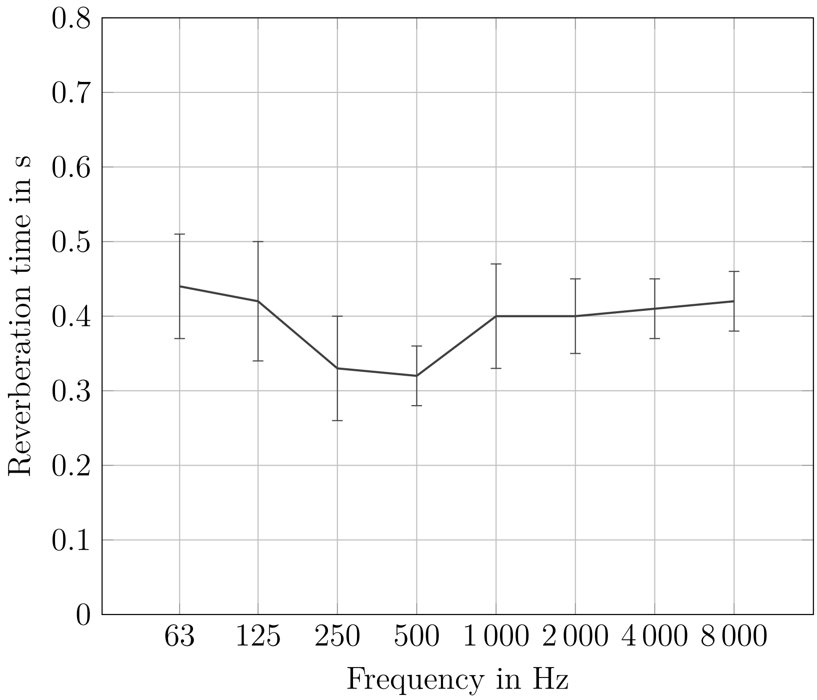

Figure B.4: Reverberation time of room B17 - ensemble jazz

Figure B.5: Picture of room B32 - practice jazz

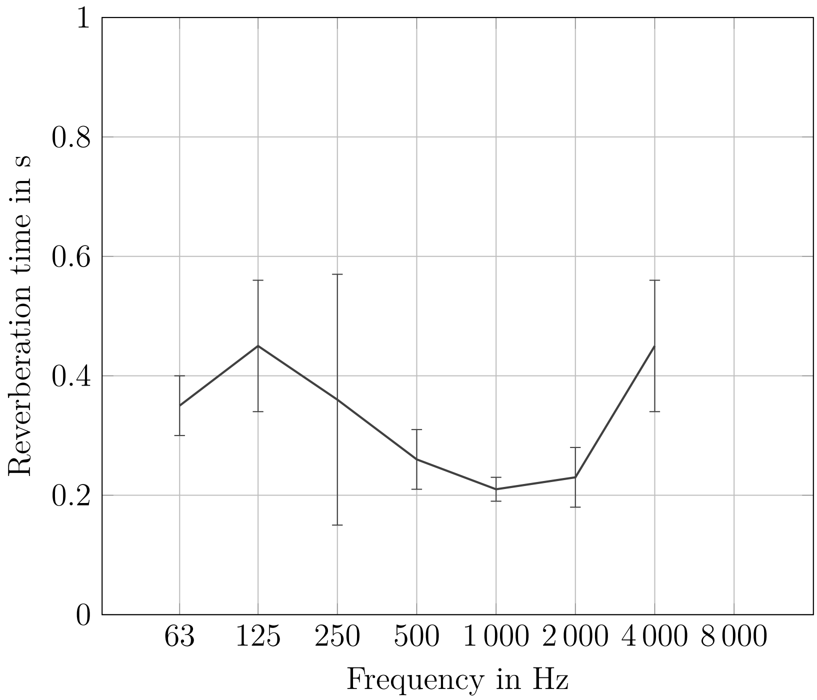

Figure B.6: Reverberation time of room B32 - practice jazz

Figure B.7: Picture of room C212 - practice

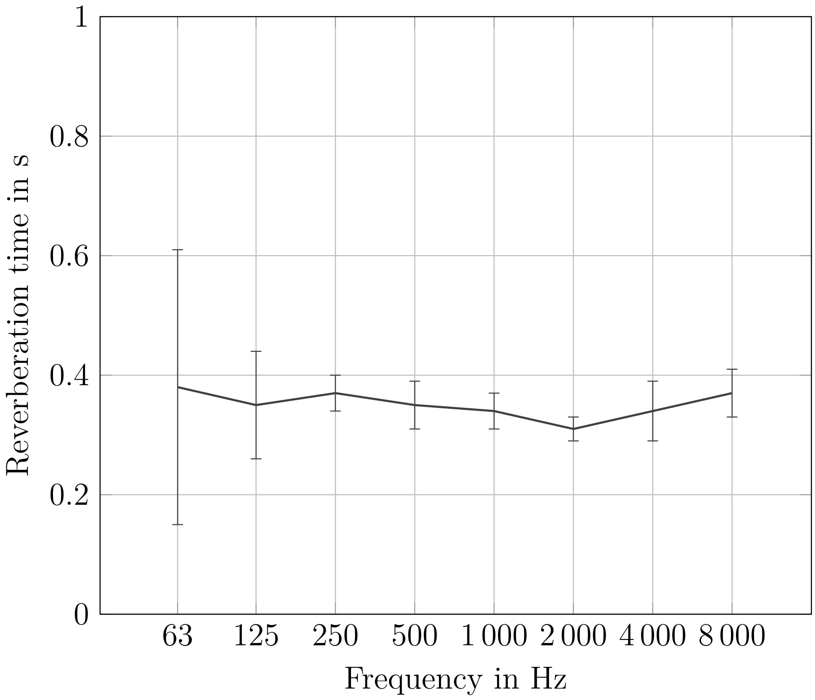

Figure B.8: Reverberation time of room C212 - practice

Figure B.9: Picture of room C204 - education

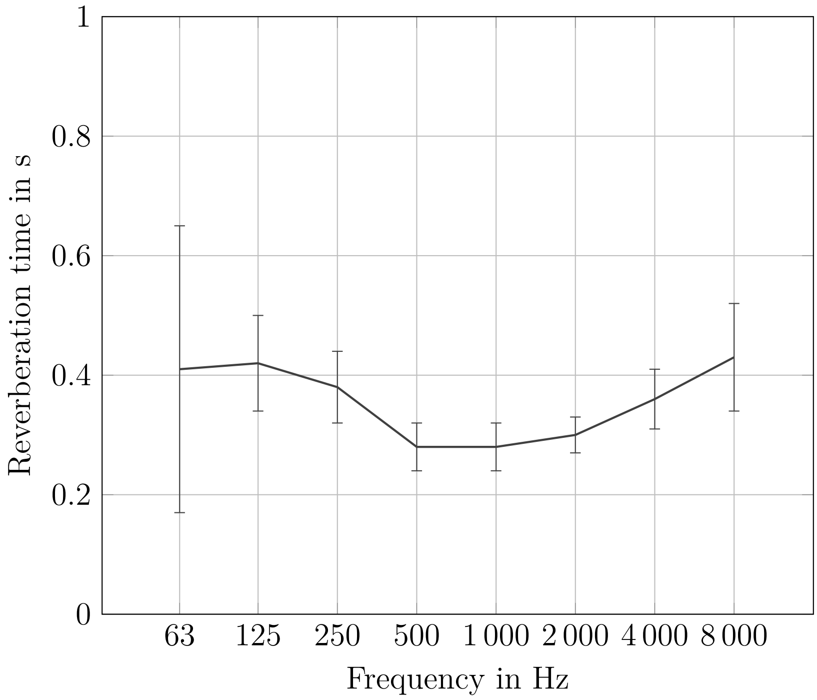

Figure B.10: Reverberation time of room C204 - education

Figure B.11: Picture of room A501 - ensemble/studio

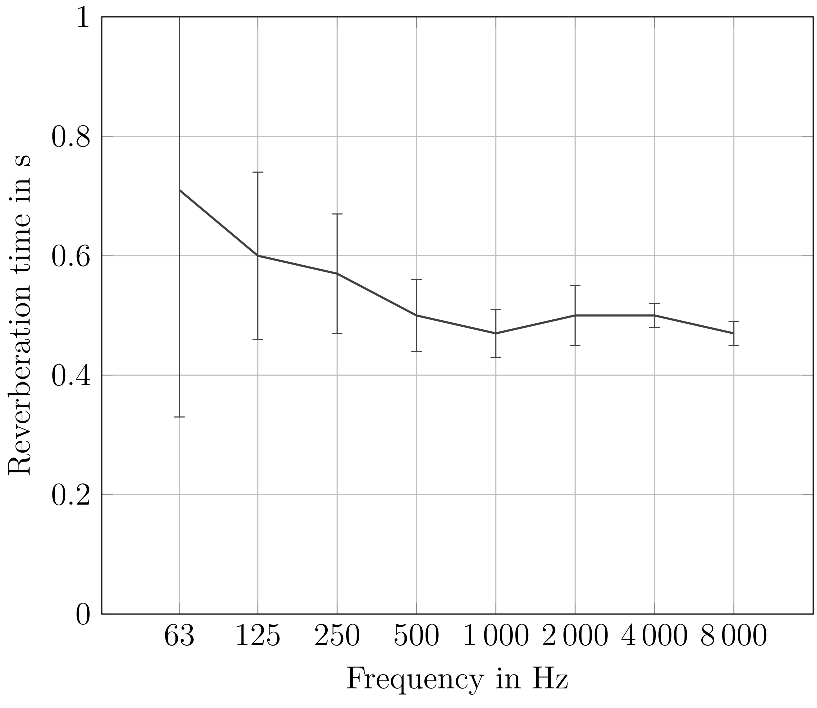

Figure B.12: Reverberation time of room A501 - ensemble/studio

C

Phase 1 - Test guidance

- Testformulär till trumstudie -

Tack så mycket för att du vill delta i denna trumspelsmätning. Mätningarna är en viktig del av vårt examensarbete och vi är mycket glada att du valt att delta. Det här testet är helt frivilligt och du kan avbryta testet när du vill utan att ge några särskilda skäl. Vi vill också poängtera att det inte finns några svar som är rätt eller fel i det här testet.
Att spela trummor utan hörselskydd kan vara skadligt för hörseln. Vi rekommenderar därför alla testdeltagare att använda hörselskydd vid allt trumspel under testet. Användandet av hörselskydd är dock valfritt.

Testprocedur:
I detta test ber vi dig att spela virveltrumma i tre olika rum. Testet tar cirka en och en halv timma och kommer att gå till enligt följande:

- Rundtur för att se de tre testrummen
- Speltest i varje rum
  - Förberedelse för att spela
  - Spela virvelstycket tre gånger
  - Svara på reflektionsfrågorna nedan
- Intervju om din upplevelse av testet

Reflektionsfrågor: Ringa in det nummer som bäst stämmer överens med din åsikt.

Fråga 1: Hur nöjd är du med framförandet?

Rum 1:	inte nöjd	1	2	3	4	5	6	7	nöjd
Rum 2:	inte nöjd	1	2	3	4	5	6	7	nöjd
Rum 3:	inte nöjd	1	2	3	4	5	6	7	nöjd

fråga 2: Hur mycket behövde du koncentrera dig under framförandet?

Rum 1:	lite	1	2	3	4	5	6	7	mycket
Rum 2:	lite	1	2	3	4	5	6	7	mycket
Rum 3:	lite	1	2	3	4	5	6	7	mycket

Integritetspolicy: I detta test kommer du och den data som samlas in att vara helt anonyma. Under förutsättning att du godkänner det skulle vi vilja publicera dina anonyma resultat på websidan www.drummingproject.com. Du kan återkalla beslutet när som helst. Med hjälp av ditt individuella testnummer kommer du att kunna identifiera ditt resultat bland den publicerade datan. Ditt testnummer kommer att lagras konfidentiellt och det är endast du och vi som kommer att kunna koppla numret till dig. Ditt testnummer är: **0**

- Test sheet for playing test -

Thank you so much for participating in our first phase playing test. This test is an important part of our Master Thesis and we are very happy that you decided to participate in it. This test is entirely voluntary and you can stop your participation at any time without giving a reason for this. Furthermore, we would like you to know that there are no right or false answers or behaviours in this test.
Playing the drums without hearing protection can harm the hearing system. We therefore strongly advise every participant to wear hearing protection during his/her drum play. However, this decision is made by every participant on their own.

Test procedure:
In this test you are asked to play the snare drum in three different rooms. The test will take ca. 1.5 hours with the following procedure:

- Walk-around and looking at the three test rooms
- Drum playing in each of the rooms
  Warm-up and preparation to play.
  performing your piece three times
  Answering reflection questions shown below
- Interview about your experience of the test

Reflection questions: Circle the number that represents your opinion best.

Question 1: How satisfied you are with your performance?

Room 1:	not satisfied	1	2	3	4	5	6	7	satisfied
Room 2:	not satisfied	1	2	3	4	5	6	7	satisfied
Room 3:	not satisfied	1	2	3	4	5	6	7	satisfied

Question 2: How much did you have to concentrate during the drum performance?

Room 1:	little	1	2	3	4	5	6	7	a lot
Room 2:	little	1	2	3	4	5	6	7	a lot
Room 3:	little	1	2	3	4	5	6	7	a lot

Privacy policy: In this test you and the data we collect will stay entirely anonymous. We would like to publish your anonymised results on the website `www.drummingproject.com`. Please let us know if you approve this. Note that you can recall this decision at any time. With the help of your individual test number you will be able identify yourself among the published data sets. This number is stored confidentially and is only known to you and us. Your number is: **0**

D

Phase 2 - Test guidance

- Info paper about 2nd phase test -

CHALMERS

Thank you so much for participating in our study. This test is an important part of our Master Thesis and we are very happy that you decided to participate in it. This test is entirely voluntary and you can stop your participation at any time without giving a reason for this.
Playing the drums without hearing protection can harm the hearing system. We therefore strongly advise every participant to wear hearing protection during his/her drum play. However, this decision is made by every participant on their own.

<u>Test procedure:</u>
In this test we investigate the quality of practice rooms focusing on acoustics. Your task is to judge a variety of practice rooms. The test will take ca. 1 hour with the following procedure:

- Introduction talk clarifying test task
- Ranking of three different rooms at HSM by
  playing the drums and getting familiar with the room
  taking optional notes
  deciding on a ranking after having played in all the rooms
- Ranking of different virtual rooms in a listening test
- Interview about your experience of the test

Please note: There are no right or false answers or behaviours in this test and the data we collect will stay entirely anonymous.

- HSM room evaluation -

CHALMERS

Comments on room C212:

Comments on room C204:

Comments on room A501:

Please rank the rooms judging only acoustics with regard to a **practice room scenario**.

Place 1: ___________
Place 2: ___________
Place 3: ___________

- Virtual room evaluation (Set 1 of 4) -

CHALMERS

Comments on room A:

Comments on room B:

Comments on room C:

Please rank the rooms judging only acoustics with regard to a **practice room scenario**.

Place 1: ___________
Place 2: ___________
Place 3: ___________

- Virtual room evaluation (Set 2 of 4) -

CHALMERS

Comments on room A:

Comments on room B:

Comments on room C:

Please rank the rooms judging only acoustics with regard to a **practice room scenario**.

Place 1: ___________
Place 2: ___________
Place 3: ___________

- Virtual room evaluation (Set 3 of 4) -

CHALMERS

Comments on room A:

Comments on room B:

Comments on room C:

Please rank the rooms judging only acoustics with regard to a **practice room scenario**.

Place 1: ___________
Place 2: ___________
Place 3: ___________

- Virtual room evaluation (Set 4 of 4) -

CHALMERS

Comments on room A:

Comments on room B:

Please rank the rooms judging only acoustics with regard to a **practice room scenario**.

Place 1: __________
Place 2: __________

E

Phase 2 - Listening test setup

In Table E.1 and Table E.2 it is shown in which order the binaural test recordings were presented to the test participants in Gothenburg and Skurup, respectively. Note that recordings of the jazz groove are indicated with blue colour and recordings of the rock groove are indicated with black colour[1].

Table E.1: Test recordings setup for participants in Gothenburg

	Test set 1	Test set 2	Test set 3	Test set 4
A (Test track 1)	C204	A501	B17	B32
B (Test track 2)	A501	C212	B32	B17
C (Test track 3)	C212	C204	B36	-

Table E.2: Test recordings setup for participants in Skurup

	Test set 1	Test set 2	Test set 3	Test set 4
A (Test track 1)	B17	B32	C204	A501
B (Test track 2)	B32	B17	A501	C212
C (Test track 3)	B36	-	C212	C204

[1]Note: Due to issues in the recordings no rock groove was available for room B36

F

Phase 1 - Time signals of accelerometer measurements

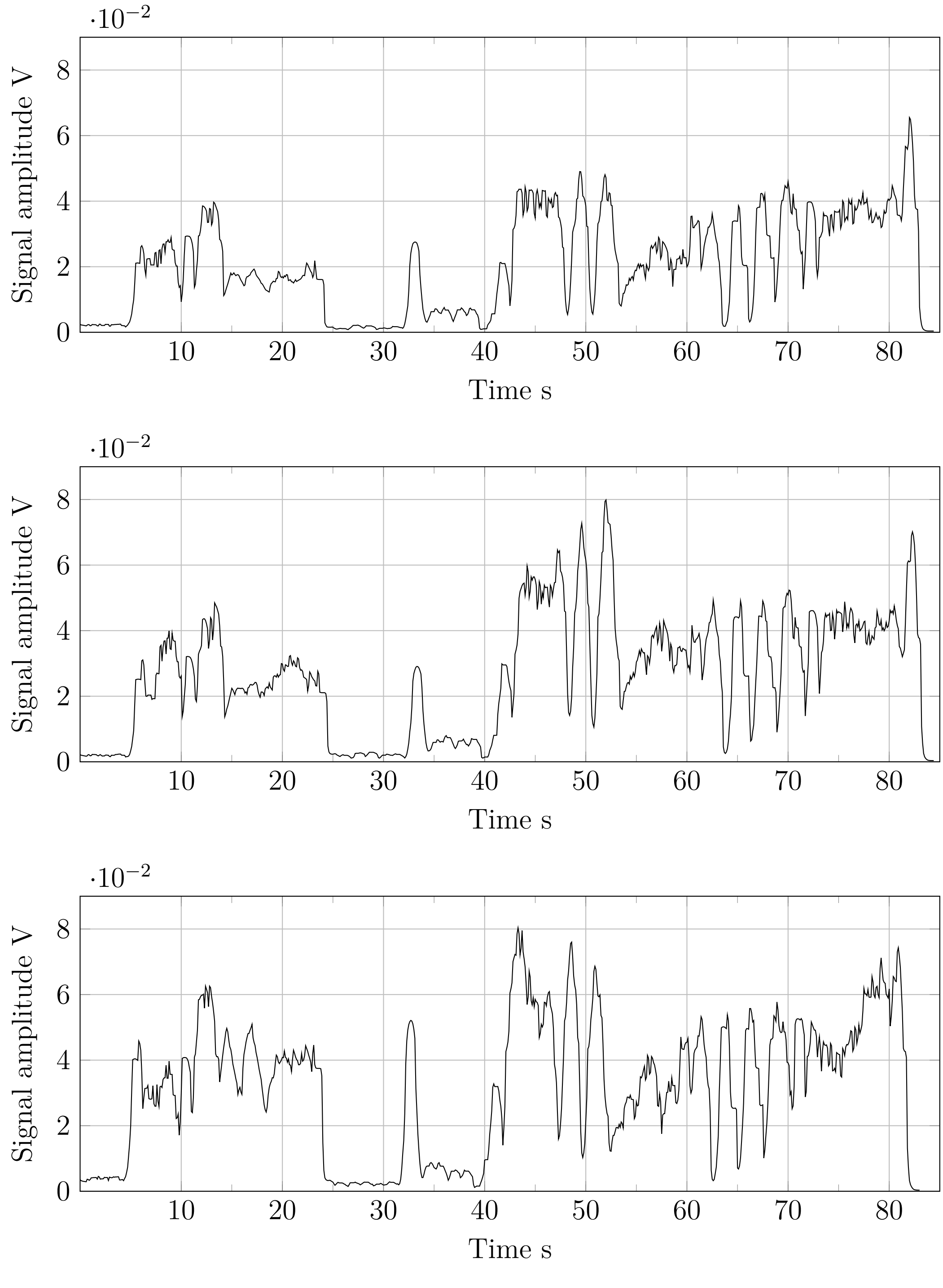

Figure F.1: Time signals of all three performances in the reverberation chamber of test person 94

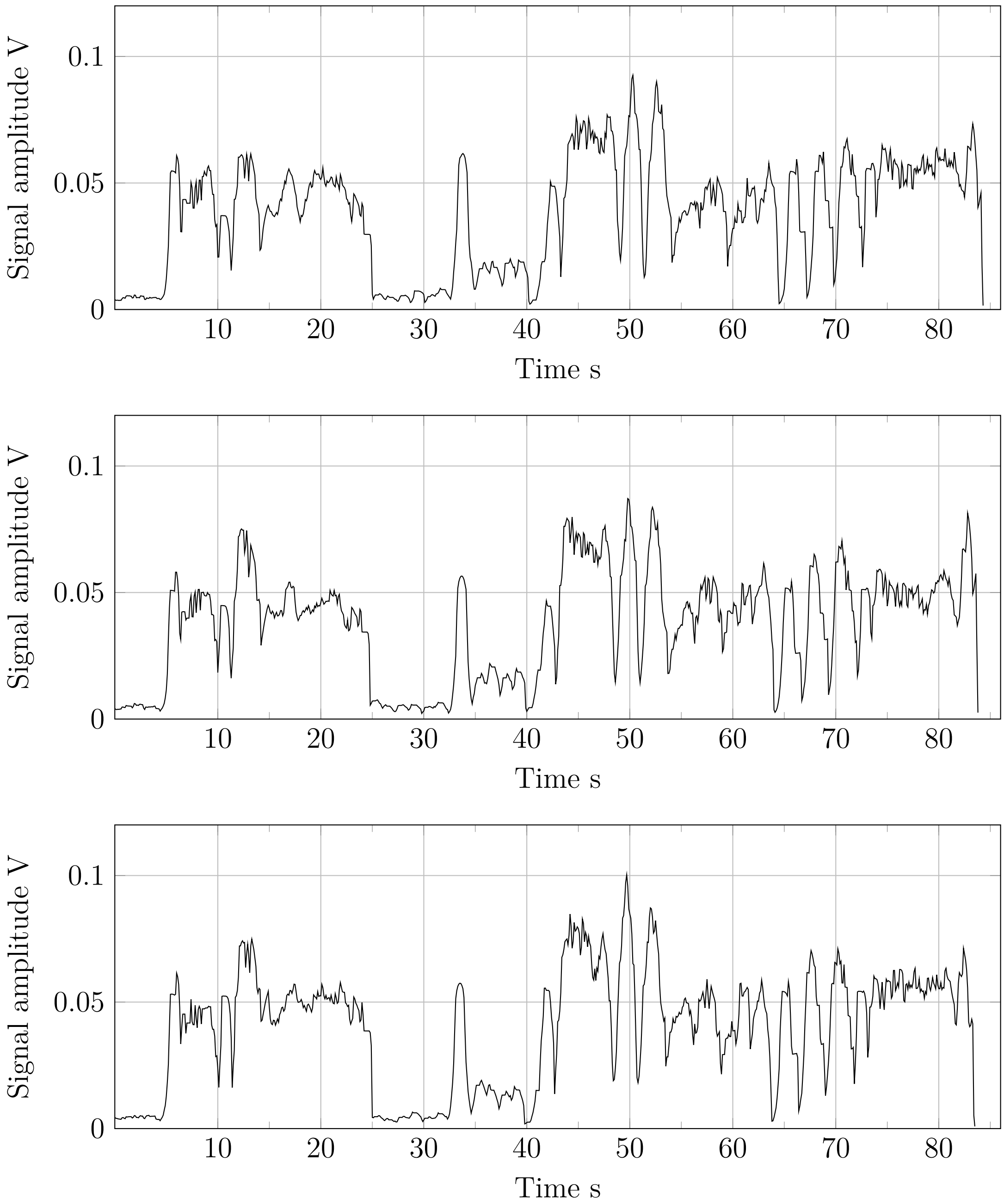

Figure F.2: Time signals of all three performances in the anechoic chamber of test person 94

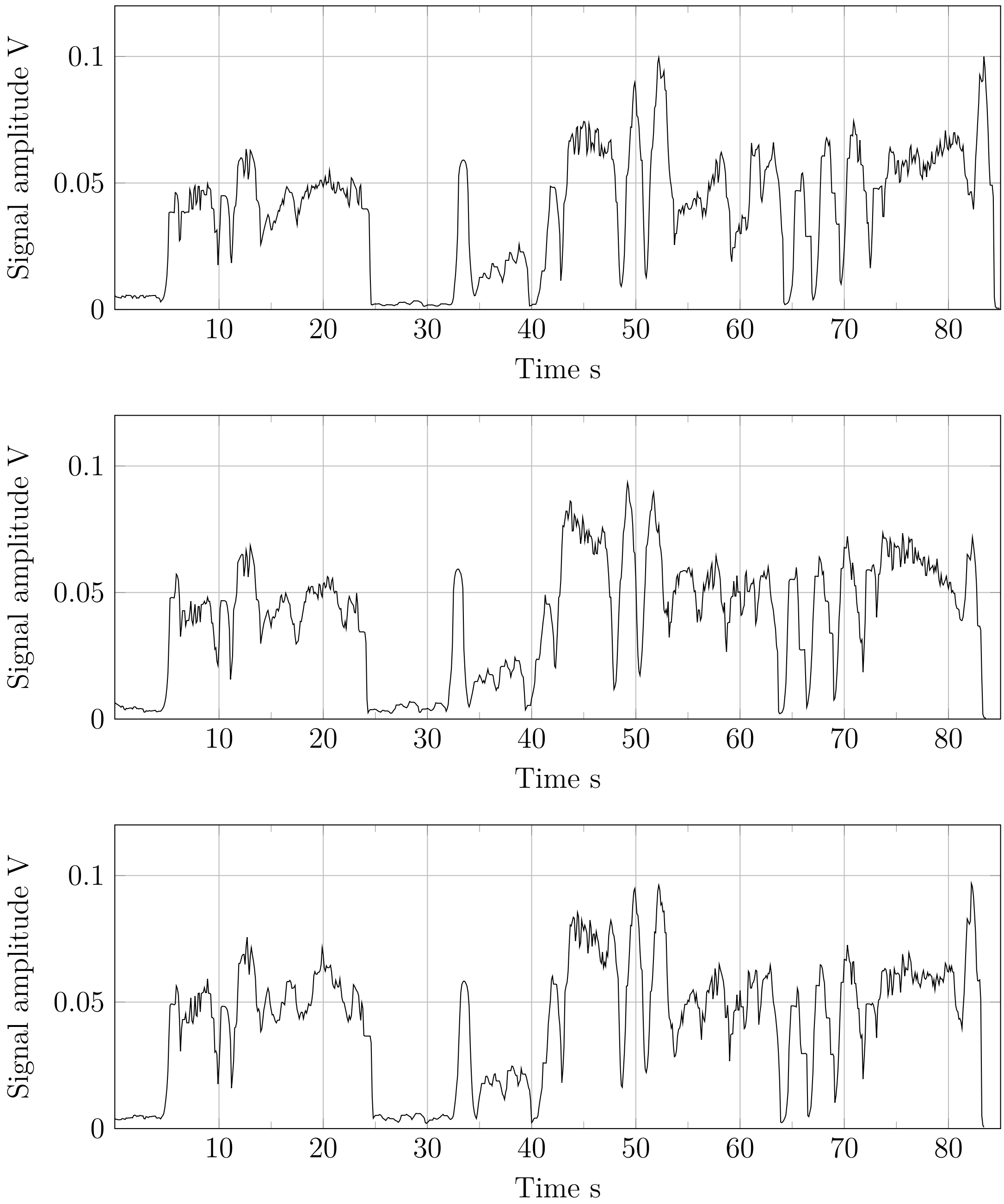

Figure F.3: Time signals of all three performances in the class room of test person 94

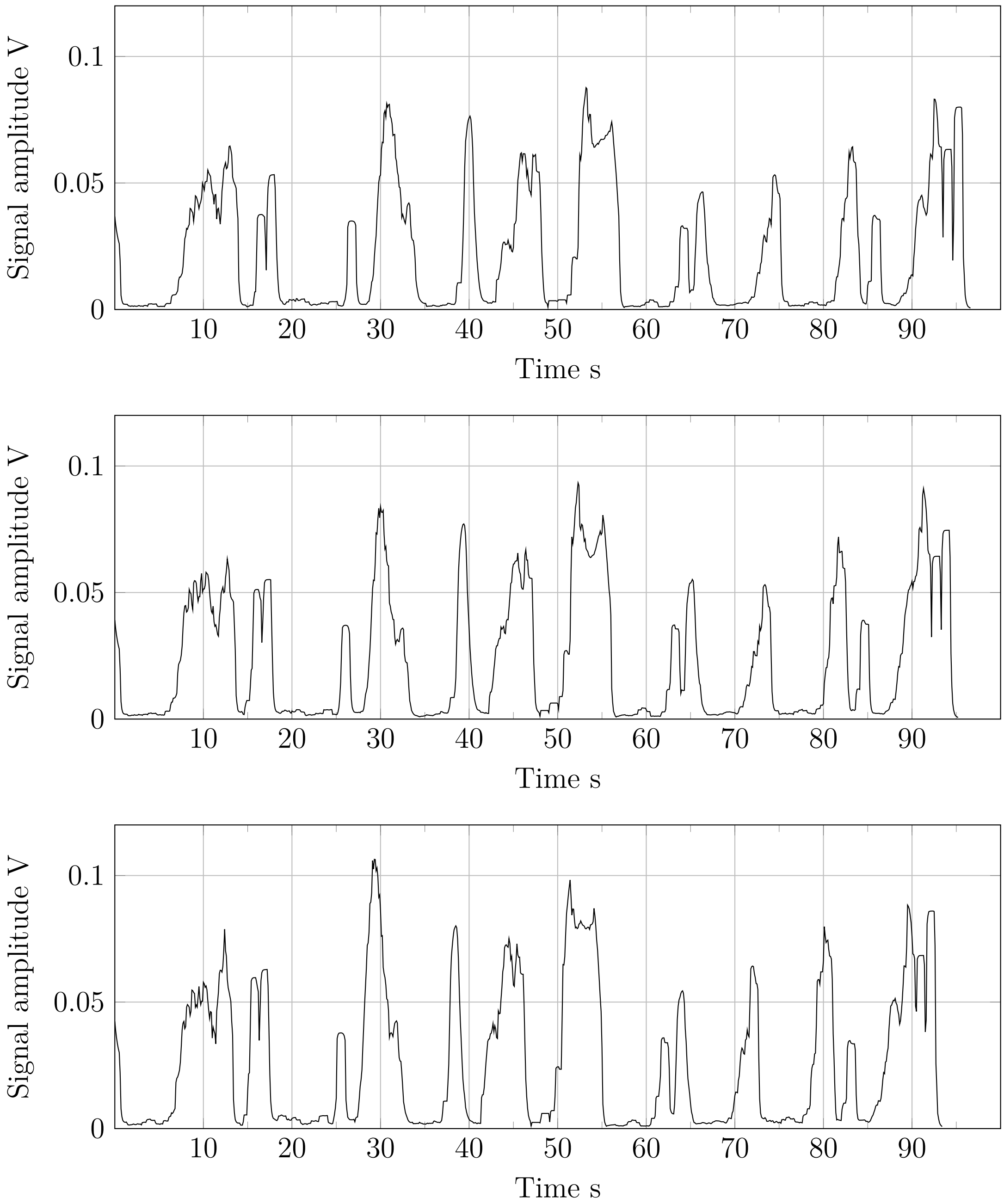

Figure F.4: Time signals of the all three performances in the reverberation chamber of test person 25

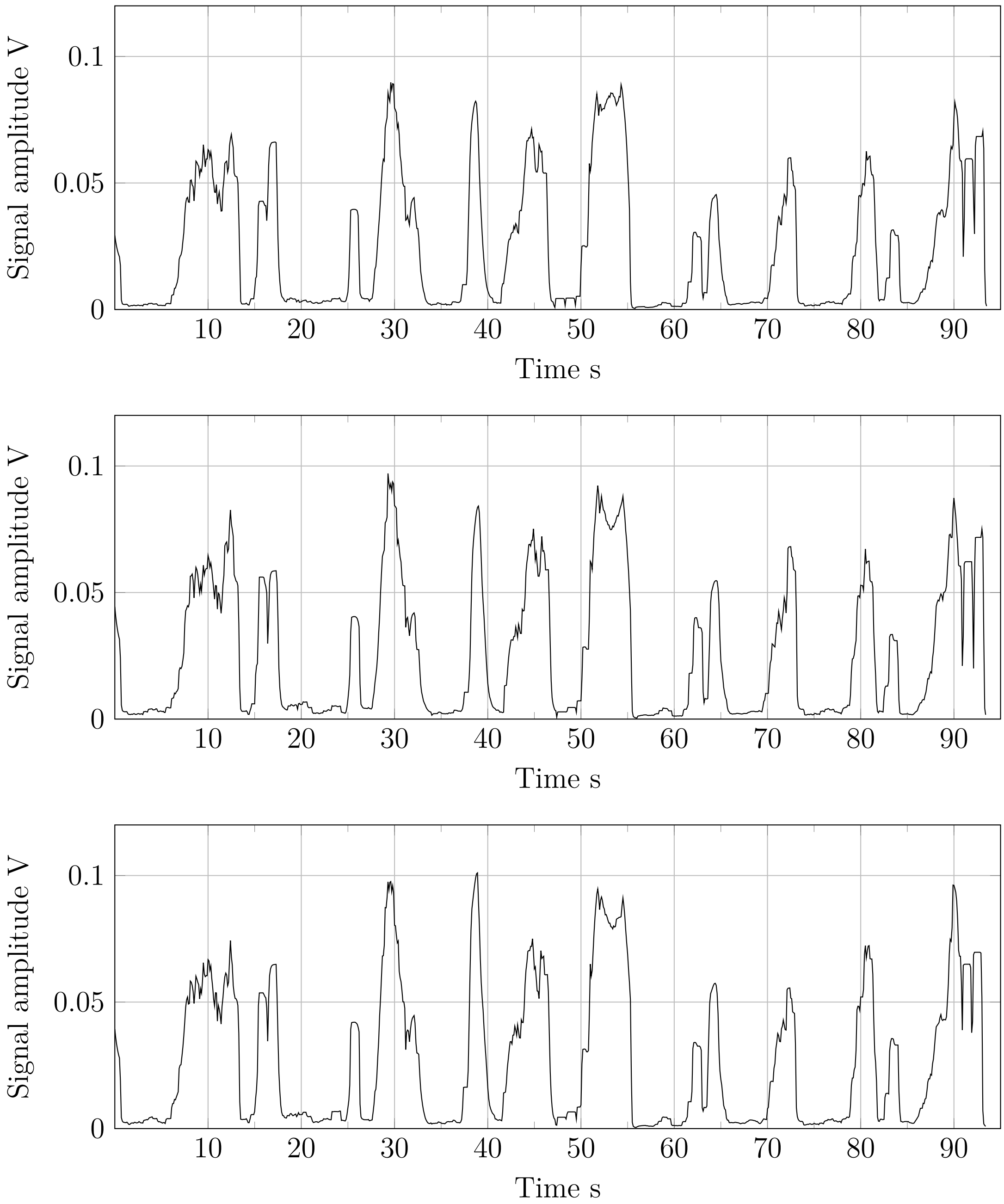

Figure F.5: Time signals of all three performances in the anechoic chamber of test person 25

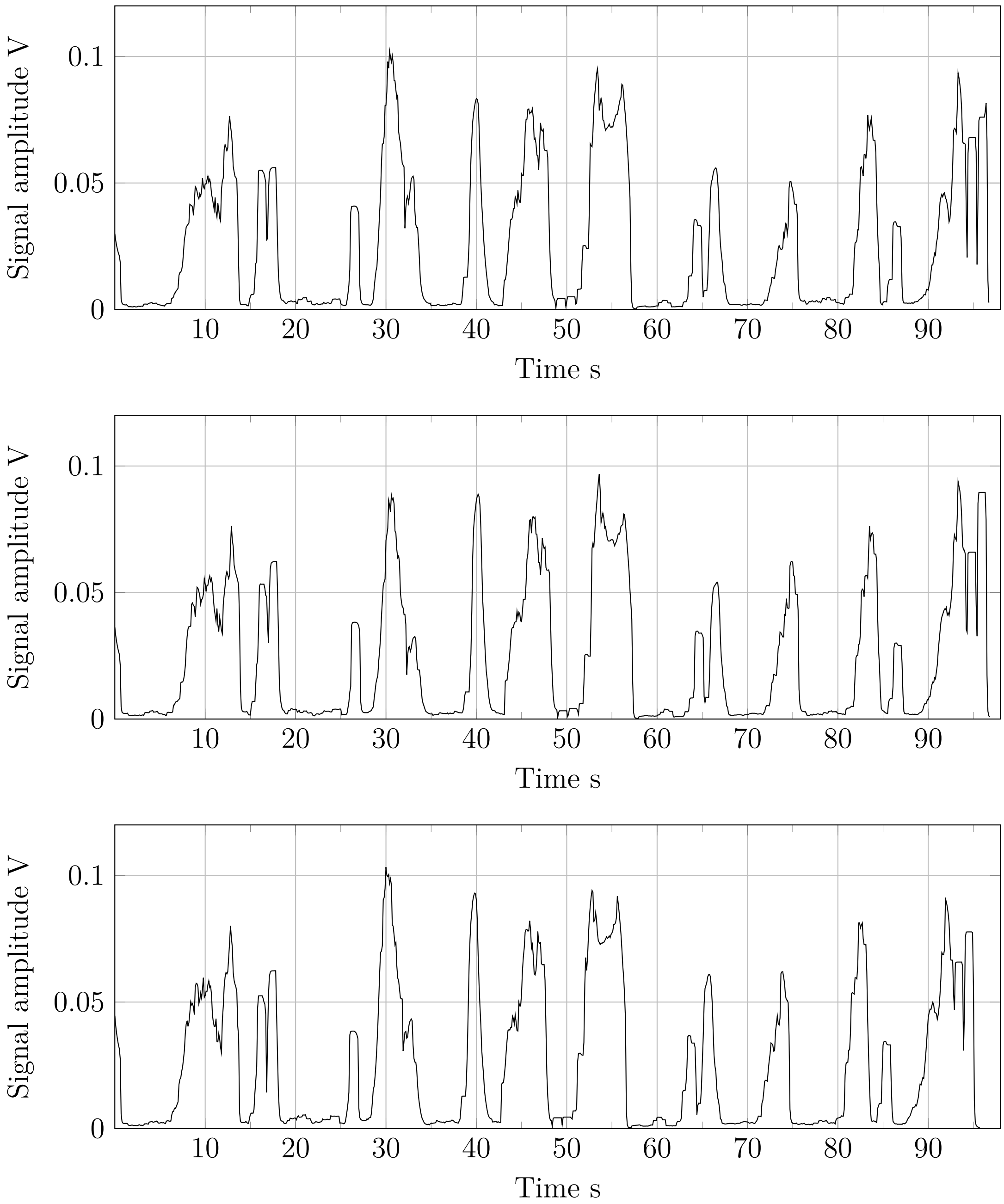

Figure F.6: Time signals of all three performances in the class room of test person 25

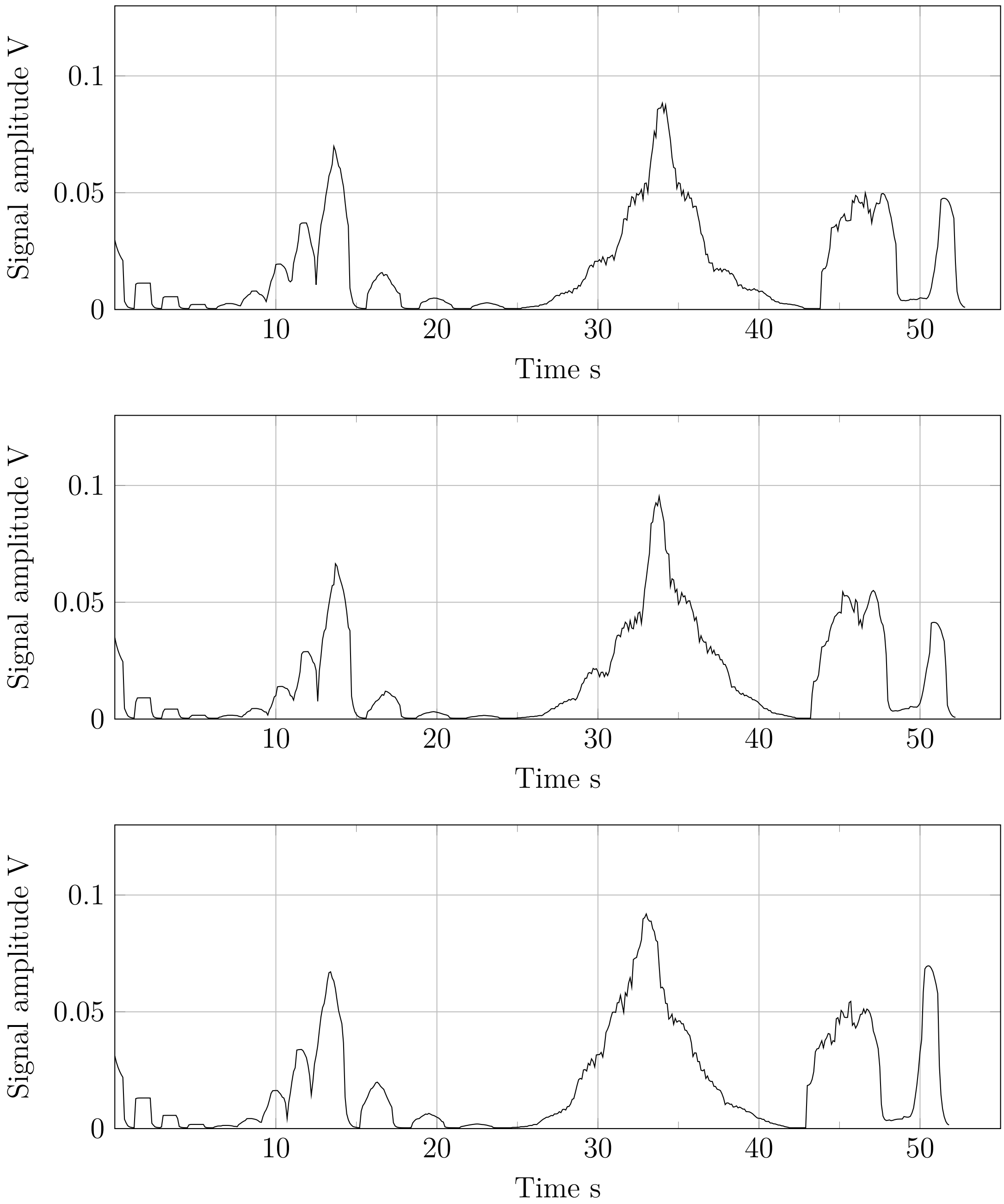

Figure F.7: Time signals of all three performances in the reverberation chamber of test person 81

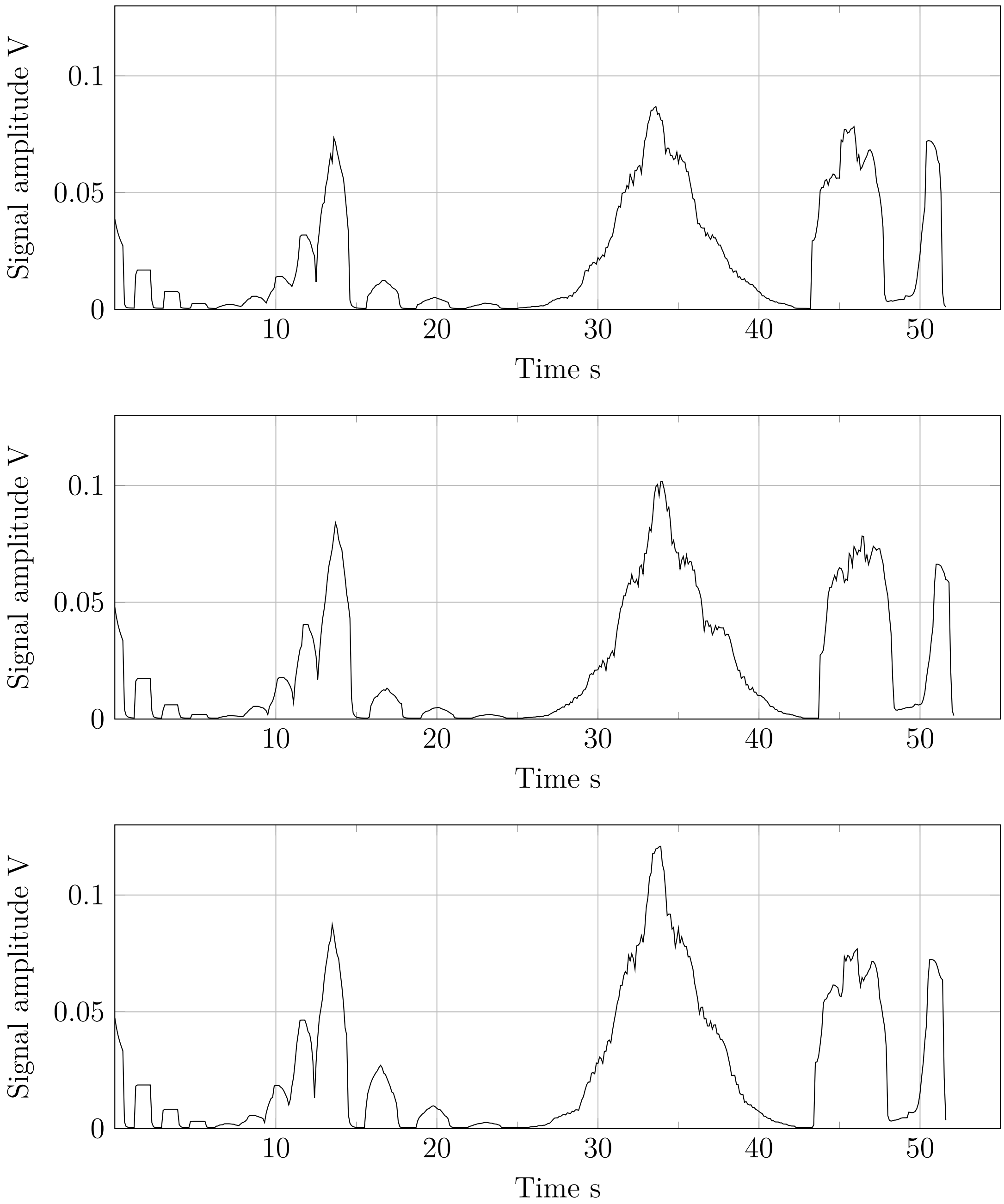

Figure F.8: Time signals of all three performances in the anechoic chamber of test person 81

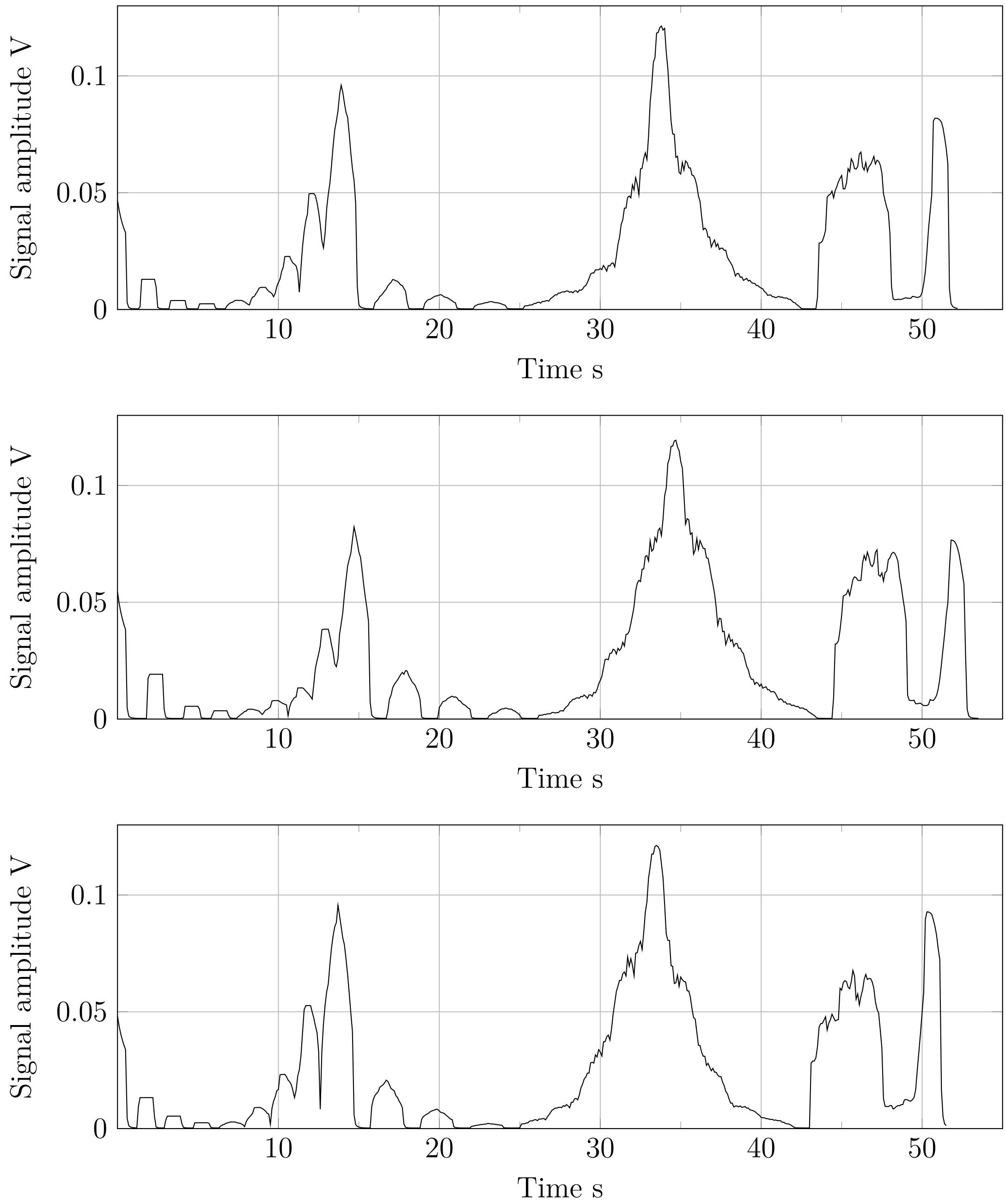

Figure F.9: Time signals of all three performances in the class room of test person 81

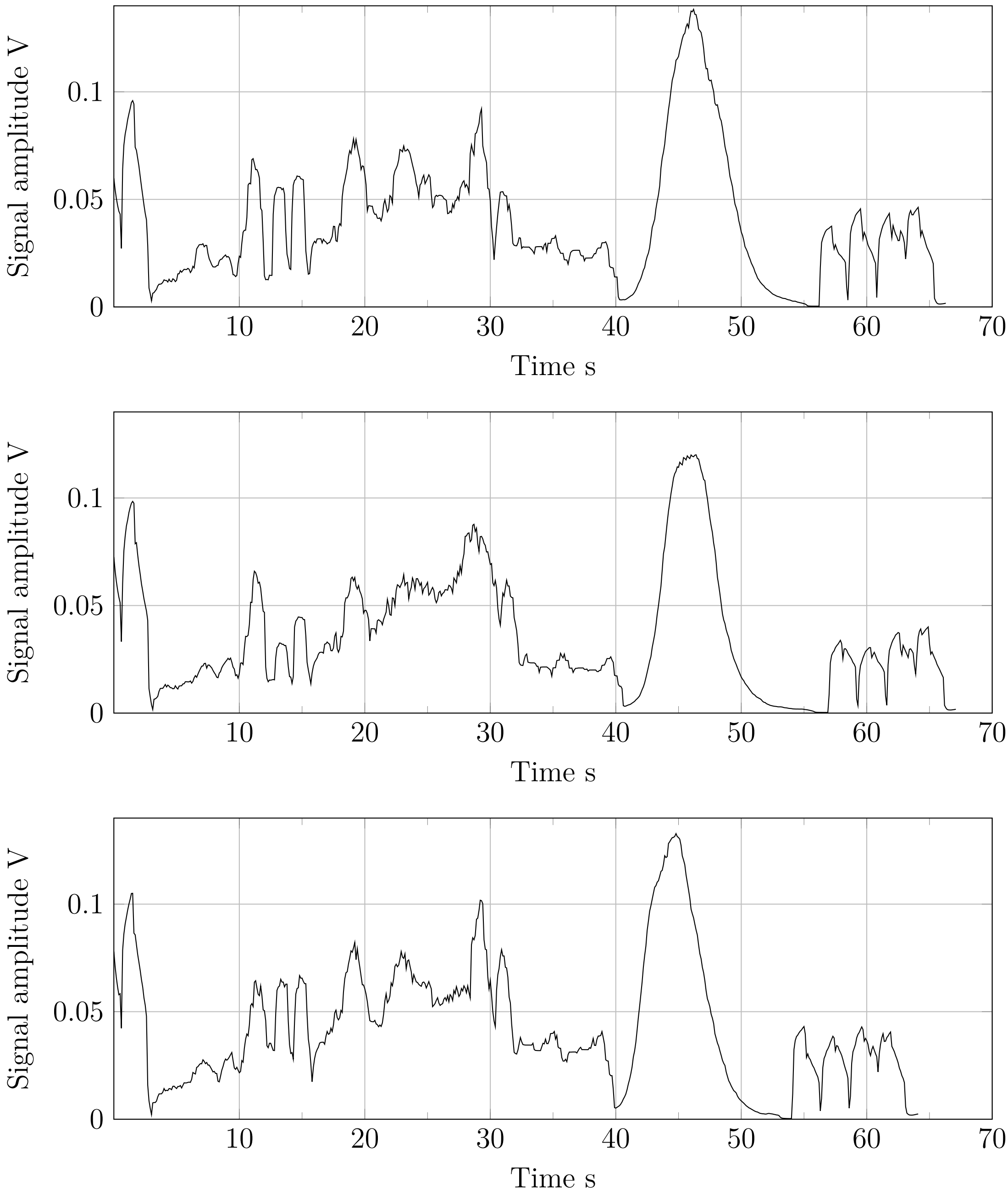

Figure F.10: Time signals of all three performances in the reverberation chamber of test person 79

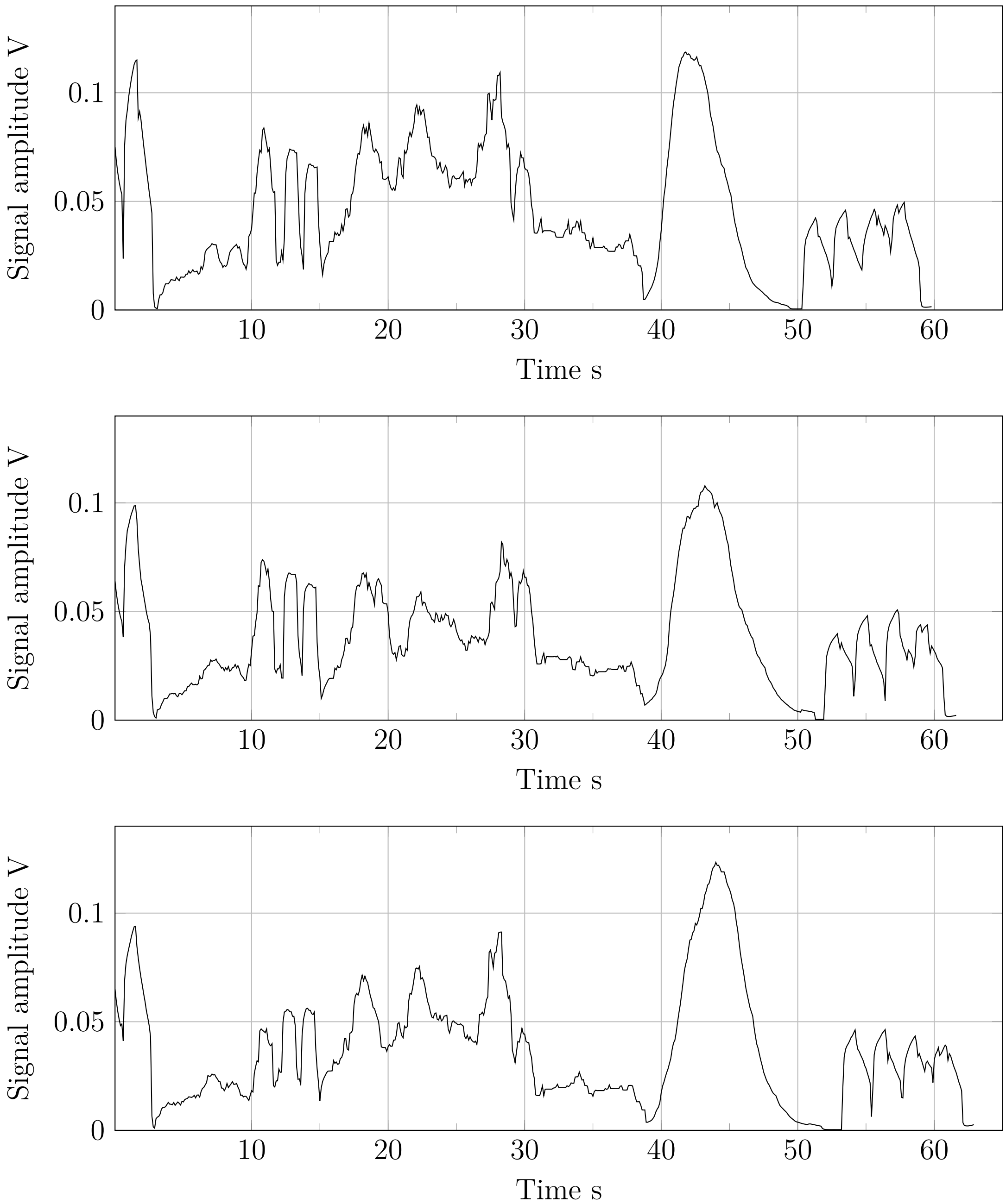

Figure F.11: Time signals of all three performances in the anechoic chamber of test person 79

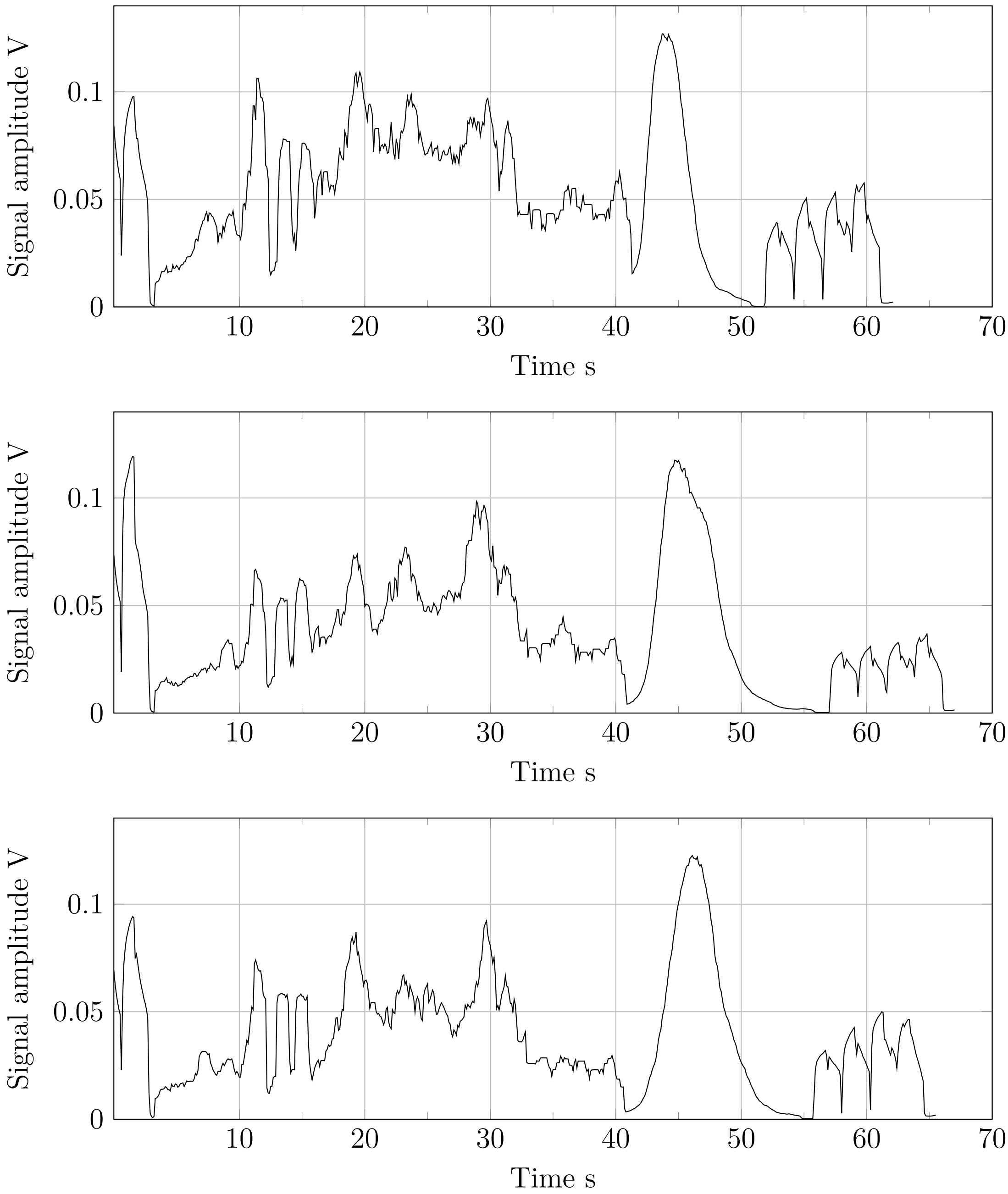

Figure F.12: Time signals of all three performances in the class room of test person 79

G

Phase 2 - Detailed overview of room rankings of indirect subjective evaluation

Below a detailed overview of the obtained room rankings of the indirect subjective evaluation is presented. Note that recordings of the jazz groove are indicated with blue colour and recordings of the rock groove are indicated with black colour.

Table G.1: Overview over room ranking of TP 1/TP 2 (Gothenburg); note that the test sets 3 and 4 were based on recordings made in Skurup

	Place 1	Place 2	Place 3
Test set 1	A501/C204	C204/A501	C212/C212
Test set 2	C204/C212	A501/A501	C212/C204
Test set 3	B36/B32	B17/B17	B32/B36
Test set 4	B17/B17	B32/B32	-/-

Table G.2: Overview over room ranking of TP 3/TP 4/TP 5/TP 6 (Skrup); note that the test sets 3 and 4 were based on recordings made in Gothenburg

	Place 1	Place 2	Place 3
Test set 1	B32/B17/B32/B17	B36/B36/B36/B32	B17/B32/B17/B36
Test set 2	B17/B17/B32/B32	B32/B32/B17/B17	-/-/-
Test set 3	A501/A501/C212/C204	C204/C212/C204/A501	C212/C204/A501/C212
Test set 4	A501/C204/C204/A501	C204/A501/C212/C204	C212/C212/A501/C212